CAR OF THE FUTURE v3.0

Mobility 2030

Citi GPS: Global Perspectives & Solutions

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CAR OF THE FUTURE v3.0

Mobility 2030

Throughout the years, the *Car of the Future* investment process was mostly defined as themes surrounding the addition of new content into the car, and usually because of regulatory elements. Think of turbochargers, stop-start systems or electrified vehicles helping automakers meet emission standards, or ADAS components and associated electronics helping automakers meet safety regulations. This process often meant that auto suppliers gained profitable content while automakers…well not so much.

This investment approach has and remains fairly straightforward. Seek out auto suppliers providing the necessary components that automakers will be forced to add no matter what happens at the macro level — and if those components also happen to improve the value proposition of the car— you could find suppliers with profitable growth profiles in excess of global auto production. Indeed, our Auto Technology Investing Framework has focused mainly on identifying such stories — and to be sure — this theme remains alive and well and addressed in this report. Regulatory driven stories remain powerful and consistent.

Yet the theme is also evolving in a major way. We believe the next *Car of the Future* chapter expands from a content-into-the-car theme into a new-economics-of-the-car-itself theme. Fully autonomous cars, driverless on-demand ridesharing networks and eventually integrated mobile networks, connectivity, over-the-air and big data aren't necessarily verticals that automakers are being forced to pursue. Rather, they're being pursued because of potentially game-changing business model economics. It's no coincidence that several prominent technology companies are entering or are reported to be considering entering the mobility space, just as it's no coincidence that the Consumer Electronics Show (CES) has become something of an auto show.

And it's not hard to see why this is happening. Even after tremendous technological advances in recent decades, the car as we know it today falls well short of maximizing its potential in terms of efficiency (both operating cost/mile & resource sharing), safety, data collection and monetization, personalization, and updating. Not only does that make the car something of an untapped well of new revenue sources, but each inefficiency also brings with it an added cost — insurance, fuel, economic, societal, recall-related, time spent driving in situations where consumers would rather not drive (like traffic jams). And the degree of stakeholder alignment is perhaps unprecedented — autonomous electric cars promise to be safer and greener, while shared on-demand mobility promises to unclog congestion in major cities.

Peak auto? Hardly, the profit potential of the car is more likely at its earlier stages, in our view. A year or two ago many of these new mobility themes were merely concepts. Now we have a number of industry players promising fully autonomous cars within five years! This means that the investment approach must also expand and evolve. Auto/Tech investing is no longer just about identifying which components go into car (though this is still a very important topic), but rather about who wins the driverless race & how, where and how will autonomous business models unfold, how will shifting industry forces impact various automakers/suppliers, and how will connectivity & data change the equation?

So whereas the prior investing framework essentially entailed one stream, today we think it entails two broad streams: (1) The content-additions that will shape the *Car of the Future*; and (2) The mobility providers of the future and the resulting industry implications on various players. We note that the scope of our analysis is the next 10-15 years.

Welcome to Car of the Future v 3.0.

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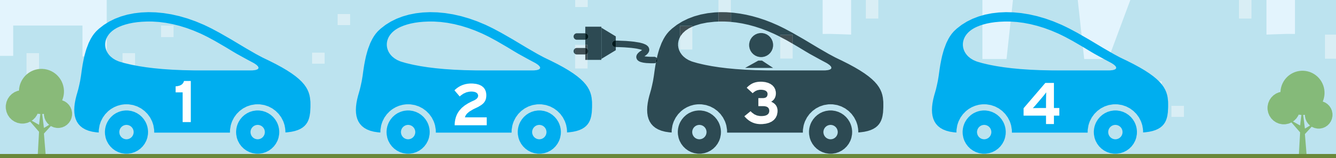
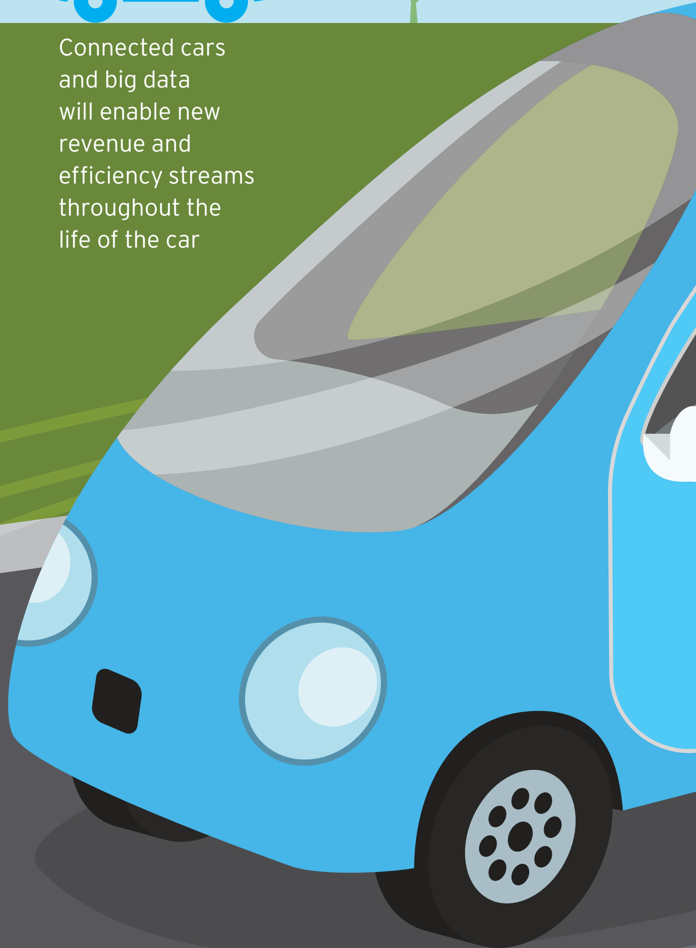
Transforming Mobility as We Know It
The ‘race’ to driverless vehicles

FOUR PROFOUND AUTO INDUSTRY CHANGES BETWEEN NOW AND 2030



1. On-demand mobility will inflect with driverless and connected vehicles entering the market over the next 4-6 years
2. Driverless cars will enable new shared-ownership business models
3. The cost of electric vehicles will reach parity with internal combustion vehicles by 2025
4. Connected cars and big data will enable new revenue and efficiency streams throughout the life of the car

THREE MUST-WIN RACES TO GET TO THE DRIVERLESS TROPHY



Now to 2021

Build automated capability, test it and start validating it.

2019 to 2025+

Validate, certify and launch rideshare ‘robotaxi’ in a geo-fenced zone.

Post to 2023

Rideshare ‘robotaxi’ beyond a geo-fenced zone and entry of personal driverless cars.

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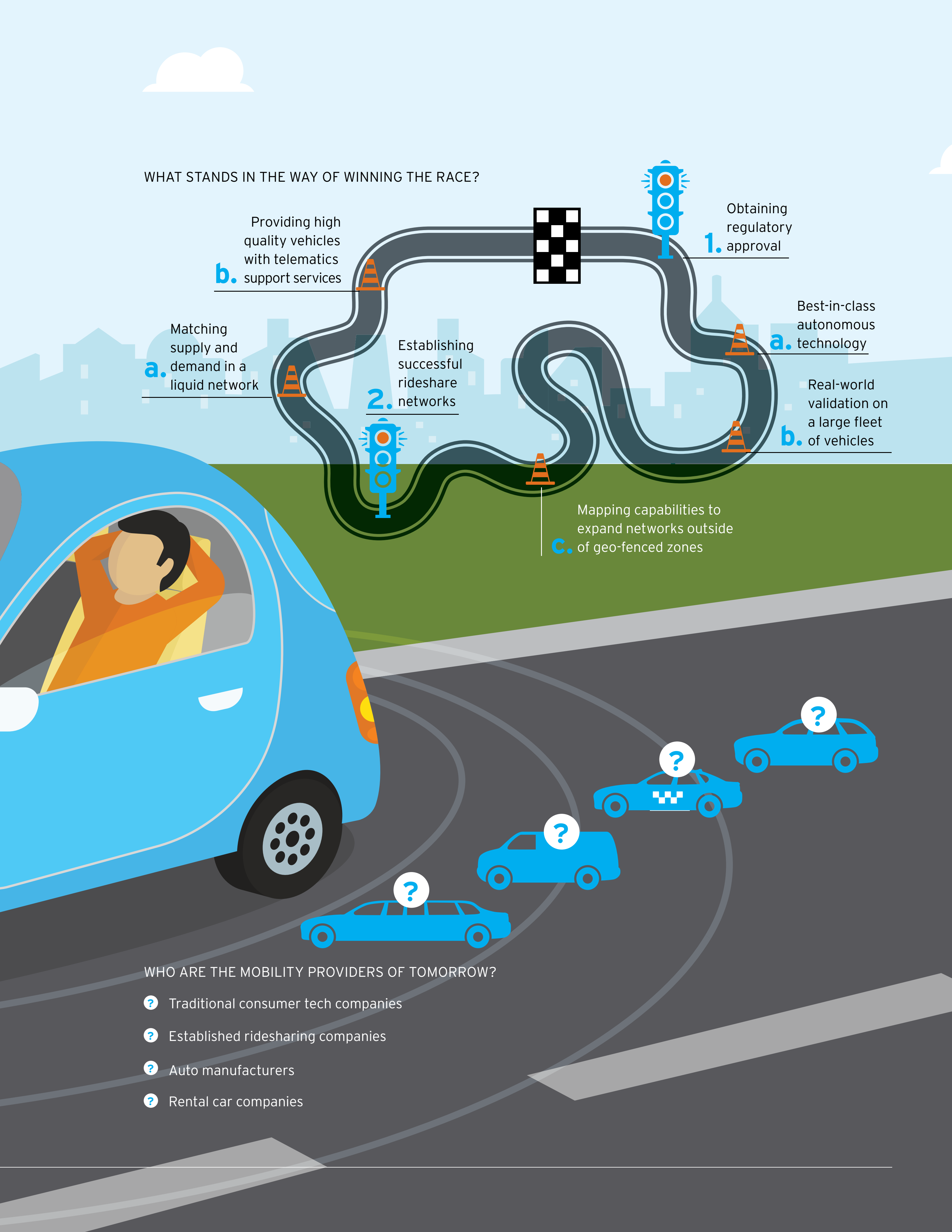
WHAT STANDS IN THE WAY OF WINNING THE RACE?
1. Obtaining regulatory approval
a. Best-in-class autonomous technology
b. Real-world validation on a large fleet of vehicles
c. Mapping capabilities to expand networks outside of geo-fenced zones
2. Establishing successful rideshare networks
a. Matching supply and demand in a liquid network
b. Providing high quality vehicles with telematics support services
WHO ARE THE MOBILITY PROVIDERS OF TOMORROW?
Traditional consumer tech companies
Established ridesharing companies
Auto manufacturers
Rental car companies

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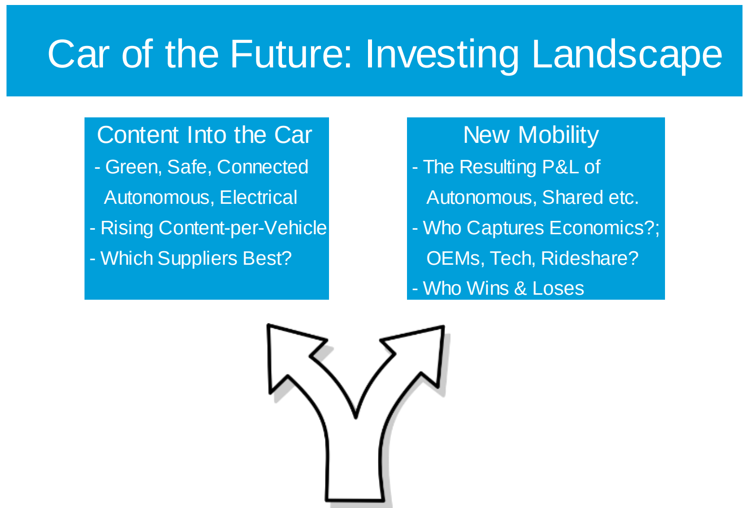
The Evolving Investing Calculus of the *Car of the Future*

"Traditional industry sees opportunity to change its business model"
– Mobileye Sept 2016

Automated Mobility on Demand (is) "motivated by economics rather than safety or convenience"
– Delphi, Sept 2016

Figure 1. Two *Car of the Future* Investing Tracks



Source: Citi Research

Summarizing Mobility 2030

At a top-down level, we believe the auto industry will undergo four profound changes between now and 2030:

- The era of on-demand mobility will reach an inflection point with driverless and connected vehicles entering the market over the next four to six years. This will yield business models providing autonomous on-demand ridesharing first in geo-fenced zones (i.e., Uber/Lyft –style services with on-demand driverless cars) and then eventually beyond. Each of tech, data, and regulatory approaches could play a role in determining leaders and laggards. Around the same time or perhaps a bit later, driverless capable cars will be offered for sale to consumers.
- Driverless cars will enable new shared ownership business models such as subscription services or timeshare approaches, ultimately culminating in broader integrated mobility networks.
- The cost of electrified vehicles likely reaches parity with internal combustion by the middle of the next decade. The resulting rise in electric vehicle (EV) penetration, safer cars (advanced driver assistance systems to autonomous), and driverless business models is likely to reduce the cost of personal car ownership.
- Connected cars and big data will enable new revenue and efficiency streams throughout the life of the car. The car becomes a central role in the internet of everything.

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What Changes the Least? Business models concentrated in rural areas or including commercial/utility vehicles like pickup trucks, large sports utility vehicles (SUVs), large vans, and luxury vehicles. These regions and segments will benefit from electrification and automated driving, but are less likely to have their consumption patterns fundamentally disrupted.

What Changes the Most? Personal mobility in major cities and surrounding areas. This is where on-demand driverless rideshare networks make the most economic sense from a congestion, parking, and pollution perspective. The change likely begins with driverless rideshare networks in geo-fenced zones before expanding beyond them. Lower cost and easier access to mobility will likely also increase the amount of miles driven and potentially take some share away from mass transit. The unlocking of time spent in the car also introduces new business models (specialized cars) and revenue (advertising etc.)

What Also Changes? New business models for consumers such as subscription services for autonomous vehicle networks. The aftermarket automobile industry could also be impacted if vehicles increasingly become managed by fleets versus individual consumers. Additionally, automakers could try to leverage big data in order to grab a greater share of aftermarket revenue throughout the life of the car. Changing tires no longer becomes a hassle if the car can drive itself to a dealer. New auto financing methods will likely also develop.

Who is the Mobility Provider of Tomorrow—Auto or Tech Companies?

Probably both but amongst automakers we think you will see both leaders and laggards. When it comes to urban on-demand autonomous networks, there is probably not enough room for every traditional automaker to participate in a meaningful way. For an automaker, a good position to start with is being less exposed to urban regions and more exposed to rural areas — and similarly less exposed to traditional sedans and more to utility/commercial vehicles. That's the defensive side. On the offensive side, automakers who aggressively embrace connectivity, autonomous, EVs, data, and partnerships could stand to gain, perhaps meaningfully. The autonomous rideshare vehicle won't be a mere commodity, in our view, as the intelligent design of both cars and the ride experience become ever so important to maximize load factor and market share. Rideshare companies have major advantages in having built liquid networks and critical data — which could have key implications both in the validation phase of autonomous cars, and competitively once driverless networks go live. Presumably technology and social media companies with existing consumer networks could also enter the market. As mentioned, the on-demand driverless business models starts with geo-fenced zones. Expanding a network beyond the geo-fenced zone will likely require crowdsourced maps from existing cars on the road — this is one aspect of the "data" we mentioned that automakers should embrace. In fact the importance of data can't be emphasized enough — from autonomous technology development for simulation and real-world miles, to validation and supply/demand matching. Those who can expand networks beyond geo-fenced zones gain a major edge over those who don't. In the final phase, automakers with a breadth of product could gain an edge in launching future autonomous subscription models (effectively a new form of leasing).

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What Happens to Automakers Who Don't Win the Urban Autonomous On-Demand Network Race?

Some automakers could pursue specialized services within autonomous ridesharing, such as shuttle services. Others could focus efforts in specific regions/countries — in fact we believe Frontier Markets are overlooked opportunities of the expansion for such services. Additional partnerships and consolidation amongst automakers is also possible, but regardless there are other areas beyond shared autonomous mobility where the *Car of the Future* is relevant. Big data analytics, other-the-air software services, and personalization could enable new revenue models, improve loyalty, and reduce automaker costs. When you really think about what's happening to the automobile — with EVs, connectivity/data, and autonomous capabilities — you're ultimately getting a vehicle with a reduced cost of ownership (EV + potential lower insurance) and a vehicle far more capable of generating revenue for the automaker/dealer/consumer over its entire life. Given that, today, automakers sort of miss out on certain lucrative parts of a car's life (aftermarket, financing), they theoretically have a fair amount to gain.

Suppliers will of course gain content with this industry change, but the bigger slice of the future revenue pie comes from integrated autonomous mobility networks combining ridesharing with new forms of car ownership. We think the question of leaders vs. laggards will become a major investor theme in the coming years.

Summarizing Technology Growth Profiles

Increasing electrification, automation, connectivity, and driver engagement technology will continue to drive content into an increasingly complex vehicle. Lear Corporation expects vehicle data exchanges to increase 20 times by 2020 and lines of software by 100 times. Delphi Automotive expects to ship 200 billion lines of code daily by 2020, up from 20 billion in 2015. By 2020+ Delphi expects multi-domain controllers to make decisions 34,000 times faster than a human.

Figure 2 summarizes expected compound annual growth rates (CAGRs) for various technologies within the car.

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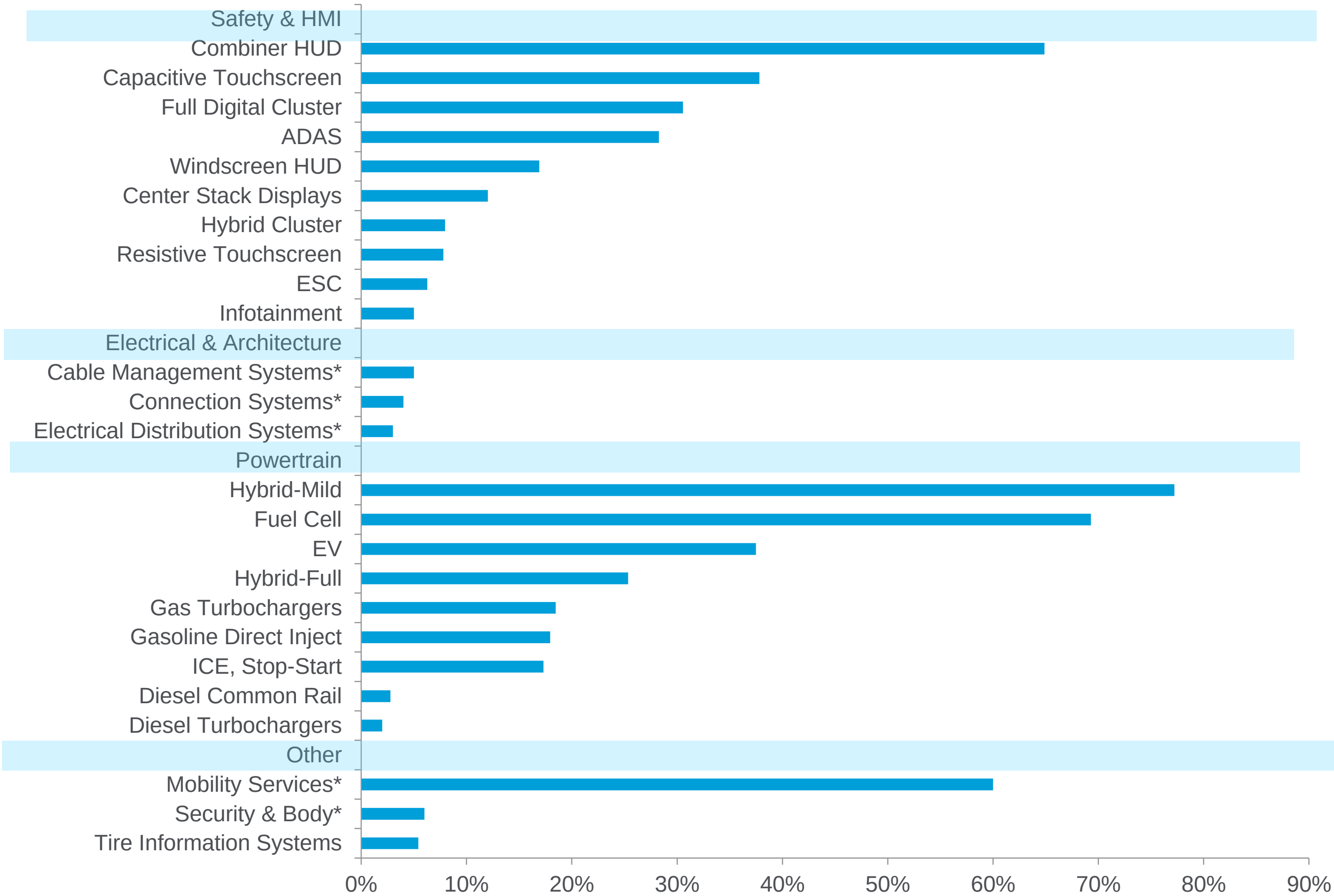
Figure 2. Growth of Major Automotive Applications and Products (Est. CAGR between 2015 and 2020)



Note: * denotes 2015-2018 CAGR
Source: Company data, Wards, IHS, Continental, BorgWarner, Delphi, Visteon, Magna, Mobileye, Citi Research estimates

Managing the All-Important Variable Cost Equation

The average car in the U.S. carries a variable cost of ~$20,000, of which we estimate that ~$14,350 comes from specific components with the remainder coming from other costs. Each year automakers must engage in a tug of war where commodity inflation, currency (FX), and regulatory requirements push up the variable cost of a car before any voluntary content is inserted. To offset these rising costs, automakers must seek efficiencies (global platforms), supplier price-downs, and de-contenting opportunities where possible. Given these industry challenges, the appetite to load non-mandated content naturally becomes more dependent on the ability to earn an acceptable mark-up on that content, market share or brand equity support. The good news for automakers is that some of the new content is expected to generate incremental revenue (i.e., big data, autonomous ride share). Indeed automakers appear engaged in a content race to chase after these new revenue streams. This can be viewed as somewhat of a departure from the more measured regulatory-driven content adds of the past.

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Figure 3. Average Variable Cost per Vehicle, Excluding Specific Original Equipment Manufacturing Cost

Variable Cost per Vehicle = ~$14,350

Component	CPV
Propelling the Car of the Future	**$4,800**
Engine (Turbos, Timing, Ignition, etc.)	$2,000
Transmission	$1,600
Fuel System	$400
Axles	$800
Full Size Trucks (front/rear axles & driveshafts)	*$1,600*
AWD	*$1,200*
Front/Rear Non-AWD / Non-Disconnecting	*$600*

Component	CPV
Saving Lives in the Car of the Future	**$700**
Passive Safety	$300
Active Safety	$400
Cost per Camera unit	*$88*
Cost per Radar unit	*$120*
Cost per LIDAR unit	*$200*

Component	CPV
Connecting the Car of the Future	**$2,150**
CSD	$500
Unconnected Nav Unit	*$600*
Hybrid MFP	*$600*
MFP	*$700*
Connected Telematics Head Units	*$300*
Instrument Cluster	$100
Touch Screen	$50
Electrical & Electronic Architecture	$1,500

Component	CPV
Building the Car of the Future	**$6,700**
Seats	$1,200
Stamping & Frame Structure	$2,100
Exterior Lights	$200
Rear	*$100*
Front	*$100*
Interior Lights	$20
Exterior Mirrors	$100
Interior Mirror	$30
Instrument Panel, Door Panel, Cockpit Assembly	$700
HVAC/Cooling	$400
Engine Cooling	*$100*
HVAC	*$300*
Brake System	$330
Pads	*$30*
Engine elements & Master Cylinder	*$200*
Calipers & Foundation Brakes	*$100*
Ride Performance	$500
Dampers	*$200*
Architecture, Leaf Springs, Struts, etc	*$300*
Exhaust System	$250
Manifold	*$35*
Cold End	*$85*
Converter	*$130*
Steering System	$340
Steering Wheel	*$50*
Full Electric Power System	*$290*
Glass Components	$130
Tires	$200
Rims	$200

Note: Individual Component values are rounded.
Source: Delphi, Tower International, American Axle, Magna, Visteon, Denso, Hella, BorgWarner, Autoliv, Lear corporation, Faurecia, Gentex, Tenneco, Superior Industries, American Chemistry Council, IHS, Citi Research estimates

It's all about the End Consumer…

What hasn't changed is our philosophy around which technology verticals are most investable. Most Tier-1 auto suppliers claim their products reduce weight, improve safety, reduce noise, vibration and harshness (NVH), and so on. Certain technologies even have regulations on their side, such as passive and active safety as well as certain emissions systems. But what ultimately differentiates good technologies from great ones is whether consumers actually demand and pay for them. Margin comparisons across the supplier group seem to support this view — it might sound simplistic but if the automaker is using a supplier's technology to promote the automaker's vehicle, that supplier should earn a good return.

So ask yourself: Is a car company using supplier XYZ's technology to sell you a car? Or does it put that automaker in a better positon to reap future revenue from the technology? If so, what does the competitive landscape look like? What value do suppliers add, what are their research and development (R&D) requirements and how scalable is this technology? And can the automaker "fund" the addition of the content by taking cost reductions elsewhere in the vehicle or by clearly improving the cost of ownership to the end user (i.e. through lower insurance or fuel efficiency)?

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As a first step in evaluating the investment worthiness of automotive technologies, we ask many of the questions posed above (outlined in Figure 4 below). This is an admittedly simplistic approach that mainly focuses on public Tier-1 suppliers as opposed to all players in a particular supply chain. But it should provide investors with a tool to compare different technologies at least during the initial screening process. The answers are color-coded from green to red depending on how well the technology screens to the question. The table below covers many of the technologies covered later in the report.

From a supplier perspective, the technologies that screened best include autonomous driving features, advanced driver assistance systems (ADAS), turbocharging, and stop-start, followed by broader electronics/infotainment. Electric vehicles are gradually getting there too as costs continue to come down, though we're not at mass market levels yet.

Figure 4. Auto Technology Investing Framework – Select Examples (green – positive, yellow = possibly, red = not likely)

	ADAS	Semi-/Full-Auton Driving	Turbos	Stop-Start	Light weighting	Info tainment	GDI	Connectors	EV	Dynamic Clusters	Emissions Systems	OTA
Regulatory Driven?	Green	Red	Green	Green	Green	Red	Green	Yellow	Green	Red	Green	Red
Customer Value-add?	Green	Green	Green	Yellow	Red	Green	Yellow	Yellow	Green	Green	Red	Green
OEM Selling Point?	Green	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Red	Green
Customer Affordability?	Green	Yellow	Green	Green	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow
OEM Scalability?	Green	Green	Green	Green	Yellow	Green	Green	Green	Yellow	Green	Yellow	Green
Competitive Landscape?	Yellow	Yellow	Green	Green	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Yellow
Funded by Content Reduction?	Red	Red	Yellow	Red	Yellow	Red	Yellow	Yellow	Green	Yellow	Yellow	Yellow

Source: Citi Research

…And It's Also About Tracking Option Take-Rates & Mix

Many Auto/Tech investing themes are indeed secular in nature; they're being driven by regulations, consumer demand or new business models. However, where Auto/Tech investing often goes wrong is with common blanket assumptions that the technology penetration curve is predictably linear. This may hold in the long term perhaps, but shorter-term it's not always the case. Often times new technologies are first offered either as options or as standard equipment on a higher trim level (i.e. available only on the "platinum" version of a vehicle). We often find misconceptions that Auto/Tech investing (i.e. a technology penetration story) is entirely removed from the macro element of autos (i.e. car pricing, mix, health of the consumer). That's simply not the case over the near-term period, in our view. For example, if one is extremely bearish about auto pricing and the overall cycle, even new technologies could take a short-term hit from that. This is important to understand.

One problem we face is that tracking real-time option take-rates and vehicle trim mix is notoriously difficult. Each month investors see sales volume data (SAAR) but not the break out of trims and options. Pricing data can help triangulate this data a bit but it is insufficient, plus not every analyst/investor accesses such data. This creates questions that are often difficult to answer: (1) How resilient are content stories to various macro inputs? and (2) What is the sensitivity of macro inputs on supplier XYZ's near-term revenue outgrowth prospects?

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The lack of data creates issues and, in our view, sets investors up for near-term revenue volatility that's difficult to track ahead of time. Even when that volatility is temporary (i.e. technology XYZ must be mandatory by 1234 year but for now is offered optional), the resulting revenue swings can sometimes catch investors by surprise and impact valuation multiples.

Over the past year the Citi Autos Team has internally developed tools to begin tracking option and trim mix penetration in real U.S. vehicles. The product, known as Megatrends LIVE!, is reviewed later in this report and is a key tool to helping investors track the more real-time progression of the *Car of the Future*.

Figure 5. Select Global Auto Supplier Exposure Matrix

	ADAS/Autonomous	Electrical/Electronic Content	Infotainment/HMI	Fuel Economy	Electric Vehicles
United States					
Magna	✓			✓	
Delphi	✓	✓	✓	✓	✓
BorgWarner				✓	✓
Autoliv	✓				
Lear		✓			
Mobileye	✓				
Visteon			✓		
TE Connectivity		✓			
Sensata		✓			
Amphenol		✓			
Europe					
Continental	✓	✓	✓	✓	✓
Valeo	✓	✓	✓	✓	✓
Schaeffler				✓	
Hella	✓	✓			
Japan					
Denso	✓	✓	✓	✓	✓
Aisin Seiki	✓		✓	✓	
Korea					
Hyundai Mobis	✓	✓	✓	✓	✓
Mando	✓	✓		✓	✓
Hanon Systems		✓		✓	✓
India					
Motherson Sumi		✓			

Source: Company reports, Citi Research

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Transforming Mobility as We Know It

Much like the rapid evolution of the *Car of the Future* itself, over the past year we've described a similar evolution in Mobility of the Future. No longer is the auto industry merely racing to build capability to improve the car (EV, connected, autonomous), but now is increasingly racing to redefine mobility as we know it (ride/car share, eventual driverless). And no longer is content rushing into the car merely to meet regulations. Today, content is entering the car to build capability and data to usher in new business models. It's probably safe to crown 2016 as the year where the industry race for new mobility became as evident as ever with partnerships and product announcements seemingly occurring every month — including the traditionally slower August. As we've argued in past reports, this is no longer some futuristic exercise but a very real race to lead the next era in mobility. It's an era that promises both lucrative new business models (vs. today's auto economics) and new competition and skill sets.

First, What's this "Race" All About?

Racing towards driverless business models

While there are clear merits within the ADAS and semi-autonomous races (particularly with over-the-air, as discussed later), as well as within current ride/car-sharing models, we believe the real industry game-changer occurs once we enter the driverless era, both within rideshare services and personally-owned vehicles. Later we'll talk about technology and the pathway but for now let's review the end game as we see it.

The following represent some of the commercial (and pretty neat) use cases:

"The ability to navigate smoothly on the road, while subtle, is also an important advanced driving skill that helps people feel comfortable whether they're inside or outside of the car"
– Dimitri Dolgov, Head of Google's Self-Driving Technology (Sept 2016)

- **On-demand driverless rideshare networks in urban environments:** This is the so-called robotaxi model situated in highly dense cities/surroundings where dedicated taxi fleets can be utilized >70% carrying multiple occupants and/or other goods. We estimate that, in highly dense cities, a robust driverless taxi network could charge $0.25-0.50 per mile (per person) and still earn strong gross margins. That would compare to a personal car costing consumers an estimated $0.76 per mile in the 2020-2025 time frame. A 2014 MIT study (Spieser, Treleaven, Zhang, Frazzoli, Morton & Pavone) calculated a total U.S. cost of shared self-driving cars at $0.71 (per km) vs. $1.37 for a human driven car. Ford recently estimated that autonomous services would cost $1.00 per mile vs. $0.70-$1.50 for personal owned vehicles. We actually view Ford's $1.00/mile estimate as conservative since it doesn't seem to account for a potential higher load factor (i.e., multiple occupants etc.). Mass transit is estimated at $0.30/mile which, while affordable, does not offer a last mile solution. We've previously estimated that the 2030 U.S. profit total addressable market (TAM) on a modest ~3 million driverless service installed base could be wrapped around $20 billion. Once arrived, these networks are likely to compete on three areas:
  - Price — a function of load factor (people & things/unit) and scale;
  - Convenience — a function of a liquid rideshare network, quality of the vehicle, and servicing of the fleet (i.e. reliability of fleet); and
  - Experience — the interior design of the car will be important to maximize load factor without sacrificing the experience. Service in the form of telematics will also be important. Ride quality comes into play here too — a sometimes overlooked aspect that was recently touched upon by Google (see quote to the left). Eventually, the customer experience could span multiple modes of transport within an integrated mobility network offering consumers various mobility choices.

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- **Expansion of addressable market:** Public transportation still captures a 5-15% share of U.S. commutes. Well-run driverless carpools (i.e. multiple occupants) could create a similar lower-cost commuting alternative with the luxury of being picked up/dropped off at home and without forcing customers to plan around bus/train schedules. Providing mobility to the elderly and disabled would also expand the market by possible raising miles driven. Other industries could conceivably also benefit from this step-function improvement in the cost and convenience of mobility. Globally, it's conceivable that mobility could expand into countries/regions that are currently under-saturated with personal vehicles (see Appendix A).

- **Car peer-to-peer timeshare models:** There is still something gratifying about owning an asset, and there is clear value in having the instant freedom of mobility that comes with having your own car. But who needs to own all of it, or any of it? Driverless cars could unlock car timeshare models where people with comparable schedules could partially own the vehicle — with a dealer in between to ensure proper care by the individual owners. Consumers owning such cars could also lend them to ridesharing networks in exchange for a fee, helping improve the affordability of personally-owned autonomous cars. And what if insurance premiums also decline for these inherently safer vehicles where the sensors revert to an ADAS role when the human is driving? That too might help fund the likely $5-8k cost of a fully autonomous feature set (in the early 2020s period) and accelerate adoption. In fact, under certain scenarios it's conceivable that fully autonomous systems could be totally or at least mostly funded by such setups.

- **Automaker subscription models and integrated mobility networks:** Hybrid models could form whereby buying a Ford or a Chevy could become a subscription to an entire fleet with the option of switching cars throughout the subscription. This could be part of an integrated mobility platform as described above. Need an SUV for a long trip? A pickup for a specific job? A sports car for an occasion? Besides new models of ownership, driverless vehicles promise to offer some pretty neat features. Going into the city for a night on the town and don't want to spend 30 minutes looking for parking? A driverless capable car could drop you off and pick you up later. And during that period you could have the option of lending your car out to a rideshare company in exchange for a fee. Don't like waiting 30-60 minutes while your car is being serviced? Have your driverless-capable car go get serviced while you're at work or while you're sleeping. No more delaying replacing your tire or other services because you don't feel like going through the shopping (and waiting) experience. Of course a fully autonomous car also unlocks value for consumers by freeing up time normally reserved for driving that can now be used for work, media consumption etc.

What also makes this megatrend so powerful — besides the commercial case — are the potential societal implications for safety, congestion, pollution, personal mobility, and efficiency. This, in our view, creates an almost unprecedented alignment of interests to pursue this path even when unexpected setbacks occur (as they often do). Automakers could eventually argue for regulatory corporate average fuel economy (CAFE) credits for removing cars from dense cities plagued by pollution.

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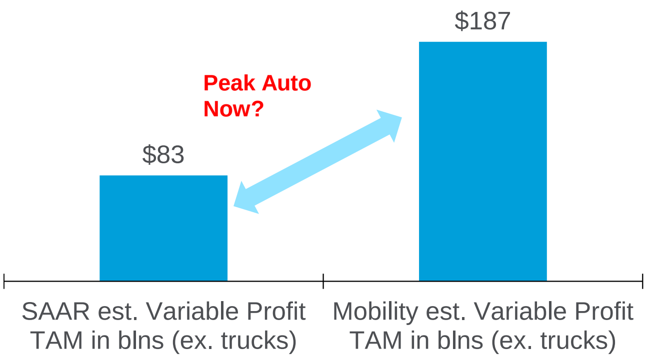
As a side note, it's ironic that here in 2016 we see the market debating whether we are at "peak auto" all the while new technology points to a future of safer, cheaper, and better experiences within a larger and more profitable future mobility industry. Collectively we continue to roughly estimate the U.S. driverless variable profit total addressable market at ~2x the seasonally adjusted annual rate (SAAR) TAM (ex. trucks). Ford has also previously pegged the transportation services revenue total addressable market at $5.4 trillion, about 2 times that of the $2.3 trillion traditional automotive revenue pool.

Figure 6. Variable Profile Total Addressable Market (SAAR vs. Mobility)



Source: Company reports, Citi Research

Figure 7. Simulated P&L for Driverless Mobility Network

	Revenue	Other Revenue	
Revenue			
Productive Miles	66,500	Weather Services	
Fee / Mile	$0.52	Road Conditions (Municipalities)	
Miles Revenue	**$34,497**	Map Updates	
+ Data Revenue	$5,175	Real-Time Parking Spaces	
Total Revenue	**$39,671**	Real-Time Traffic	
		Location & Trip Based Advertising	
COGS		Leveraging Consumer Time in Car	
Propulsion (EV)	($2,030)	Live 3D Maps	
Insurance	($1,620)	Delivery Services	
Car Payment	($9,148)	Law Enforcement Services	
		Social Media (increase riders/ car...user experience)	
Maintainence	($8,546)		
Total:	**($21,344)**		
		Fleet Size	600,000
Gross Profit	**$18,327**	Revenue	$23,803
Gross Margin	46%	Op Margin (@8p	16.5%
		Op Profit	**$3,920**
D&A	$8,620	Tax Rate	30%
Gross Profit (D&A)	**$9,707**	**Net Income**	**$2,416**
Gross Margin	**24%**	- Multiple	15.0x
		Value:	**$36,243**

Source: Company reports, Citi Research

While the race is often described as singular, in reality one could break it down into three distinct stages:

- **Stage-1: Rideshare "robotaxi" in a geo-fenced zone:** Offering autonomous on-demand rideshare services such as Uber/Lyft-like services in a specific zone within a city. We're not referring to a small zone where only autonomous taxis can operate (though some cities might conceivably opt to start like this including with pre-determined routes) but rather a zone that's shared with human-driven cars. That zone would likely be mapped through high definition (HD) maps and camera-based crowdsourced maps.

- **Stage-2: Rideshare "robotaxi" beyond a geo-fenced zone:** The expansion beyond the geo-fence occurs once confidence is gained about the performance within the geo-fenced zone. The key to this expansion, in our view, lies in having broader real-time mapping capabilities and the ability to service fleets beyond geo-fenced zones. This is an important step because it could be the catalyst that actually encourages owners of vehicles in cities to abandon their owned cars in favor of the rideshare services. Said differently, we don't view it as likely that car owners living in major cities (including high income earners) abandon their owned vehicles merely to access geo-fenced robotaxis. But perhaps they might if they feel those taxis can take them beyond the cities. The expansion beyond geo-fences might really be regarded as the true arrival of the driverless car era.

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- **Stage-3: Driverless capable cars you and I can buy or lease:** Once a rideshare robotaxi can go anywhere, it's only logical to begin offering such features on personal-owned cars. We imagine these features would be offered as options given their high cost ($5-8k). Here, servicing and real-time crowdsourced mapping are also important. While this model could be similar to today's auto model of selling vehicles direct to consumers, here too interesting new models exist including subscription services and timeshare models. Given the projected high cost of autonomous systems, rideshare outlets could also become vital as consumers could be offered cash in exchange for loaning out their cars to rideshare fleets during certain times. This would help keep rideshare fleets more asset light, reduce congestion even further, and allow more consumers to afford the safety and convenience fully autonomous cars can offer.

Ok, so that's a brief summary of some of the business models in play.

So What's Everyone Racing Towards?

As we currently see it, two things:

1. Obtaining regulatory approval to sell and distribute driverless cars, and

2. Establishing successful rideshare and other business models around them.

Throughout the discussion we'll refer back to the 3 pillars we view as being important to succeed in this race.

1. Obtaining Driverless Regulatory Approval

Launching a driverless car service isn't straightforward given prevailing regulations that mandate a human driver inside the car. And to be sure, the U.S. regulatory process for obtaining driverless certification hasn't really been fully established yet, at least broadly. A number of states like Florida and Michigan have offered legislation that's seemingly friendly to self-driving cars, as did California most recently. But several companies, including Google, have called for federal government leadership to avoid having a patchwork of state laws and regulations. According to Google's March 2016 Congressional testimony, 23 states had at the time introduced 53 pieces of legislation affecting self-driving cars. While the five states that passed legislation all intended to assist self-driving development, Google noted a lack of consistency with respect to definitions, licensing structures, and expectations. Delphi also called for uniform rules across all states addressing issues like state licensing requirements and federal mandates for certain features that presume a driver is in the car. Recent discussions with Ford also suggested a desire for a federal approach much like that of CAFE fuel economy regulations.

Thus, the regulatory framework for the final leg of the climb — that is, obtaining regulatory approval to operate driverless cars — is absolutely critical to monitor and could conceivably have implications on leaders and laggards, as described in more depth later in the report. Note that when we discuss driverless certification we generally focus on driverless "everywhere" and not merely a fleet operating in a geo-fenced zones or Level-4 vehicles with driver monitors. While it's unclear whether regulators will necessarily distinguish certifications by a car's use case, the race we refer to is really about driverless operation everywhere.

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In September 2016, the U.S. Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA) published guidelines for federal automated vehicle policies. While the guidelines are just that, they do provide a detailed look into the current regulatory thought process. The guidelines listed 15 safety assessment buckets ranging from safety, privacy, cybersecurity, design domain and validation, amongst other.

The regulators noted that companies, "should follow a robust design and validation process based on a systems-engineering approach…The overall process should adopt and follow industry standards, such as the functional safety process standard for road vehicles and collectively cover the entire design domain of the vehicle". Further, regarding validation the guidelines suggested that it "should include a combination of simulation, test rack and on-road testing".

The DOT/NHTSA guidelines went on to offer possible paths to certification including:

- **Safety Assurance:** Companies reporting pre-market testing, data, and analyses to demonstrate best practices and other performance criteria.

- **Pre-market approval authority:** Though not presently part of NHTSA's authority, this approach would replace the self-certification process currently done under the Federal Motor Vehicle Safety Standard (FMVSS). The approach would be similar to how the Federal Aviation Administration (FAA) regulates the safety of autopilot systems on commercial and unmanned aircraft.

As we see it, the critical issues/questions are as follows:

- What are the regulatory and societal tolerances for accidents/malfunctions for driverless vehicles? And based on that how does one define industry best practices around safety and cybersecurity?

- If the tolerance is extremely small, then part of this race ends up being about extensive validation in order to ensure full discovery of rare corner cases for sensing and driving behavior…

- …such discovery could be done in lab simulations, real-world driving or some combination of the two. This is actually somewhat of an area of debate, as some artificial intelligence (AI) experts believe simulation is sufficient while others believe real-world must be utilized even more.

- This lab vs. real-world validation debate could actually become important for the outcome of the race. For instance, rideshare firms or automakers with ties to rideshare firms could be advantaged if regulators lean towards real-world validation, since rideshare outlets arguably allow for higher-quality (random, unbiased) mile accumulation. Similarly, automakers with large fleets could be advantaged to the extent fleet learning can be used to train driving behavior simulations. Later we'll talk about the advantages of crowdsource mapping, but regardless in all aspects the extent of real-world data usage to learn, simulate or validate could become a key element of this race.

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The DOT/NHTSA guidelines didn't appear to take a strong side on the lab vs. real-world validation debate. Our own discussions with automakers and suppliers also yielded differing views. Few deny that real-world validation has significant merit in finding ground-truth both to satisfy regulatory concerns and improve customer adoption. However, other companies, including Ford, have suggested a balanced view noting that simulating scenarios in the lab is more productive than accumulating miles for the sake of accumulation, though miles accumulation clearly is part of the equation too. We tend to agree that all miles are not created equal — the key, in our view, is to accumulate valuable miles in different settings under different sets of challenges.

For now our working assumption is that real-world validation will likely be preferred both by regulators and consumers with respect to accepting driverless cars everywhere (i.e. many Level 4/Level 5 vehicles have driven a huge amount of miles in varied conditions with a driver or controlled condition with zero serious disengagements).

So this takes us into a brief review of pillar #1.

Pillar #1: Full Autonomous Capability (and Data)

This pillar is about achieving state-of-the art capability in sensing, mapping, path planning, driver policy, cybersecurity, redundancy, and quality. So in other words achieving a fully operational, safe, and secure autonomous vehicle that can eventually drive everywhere under any condition without the need for a human driver.

We'll discuss product plans and technology in the more detailed section below, for now we continue the discussion on the end-game — achieving satisfactory validation results to either be approved or have the confidence to launch driverless cars.

As noted above, our working-assumption is that regulators will ideally prefer seeing tons of real-world validation data — i.e. I've operated a Level-4 fleet with driver monitors for XYZ miles (very big number…the bigger & more diverse the better) and experienced ABC disengagements (very low number or 0).

Becoming "road worthy": The aviation market is actually an interesting one to compare to autonomous cars. Even today's modern commercial aviation operate in what can be described as Level-2/3 autonomy, despite the fact that planes fly in generally controlled environments and often with the assistance of air-traffic-control. When thinking about the ultimate process that driverless cars will need to undergo for certification, we find it interesting to revisit the history of the Concorde. A timetable is shown in Figure 8 below, but it's notable that the Concorde took several years after first-flight to achieve airworthiness certification.

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Figure 8. The Flight of the Concorde

The Flight of the Concorde

Event	Concept	Feasibility Study	UK, France sign draft treaty for development	First prototype unveiled	First flight	First supersonic flight	First non-stop crossing of the Atlantic	French Certificate of airworthiness	British certificate of airworthiness	First commercial flight
Time	1950s	11/4/1956	11/28/1962	12/11/1967	3/2/1969	10/1/1969	9/26/1973	10/9/1975	12/5/1975	11/21/1976
Timeline Between Events		6.1 yrs	5.0 yrs	1.2 yrs	0.6 yrs	4.0 yrs	2.0 yrs	0.2 yrs	1.0 yrs	
Time to Commercialize		20.1 yrs								

Aircraft Used During Testing

	Production Model Number	Date of First Flight	Location of First Flight	Date of Last Flight	Total Flights	Total Block Hours	Average Block Time Per Flight	Supersonic Flights	Supersonic Flight Time
<u>**Prototype Aircraft:**</u>									
Concorde F-WTSS	1st Prototype	3/2/1969	Toulouse, France	N/A	397	812.3 hours	2.0 hours	249	254.8 hours
Concorde G-BSST	1st UK Prototype	4/9/1969	England	3/4/1976	438	836.2 hours	1.9 hours	196	173.4 hours
<u>**Development Aircraft**</u>									
Concorde G-AXDN	UK PPM	1217/1971	Filton, England	4/16/1969	273	632.9 hours	2.3 hours	168	Mach 1+: 217 hrs; Mach 2+: 170 hrs
Concorde F-WTSA	French PPM	1/10/1973	Toulouse, France	5/20/1976	314	656.6 hours	2.1 hours	189	280.8 hours
Concorde F-WTSB	100-001	12/6/1973	Toulouse, France	4/19/1985	423	909.9 hours	2.2 hours	247	339.4 hours
Concorde G-BBDG	100-002	2/13/1974	England	12/24/1981	633	1435.1 hours	2.3 hours	374	514.2 hours
Total					2,478	5,282.9 hours	2.1 hours	1,423	1,779.6 hours

6.1 yrs 5.0 yrs 1.2 yrs 0.6 yrs 4.0 yrs 2.0 yrs 0.2 yrs 1.0 yrs 20.1 yrs

Source: BBC News, Concorde SST, Citi Research

We've recently seen supportive comments for our long-held view that much of this race is ultimately about data — both for training AI networks (fleet learning), mapping, policy, and eventually validating Level-4 cars. A few data points:

Mobileye's Professor Amnon Shashua, June 2016:

"…from a regulatory point of view, you'll have to have someone behind the steering wheel for a few years in order to gain confidence, in order to gain statistics that these things are safe. And then only when society has enough statistics that these cars are really safe then the driver can be out…"

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(Regarding full-autonomous driving) "we're shooting for 99.999999% accuracy"
– NVIDIA CEO, Jen-Hsun Huang, Sept 2016

Dmitri Dolgov, Head of Google's self-driving technology, in Sept 2016:

"A self-driving car that can get you safely from door to door has to understand the nuances of the road, which only comes with experience. That's why our team has been focused on gaining real-world experience….it's relatively easy to master the first 90% of driving where you're traveling on freeways, navigating light city-street traffic, or making your way through simple intersections. But to create a truly self-driving car that can do all the driving, we knew we'd need experience in the most challenging situations. That's why we now spend the vast majority of our time on complex city streets…It takes much more time to accumulate miles if you're focused on suburban roads; still, we're gaining experience at a rapid pace. In the last few years, we've been focusing on the harder tasks of driving—the final 10%--that takes much more time and experience to master."

So How Many Cars? How Many Miles?

A recent RAND Corporation study concluded that it would take a fleet of 100 autonomous cars 11 billion miles (or 500 years) to demonstrate better safety performance than human drivers. Similarly, in September 2016 Toyota was quoted (by Forbes) as estimating that 8.8 billion miles of testing, including simulation, are required.

One way to solve this would be to allow for simulated virtual driving not only for testing but also for validation. Another would be to collect real-world data for testing purposes using existing cars or even dash-cams as some companies are pursuing. Another would be to rely mostly or entirely on tens of thousands of validation cars driving in the real-world. Of course, even then it would be crucial that companies not move into the validation phase from the development/testing phase too quickly, since presumably every major disengagement event during validation could set the clock back meaningfully. And then comes the question of what is the right validation, or the right types of miles to ensure safety in all reasonable conditions. As discussed later, this is where having rideshare outlets could come advantageous since validating in rideshare settings (i.e. autonomous car with a safety monitor) would arguably allow for the most real-world and unbiased mile experience.

Even after achieving a driverless certification for a geo-fenced zone, the work isn't done. For example, we believe that expanding a driverless network beyond a geo-fenced zone will likely require greater crowdsourced mapping capabilities to augment onboard sensors. This is because maintaining HD mapping becomes increasingly difficult over a larger region, thus data from other cars on the road is critical to gaining confidence outside a geo-fenced zone.

So to sum up this pillar, we believe keys to success include:

- Best-in-class autonomous technology in sensing, mapping, policy/controls, and related areas like cybersecurity, privacy, telematics etc.;
- Potentially access to real-world data for training purposes;
- To the extent regulators end up preferring real-world validation as a best practice, the ability to execute validations on large fleets; and
- Crowdsourced mapping capabilities to expand networks outside of the geo-fenced zones

Later we'll quantify the data portion of this in more detail.

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2. Establishing Successful Rideshare Networks & Other Business Models

This is where the next two pillars enter the equation:

Pillar #2: Supply/Demand Matching (The Network)

The robustness of a driverless mobility network also depends on the network itself. A more liquid network (i.e. larger in size with ample supply of riders and cars) would maximize the fleet's load factor (or # of people/things per car) thereby allowing fleets to charge even lower fares and compete more effectively. For regulators, the preference for a liquid network with a higher prospective load factor would stem from the need to reduce congestion & pollution.

Ride sharing could also be advantageous during the validation phase described above. Seeing that fully autonomous cars will initially be fairly more expensive ($5-8k or more system cost + safety driver salary), leveraging a revenue-generating rideshare outlet could enable a larger validation fleet than someone without such an outlet. Ride sharing firms like Uber/Lyft/Gett/Juno (and Didi, Ola outside of the U.S.) could have an inherent advantage here having already built a customer network and strategic data in key cities.

So which is more important: Pillar #1 (autonomous capability) or Pillar #2 (rideshare or supply/demand matching)? Well since you can't get to the finish line without Pillar #1, then by default it can be considered most important. In addition, winning the driverless race could allow someone to quickly build a rideshare network and catch up — particularly if they already have established consumer networks such as the likes of Apple, Google, Amazon or Facebook. This likely explains why both Uber and Lyft are engaged in self-driving efforts of some fashion — Uber developing mostly in-house while Lyft leaning on the GM partnership at the moment.

But while Pillar #1 is more important, the margin isn't necessarily huge if one subscribes to the view that rideshare outlets could become a major competitive advantage in validating Level-4 vehicles with safety drivers (more cars = more data). In other words one could argue that you almost need Pillar #2 to successfully complete Pillar #1, though again this depends on our working assumption around regulatory validation requirements/preferences. So this likely explains, at least partially, why GM partnered and invested in Lyft, why GM launched its Maven car-share business (who also recently announced a pilot with Uber), why VW partnered/invested in Gett, and why Toyota and Volvo have both partnered in some capacity with Uber. One could also surmise that Google and Apple could also consider playing a future role in the network-related pillar, and at least Google is actively pursuing self-driving capability.

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Pillar #3: Fleet Service/Hardware

A slightly less exciting pillar of the three but nonetheless vital is fleet service and hardware. In order to encourage consumers to abandon personal cars (in dense cities) and switch to networked mobility, the quality of the vehicles and the servicing of the vehicles is imperative. Think of the load factor point from above — cars designed with partitions to comfortably accommodate multiple passengers could be preferred in a dedicated urban rideshare setting. Networks with readily available dealers and telematics support services (what happens if a rider refuses to get out of the car or a crime is committed inside the vehicle?) will also be important. Those automakers with existing telematics infrastructures could also leverage those costs on the mobility network, thereby being able to compete better on price. Remember, networks compete on the basis of price, convenience and experience.

Electric vehicles also come into play here, as EVs can have inherent advantages with fully autonomous features and might also be preferred by regulators. Automakers ahead on EVs could have a key advantage in offering EV vehicles with superior cost and range performance to a rideshare network.

In our view, to run driverless networks, you need cars — high quality, highly engineered cars likely with some degree of electrification. And you need a lot of service and know-how to complete the circle of a successful network.

Three Phases to the Driverless Path

Today, the industry is racing towards advancing autonomous capabilities (deep learning, AI, computer vision, sensors, mapping) and all of its surrounding verticals (cybersecurity, connectivity, legal issues). These are all obviously critical and we've seen various investments, mergers & acquisitions (M&A) and collaborations around it. We refer to these as the development & testing phase. Once systems are deemed fully developed, the validation phase begins followed by production.

Phase #1: Build Capability, Test & Start Validating (<2021)

Today the industry appears fully engaged in developing: (a) autonomous capability and related verticals; and (b) ridesharing outlets, or increasingly both. The technology isn't quite ready from both a hardware and software perspective, but it's moving along rapidly and companies aren't waiting around to watch it pass by. Over the next few years we expect major advances in sensing hardware (fields of view, resolution, range, advanced radars, solid-state LiDARs), software (deep learning etc.), and computing power. A full product review section is provided later, but a few examples of recent events:

- BMW-Mobileye-Intel announcing a fully autonomous program by 2021
- Google, Uber and others testing autonomous cars on real roads
- Nissan's Intelligent Driving System (IDS) vehicle concept
- Ford committing to a driverless car by 2021
- VW also committing to fully autonomous by 2021
- Delphi-Mobileye autonomous car partnership for production readiness in 2019
- Volvo-Autoliv to create a new company for autonomous offerings by 2021
- A number of partnerships, M&A, collaborations and investments

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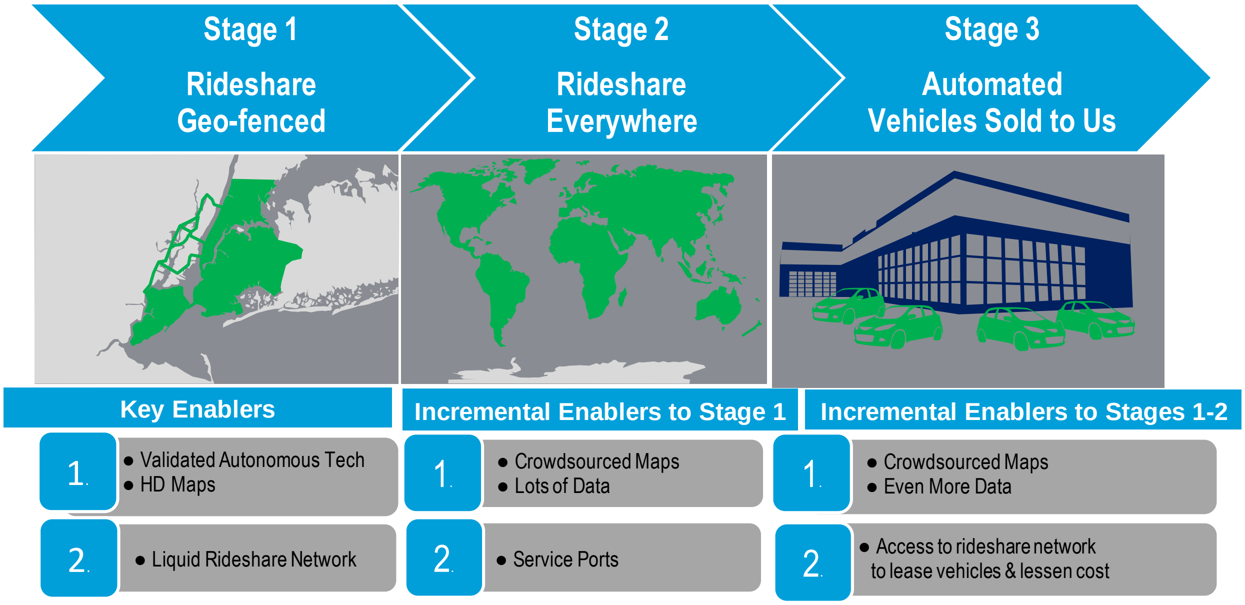
Figure 9. Three Stages to the Autonomous Race



Source: Citi Research

Phase #2: Validate, Certify & Launch Geo-Fenced Autonomous On-Demand Rideshare Networks (2019-2025+)

After the development and testing phase comes the validation phase. Based on our regulatory working assumptions from above, we believe that regulators will want to see compelling evidence of the safety and robustness of a driverless fleet before approving the removal of the driver. In other words, show me that the very car you intend to use for driverless services has proven its "road worthiness" to be much safer than a car with a human driver. So over the next few to several years we're likely to see Level-4 fleets deployed in commercial environments for validation in addition to testing/developing. These fleets would gather validation data and build customer confidence in the services. At first the geo-fenced vehicles could have drivers, then shift to a driverless phase (perhaps at low-speed) but still confined to the geo-fenced zone. A couple of points on this phase:

- GM has already indicated that it will launch Level-4 capable vehicles (with a driver monitor) into the Lyft network within the coming years. This was first indicated at the 2016 Citi *Car of the Future* Symposium. In September 2016, Lyft, who is aligned with GM for on-demand autonomous networks, predicted that the majority of its rides would be autonomous within 5 years.

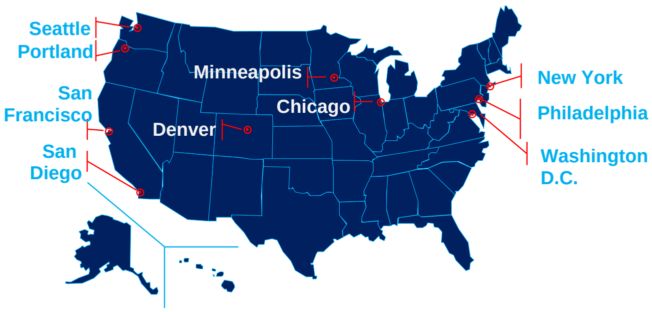
- Interestingly, in August 2016 Uber announced a partnership with Volvo whereby Uber will start deploying specially-equipped self-driving Volvo XC90s in Pittsburgh. The self-driving technology mounted on the XC90 appears to be Uber's — Tier-1 automotive suppliers appear to be involved but the policy software appears to be under internal development by Uber. What's notable is that Uber will utilize the vehicles in actual ridesharing around Pittsburgh. Given that the fleet is confined to Pittsburgh (where Uber's self-driving team is located), we assume that this is still a development/testing effort rather than validation.

Not everyone has outlined a path that goes through a commercial Level-4 phase — again as the regulatory framework still hasn't been fully defined yet. Ford, for example, did not seem to outline this intermediate phase when committing to a 2021 driverless vehicle. Google has also not outlined its specific commercial steps yet but Google continues to develop its fleet.

Which U.S. Cities?

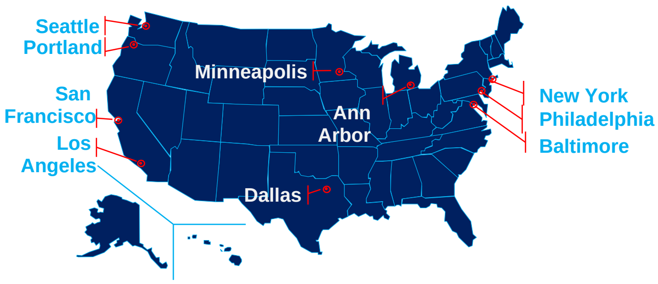
Factors to consider when evaluating cities for autonomous rideshare services include things like urban density, parking costs in that city, environmental factors, and mobility patterns. According to the Shared Mobility City Index (SCMI) (an index created in collaboration between movmi & Inov360, which was originally presented at a conference in Berlin), the top five North America cities ranked by urban density include: (1) New York; (2) San Francisco; (3) Vancouver; (4) Los Angeles; and (5) Baltimore. Figure 8 and Figure 9 show the top cities ranked both by SMCI's own chosen weightings for various factors as well as on urban density alone.

Figure 10. Top Cities Ranked by SMCI Index Criteria



Source: SCMI Index (movmi & Inov 360), Citi Research

Figure 11. Top Cities Ranked by SMCI Index Ranked on Urban Density



Source: SCMI Index (movmi & Inov 360), Citi Research

Is the U.S. Really a Single Market Anymore?

As investors ponder the impact of new mobility on automakers/mobility providers and their key suppliers, we believe they will increasingly distinguish the U.S. market into two buckets. The first is segmentation — for instance segments likely less suitable for immediate sharing models such as large pickup trucks, large SUVs, large vans and luxury vehicles. This view, which we've expressed in the past, has also been conveyed by both automakers and tech companies. Thus we don't view it as controversial. The second distinction is geographic. The market share of automakers actually varies across the U.S. quite a bit depending on region — the Detroit 3 tend to be stronger in the middle of the country and softer on the coasts. Similarly city versus rural share can also vary. So when contemplating the impact of new mobility on auto sales and therefore the various automakers, it also becomes important to understand segmentation and regional distribution exposures, as these exposures at least partially define future winners and losers. Thankfully we are able to track both.

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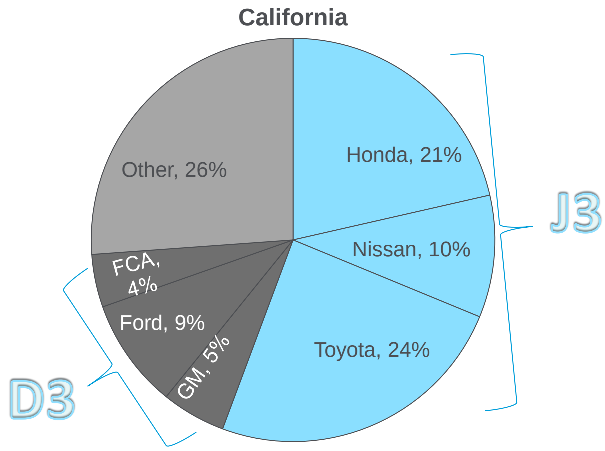
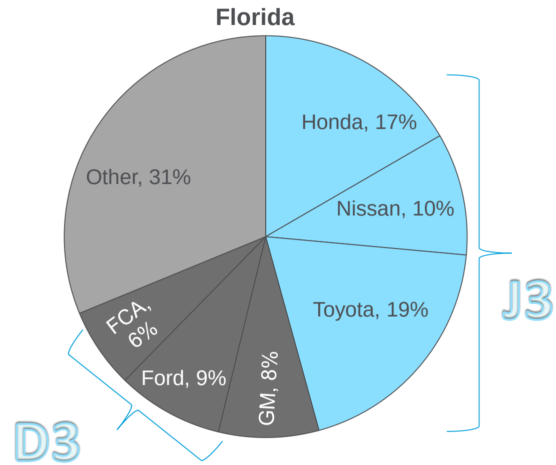
Figure 12. Market Shares in California



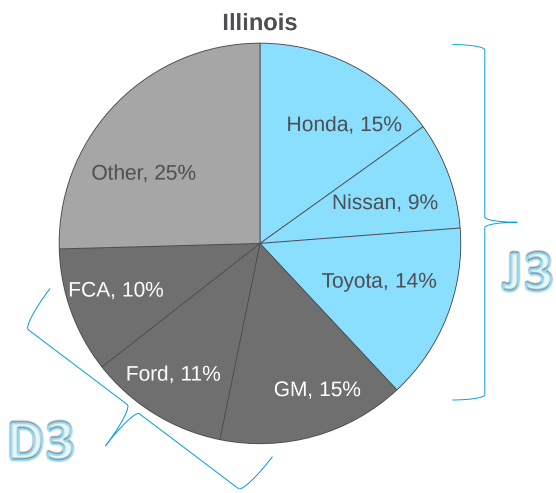
Note: Excluding less susceptible segments like pick-ups and
Source: Experian, Ward's, Company Reports, Citi Research

Figure 13. Market Shares in Florida



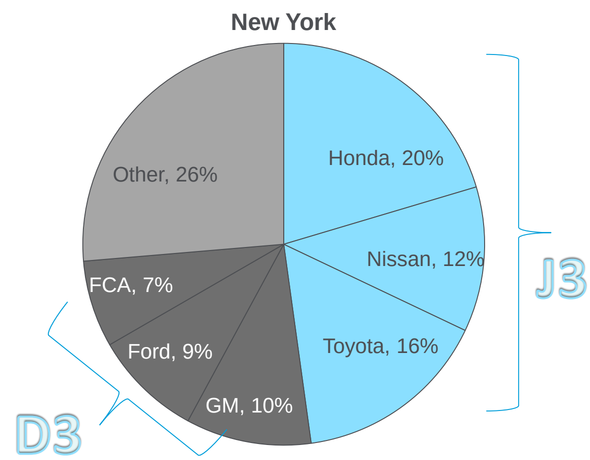
Note: Excluding less susceptible segments like pick-ups and
Source: Experian, Ward's, Company Reports, Citi Research

Figure 14. Market Shares in Illinois



Note: Excluding less susceptible segments like pick-ups and
Source: Experian, Ward's, Company Reports, Citi Research

Figure 15. Market Shares in New York



Note: Excluding less susceptible segments like pick-ups and
Source: Experian, Ward's, Company Reports, Citi Research

What Might the P&L Look Like?

In our prior work where we modeled a 2030 US auto sales (SAAR 2030) scenario that's also reviewed later in this report, we estimated a 2030 driverless mobility industry fleet size of ~3 million. Capturing a 20% share of that industry fleet equals nearly a 600k mobility fleet. If that fleet can earn an average revenue mile of $0.52 (at 95k annual miles with 70% utilization) and some added revenue streams from data, we forecast the annual revenue pool comes out to around $24 billion. We estimate gross margins (including depreciation & amortization/payments for the vehicle) range in the mid-20% or higher — a function of vehicle price, EV performance, cost of autonomous technology, and of course the utilization of the fleet. This is a business where the gross margin should improve over time as vehicle cost declines and software yields robust data to improve both car and rider utilization. We assume sales, general and administrative costs (SG&A) at 8% of revenue (automakers with existing telematics services could leverage those costs) with a 30% tax rate. That yields a $2.4 billion simulated net income pool. Putting a multiple of 15 times on that creates a $36 billion business on a driverless industry fleet of only 3 million units (there are >250 million light vehicles on U.S. roads).

Figure 16. Simulated P&L for Driverless Mobility Network

	Revenue
Revenue	
Productive Miles	66,500
Fee / Mile	$0.52
Miles Revenue	**$34,497**
+ Data Revenue	$5,175
Total Revenue	**$39,671**
COGS	
Propulsion (EV)	($2,030)
Insurance	($1,620)
Car Payment	($9,148)
Maintainence	($8,546)
Total:	**($21,344)**
Gross Profit	**$18,327**
Gross Margin	46%
D&A	$8,620
Gross Profit (D&A)	**$9,707**
Gross Margin	**24%**

Other Revenue	
Weather Services	
Road Conditions (Municipalities)	
Map Updates	
Real-Time Parking Spaces	
Real-Time Traffic	
Location & Trip Based Advertising	
Leveraging Consumer Time in Car	
Live 3D Maps	
Delivery Services	
Law Enforcement Services	
Social Media (increase riders/car…user experience)	
Fleet Size	600,000
Revenue	$23,803
Op Margin (@8pts OpEx)	16.5%
Op Profit	**$3,920**
Tax Rate	30%
Net Income	**$2,416**
- Multiple	15.0x
Value:	**$36,243**

Source: Company Reports, Press Reports, Citi Research

Figure 17. Chevrolet EN-V Concept

Source: GM Media Website

Spotlight: What Will an Autonomous Rideshare Car Look Like?

An autonomous on-demand service will compete on the basis of price, convenience, and experience. Price is a function of: (a) the liquidity of the network — a higher load factor can improve the per-user cost; and (b) the cost of the machine. Convenience is a function of the ease-of-use and speed by which consumers can access the car. Experience is about the ride itself — the comfort, ride quality, ride style, and the time spent in car. The experience is also about the in-vehicle comfort and support. Seats, for example, could become more important. Privacy partitions could be designed to allow for privacy when more than one occupant is sharing the ride. An accessible telematics support staff will likely be necessary to answer questions and concerns. Infotainment and telematics become more important both to entertain and allow the car to communicate with the occupants. If multiple riders want to engage each other during a ride, the ability to conduct meetings or share a snack could become a differentiator too. To the extent regulators allow automakers to radically change the seating and interior design of the car; this too could lead to interesting content opportunities. Eventually once safety is statistically assured the cars can be designed differently with different materials and fewer passive safety systems — though this is probably less likely in the first generation of vehicles. The ultimate goal here, in our view, is to maximize load factor without sacrificing the comfort, experience or privacy of individual riders. While there are views out there arguing that the autonomous on-demand car will be a commodity in the eyes of the consumer, we don't agree. Perhaps occupants won't care so much about the external aesthetics, but the internal user(s) experience will likely make up for that, particularly in regions such as cities where consumers might give up personal car ownership. We could also see different designs depending on the regions — for example megacities could opt for a mix of small pods operating within the city and larger, more traditional vehicles that venture outside. We think the ultimate end-game is to provide consumers with an integrated mobility experience that sees a mix of dedicated rideshare vehicles (such as in major cities) alongside subscription-based vehicles owned/shared by network users that can toggle between being a driverless and human-driven mode.

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Phase #3: Expansion Beyond Geo-Fence, Entry of Personal Driverless Cars & Integrated Mobility Networks (>2023)

Assuming a successful driverless deployment in cities, we believe the next phase would likely entail expanding ridesharing fleets beyond geo-fenced zones (i.e. leaving the city on a weekend trip) and selling driverless-capable cars directly to consumers with the features likely sold as options.

Technically speaking this leap probably revolves around having more robust real-time crowdsourced maps in areas that cannot be as readily updated with HD maps. Here traditional automakers already building crowdsourced maps could have an advantage, plus those who have developed AI policies to deal with more rural use cases like traffic circles, complex intersections etc. might have greater confidence in venturing outside the geo-fenced zone. Sensitivity to cost rises here as well. We think that offering conditional Level-4 vehicle (i.e. fully autonomous but let's say only on highway) would be a nice feature but probably low volume given the costs involved. Rather, we think the consumer market starts to look interesting, if not transformative, once the car can become a true Level-5 (driverless everywhere).

When Will Consumers be Able to Buy Self-Driving Cars Outside of Ridesharing?

Though the industry is focused on ridesharing, some have opined on when the technology would be offered to consumers. Ford noted in September 2016 that it expects to be able to sell driverless capable cars by ~2025 or so, or ~4 years after launching a rideshare version. Volvo is the one outlier in planning a Level-4 vehicle to be offered to consumers at a cost of $10,000 — a steep cost by auto standards unless backed by insurance savings, in our view. It's unclear to us if the planned Volvo vehicle offering would have limitations (such as Level-4 highway-only).

While much attention is often paid to the on-demand rideshare mobility, the introduction of driverless technology outside of on-demand mobility could have industry implications just as meaningful. No matter how convenient ridesharing services are, owning/leasing one's own vehicle provides one key advantage—instant access to mobility whenever you want it. The value of this should not be underestimated, in our view. Forgot to purchase something at the store? Need to urgently get somewhere, or perhaps your family does? In the middle of a storm? In the middle of the night?

Now, consider that many of the trends enabling on-demand autonomous mobility also improve the vehicle ownership proposition — affordable EVs with better performance at a lower cost-per-mile and lower maintenance, safer vehicles that are perhaps less expensive to insure, and driverless capable vehicles that can perform service while you sleep.

Some of the use cases could include:

- Use the driverless technology to offer customers new services such as nighttime car washes and maintenance (i.e., the car gets serviced and washed while you sleep);
- Peer-to-peer car timesharing to improve pricing and affordability;
- Ability to sell time on your car to ridesharing networks;

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- Various use cases of sending the car to pick up friends/family, goods from stores/distribution centers with no need to worry about parking; and
- Expanding globally into the Frontier Markets where we've previously estimated in a separate report that the driverless era could add ~8 million of new SAAR in certain on-the-cusp markets.

Automated Vehicles = Ridesharing & Car Sharing Become One

Today... Ride sharing and car sharing are pretty distinct services. Car sharing serves the need for that instant freedom of mobility, control (i.e. I have multiple stops) or privacy — you're driving it wherever and whenever you want for a fixed period of time. Ridesharing/hailing is more about getting from A to B using a shared car like a taxi or Uber/Lyft. A driverless vehicle service would be capable of doing both — driving you when you want and letting you drive when you want, again for a fixed amount of time. Mobility providers such as auto companies could thus aim not only to capture the growing ride share in dense urban areas, but also attempt to capture traditional car rental share such as vacationers who normally rent vehicles in airports. Automakers could do this in partnership with rental car companies who have strong real estate positons in airports and brand recognition on this front, or leverage nearby dealers who could provide access to the vehicles.

Personal Subscription Models

So we've already discussed autonomous rideshare models in urban areas — first in geo-fenced zones and then beyond. But how will autonomous driving impact more rural areas where the consumer cost-benefit of ridesharing isn't as robust as in cities? One business model that could arise from autonomous vehicles is a networked subscription model to an automaker fleet.

In recent years auto leasing has become a popular form of mobility consumption particularly within premium segments where consumers value accessing a new car every few years. We believe consumers value the option of accessing new and different types of vehicles more than just once every three to five years — either because of changing tastes, changing needs or merely the pleasure of experiencing new vehicles.

Driverless vehicles could conceivably introduce new "leasing" business models where consumers subscribe to a particular automaker's entire fleet of vehicles. Different tiers could be created depending on the age and price of the particular vehicle group such that every few years a new group of vehicles enter that fleet. It would essentially be a form of anonymous peer-to-peer car sharing with a small number of excess vehicles (varying in segment) available in the fleet and dealers to ensure proper maintenance and cleaning prior to a user switch.

While the somewhat higher monthly cost of such a service (to cover the presumed small amount of excess vehicles available) would probably initially make this more of a premium service, there are a number of interesting advantages for both consumers and automakers:

- For consumers, the model would offer a personalized mobility option that doesn't sacrifice the freedom of having instant access to a car, while also allowing unprecedented choice of vehicle experience throughout the subscription. This would be especially true for consumers who normally purchase used cars, where traditional leasing is fairly small.

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- For automakers, such a model could allow for a greater share of lifetime vehicle economics both in the form of captive auto financing and aftermarket maintenance revenue. It would also ensure proper maintenance of driverless-capable cars and proper monetization of data.

There are a number of forms and pricing options that such approaches could take. One of the advantages automakers can leverage here is the potential lower per-unit insurance costs of an autonomous fleet and lower maintenance and operating costs of an EV. Essentially these savings could help fund the monthly payments on autonomous vehicles (which initially are more expensive) and allow consumers to access more of them throughout the subscription without having to deal with the hassles of car ownership (i.e. the vehicle can drive itself to perform maintenance overnight).

Automakers who are ahead on driverless technology, have strong dealer distribution systems, strong connectivity/telematics platforms, and a wide offering of vehicle choices could have an advantage. Social media could conceivably also play a role here in connecting networks who wish to peer share.

Is There a Phase #4?

Does it end with driverless cars? Perhaps not. In recent months we've seen articles and companies discussing investments in autonomous flying drones, or "flying cars", aimed at urban areas. These efforts are apparently being worked on by Airbus as well as startups including one reportedly (Bloomberg) funded by Larry Page, Google's co-founder. Airbus has discussed having products on the market in the next 10 years. Just recently in October 2016, Uber published a paper on the potential of having a future network of small, electric VTOL (vertical take-off and landing aircraft). Like in cars, technological and regulatory issues need to be overcome (particularly for any autonomous flying), and it's unclear what the cost equation might look like. Airbus noted that global demand for such aircraft could support fleets of millions of vehicles worldwide. Something to keep an eye on.

2030 Vehicle Mobility End Game: Integrated Network

When it comes to various forms of mobility, we don't necessarily foresee a one-size-fits-all mode of transport. Depending on one's location, the car's particular use case, and one's desire for instant mobility or privacy, different mobility solutions can make sense. Given that people's tastes, moods, needs, and circumstances can change quickly, consumers are likely to prefer a mobility solution that's all-encompassing — again competing on price, convenience, and experience.

Below we illustrate four different customer scenarios and their likely mobility preference.

- **Customer #1 lives and works in the city and doesn't care for car ownership.** The customer prefers to rideshare around the city and its surroundings. However, occasionally s/he wants to take a road trip or embark on a multiple-stop trip that isn't necessarily predictable ("Hey, let's stop there"). The customer is neutral about driving — the option to drive would be desired under the right circumstances but mostly the car would be used as a riding mechanism. So this customer would predominantly use ridesharing but would likely also value the ability to subscribe to a service where a car can be summoned on demand for more than just a ride.

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- **Customer #2 lives in a rural area and commutes to work, possibly in a city.** This customer values the freedom of instant mobility and so rideshare isn't a day-to-day option. Rather rideshare is used for commuting and while that customer is spending time in a city either for work or pleasure. Perhaps the customer enjoys leasing vehicles and occasionally does need a utility vehicle for a project or long trip with friends and family. This customer, who might own two vehicles in the household, would probably utilize a subscription model for one or both vehicles, and ridesharing on occasion. The ability to integrate the subscription vehicle with the rideshare network would also be valued if it were simple.

- **Customer #3 lives in a rural areas and works in both city and rural areas.** S/he utilizes pickup trucks more often, either as a sole proprietor or through a small fleet. Instant mobility freedom is very high priority and leasing isn't often desired since the vehicle undergoes significant wear and tear. But occasionally, this customer can find value in having access to a car temporarily. Here this customer might stick to a traditional ownership model while subscribing to a subscription on-demand for occasions.

- **Customer #4 loves cars**, particularly performance vehicles and those taking advantage of new technology like heads-up displays and connected infotainment. This customer might want to own one car and subscribe to another to enjoy a menu of offerings. Ridesharing would also come into play.

In prior sections we described various stages of autonomous business models and various pillars required to achieve these models. But ultimately we think the winners in the race will be those who can establish broad personal mobility networks for consumers — combining ridesharing, subscription-based car access, peer-to-peer timeshare models, and traditional car ownership. Think of a single application that runs your ridesharing, car subscriptions, car ownership experience, and perhaps even one day a future aerial drone service. Belonging to an integrated network could lend itself to greater travel options, vehicle choices, lower prices/discounts, and superior service with added convenience.

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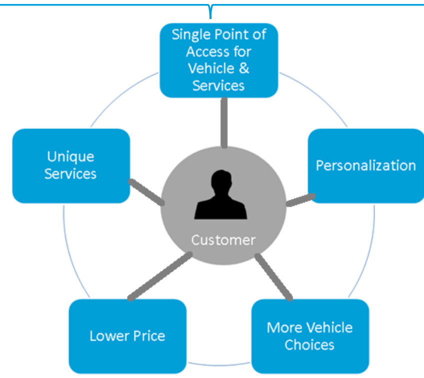
Figure 18. Illustrative Customer Profiles and Mobility Solutions

	Customer #1	Customer #2	Customer #3	Customer #4
Resides in	City	Rural	Rural	City or Rural
Works in	City	City or Rural	City or Rural	City or Rural
Cars Now Owned/Leased	0 or 1	1 or 2	1 or more	1 or more
Needs Utility Vehicle?	No	Occasionally	Always	Rarely
Priority of Instant Mobility	Low	High	Very High	Low
Takes Road trips	Yes	Yes	Yes	Yes
Likes Driving	Rarely	Sometimes	Sometimes	Loves
Typical Vehicle Choice	Sedan/CUV	CUV, Minivan	Pickup Truck, Van	Varies
Mobility Preference	1. Rideshare for Daily Use 2. Occasional Subscription Car For Longer & Multi-Stop Trips	1. Subscription Car for Daily Use 2. Rideshare for Commute etc. 3.Own Car	1. Own Car 2. Subscription Car	1. Subscription Car 2. Own Car 3. Rideshare

Network Benefit



Automaker of the Future = An Integrated Mobility Network (with partners)

Source: Citi Research

Who are the Mobility Providers of Tomorrow?

The driverless race spells both opportunity and risk to traditional automotive players. Sure, the totally addressable market appears substantial and the economics at many levels superior to traditional automotive models. But the barrier to entry also declines particularly for the limited urban mobility market. And the shift from hardware to software suddenly provides companies outside of the automotive industry with an inherent advantage. So who will be the mobility providers of tomorrow, particularly in urban shared settings?

- **Traditional Consumer Tech Companies:** Apple? Google? Why stop there? Why not Amazon, Facebook and others? Autonomous networks are just that — networks. Tech companies with leading brands and established networks naturally carry an advantage in capturing consumer mobility share. Providing their customers with instant or even predictive mobility options feels like a natural extension of established networks and big data companies.

- **Established Ridesharing Companies:** The likes of Uber, Didi, Lyft, Gett, Ola, Juno, etc. Not only are ridesharing companies already establishing their own mobility networks, but are likely collecting critical data that could be instrumental in maximizing load factor of future driverless networks. These companies will also have an advantage in offering consumers both autonomous and driver-based mobility, since the former isn't likely to happen overnight and could conceivably suffer setbacks along the way.

- **Automakers:** Not only bring the advanced hardware (the car), but can bring critical systems integration know-how for an increasingly complex machine, autonomous technology, the critical data gathering needed to perfect that technology (including crowdsourced maps), and scale benefits, financing as well as fleet management & service. Some automakers by now have acquired tech companies while partnering with leading Tier-2 and Tier-1 auto suppliers. Of course in the years leading towards driverless certification, the automakers could have a nice advantage by leveraging their current fleets to perform mapping, fleet learning, and other key data collection to prove-out Level-4 vehicles. Lastly, automakers who can better connect to consumers (through apps) in the years ahead might also have a better shot at establishing integrated mobility networks.

- **Rental Car Companies:** Already operate forms of car sharing and have key assets in their fleet management expertise and real estate assets.

Is This a Silicon Valley vs. Detroit "Winner Take All? No. We first expressed the view last year that this won't be a Silicon Valley vs. Detroit winner-take-all. Given the importance of speed in this race and given that many companies understand their strengths and weaknesses, we continue to expect partnerships to be formed. Indeed, we have already seen several partnerships announced across automotive, tech and rideshare companies. Not all partnerships are exclusive so the battleground remains fairly open.

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Figure 19. Autonomous Driving/Shared Mobility Partnership Review

Autonomous & Ride Sharing Partnerships - OEM to Tech Partners

OEM	Tech Partner(s)	Autonomous / Ride/Car-sharing	Economics	Key Dates	Partnership Type
General Motors	Uber	Ridesharing	No Data	Announced: November 1, 2016	90-day Partnership pilot
Toyota	Getaround	Carsharing	No Data	Announced: October 31, 2016 Pilot begins: January 2017	Investment & Collaboration
Volvo	Autoliv	Autonomous	No Data	Announced: September 6, 2016 Operations begin: 2017 Auton. Antcptd Dplymnt: 2021	50/50 JV
Volvo	Uber	Autonomous Ridesharing	$300mln pact for AVs for 2021	Announced: August 18, 2016 Fleet Testing: 2016 Anticipated Deployment: 2021	Non-exclusive JV
Toyota	U of M	Autonomous	$22mln R&D partnership	Announced: August 10, 2016	R&D partnership
BMW	MBLY & INTC	Autonomous Ridesharing	No Data	Announced: July 1, 2016 Fleet Testing: 2017 Anticipated Deployment: 2021	Partnership
Toyota	Uber	Ridesharing	<$100mln investment	Announced: May 24, 2016	Investment & Partnership
Fiat-Chrysler	Google	Autonomous	No Data	Announced: May 3, 2016	Non-exclusive JV
General Motors	Lyft	Ridesharing & Auton. Ridesharing	$500mln investment	Announced: January 4, 2016 Fleet Testing: 2016	Investment & Alliance
Nissan	NASA	Autonomous	No Data	Announced: January 8, 2015 Testing: 2015	Partnership

Source: Company reports, Citi Research

GM-Lyft Partnership Example: GM and Lyft have partnered to develop a future on-demand autonomous rideshare network. Figure 16 below shows how we think GM's and Lyft's combined partnership could address the three pillars discussed earlier (autonomous, supply/demand match, fleet service) and ultimately perhaps establish an integrated mobility network initially concentrated in major cities. Interestingly, in a recent Bloomberg interview Lyft Co-Founder & President, John Zimmer, predicted that consumers would "pay for a monthly subscription to transportation" and be offered several choices of consistent experiences, with the network taking care of fueling, parking etc.

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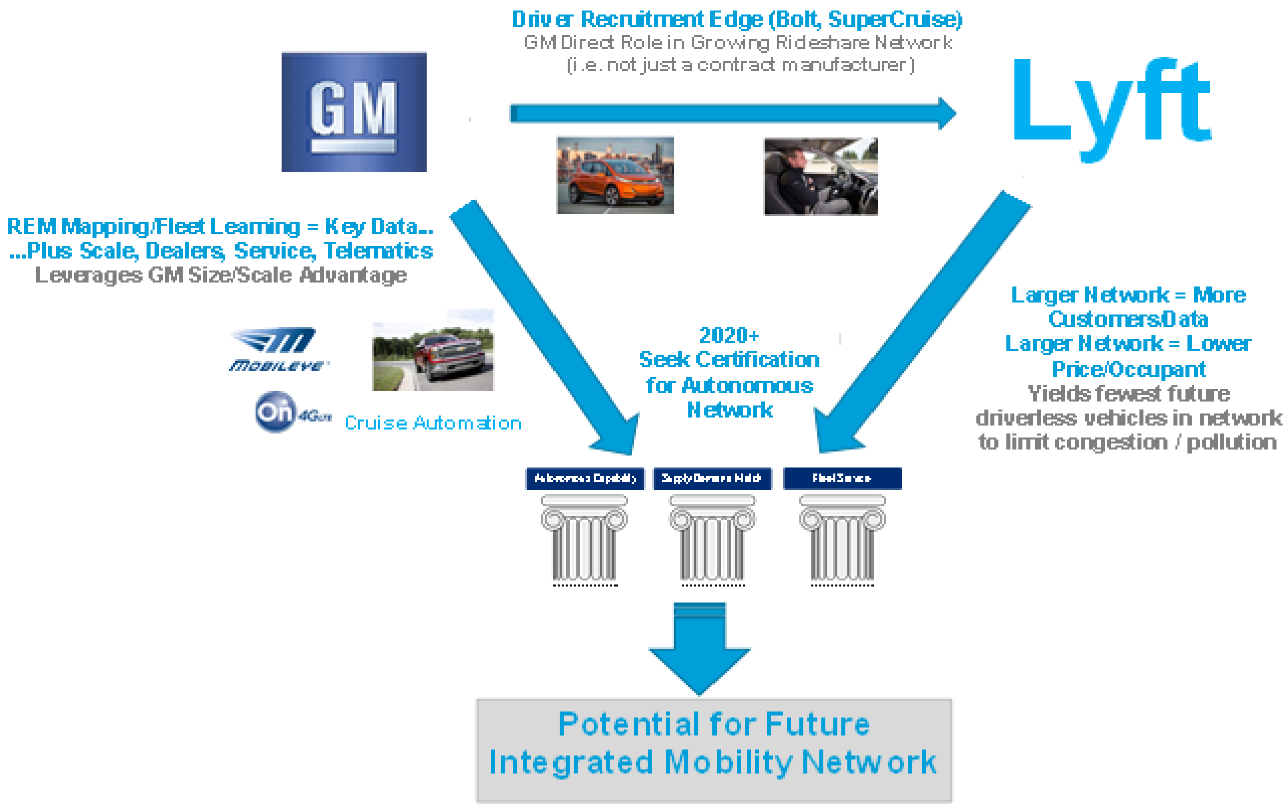
Figure 20. Potential Future GM-Lyft Integrated Mobility Network



Source: GM, Lyft, Citi Research

So Traditional Automakers Have Three Options

Today, the U.S. rideshare/car-share industry is dominated by a handful of players, and the market is more concentrated than the automaker market. While much could still change, the current vantage point suggests that not every automaker can necessarily form strategic partnerships with rideshare firms — though that wouldn't of course preclude automakers from selling cars and services to rideshare firms absent exclusivity agreements.

So for traditional automakers we essentially see three options:

1. **Strategically partner to operate on-demand autonomous networks with rideshare firms.** In other words try to directly participate in the future economics of rideshare networks by partnering early with rideshare firms on autonomous, service and connectivity. Possible advantages of strategically aligning early in the process include: (a) arguably easier access to performing real-world validation of Level-4 and Level-5 vehicles; (b) designing the rideshare vehicle specifically to maximize comfort and load factor based on known customer experiences; and (c) achieving some forms of exclusivity (perhaps regional) to secure market share in strategic places. This more or less seems to be the approach that GM has taken with Lyft, though we note that the GM-Lyft partnership isn't exclusive as we understand it.

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2. **Develop their own networks either for ridesharing (if not partnered), a subscription ownership, or both:** Automakers could attempt to compete with rideshare firms by developing their own networks, from regional networks to even global networks. Though automakers have not traditionally been as directly connected to the consumers over the life of the car, the rise of the connected car has recently allowed automakers to install mobile apps providing convenience features such as real-time vehicle health reports, heating, ventilation and air conditioning operation, and engine operation. Additional value-added services such as predictive diagnostics and features sold over-the-air (OTA) should continue making such apps more useful to consumers. Over time, automakers could try to introduce ridesharing services through these apps. Such apps could target consumers who might already own that automaker's vehicle but who also rely on other transport means for commuting and urban travel. GM, for example, already has 2.6 million mobile app users globally, a 175% increase since year-end 2011. GM has also established a car-sharing brand called Maven which has been expanding across U.S. cities. Apps like Maven could also morph into providing consumers other options within rideshare. Other automakers, including Daimler and BMW have also established car share outlets (Car2Go & DriveNow, respectively). In our view, establishing a direct link with consumers years in advance of the driverless car (a function of that automaker's willingness to aggressively pursue connectivity and OTA) could become a key advantage for automakers looking to run their own networks. Still, to build a network that competes with established rideshare networks could prove difficult and costly. Thus, on a large scale we tend to favor partnerships when it comes to the pursuit of a large rideshare network. Another way automakers could run their own networks is through specialized services such as shuttles. This is an area Ford highlighted at its September Investor Day through its Dynamic Shuttle business, where Ford sees a 2025-2030 total addressable of $100-$200 billion.

3. **Sell and service autonomous vehicles directly to third party networks:** Rather than strategically align with one particular rideshare firm or mobility network to operate the on-demand mobility network, some automakers could develop and sell driverless vehicles and related services (finance, insurance aftermarket, disposals) to any and all rideshare plus other service providers. Since Level-4 vehicles are expected to be far more highly engineered than a typical passenger sedan, automakers could try to "mix-up" their sedan business (typically low margin) by selling vehicles to rideshare fleets and then servicing those vehicles (as automakers today are fairly underserved in the aftermarket revenue earned throughout a car's life). Automakers could differentiate their offerings on the vehicle design itself, the driving style, price, technology (EV in particular), and data access (crowdsourced maps that automaker might have accumulated in its own fleet of vehicles). In its September Investor Day Ford quantified its profit opportunity at both the vehicle and service level, but not the operator level. Ford quantified this vehicle management as a service (VMass) market alone at $100-$400 billion in the 2025-2030 period.

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Who are the Leaders & Laggards?

So how does one define a “leader” or a “laggard” in this field? To start, it’s not easy and frankly still fluid as companies position/partner for the race. We often notice that observers take the path-of-least-resistance such as the one that seems to cast all automakers as effectively laggards at best and disrupted at worst. Yet considering what’s on the line in terms of total addressable market and future business models, we think it’s crucial to develop metrics and tools to dig in a bit more.

So we’ve set out to create a quantitative methodology that ranks mobility players on several metrics. Our first stab focuses on the U.S. market.

Let’s revisit the three pillars described above as the general guideline and now we’ll revisit each one with a deeper look into individual players and our best efforts to quantify progress.

Pillar #1: Gauging Autonomous Capabilities

As noted earlier, we view this pillar as being about: (1) tech capability; and (b) testing and eventually validating performance (data).

There are two schools of thought around the path to Level-4 and eventually Level-5 vehicles. The first suggests a gradual approach whereby automakers gain know-how from gradual steps starting with basic ADAS (i.e. automatic emergency braking) to semi-autonomous systems ranging from traffic jam assist and highway piloting all the way up to Level-3 partial automation. Through this process companies performing real-time crowdsource mapping (such as Mobileye REM) would also gain know-how from that. The other school of thought says that you can skip this step (or most of it) and jump directly into developing a Level-4 system. For example, Ford appears to be in this step as the company has confirmed that it will not seek out Level-3 vehicle but rather will jump directly towards Level-4. Google also appears to be in this camp.

Time will tell which camp is correct. For the purposes of our analysis, however, we lean towards camp #1 where we give credit to companies pursuing Level-2 and Level-3 as well as those pursuing crowdsourced mapping. Our rationale is that companies pursuing semi-autonomous and mapping will gain natural know-how that could be used for Level-4.

So to gauge the capabilities of automakers/mobility providers we first take a detailed look at known product plans followed by a new data tracker that measures the capability of different players to build validation data in order to perfect and then seek approval for driverless offerings.

First, Let’s View Industry Autonomous Product Plans

Citigroup Global Markets Inc acted as an advisor to SolarCity Corp in relation to the announced acquisition of SolarCity Corp by Tesla Motors Inc (“The Company”). Consequently Citi will not offer any view, opinion or recommendation on the Company in this report.

Based on publically available information, we have built timelines for select automakers and mobility players bucketing: (1) past and anticipated product plans characterized by level of autonomy (Levels 1-4); and (2) known plans around mapping and shared mobility. The list is naturally fluid as not all automakers have likely disclosed plans, so it should be read as our best view at this point in time. As automakers plans become better known, this analysis will be updated.

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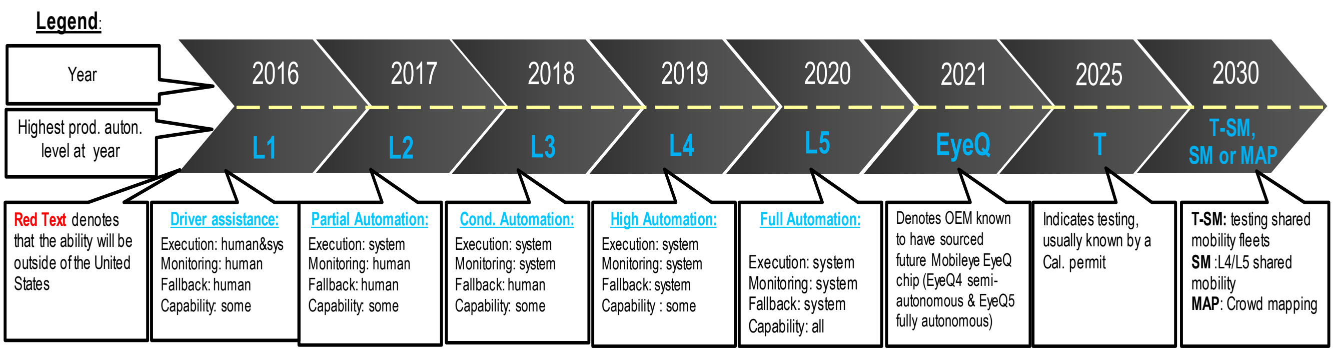
In order to illustrate these paths to autonomous driving, we created a simple and intuitive road which displays the specific steps and actions the referenced company is making at each year. Our display for each company incorporates public announcements as well as our own estimates based on timing high-probability programs.

The full legend is displayed below.

Figure 21. Autonomous Driving/Shared Mobility Legend



Source: Citi Research

Detroit 3 ("D3")

Within the D3, thus far we've observed fairly different approaches towards pursuing full automation. All three automakers certainly offer ADAS and some Level-2 features in the form of adaptive cruise control. But beyond these features their approaches seem to be different. For instance, GM is the only D3 automaker thus far who appears to be aggressively pursuing semi-autonomous Level-3 (SuperCruise feature due 2017), real-time mapping (Mobileye REM) and Level-4 vehicles for ridesharing (we expect around 2019-2020). GM also purchased Cruise Automation earlier this year, invested in Lyft, and launched its Maven car-share business. Ford is skipping Level-3 to focus directly on driverless in the 2021 period of time, but we do expect a traffic jam assist feature (Level-2) in the coming years. Fiat Chrysler Automobiles (FCA) earlier this year announced collaboration with Google to expand self-driving testing on the Chrysler Pacifica minivan. However, FCA has not articulated a go-to market strategy for Level-3 and 4 as we're aware.

"Also, we are very committed to being among the leaders or leading in autonomous technology. Clearly the Cruise Automation was a big piece of that... And we do believe that autonomous will first be tested out in the marketplace in a sharing type environment…
- Mary Barra, 2Q16 GM Earnings Call

- **General Motors** has appeared the most aggressive with its plans thus far having committed both to Level-3 and Level-4, and has partnered with a ridesharing firm (Lyft). The SuperCruise feature is expected to launch in 2017 on the Cadillac CT6. Like comparable systems, SuperCruise is expected to offer hands-free highway driving in certain conditions. What's unique about SuperCruise is the expected driver camera monitoring system that should allow drivers to take their hands off the wheel for a period of time so long as their eyes remain on the road. This should allow for a true Level-3 experience under certain conditions while ensuring the driver remains in the loop. GM is also one of a handful of automakers who have already sourced production for the Mobileye EyeQ4 chip that is launching in 2018. GM's Level-4 plans appear to initially entail the launch of a fleet of fully autonomous vehicles operated by a driver in the Lyft network. GM has been testing autonomous technology fitted onto its all-electric Chevy Bolt EV — in a fleet of ~30 vehicles that have leveraged the Cruise Automation team (which has grown to ~100 from ~40 when GM acquired Cruise in March 2016). The vehicles are being tested on public roads in Arizona and San Francisco.

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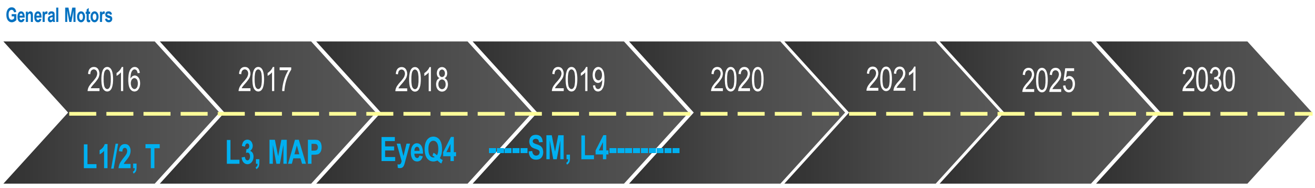
Timing for GM's Level-4 launch plans remains unclear. The company has discussed launching fully autonomous vehicles (with a driver monitor) in the 2018-2020 period but a recent outlook from Lyft (GM's rideshare partner) implied an earlier and even more aggressive rollout starting in 2017 that would see the majority of Lyft's rides be autonomous within 5 years. It's not exactly clear whether Lyft's vision definitely ties into GM's rollout plan, but Lyft's outlook did reference its partnership with GM in its article. Our assumption is that GM will initially use these vehicles to gather highly valuable validation data to perfect the system in order to eventually obtain regulatory approval to leap towards driverless. GM has yet to set a deadline for going driverless.

Figure 22. GM's Path Towards Automation



Source: Company reports, Citi Research

"The general timeline is 2020. We believe that by the end of the decade someone will be there. We think first mover advantage is important but don't believe one can fulfill the entire market. We want to be a credible player in that space. Our goal is not to be first to market, but to be relevant. We want to be available to a very broad market"
-Dr. Ken Washington, Citi CoTF Symposium '16

- **Ford** made headlines in August 2016 when it announced plans to launch a fully autonomous (no driver) vehicle by 2021. The vehicle will be used in a ride sharing platform. Unlike GM, Ford is not pursuing Level-3 as the company believes that Level-3 poses challenges in terms of the human-machine handoff (though Ford does appear to be working on a traffic jam assist function). Rather, Ford is moving directly to Level-4 with an emphasis on in-house software development aided by recent partnerships and acquisitions. Ford this year is tripling its autonomous vehicle development fleet (from 10 vehicles to 30) and expects to triple that again next year to 120 and then to 140 by 2018. Ford's Level-4 ambitions are technically the most, or one of the most, aggressive in the industry — the automaker is planning to commercialize a high-volume driverless car immediately in 2021 after a transition phase of running Level-4 vehicles with safety drivers beginning in 2018. Ford's approach appears similar to Google's in that Ford appears to be heavily leveraging Velodyne LIDAR (laser imaging detection and ranging) sensors while opting to develop the autonomous software mostly in-house, at least for now. Ford has yet to announce any partnerships on the mobility network side (i.e. Lyft-GM), and it's possible the automaker plans to sell its vehicles to ridesharing firms while offering aftermarket and financing services. On the technology side, it will be interesting to compare Ford's in-house approach to that of its peers. Considering the amount of testing years that Google has performed since 2009, Ford's plans appear aggressive on the surface as it seems to imply a rapid advanced engineering phase and an accommodating regulatory approval process. That said, it's likely too early to assess how this program is proceeding. Besides "robotaxi" like services Ford is also pursuing shuttle-based mobility leveraging its strength in vans.

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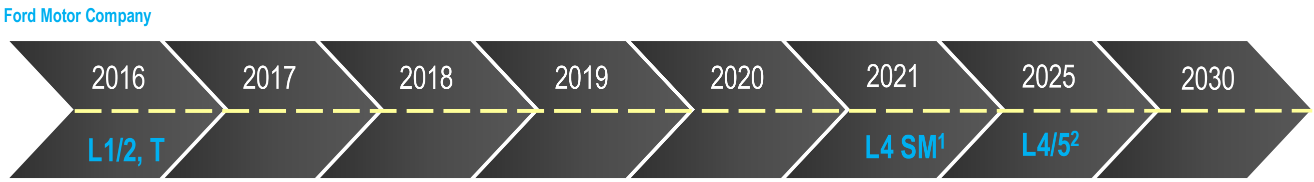
Figure 23. Ford's Path Towards Autonomous

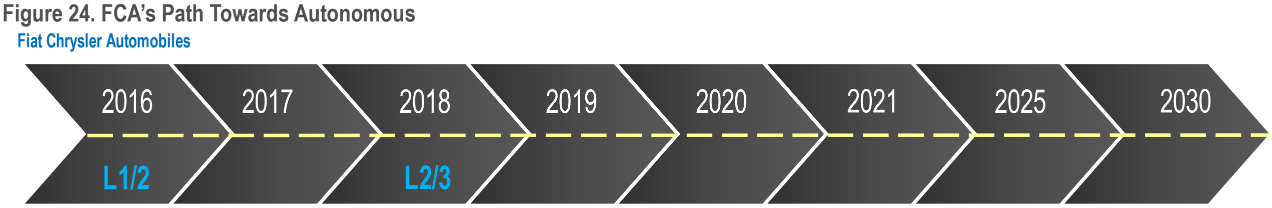


1) Shared mobility will be capable of free routes within a geofenced area in a city environment (L4 capabilities)
2) Ford is targeting sales of personal use AVs "around mid-decade"

Source: Company reports, Citi Research

- **Fiat-Chrysler** offers ADAS and Level-2 features (including a stop-go automatic cruise control) across many of its vehicle lines. The automaker appears to be rapidly deploying Mobileye's EyeQ3 chip as noted by a 2016 automatic emergency braking (AEB) Fusion launch (minivans) and a recent high-volume program scheduled for late-2017. In March 2016, Maserati's CEO. Harald Webster. noted that the company was planning on automating "the boring part" of driving using a highway pilot system which is under development. The Level-2 or Level-3 system will likely find its way into the Ghibli and Quattroporte sedans within the next two years. Additionally, the non-exclusive Google-FCA alliance for 100 autonomous minivans is noteworthy and worth continued monitoring, though it's unclear what the end-state implications from this partnership will be. We're not aware of firm Level-4 plans at this point or a shared mobility pathway.

Figure 24. FCA's Path Towards Autonomous



Source: Company reports, Citi Research

Japan 3 ("J3")

Within the J3, Nissan stands out as the most visibility aggressive with respect to automated driving at this point — predicated on its announced launch of ProPilot and its planned timeline for subsequent rollouts of multi-lane highway and "intersection autonomy". Nissan's timeline for the rollout of ProPilot starts out with vision-only single-lane autonomy in 2016, and eventually culminates in "intersection autonomy" utilizing a host of sensors around 2020. For Honda and Toyota, there is a relative convergence of goals, as both companies seek to offer some form of highway-only autonomy by 2020.

- **Nissan** has outlined a fairly clear path towards autonomous driving. Nissan's near-term step towards autonomous (Level-2) starts this summer in Japan on the Serena minivan. The Serena will feature the first iteration of ProPilot, which will allow for vision-only, single lane highway adaptive-cruise-control with automated steering. Nissan is one of a handful of automakers who has sourced production for Mobileye's EyeQ4 chip. Nissan's third step is slated to come in 2018 when the automaker plans to release multi-lane highway autonomy functions in some capacity, with a Road Experience Management (REM) launch (mapping using onboard vision sensor) apparently also planned for the same year. The journey is set to culminate around 2020 when Nissan releases "intersection autonomy" which it says will navigate city intersections and heavy traffic without driver intervention. Nissan has shown the future ~2020 IDS concept electric vehicle capable of Level-4/5 autonomy with a two-mode interior system that toggles between driving modes and uses advanced heads-up displays. It's less apparent at this point whether IDS will be positioned for consumers, ride-sharing applications or both.

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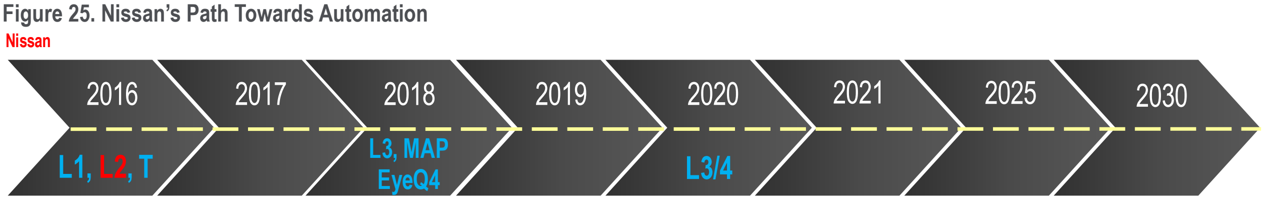
Figure 25. Nissan's Path Towards Automation

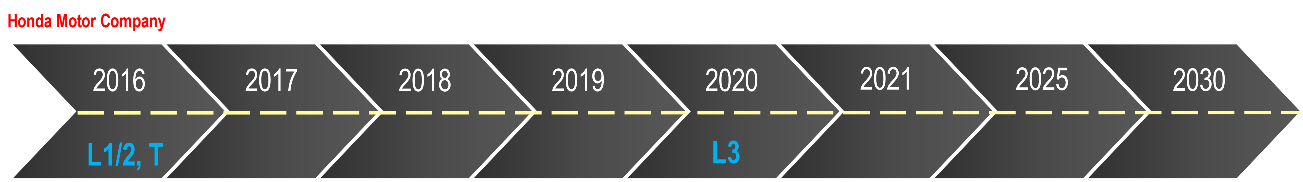


Notes: Nissan plans to offer the vision-only first iteration of the ProPILOT on its Serena in Japan in 2016. The Qashqai in Europe will get the feature in 2017

Source: Company reports, Citi Research

- **Honda** has not been quite as vocal as its peers regarding autonomous plans beyond ADAS and Level-2. A Reuters article in June 2016 covering a "sneak preview" event Honda hosted provided some detail, such as plans for full highway autonomy by 2020. The vehicle shown at the event appeared to have an array of sensors mounted to its roof. Honda has been engaged in testing including having an autonomous testing permit in the state of California. To us, it appears that Honda's course is comparable to Toyota (Level-3 or perhaps 4 highway 2020 plans) but somewhat less aggressive than Nissan's.

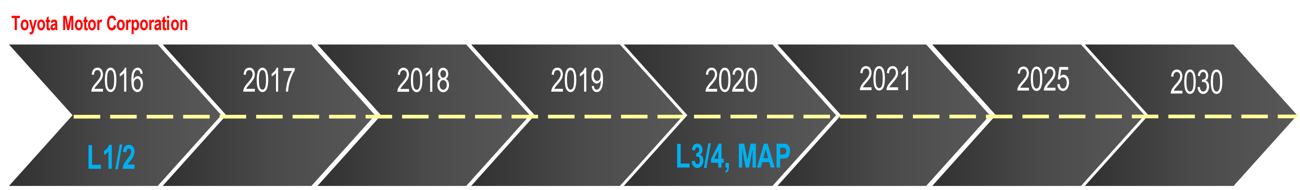
Figure 26. Honda's Path Towards Autonomous



Source: Company reports, Citi Research

- **Toyota** in 2015 unveiled an automated driving test vehicle called the Highway Teammate that they plan to launch around 2020. From what we can tell the vehicle appears to be an advanced Level-3 highway system but not the full Level-4/5 capability suggested by the Nissan IDS concept. The Toyota Highway Teammate vehicle shown in 2015 leverages stereo vision and surround radar and laser scanners. Toyota also announced late in 2015 that it will utilize on-board cameras in vehicles to perform map gathering in a similar concept as Mobileye's REM system. Although Toyota doesn't seem to be racing towards a first-mover advantage in fully autonomous vehicles, it's committed to invest $1 billion over the next five years in its in-house research division, Toyota Research Institute (TRI). The institute appears to be focused in areas within robotics having launched several research partnerships with MIT and Stanford. In May 2016 Toyota also announced collaboration with Uber to explore different aspects within ridesharing and financing for current Uber drivers. As part of that agreement Toyota Financial Services made a strategic investment in Uber.

Figure 27. Toyota's Path Towards Autonomous



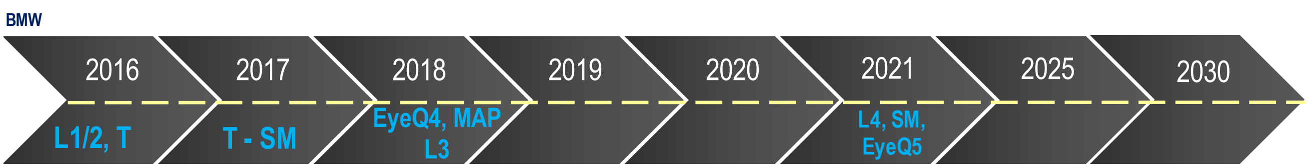
Source: Company reports, Citi Research

German 3 ("G3")

All G3 automakers appear focused on furthering autonomous driving and even shared mobility. The automakers also have a shared interest in HD mapping. Within the group, BMW appears to be the current leader having announced a firm timeline for Level-4 shared mobility vehicle.

- **BMW** made headlines in July of 2016 when it announced a partnership with Intel and Mobileye for a fully autonomous driving alliance centered on highly autonomous, as well as fully autonomous (with a focus on shared mobility in geo-fenced areas within Europe). The significance of this announcement was due in part because it was a production commitment as opposed to a mere development program. BMW is aiming its iNEXT model to serve as the basis for a fleet of fully autonomous vehicles, as the alliance with Mobileye-Intel will create an open platform. Within the program, testing within a shared mobility network is expected to begin in 2017. BMW also has a current testing permit in the state of California, and an expected EyeQ4 deployment in 2018 including we believe a future Level-3 program. Lastly, BMW, like its G3 peers, is expected to deploy mapping capability both from its stake in high-definition map maker HERE and Mobileye's REM feature expected to go into production in the future.

Figure 28. BMW's Path Towards Autonomous

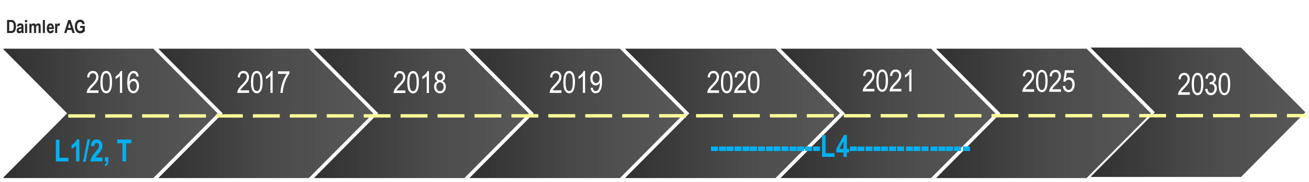


Source: Company reports, Citi Research

"As far as autonomous driving is concerned… We have a lot of in-house capability… As you know, we do cooperate as far as HERE is concerned together with Audi and BMW, and we think that makes a lot of sense to have a common platform on the autonomous side."
-Dieter Zetsch, Daimler CEO, 2Q16 earnings call

- **Daimler** has been at the forefront of ADAS and automated driving for some time. A number of Mercedes models offer a Level-2 feature called Distronic Plus with Steering Assist and the newly launched E-Class launched Drive Pilot which appears to be a more sophisticated though still Level-2 highway driving feature that also performs lane changes on command. The new E-Class uses multiple radars and stereo cameras, and the Drive Pilot system also uses car-to-car communication. At this point we are not aware of concrete Level-3 or Level-4 plans though Daimler has shown fully autonomous passenger vehicle concepts (F 015) and fully autonomous trucks including for platooning. Daimler does have an autonomous testing permit in California. The company recently characterized leadership in future mobility as being determined by four dimension: (1) e-mobility; (2) digitalized ecosystems; (3) shared mobility; and (4) autonomous driving.

Figure 29. Daimler's Path Towards Autonomous



Note: Daimler has given a timeline for autonomous CVs only, 2020.

Source: Company reports, Citi Research

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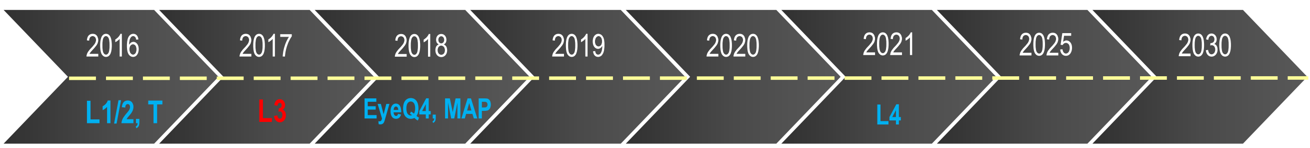
- **Volkswagen** has recently taken a path that's more or less similar to GM's. First, Volkswagen announced an investment and strategic partnership with Gett, a global ride-hailing provider, for future ride sharing. VW has put out a multi-billion euro revenue range by 2025 on such activities. Second, VW has also signed up for Mobileye REM mapping services and has committed to the EyeQ4 chip launching in 2018. Third, Audi is expected to launch a Level-3 traffic jam pilot on the A8. The vehicle is expected to feature the zFAS multi-domain controller receiving signals vision, laser, radar, and ultrasonic sensors. Audi is also a partner in the HERE mapping consortium along with Daimler and BMW. In terms of Level-4+, in mid-2016 VW committed to launching fully autonomous vehicles from 2021. VW's path appears directionally similar to that of BMW's though it's unclear whether VW has firmly committed to producing a fully autonomous vehicle in 2021 or whether they'll be used for ridesharing. In August 2016, media reports (Autocar) suggested Audi is working on a 4-door electric sedan (A-etron) that will achieve a 311 mile EV range and Level-4 autonomous technology.

Figure 30. Volkswagen's Path Towards Autonomous

Volkswagen AG



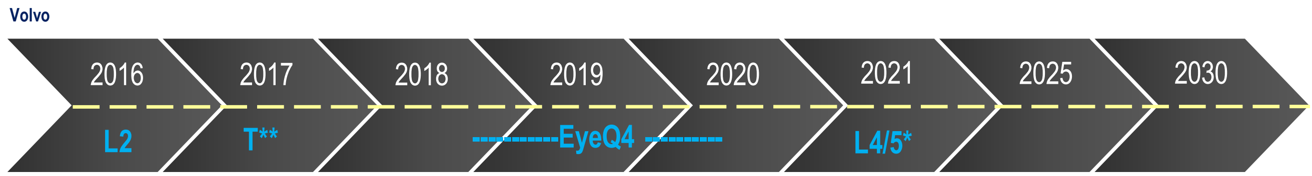
Notes: VW plans to offer traffic jam assist (up to 37 mph) on the A8 in 2017

Source: Company reports, Citi Research

Other Automakers

- **Volvo** has been active all around with plans for semi- and eventually fully-autonomous vehicles. This year Volvo will offer its Pilot Assist II feature on the model year 2017 XC90 and model year 2016 S90. The feature (standard on the S90) allows for semi-autonomous driving up to 130 kmh (~80mph) and does not need to follow a car in order to work. The system leverages the Delphi RaCam system using a mono camera (EyeQ3) and radar mounted behind the windshield. In 2021, Volvo hopes to have a car that is capable of complete highway autonomy likely stemming from its DriveMe initiative. Indeed, Mobileye recently announced a trifocal award from Volvo under this program. In September 2016 Volvo reportedly (Bloomberg) indicated that it would launch self-driving features available to consumers by 2021 at a cost of around $10,000 in what read to us as a conditional Level-4 feature (car will have a steering wheel). Volvo also made news in August 2016 by partnering with Uber (non-exclusive) to promote self-driving development. Under that agreement Volvo will provide Uber with a fleet of XC90 SUVs "base vehicles" that Uber will fit with its own self-developed autonomous driving sensors. Volvo will also use those same base vehicles for its own autonomous driving development. The two companies are contributing $300 million to the project. In September 2016 Volvo also announced that it would join forces with Autoliv to create an autonomous-car software company. The new company, expected to commence operations in early 2017 with ~200 engineers, is expected to launch highly automated driving solutions in 2021. The new company will be owned in equal shares by Volvo Car Group and Autoliv. Net-net it appears that Volvo is developing its own autonomous system (with the aide of suppliers) while also simultaneously working with Uber. It's unclear whether the two programs are using the same sensor suite though our initial impression is that they're not.

Figure 31. Volvo's Path Towards Autonomous

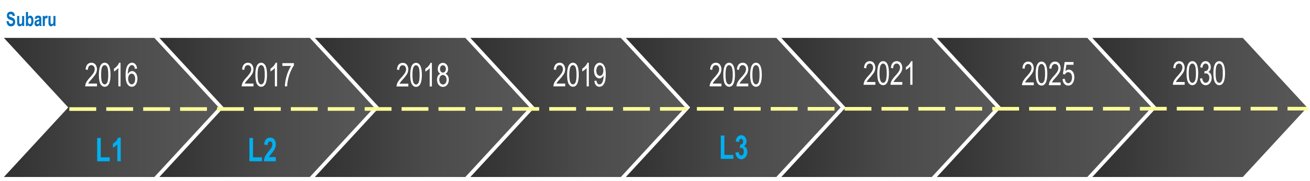


*Volvo has a 50/50 JV with Autoliv to develop ADAS (2019) and Automated Driving (2021) systems for use in Volvo cars and for sale by Autoliv to car makers globally
** Under Uber XC90 testing program in Pittsburgh

Source: Company reports, Citi Research

- **Subaru** plans to expand on EyeSight (currently Level-1 features) in 2017 by offering traffic jam assist. The traffic jam assist feature will allow for automated acceleration and braking, as well as steering around curves up to 40 mph. In 2020, Subaru said it will introduce a semiautonomous function for highways that will allow for automated lane changing and steering.

Figure 32. Subaru's Path Towards Autonomous

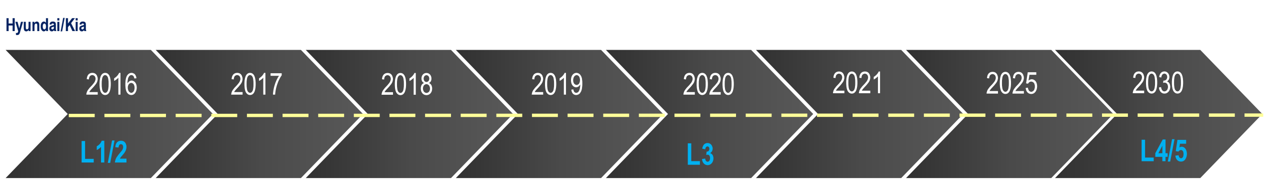


Note: TJA coming in 2017, highway autonomous coming in 2020

Source: Company reports, Citi Research

- **Hyundai/Kia** plan to introduce partially autonomous technologies by 2020 and to bring its first fully autonomous vehicle to market by 2030. The timeline appears similar to if not slightly behind that of the J3, though the company appears to be investing aggressively to improve capability.

Figure 33. Hyundai/Kia's Path Towards Autonomous



Source: Company reports, Citi Research

Tech Players and Startups

- **Google (Alphabet):** Has been a leader in developing fully driverless technology and has been most vocal about skipping Level-2 & 3. As noted above, Ford is perhaps the first automaker to have taken a similar approach as Google's. As of September 30th of 2016, the Google self-driving car project has amassed over 2.1 million autonomous mode miles since the project began in 2009. The company currently tests 58 vehicles on public roads across four states, and accumulates between 20-22k miles per week. Google is quite transparent to the public with how the test fleet is performing. While disengagements were still

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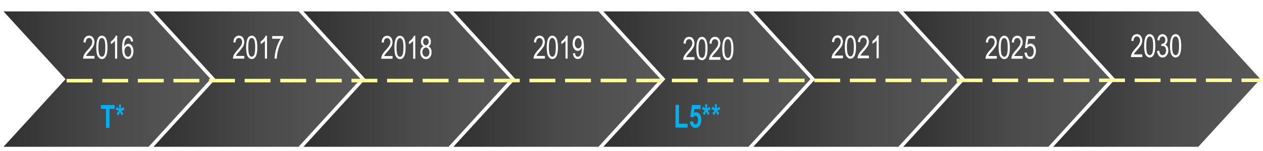
common throughout 2015, the fleet did see a noticeable and steady rise in intervals between disengagements. Google has not explicitly outlined its go-to-market strategy with the exception of making it clear that it would rather partner with automakers as opposed to build its own cars. Earlier in 2016 Google partnered with FCA for a fleet of test minivans. As for timing, in previous years 2020 was hinted to be the self-driving finish-line, however, more recently management has suggested in public forums that commercialization could end up staggered by regions/cities. The regulatory framework is also important to Google's approach given the company's philosophy of going directly to driverless. With regards to ridesharing, in August 2016 the WSJ reported that Google was expanding its peer-to-peer ridesharing service that's offered through the Waze app. Unlike Uber/Lyft, the Google services doesn't appear to recruit drivers but rather connect Waze users whereby drivers would be connected with prospective riders headed in the same direction. The service would charge $0.54 per mile with Google not taking a cut.

Figure 34. Google's Path Towards Autonomous

Google



* Worked on L4/5 technology since 2009. Now testing 58 vehicles on public roads (24-26k autonomous miles/week, 2.1 million accumulated through Sept 2016)

** Not an official completion or launch date, 2020 is based on past public comments

Source: Company reports, Citi Research

- **Uber:** As mentioned earlier, in August 2016 Uber announced that it would partner with Volvo to develop fully autonomous cars. Uber's self-driving development has been centered in Pittsburgh (in conjunction with a Carnegie Mellon team) and more recently expanded through the August 2016 acquisition of Otto. The Volvo partnership, which is not exclusive, appears to provide Uber with ~100 Volvo XC90 SUVs retrofitted with Uber's self-driving system. Interestingly, Uber plans to utilize its autonomous test fleet (which will have drivers to monitor the system) in real-world ridesharing trips throughout Pittsburgh starting in 2016. From publicly available pictures of the Uber-equipped XC90, the roof-mounted self-driving systems appear to contain LiDAR and various other sensors around the vehicle. We believe Uber is working with Tier-1 auto suppliers but developing the control software in-house, at least for now. Like Google, Uber has also publicly commented that it does not want to build cars but rather partner with automakers. This makes sense to us given the automakers' advantage in systems integration and in servicing the vehicle. Uber's advantage in this race is significant given its leading rideshare network that's rich with data and arguably ideal to conduct Level-4 validation testing. This network would also give it a significant advantage in maximizing the load factor of a commercial driverless fleet — something regulators would likely favor given congestion benefits. Yet given that Uber's self-driving efforts started later than other players, it'll be interesting to see whether Uber ultimately does partner with an automaker for more than just the "car" or whether it insists on using its own self-driving software. Early media reports from Uber's Pittsburgh test fleet did point out a few instances of disengagements — though it's unclear if there is a trend or how this compares with competing programs.

- **Lyft:** The U.S. rideshare firm recently shared its vision for future mobility. The vision called for autonomous fleets to account for the majority of Lyft rides within

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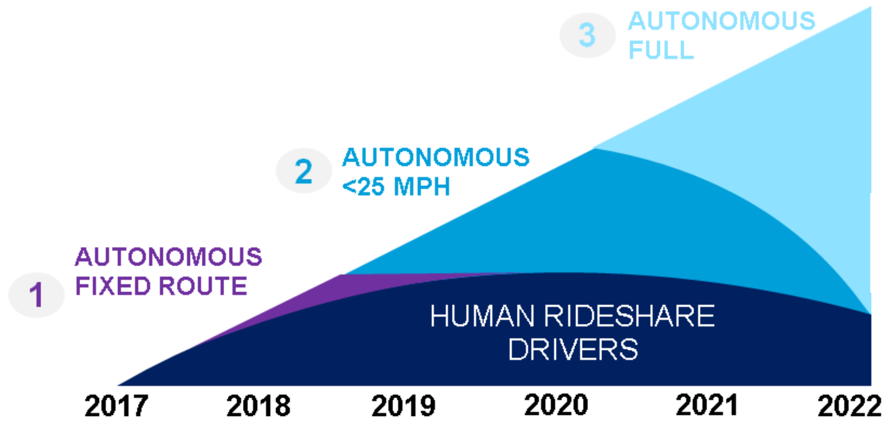
five years. In January 2016 Lyft partnered with GM to launch an on-demand autonomous vehicle network (GM owns ~9% of Lyft).

Figure 35. Lyft's Vision for Autonomous Mobility Path



Source: Company Reports, Citi Research

- **nuTonomy:** The company is an MIT-spinout who launched a pilot for a robotaxi service in Singapore this year (Level-4 with a driver) and is set to launch a commercialized robotaxi service in 2018. In October 2015 one of nuTonomy's vehicles got into a minor accident with a truck, the cause of which is under review. The technology appears to leverage robotics relying on LiDAR sensors and utilities NVIDIA's hardware. nuTonomy's plan is to continue expanding robotaxi services around the world. Citi hosted nuTonomy at our 2016 Technology Conference in New York and the discussion touched upon the company's plans to expand as well as the importance of data and sensors. nuTonomy will be interesting to track since the company took a different approach in developing robotaxi services fairly quickly on the road.

- **Baidu:** Currently testing its autonomous vehicles in China, with a plan to start testing in the U.S. by year end. In fact, in August 2016 Baidu obtained an Autonomous Vehicle Testing Permit from the California DMV. Baidu has partnered with Nvidia to build a comprehensive cloud-to-car platform combining Baidu Cloud platform, mapping technology with NVIDIA's self-driving car platform based on an NVIDIA GPU. Ultimately, Baidu's goal is to introduce a shuttle service within a limited area in China by 2018, and to "mass produce autonomous vehicles in five years" according to recent statements. Baidu's deep learning capability appears strong led by Chief Scientist Andrew Ng, who is well-known in the machine learning community.

- **Zoox, Drive.ai, Comma.ai, FiveAI:** All independent start-ups working on software for autonomous driving and testing vehicles. Zoox currently has a valid autonomous testing permit for the state of California, and has plans to launch a robotaxi service by 2020. Zoox reportedly raised $200 million at a $1 billion valuation earlier this year. Comma.ai was working on an aftermarket device for Level-2 automated driving, leveraging vision and radar, though the company recently pulled its first product launch after receiving a letter from NHTSA expressing concern.

- **Lucid Motors (formerly known as Atieva):** Electric vehicle startup based in California aiming to launch a 300-mile high performance premium vehicle in late-2018. The company recently discussed its technology and industry outlook at the September 2016 Citi Technology Conference.

- **Fisker Inc:** In October 2016 Henrik Fisker, previous founder of Fisker Automotive, announced the launch of a new company, Fisker Inc., that is developing a premium EV. Set to be showcased in the second half of 2017, the vehicle is being designed with new battery chemistry and materials. According to press reports the company claims unique technology that promises to deliver >400 miles of EV range with industry-leading battery life. The plan would then be to follow-up for a more EV vehicle more inexpensive EV vehicle? (<$40k) in the years after the initial launch. Notably, press reports suggest that Fisker's ultimate goal is to sell the new battery technology to OEMs.

- **Faraday Future:** The company received its autonomous testing permit for the state of California earlier this year. The relatively new, aspiring automaker appears well-funded and has hired some notable talent. That said, its commercialization plans remain unknown at this juncture though the company does appear to be testing vehicles. The company is expected to reveal its first production vehicle soon, possibly at the 2017 Consumer Electronics Show (CES).

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- **LeEco:** A China based tech/entertainment company that is reportedly developing an electric car. Media reports suggest LeEco is investing $1.8 billion to build an EV car plant with 400k units of capacity. The vehicle will be connected, electric, shared, and autonomous. LeEco is also reportedly partnered with and backed by Faraday Future in areas like manufacturing/supply chain and R&D.

- **NextEV:** A China based company focused on delivering next-gen connected EVs in new vehicle ownership models. The company was recently issued an autonomous vehicle testing permit in California and has offices in Asia, Europe, and Silicon Valley. Media reports suggest the company plans to first sell vehicles to Chinese consumers and expand around the world thereafter.

- **Delphi:** A large Tier-1 auto supplier that sells into the automakers and has partnered with Mobileye to offer a turnkey solution for fully autonomous driving, Delphi is also developing an automated on-demand pilot for the government of Singapore. Delphi has a fleet of 6 fully-autonomous vehicles (with safety drivers) offering an end-to-end ecosystem for the on-demand platform. In an interview with Automotive News in September, Delphi CEO Kevin Clark noted that Delphi is talking to multiple cities and could announce one or two additional partnerships by the end of the year".

Spotlight on Israel Auto Tech Scene

Israel has become one of the main hubs for technology development across numerous verticals within the *Car of the Future*. In September 2016, we had the opportunity to travel to Israel to meet several companies in the field of sensors, data, AI, ride sharing, electronics, and cybersecurity (where many companies in Israel participate including Argus, GuardKnox and many others). Mobileye has served as a key example leading the Israeli Auto/Tech scene with a successful 2014 initial public offering that later saw market cap approach $10 billion. In 2013 Google purchased the real-time traffic mapping app, Waze, first developed and popularized by the Israeli company Waze Mobile. More recently we've seen VW and Ford make investments/acquisitions in Israeli companies, as have Tier-1 suppliers. We think it's important to track companies in this region both to understand emerging technology that might make its way into production and to understand the competitive landscape of the Auto/Tech industry.

Below we highlight just a few private companies involved in future mobility trends:

Oryx Vision: Developed sensing using nano-antenna technology that promises greater resolution across a longer range (150 meter) with no moving parts, blinding resistance and in all-weather conditions. The technology is explained as follows: Instead of capturing light particles with photo-electric, Oryx Vision receives light as waves using tiny antennas manufactured in silicon arrays in a thin film process.

otonomo: Provides cloud-based services and data analytics enabling car companies to monetize data in the car. otonomo sits between the auto manufacturers and the various vendors who would leverage the data (insurance, safety, maintenance, gas stations, fleet). otonomo's service role is a reminder of the potential value in turning the car into a data gathering nod in the Internet-of-Things.

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Autotalks: A vehicle-to-vehicle (V2V) provider, Autotalks implements a complete vehicle-to-everything (V2X) solution for all use cases including: (a) standalone or integrated in other electronic control units (ECUs); (b) placed anywhere in the vehicles; (c) leveraging the company's deep architecture knowledge.

Valens: Advanced vehicle connectivity leveraging HDBaseT technology. Valens founded the HDBaseT alliance for consumer electronics in 2010, and in 2016 the alliance's automotive group was established. Members include GM, Daimler, Delphi, Mitsubishi Electric, Harman, LG, Samsung and Panasonic. Valens' technology is capable of tunneling up to 6Gbps of simultaneous streams of HD video/audio, data, USB, and power over an unshielded twisted pair cable (50ft).

Cortica: Founded in 2007, Cortica interprets images by simulating how our brains work. Cortica explains that its technology can capture complex structures and relationships in large quantities of low-precision and noisy data. In a car, Cortica's technology could perform highly detailed mapping/localization in ambiguous scenes such as adverse weather where traditional localization cues might not be visible.

Nexar: In-dash camera service providing accident and safety related services for drivers. The app processes data and leverages machine vision to amass training datasets. Nexar has already amassed 5 million miles and adds about 500,000 miles per week.

Gett: On-demand mobility company who recently received a $300 million investment from VW. Gett holds strong positions in Europe particularly in London and Moscow. The company also has a presence in New York. In London more than half of black cabs run on Gett. Besides serving consumers through an app, Gett also has corporate clients. The company sees two models for capturing what it views as "massive" mobility revenue: (a) on-demand provider and automaker collaborate in partnership; and (2) on-demand provider captures all of the value.

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Now, Let's Delve Into Autonomous Technology & Data

Mobileye often describes the technology building blocks for autonomous cars as having essentially 3 pillars: (1) Sensing; (2) Localization/Mapping; and (3) Driving Policy or controls. NVIDIA describes three similar pillars in; (1) Perception; (2) Reasoning; (3) Driving.

Sensing/Perception

The four most used modalities of sensing include vision, radar, LiDAR, and ultrasonic. ADAS applications usually rely on one or two of these modalities, often vision paired with radar. ADAS applications today require front-facing sensing for other vehicles, lanes, pedestrians, cyclists, animals, and other objects. Increasing levels of automation will require a larger sensing area (mostly 360 degrees), the ability to effectively detect everything in a scene, build a robust environmental model, and establish a path planning output. For example, an automated vehicle must understand any lane boundary, all drivable paths, and the general context of the scene. To achieve robust human and superhuman sensing capabilities, superior software capability leveraged on multiple sensor modalities will likely be required for full-speed Level-3 and above. Later we discuss the basics of sensors, but in summary we believe vision has the advantage of attaching context to a scene and path, while radar can detect objects in all weather and lighting conditions. LiDAR can also serve an important role in redundant sensing and unlike radar can also aide in path planning. The Mobileye-Delphi partnership relies mostly on vision and radar but also uses LiDAR for redundancy. Meanwhile the Mobileye-BMW-Intel partnership described a sensor suite of 8 cameras, 4 radars and 4-6 ultrasonic sensors (aimed for level-4 ride sharing). Ford and Google have displayed Level-4/5 vehicles relying more so on LiDAR as a primary sensor though cameras and radars were present as well. It will be interesting to see whether the industry converges on a standard sensor suite for Levels 4/5 or opts for different routes. Regardless, we expect at least two or all three core sensors to be present in such cars. In addition, vehicle-to-vehicle communication could add another layer of sensing in situations that fall outside the coverage area onboard sensors (for situations such as predicting cars entering intersections). Though vehicle-to-vehicle might not be well-represented in first generation Level-4/5 vehicles, we would expect to see more in subsequent generations.

Of course the sensors themselves are just a small part of the battle, as the real challenge lies in developing the software and then perfecting that software to an automotive grade level. This is where computer vision, deep learning, and other image processing techniques come into play. Perfecting software requires key domain expertise and very large amounts of data to train systems and discover corner cases. Some of the software involves annotating images for object detection while others involve training neural nets to solve drivable path, object detection and the free space.

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Deep Neural Networks – Can AI Do It All?

Sensors are merely the input feeds for gathering data. The data must then be parsed through, in order, to come up with a solution and ultimately a vehicle control action (output). One area of industry debate tends to come from the parsing step. With the resurgence in recent years of deep neural networks (DNNs) thanks in part to far greater computing power and the availability of training images (ImageNet), DNN's have achieved sufficient scale to be deployed. Two ways to consider the use of DNNs include: (1) end-to-end solution; and (2) semantic abstraction.

End-to-End

End-to-End is just one massive deep neural network performing all types of functions and algorithms under one house with no specific domain expertise or image annotation — effectively raw data goes in and driving control output comes out. In this model the "problem" is viewed as one giant packet of data that the system solves without breaking the "problem" into unique components. For example the car can detect the free-space on the road and understand the various boundaries around the vehicle, as opposed to bucketing individual detection algorithms which often requires previously annotated images to train the software. Some companies have shown seemingly impressive feats with this framework — for example "teaching" a car how to drive in a short amount of time and seeing real results (NVIDIA's AI trained vehicles in New Jersey as one example). One potential issue with this approach in an automotive setting is that with end-to-end it's arguably more difficult to diagnose a misdetection. In other words, it can be more difficult to find and document rare corner cases (cases that involve a problem of situation that occur outside of normal operating parameters) that maybe didn't cause an accident this time but might next time. Our read of the DOT/NHTSA regulatory guidelines in September 2016 suggested that regulators prefer that automakers essentially have a full accounting of the autonomous system's workings, so if something goes wrong it's easier to diagnose, understand and fix. Additionally, NHTSA's October 2016 letter to Comma.ai also seemed to request a detailed description of testing and analysis for automation functionality and limitations under certain circumstances. That said, various forms of end-to-end could still be used in training various modules such as with object detection, facial recognition, and perhaps vehicle behavior. Also, the end-to-end approach would improve with more training data and validation statistics, thus we do expect some industry participants to pursue this approach though it will be interesting to see whether it ends up requiring lengthier validations versus other methods.

Semantic Abstraction

In semantic abstraction, the video input is analyzed by many individual DNNs and computer vision training, each with a specific task, i.e. object detection, vehicle detection, pedestrian detection, drivable paths, path delimiters and many others. The tasks would then feed into another DNN for the driving policy and then ultimately lead to a vehicle control action. The big difference between semantic abstraction and end-to-end is that in this semantic abstraction model, the "problem" is broken down into individual components, with each module performing a certain set of analysis based on the same input feed. This requires many deep learning networks each designed to solve that particular module. This method has the benefit of being able to identify corner cases even if that corner case wouldn't have necessarily caused an accident at that point in time.

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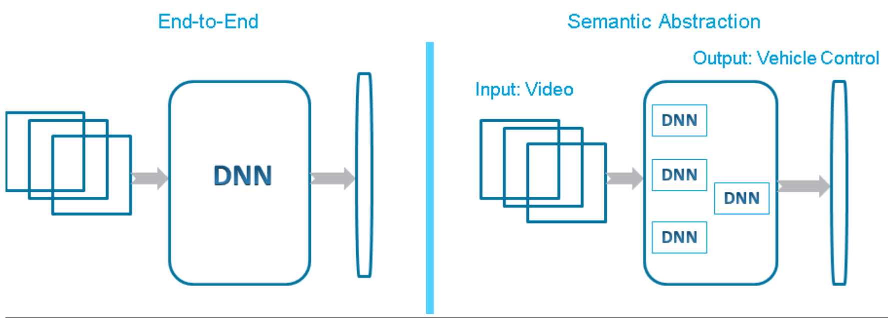
Figure 36. End-to-end vs. Semantic Abstraction



Source: Mobileye, Citi Research

Localization/Mapping

Mapping is interesting because human drivers don't need maps to drive, though humans tend to be more comfortable driving on roads that are already well-known. For autonomous driving, mapping can be thought of as another redundancy layer for precise localization (where am I?), path delimiters (what's around me now; what's coming in XYZ seconds?) and drivable paths (where can I go, what are my options?). Traditional navigation (GPS) maps can localize a vehicle to ~10m range, which isn't accurate enough for autonomous vehicles. Detailed HD maps and 3D maps are able to map at a high detail with centimeter scale. HD maps are typically built with dedicated cars carrying numerous sensors such as LiDARs. Companies engaged in building HD road maps include HERE, Google, Tom Tom and others. HD maps are a key component of autonomous driving and will play a central role particularly in geo-fenced zones and eventually outside as well. However, the main challenge for HD maps relates to a lack of frequent updating. This is a major issue particularly for autonomous driving outside of geo-fenced zones where frequent map updates will be important. Thus, the third approach is a crowdsource map that leverages existing onboard sensors (cameras already performing ADAS) to create a sparse 3D and dense 1D map in near real-time. So think of the millions of cars on the road collecting information (including their drivable path) which is then fed to a network that can provide a near real-time mapping layer for autonomous cars in that network. The set of collected data would sit on top of a typical navigation map (or HD map) to create an effective high-resolution map that can help with features like road hazards, traffic flow, predictive routes, and environmental information. We believe such crowdsourcing capability is critical to ensuring autonomous vehicles have access to live maps across a wide region.

Similar to sensing, we expect vision to play a primary role in crowdsource mapping since: (a) cameras are ideal for crowdsourcing given their role in ADAS vehicles; and (b) cameras can gather more data than radar including lanes, and arguably do not need as much validation data to identify objects. Mobileye REM is a leading example of crowdsource mapping available to all of its automaker customers. Toyota is pursuing a similar camera-based crowdsource map on its own fleet.

Driving Policy & Controls (Behavior of the Car)

This pillar is perhaps the most challenging in the race. It can be thought of as teaching a car how to drive and negotiate in a multi-agent forum where predictability isn't assured. It's also about adopting that car to different driving behaviors in different regions. Examples include negotiating lane merges, intersections, roundabouts, lane changes, negotiating around cars that are double-parked on a single lane road, forming rules to "violate rules" and so on. The industry's approach to this problem has generally been to train software through the use of simulated reinforced learning, where the car is effectively rewarded for finding the appropriate behavior in a simulated scene. The simulator is typically fed an environmental model (what's around the car) after which the reinforcement learning tools train the host vehicle to behave properly in the context of the complex scene. The environmental models can be artificially created in the simulator or created through real-world data — this can come from real mapping data to understand actual road scenarios or even driving data to better capture an entire scene.

Similar to the mapping problem, we think winning the driver policy race is partially a function of data availability, as a greater abundance of real-world data from different regions/automakers would likely be beneficial to simulator training. This can become particularly important for Level-4 test fleets equipped with driver monitors, as those fleets would contain the full sensor suite to test out trained policies and collect more data for future simulations (such as 4-way stop sign intersections). Thus, suppliers who can gain more data (such as by having automakers agree to share fleet testing and mapping data with each other) could become more advantaged in this development. For automakers, the decision tree is about whether to develop policies in-house or outsource to suppliers, and also whether to share data and learnings with other automakers. It will also be interesting to see whether driving policy eventually morphs towards something resembling the crowdsourced mapping concept — in other words where millions of cars on the road can "learn" driving behavior by picking up behavioral cloning cues from the scene (i.e. to tailor vehicles to different regional driving styles) that are subsequently trained to improve driving behavior. Driving policy not only is an enabler of autonomous driving but also a potential differentiator between mobility service companies as consumers might prefer certain riding styles or vehicles that can behave more like humans than machines (particularly when you're running late somewhere).

In theory, over time it could be possible to create unique driver policy rules at a micro level for different regions or even particular towns/roads using a mixture of simulations and real-world behavior data.

Automakers' Options: Source from Suppliers or Develop In-House? Form Alliances for Data Share?

The decision of in-house versus supplier sourcing is one that automakers constantly ponder, particularly when it comes to Level-4 where the autonomous technology effectively becomes the central nervous system of the car. When it comes to sensing and mapping, we expect automakers to outsource as many already do — these pillars are as relevant for ADAS and Levels 1-3 as they are for Level-4.

However, driver policy is an area that some automakers appear to want greater internal control. On the surface this makes sense since one differentiation point of autonomous Car X vs. Car Y could be the driving style. Of course automakers could work with suppliers to outsource some parts of driving policy while internally developing others. Regardless, certain automakers are clearly taking action to at least bolster internal capabilities through M&A (GM-Cruise, Ford-SAIPS), collaborations (BMW-Mobileye-Intel, Volvo-Autoliv) or other internal investments.

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At our Citi's Global Technology conference in September, Mobileye described the landscape in two buckets. The first are large auto manufacturers who prefer company-specific Level-4/5 programs. These automakers would source either in full partnership (BMW-Mobileye) for all three pillars (sensing, mapping, and policy) or buy components for one or two of the pillars. The other bucket contains the mid-size automakers preferring a turnkey solution such as what Mobileye-Delphi are offering the industry.

Even with the different approaches in place, there's a potential for standardization of sensors and mapping data. The sharing of validation and testing data amongst automakers is an interesting possible path to monitor going forward — some automakers might opt to share such data in order to get further ahead in the race. For example, automakers who don't have massive competitive overlap could consider sharing such data. Possible advantages of alliances could be: (1) automakers who share data can pool precious resources and accelerate their position in the race; and (2) autonomous cars having a common driver policy language could be better than having many different approaches.

Introducing Citi's U.S. Autonomous Data Race Tracker

Citigroup Global Markets Inc acted as an advisor to SolarCity Corp in relation to the announced acquisition of SolarCity Corp by Tesla Motors Inc ("The Company"). Consequently Citi will not offer any view, opinion or recommendation on the Company in this report.

Looking at the three pillars of autonomous driving and considering the regulatory element within the driverless race begs a key question — How is one to measure which automaker/mobility provider is ahead or behind?

To be sure, there's no perfect or easy way, and any method chosen, including ours, is naturally fluid as new information rolls out seemingly every week.

Yet one area we can attempt to quantify is data since it's so vital in the race to perfect sensing, build crowdsourced maps, and perform 'fleet learning". Thus, we're introducing a model that computes a U.S. "autonomous data mile score" for select automakers. The model is intended to provide insight at a given point in time and will be updated to reflect future product and other relevant announcements.

Methodology

The model is fairly rigorous, so we've provided a summary methodology flow chart below. As a brief summary, the calculated scores are tallied on a cumulative basis out to 2019. For each automaker evaluated the model takes into account: (1) current ADAS features deployed, future ADAS and autonomous product plans and penetration rates by vehicle model; (2) current vehicles offered with embedded two-way 3G+ cellular technology; (3) U.S. vehicle sales by make/model at the state level for each auto manufacturer (key differentiator for our analysis, in our view); (4) average personal miles traveled vs. average work miles traveled; and (5) rural and urban miles of road by state. Each of these inputs then receives a weighting to determine an automaker's earned miles.

After taking these factors into consideration, two scores are assigned to each evaluated automaker.

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- The first is a Level-4 miles score — the accumulated miles on the vehicles carrying the sensor package that will likely also be used in a driverless setting — essentially the validating miles required to eventually obtain regulatory certification. So if you're an automaker launching Level-4 vehicles on the road, you earn miles for having validation data on the presumed same vehicle configuration that you'll aim to go driverless with. One of the challenges here is that the line between testing (i.e. autonomous-equipped cars on the road to develop software) and validating (proving out system design) isn't clear. So some assumptions/rules are put into the model. Over time we expect it to become clearer and hence our analysis remains fluid in this area.

- The second score takes into consideration Levels 1-3 and mapping capability. The thinking here is that the learnings obtained from Levels 2-3 and mapping could make for a better Level-4 system. So think about it as a "quality of Level-4" miles indicator—if two automakers have 1 million Level-4 miles logged, then the automaker with a higher Level 1-3 score would presumably be better positioned to leverage those learnings on those 1 million Level-4 miles.

Note that we do not give companies credit for simulated miles either in a computer or a geo-fenced testing center such as M City. We do this because we do not have sufficient information to gather such data. The model, at least for now, also doesn't give credit for aftermarket devices such as dash-cams that can also gather data for mapping and policy surfaces. That said, our model is fluid in that if such data were to become available we'd be able to tweak the methodology. So this is really a first iteration and we of course welcome feedback.

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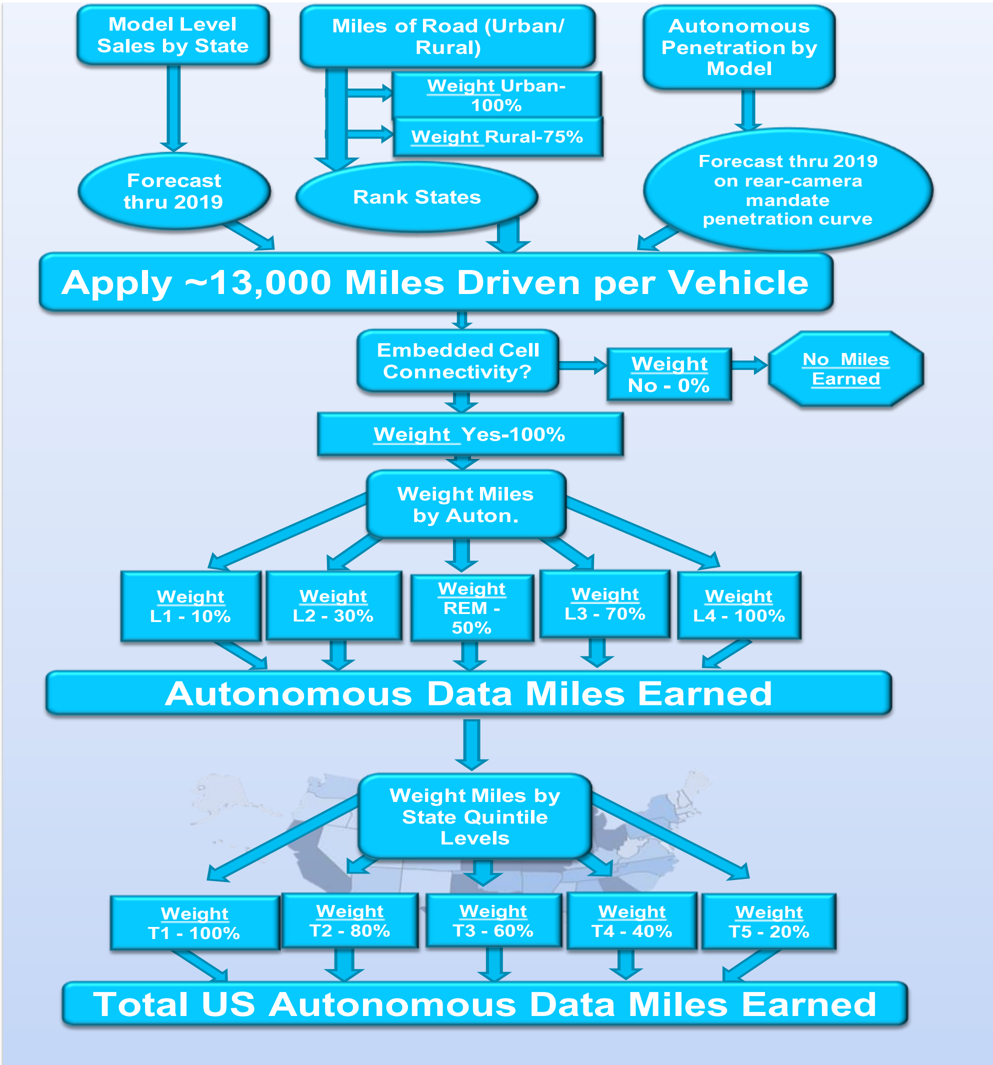
Figure 37. Citi Autonomous Miles/Data Trackers: Interactive Model Flow Chart



Source: Citi Research

Readers of our past *Car of the Future* reports know that our driverless mobility thesis contemplates four states leading the expansion next decade — California, Florida, New York, and Illinois. One of the advantages of our model is being able to analyze automaker scores both at a state and national level. So if you're strong in California and collecting a lot miles already, that should help your score for that state. For the time being we're presenting the data on a national level since we're early days in the data gathering phase.

In terms of the Level-4 miles score, the top four include GM, Google, Ford, and Uber. GM's outlook is based on public commentary and our assumptions from Lyft's outlook that GM will roll out autonomous Bolt EVs in the coming years into the Lyft network. We believe there is a possible advantage in validating through a rideshare network because of the greater randomness and unbiased nature of the miles being accumulated. Google is in the advanced testing phase while Ford and Uber are gearing up larger fleets of vehicles (i.e. >100) for more advanced development. Again, the exact line between validation & testing isn't entirely clear at this juncture.

GM also ranks well on the Level 1-3 score because of the company's aggressive ADAs deployment, expected launch of Super Cruise next year and the expected launch of REM crowdsourced mapping next year. Combined with GM's size, this suggests a capability to amass large amounts of data by 2019.

Figure 38. Full Autonomous Driving Miles – U.S. Total Through 2019

Level 4
Fully Autonomous
United States

Company	Earned Miles	Rank
GM	267	1
Google	18	2
Ford	2	3
Uber	1	4
Daimler	0	5
Nissan	0	5
Toyota	0	5
Volkswagen	0	5
BMW	0	5
Honda	0	5
FCA	0	5

Source: Citi Research

Figure 39. Miles of Quality – U.S. Total Through 2019

Level 1 - Level 3
Miles of Quality
United States

Company	Earned Miles	Rank
GM	18,670	1
Toyota	4,163	2
Nissan	3,766	3
Daimler	3,504	4
BMW	2,764	5
Volkswagen	2,441	6
Ford	1,918	7
Honda	1,779	8
FCA	1,744	9
Google	0	10

Source: Citi Research

Detailed Methodology

Without the use of weightings we would not be able to accurately assess an automaker's competitive position because the equation would be largely skewed by auto manufacturer size rather than adoption curves, product roadmap, and state concentration. Thus we developed a weighting system based upon certain fractional multipliers.

Drivable Miles:

- We assume the average individual/vehicle is driving ~ 13,000 miles/year. We partition these miles traveled per year into two categories: work and personal, since not all miles are the same (for example, driving around the block would technically accumulate miles at a diminishing value).
- We weigh work miles at 20%; we use a similar scale in which Alphabet updates it satellite imagery (~1 per 5yrs) — or said differently we give credit for 1 work day out of a 5 day work week. Work miles are ~60% of total annual miles in our model.

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- We weigh personal miles at 65%; this gives credit for a large percent of personal miles, but helps to eliminate redundancy from repetitive personal drivable routes. Personal miles are ~40% of total annual miles, in our model

State Roadway Weightings:

- The states with the largest miles of drivable roads should receive the most credit, but only after weighing them by their urban and rural roadway splits. We believe urban miles should carry a weight in excess of rural miles. We weigh urban road miles at 100% and rural at 75%
- We combine the adjusted results into a weighted road miles by state
- We then rank the states in quintiles:
  - Top Quintile weight = 100%
  - Quintile 2 weight = 80%
  - Quintile 3 weight = 60%
  - Quintile 4 weight = 40%
  - Bottom Quintile weight = 20%

Connectivity Weighting

- In order for an auto manufacturer to be able to record and access real-word data from its automation technologies we measure whether a vehicle has embedded two-way 3G+ cellular technology. At the model level, if a vehicle has this connectivity element it receives a binary weighting of either 100% or 0%. We assume all auto manufacturers will have this type of connectivity by 2018.

ADAS Weighting

- ADAS capabilities are weighted by the level of autonomy each feature is applicable to. We weigh on five levels:
  - Level 1 – 10%
  - Level 2 – 30%
  - Level REM (Mobileye crowdsourced mapping) – 50%
  - Level 3 – 70%
  - Level 4 – 100%

Model Building Blocks

The model incorporates our best attempt to complete a bottom-up analysis starting from sales forecasts at the state levels. We make the following assumptions:

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- We assume all vehicles in the U.S. will have embedded cellular (3G+) connectivity by 2018
- We assume that if any trim of a vehicle offers connectivity, even as an option, then that the entire vehicle line will receive full credit for it;
- We assume a ramp to 100% ADAS penetration in the U.S. by 2022; in the model year 2015/2016 build we start with lane departure warning (LDW) penetration rates by model (import and export) and grow the base value at a cadence commensurate with the rollout and penetration of rear-camera regulatory mandates;
- We assume a different path progression for each auto manufacturer in the race to fully autonomous;
- We assume that auto manufacturers with an undefined or ambiguous autonomous plans first deploy the more advanced features on luxury models, followed gradually by mass market models;
- We assume that sales growth will occur at the same rate as production growth; and
- We assume that new vehicle entrants sell at levels commensurate with their production estimates for one full year post a stub-year entry/ramp.

Pillar #2: Gauging Supply/Demand Capability

As noted above, the robustness of a driverless mobility network also depends on the network's load factor, or the number of people/things per mile. To regulators, the preference for a network with a higher prospective load factor could also stem from the need to reduce congestion and pollution. Of course for the networks themselves a higher load-factor = lower prices and therefore a competitive advantage. The other advantage in a ride sharing network comes from being able to presumably validate a Level-4 fleet (with a driver monitor) faster and more economically than a non-revenue generating fleet.

Ride sharing firms like Uber/Lyft/Gett have an inherent advantage here having already built a customer network and the related strategic data in key cities. Of course if these companies were to fall behind in the autonomous capability race (the pillar described above) then the value of their existing networks would come under risk — this likely explains why both Uber and Lyft are engaged in self-driving efforts. It also likely explains why GM partnered and invested in Lyft, why GM launched its Maven car-share business, why VW partnered/invested in Gett, and why Toyota and Volvo have both partnered in some capacity with Uber. One can surmise that Google and Apple could also consider playing a future role in this capacity, and at least Google is actively pursuing self-driving capability.

Uber is presently the clear leader in this pillar. It's also notable that Uber is most visibility investing and acquiring to develop its own autonomous car technology, unlike its smaller peers (Lyft & Gett) who have partnered with traditional automakers. Yet, even Uber will likely depend somewhat on automakers both to supply the driverless cars and the necessary service/telematics support (i.e. the next pillar). For example, industry contacts suggest to us that retrofitting a Level-4 car with sensors will likely prove difficult for a production vehicle, making auto manufacturer integration critical for the final product.

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What we don't know is how willing automakers are to work with Uber on exclusive terms? If the answer is not very willing, then Uber's decision to develop its own autonomous technology makes complete strategic sense in that it could strengthen Uber's position to negotiate favorable sourcing deals with automakers in the future. Without these efforts Uber could conceivably have one day found itself stuck between automakers developing their own driverless technology and tech giants (Google, Apple) who — with driverless tech — could probably build their own rideshare networks. In other words, having driverless certification makes it easier to build a ridesharing network, particularly for technology companies with established ecosystems. So for Uber, being first or amongst the first in the driverless race is important as that could be the ticket to maintain a sizable share of the (more profitable) driverless urban robotaxi market. For Uber's U.S. competitors there's probably less of a choice given financial constraints, thus partnering with automakers makes sense.

The questions now are: (a) From an autonomous tech perspective how far is Uber relative to the automakers and to Google?; (b) How far could Uber's partnerships with Toyota and Volvo go?; and (c) With Uber taking aggressive steps into autonomous, will other automakers decide to partner with Uber on a more exclusive basis? Frankly the answer is unclear though Uber's Pittsburgh fleet of Volvo vehicles (fitted with Uber self-driving technology) could provide some clues in the coming year.

Regardless, for automakers we view partnerships with ridesharing firms as a positive since it injects that critical pillar to run a successful future driverless network in a geo-fenced urban setting. GM appears to be most ahead in terms of its relationship with Lyft — which entails an equity stake, the Express Drive platform and future Level-4 vehicles (likely Bolt EV vehicle). Volkswagen also appears committed and has forged a relationship with Gett. And of course Volvo and Toyota appear aligned with Uber in different aspects.

Figure 40. Automaker Rideshare vs. Carshare Landscape

Automaker	Rideshare Partner	Carshare Partner/Company	Other Mobility Ventures	Details
Ford	n/a	n/a	Chariot, GoBike bike sharing	GoDrive is a small carsharing program in London within FSM
GM	Lyft / Uber-pilot	Maven	n/a	GM is partnering with Uber for a 90 day pilot program in San Francisco to provide drivers with rentals
Toyota	Uber	Dash - pilot, Getaround - pilot	n/a	Toyota has Dash, a car sharing pilot with City CarShare. One location, 30 EVs. It also has a pilot with Getaround for 2017 in San Francisco, California
Volkswagen	Gett	n/a	n/a	VW formerly had a Car Sharing program, Quicar which was transferred to Greenwheels (60% project stake by VW) in March 2016
BMW	Scoop	DriveNow	n/a	DriveNow is Euro only, was formerly in SF but stopped because of parking
Mercedes-Benz	n/a	Car2Go	Via On-Demand Shuttle - pilot	Ridescout acquired in 2014
Volvo	Uber	n/a	n/a	

Source: Company reports, Citi Research

What About Car Sharing?

Car sharing could also become an outlet for automakers to form direct connections with consumers and thereby establish networks. These would include services such as Zipcar (Avis), Car2Go (Daimler), DriveNow (BMW), Maven (GM) and of course the rental car companies themselves. Having such networks could allow companies to establish a footing for the driverless race. GM's Maven unit just recently announced a 90-day pilot with Uber to make GM vehicles available to Uber drivers in San Francisco. This service offers a weekly lease of $179 (plus taxes and fees),

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which includes insurance and no additional fees for utilizing the vehicle for personal use. Just recently, Toyota made a strategic investment in Getaround to launch a car sharing service in San Francisco. Under this service, owners of Toyota-vehicles will be able to make monthly lease payments directly through earnings derived through the Getaround car share platform. Besides traditional rideshare networks (Uber, Lyft, Gett, Ola, Didi) and the car sharing services mentioned above, carpooling services such as BlaBlaCar and recently Waze have also entered the mix.

Pillar #3: Gauging Fleet Service & Hardware

We think about this in three simple buckets.

First, automakers with greater global scale and larger dealer networks should have some advantage. Robust dealer networks are important for servicing, parking, and inspecting driverless vehicles. Like aircraft, we suspect that driverless vehicles will require routine inspections that normally would be done by the owners of the vehicles. Rental car companies could also play a role here.

Second, telematics services will be important too. Robotaxi riders will likely need access to a human assistant in case of questions/concerns. Human surveillance will likely also be required to ensure a smooth transition between riders (need to make sure prior rider indeed left the vehicle) and in case of immediate service needs in the vehicle. Automakers with established telematics and connectivity support services could therefore gain some advantage here too.

Third, automakers with strong electric vehicle capabilities should also be advantaged. Electric cars tend to be a good fit for autonomous cars. While it's conceivable that by 2020-2025 there will few competitive advantages within EV technology, this is not a foregone conclusion. Automakers with superior technology that can squeeze more range and/or lower costs per revenue mile could gain an edge here.

2030: Whose Comes Out Ahead in the Race?

While it's still early to call leaders and laggards in the mobility race amongst the automakers, we tend to favor companies/consortiums that:

- Are aggressively pursuing autonomous including through partners;
- Are highly data rich, including crowdsourced mapping, and strategically partnered with rideshare outlets;
- Have a strong connectivity/telematics presence and are establishing direct links to consumers through apps;
- Are showing leadership in EVs; and
- Have scale and large dealer networks that play a fleet management role.

How many winners are likely to emerge? It is clearly too early to tell but industry contacts have expressed their belief that each region is likely to have two to three large players, but that each country or region could have two to three different companies. This seems logical to us. We should stress that automakers do have other opportunities to pursue beyond driverless models such as leveraging connectivity/big data to secure more aftermarket revenue.

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How about suppliers? The trend of higher content for autonomous, connected, and electric vehicles should bring about opportunities for certain auto suppliers. Newer verticals such as cybersecurity and big data can also play a role. The advantage suppliers have not only sits in higher content (particularly vs. sedan/small car segments) but also in the resulting complexity and therefore higher switching costs that result.

Figure 41. 2030: Who Comes Out Ahead in the Race?

Source: Citi Research

What Happens to U.S. Auto Sales?

SAAR 2030

Our goal of this analysis was to speculate as least as possible in what's naturally an illustrative auto sales model out to 2030. Thankfully we believe we have some proprietary tools that allow us go deeper than a simple "choose your own adventure" exercise. At the same time, because we're stress testing the long-term outlook of the automotive industry, we do want to make some purposefully conservative assumptions at times — for example; (1) we do not assume that driverless cars gain any share from other modes of transportation; (2) we assume that all driverless cars are served by autonomous fleets (FLEET-AVs) as opposed to autonomous vehicles owned by consumers (PERSO-AVs).

- Step 1 is to break the industry thought process as follows: (1) implications to fleet vehicles (rental cars, taxis); (2) implications to retail vehicles from the vantage point of geography (cities/rural/regions/states); and (3) implications to retail vehicles from the vantage point of segmentation (pickups vs. cars vs. SUVs etc.).
- Step 2 is to establish the 2020-2030 driverless car industry scenarios leveraging our density survey history and then determining lost auto sales by focusing on state-level market share data by auto manufacturer.

Let's begin the process:

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Fleet vs. Retail:

1. **Fleet (~20% of U.S. light vehicle sales):** Perhaps the least debatable assumption is that taxis and rental cars are likely at greatest risk of being displaced by FLEET-AVs and PERSO-AVs. Note that this is not a view on the role of rental car companies — in fact fleet management will become increasingly important—but rather the need for dedicated fleets as we know them today. We estimate U.S. daily rental car sales are in the 1.0-1.5 million range, or 7% of total U.S. light vehicle sales. Of course these tend to be low-margin sales for car companies. In our simulation we assume that this channel gets cut by 50% by 2030. The remainder of the fleet channel consists of government and corporate customers. For them we assume no change in buying habits.

2. **Retail vehicles (~80% of U.S. light vehicle sales):** Here a shift away from traditional personal mobility would likely first depend on the segment (truck vs. car) and then the location within the U.S. — at least in the onset of the industry (first ~10 years). Thankfully we have detailed data and internal tools to break these down.

Retail: Which Segments Are Most Likely To Be Disrupted?

1. **Trucks, Luxury Less At Risk (38% of U.S. sales):** Segments here include pickup trucks, SUVs, vans, large crossovers, large cars, and luxury cars — all by and large likely to remain personal use vehicles. These are essentially vehicles that provide utility to the end-user (larger families, towing) or luxuries that consumers will likely (albeit perhaps irrationally) refuse to abandon. These segments account for roughly 38% of U.S. vehicle sales. For GM & Ford, they make up close to 50% of unit sales and a comfortable majority of variable profits. So at least through the current 2030 analysis, we consider these vehicles beyond the initial addressable market of driverless mobility networks.

2. **"At Risk" Segments = Everything Else (62% of U.S. sales):** Traditional mass market vehicles like small cars, midsize cars and crossovers. Think of the underutilized second or third car in a household or that excess car owned in/around a major city. Going forward our model isolates these segments as the "at risk" addressable market ripe for disruption.

Retail "At Risk" Segments: Which Regions Are Most Likely To Be Disrupted?

So after establishing the number of retail vehicles within the "at risk" segments (~62% of auto sales), the next step is to consider regions most/least ripe to be impacted by driverless taxi networks. Our assumption here is that driverless networks will at first aim at: (1) highly populated cities and their surroundings — where higher utilization can reap the most monetary and environmental gains and; (2) warmer weather states (California, Florida) where logistics and maintenance issues (snow) are less problematic. Next we dimensioned three types of markets:

- **Major cities:** Census data suggests the top 30 U.S. cities sport a population of ~39 million people, suggesting that ~23 million vehicles reside in them or ~9% of the total U.S. light vehicle population. Note the top three cities (New York Metro, Chicago area, Los Angeles County) are fairly underweight for GM and Ford as the companies' combined market shares in these 3 cities stand around 10% and 8%, respectively, well below the companies' national market share of 18% and 14%.

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- **Suburbs near major cities:** Commuting towns. This is an interesting vertical and probably most difficult to precisely model as some of this gets blurred between city/suburb. Here in particular subscription models or personally-owned autonomous vehicles could play a key role. If I don't leave for work until 8:30am, I can loan out my driverless-equipped car from 6:00-8:15am to transport local residents to public transportation stations — reducing the need for second or third vehicles used primarily for "last mile" commuting purposes. How about the commute itself? Can dedicated taxi-robots designed for multiple passengers take share from public transportation or single occupant vehicles? Why rely on a bus or train schedule when you can set your own departure time?

- **Personal cars in rural areas:** Least likely to be impacted initially.

But we ran into a problem as ultimately we felt it too blurry to split the market between major cities vs. minor cities vs. suburbs vs. "pure" rural. The workaround came from us having granular retail sales data in every state, every segment in that state and then the auto manufacturers' market shares in those segments and states — giving us high detail to assess how many "At Risk" segmented vehicles sell in each state and by each manufacturer. So we decided to focus the exposure analysis on individual states that: (a) have major cities; and (b) may be more prone to adopt driverless networks based on past vehicle density trends, population and weather. Doing it this way also ensured some conservatism by essentially assuming that driverless cars impact an entire state as opposed to parts of it. The four states chosen through 2030 include:

1. California
2. New York
3. Florida
4. Illinois

Combined these states generate roughly 30% of U.S. auto sales, each having a key populated city and two out of three having good weather. We held other states constant in our model.

Spotlight on Citi Proprietary Density Survey

The question of what happens to auto sales from the rise of new mobility is really a question about the future direction of household vehicle density. The decision around vehicle ownership is one that combines several variables (needs, desires) that can change throughout a person's life. Vehicle density was a major force behind the severity of the U.S. auto sales downturn of 2008-09, which then took many forecasters by surprises. In 2010-11 it wasn't clear if U.S. household density would ever return to 2007 levels. So the Citi Auto Team began running surveys that asked consumers three key questions:

1. How many vehicles do you have in your household currently?;
2. How many vehicles do you expect you'll have in your household 2 years from now?; and
3. Why?

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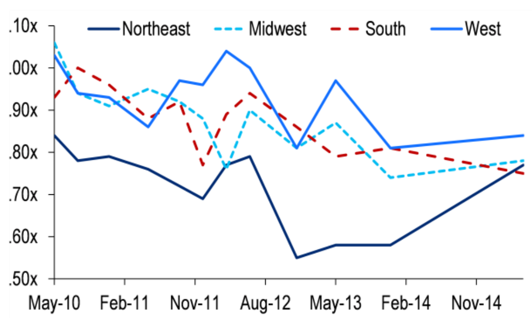
Though the Citi density survey was built to forecast U.S. auto demand, it is now becoming increasingly useful in tracking how new mobility options influence people's future density plans. How is car and ride sharing impact people's plans for personally accessible mobility? How will that change when we enter the era of driverless cars? Our survey yields insights into density plans by region, age group, income level and many other factors. And with over six years of historical data, we expect to yield valuable insights with future surveys.

Forecasting Density Declines in Impacted States

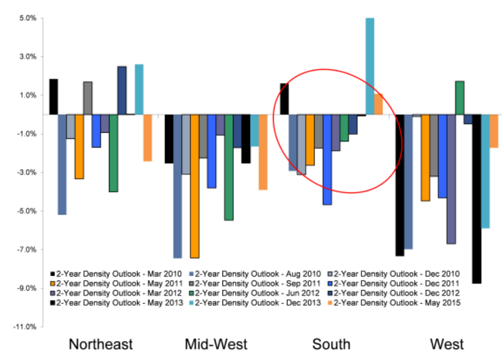
So this part is where our survey comes in. It goes without saying that modeling potential 2020-2030 density declines is far from an exact science. That being said, our survey work over the past five years does provide some clues to work with — our survey chronicled the country's first meaningful decline in household vehicle density that began with the 2009 recession. Now we can look back at that period as a proxy for what might happen once we enter the driverless car era. We can also leverage our survey for a few pinpointed data points: (1) the rate of annual declines in household density by region, matching that region with each of the 4 states chosen above; and (2) assessing how consumers in different regions predicted their future household density to see which regions appeared more or less resilient, which were most volatile etc.

Figure 42. U.S. Density Trends By Region (May 2010-May 2015)



Source: Citi Research

Figure 43. Regional Density Analysis (% Chg. Intent 2-yrs from Now)



Source: Citi Research

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SAAR 2030: Introducing Citi's LT Auto Disruption Model

Citi's Edge: We believe we have a decent sense of how density has trended in each U.S. region over the past 5 years. Additionally, we can precisely break out U.S. retail sales first by region/state and then by the "At Risk" segments described above. For example, our data can tell us how many "At Risk" vehicles are sold in each state, and then how many "At Risk" vehicles GM, Ford and others sell in that state. We believe this gives our model an edge in understanding both the SAAR aspect (density) and then importantly which automakers may be more/less exposed.

The SAAR 2030 Model: Based on the framework described above, our model makes the following assumptions:

1. Our previously published SAAR estimates through 2018;
2. A simulated U.S. recession occurs in 2019-2020. This keeps the model realistic for cyclicality and ensures we don't work off an unreasonably high starting point for the simulated 2020-2030 period;
3. A recovery begins in 2021 just as the driverless car era begins;
4. Driverless on-demand rideshare networks start expanding in California, Florida, New York and Illinois — the entire states not just the major cities;
5. As mentioned, we assume 100% of driverless car fleets are represented by dedicated vehicles as opposed personally-owned vehicles;
6. We assume that every six personal cars can be replaced by an autonomous car;
7. Based on our prior regional density surveys, we estimate annual density declines in each of the four targeted states. Our survey suggests a baseline declining annual range of 3-5%; rarely have we observed extreme drops of 8-12%. So we assume each of the four states experience annual density declines of 6-9% from 2021-2024 and then 5% through 2030;
8. The non-impacted states experience zero density movements from 2021-2030;
9. For the entire country we assume household growth trends at 0.75% annually, a slight rate of population growth;
10. (No macro cycles are assumed in the 2021-2030 period, so think of that period as "normalized" adjusted for the impact from driverless cars; and
11. No assumptions are made for subscription-based autonomous models, but also no assumptions made on rising miles driven.

SAAR 2030E Base Case = 15.7 million

1. **SAAR likely stays > 15 million units:** Our baseline simulation suggests the U.S. SAAR staying in the high-15 million unit range by 2030. The rough bridge from the current 17.0 million level is as follows: (1) lose 0.5 million units from rental/taxi fleet channel; (2) lose ~1 million annual retail sales; and (3) gain 0.1-0.2 million units from household population growth.

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2. **By 2030 we shed nearly 17 million vehicles from the road,** net of population growth. Assuming one driverless car can replace six personal cars that would place the driverless car market at about 3 million units.

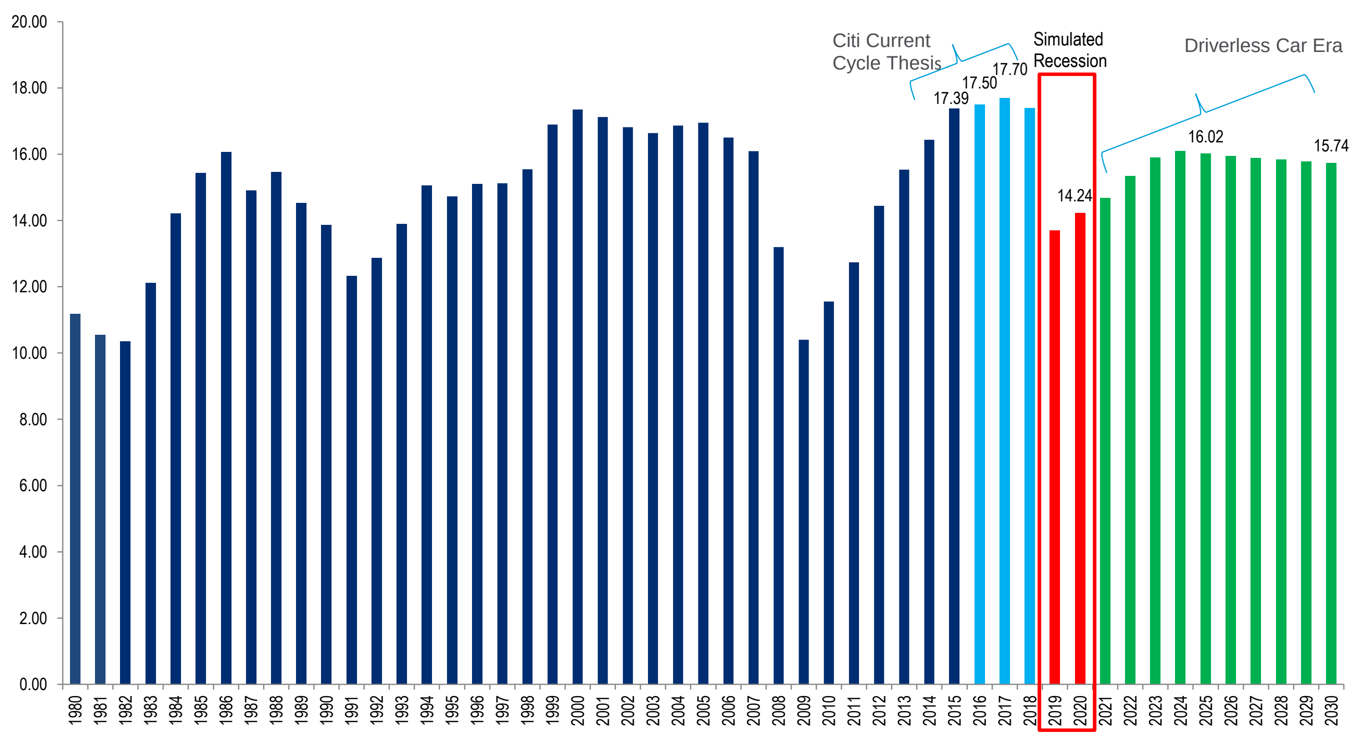
3. **2030 driverless car market exceeds $100 billion:** If 3 million units collect $0.70/mile (multiple occupants in high dense regions) and drive 50,000/year that means the total market size = $100 billion before any other benefits from leveraging the ecosystem. That's the size of GM North America but with a far higher gross margin, by our estimation.

4. **Three million driverless cars being replaced every four years** means the industry can serve a $100 billion market with ~750,000 units of annual production. If three networks capture 100% of the market hypothetically, that means the barrier to enter is only 250,000 units of annual production—essentially the size of a single major auto plant. This underscores the declining barriers to enter for this part of the market.

SAAR 2030E Further Stress Case = 14.5 million

If we further stress our model to assume broad 1% annual density declines in the remaining states (not the four we chose) the 2030 SAAR falls to 14.5 million units. That would be the removal of 34 million cars from the road. This scenario assumes aggressive penetration in the four states chosen and modest penetration of the others, whereas the base case assumes flat density in the others. Because we feel our base case embeds conservatism, we show the stress case for sensitivity purposes only. The remainder of the analysis reverts back to the base case.

Figure 44. U.S. SAAR Simulation, 1980-2030E



Source: Company reports, Wards, Citi Research estimates

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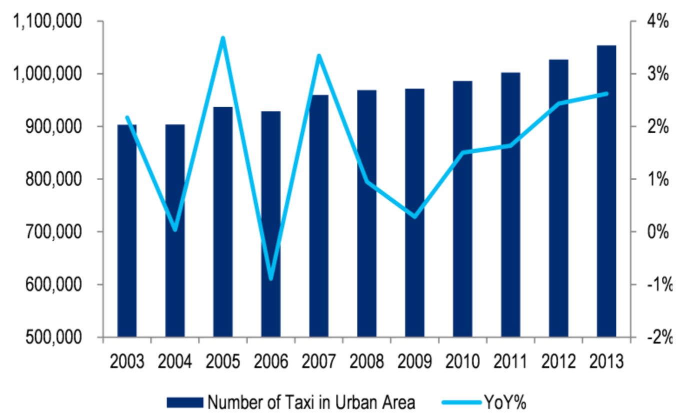
Car Sharing and Ride Hailing in China

Stagnated Taxi vs. Growing Mobile Internet

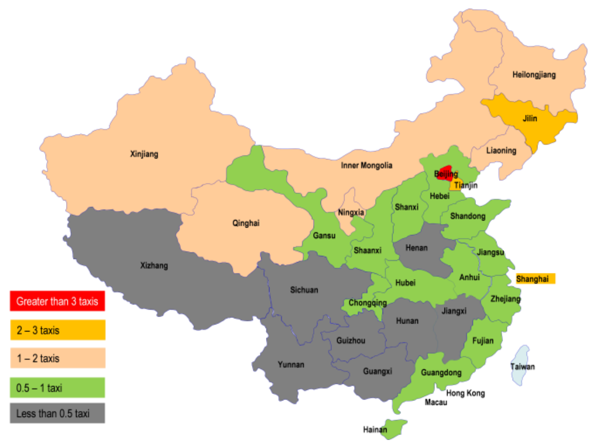
China's urban taxi business has been highly regulated as municipal government controls taxi licenses and regulates taxi fares. According to the Ministry of Finance, there are 1.3 million taxis in China, of which ~1 million are running in urban areas. During the 2002 to 2014 period, the total number of taxis in urban areas increased no more than 3% per year because of such restrictions. With rapid urbanization, the average number of taxis per 1000 people in Beijing and Shanghai has dropped 30% during the period, creating a shortage of taxis, especially during rush hours.

Figure 45. China - Number of Taxis in Urban Areas



Source: Wind, NBS, Citi Research

Figure 46. China – Taxi Penetration, per 1,000 people



Source: Wind, CEIC, Citi Research

Chauffeured car service, a substitute and upgrade to traditional taxi service, has been expanding rapidly since 2014 thanks to the wide adoption of smartphones and mobile Internet, aggressive subsidies from operators, and a relatively low cost of labor. Didi and Kuaidi, who started with taxi-hailing services and later merged as Didi Chuxing, extended their service to chauffeured cars in mid-2014 and soon expanded their registered drivers to the one million level. Meanwhile, U.S. ride-hailing service Uber also entered the market soon after its trial operation in Shanghai in late 2013. Yidao and China Auto Rental ("CAR") also launched their own chauffeured car services under the Yongche and UCAR brands, respectively.

Fast Expansion of Major Players

According to Roland Berger, as of December 2015, Didi Chuxing led the leader table with a 77% market share by combining services in all categories. Uber followed with 14% market share, primarily coming from its economic People's Uber service. UCAR's overall market share is roughly 6% as it focuses on the premium market.

Among these major players, Uber is pervasively using third party drivers and vehicles, and is closest to the definition of "shared economy". UCAR is at the opposite extreme, with employed drivers and its whole fleet self-owned or rented from its related company CAR Inc. Didi and Yongche are adopting a hybrid model. However, we believe none of them are likely profitable at this moment, as all need to subsidize both the drivers and passengers.

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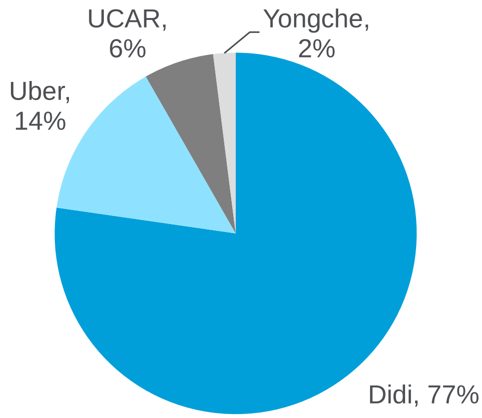
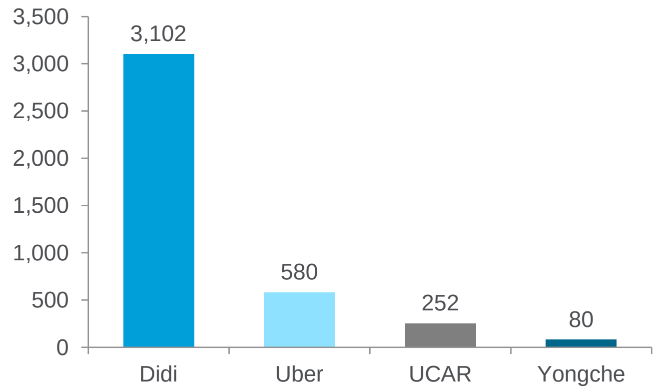
Figure 47. China – Market Share by Average Daily Orders



Source: Roland Berger, Company data, Citi Research

Figure 48. China – Average Daily Orders as of December 2015 ('000)



Source: Roland Berger, Company Data, Citi Research

Figure 49. Business Models of Major Car-Hailing

	UCAR	Uber China	DiDi Chuxing	Yidao Yongche
	神州专车	优步	滴滴出行	易到用车
Cars	100% rent from CAR	Mainly private cars	Rent from third party car rental companies	Rent from third party car rental companies
Car Drivers	Employed by third party labor companies	Mainly individual drivers	Employed by third party labor companies and also individual drivers	Employed by third party labor companies and also individual drivers

Source: Company reports, Citi Research

Policy Risks Linger

On October 10, 2015, the Ministry of Transport of China ("MoT") issued draft guidance on reforming the taxi industry and regulating car-hailing services. According to the guidance, mobile-based chauffeured car service will be included into the taxi regulation and classified as 'appointment-oriented services'. The major implications include:

- All vehicles in the fleet must be registered as taxis and private cars are not allowed to carry out such business.
- Drivers need to be full-time employees to do the business and have to obtain additional license.
- Companies are prohibited from connecting passengers and unregistered vehicles, applying to providing platform for car riding.

On July 27, 2016, the MoT formally legalized on-line car-hailing services with the new regulation framework being effective from November 1, 2016. The new regulation was more accommodative then the previous version as it welcomed car-pooling and ride-sharing by acknowledging private cars can provide car-hailing services with regulatory requirements.

Following the MoT's new regulation framework, in early October 2016, the local authorities of several major cities issued their respective execution versions, which set more detailed regulation on the vehicles and drivers. The major requirements include:

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- Vehicle specifications are typically set above taxi standards, especially in terms of wheelbase, engine size, and years of service.
- Private cars have to be registered as an operating vehicle which pays higher insurance, fees, and has a shorter vehicle life.
- Stricter screening and restrictions on a driver's background.

The new policy, which legalized private cars, seemed in fact to discourage individuals to join the business. It also limited the market segment of car-hailing service to the high-cost, high-end model.

The regulations are still tentative and pending adjustment and we see operators, taxi drivers, and passengers react in various manners. We expect the market consolidation continues with regulation settle down.

Cash Burning Business

Despite the ambiguous tone on car-sharing or car-hailing services, Uber's service is currently available in 36 Chinese cities. Forbes magazine reported Uber is losing $1 billion per year in China to promote its service. Per our price survey, Uber is charging even less than the already cheap taxi service in China to promote its service, while our discussion with Uber drivers in Shanghai and Chongqing unveiled that drivers pervasively said they earned more by driving for Uber than a regular taxi, with less working hours.

Figure 50. China – Price Comparison of Car Hailing Businesses

Company	Brand	Base Fare (Rmb)	Milage Charge (Rmb/km)	Waiting Time Fare (Rmb/Min)	Price 10km + 5min Waiting (Rmb)
Economy					
Uber	People's Uber	0.00	1.50	0.25	16.25
Didi Chuxing	Didi Kuaiche	0.00	1.50	0.30	16.50
Yongche	Yongche	10.00	2.40	0.40	36.00
Standard					
Uber	uberX	15.00	2.30	0.40	40.00
Didi Chuxing	Didi Kuaiche	11.00	2.70	0.75	41.75
Yongche	Yongche	15.00	2.80	0.50	45.50
CAR	UCAR	15.00	2.80	0.50	45.50
Didi Chuxing	Kuaidi ONE	15.00	2.90	0.50	46.50
Premium					
Uber	uberBlack	18.00	3.85	0.70	60.00
CAR	UCAR	23.00	4.60	0.80	73.00
Didi Chuxing	Didi Zhuanche	22.00	4.60	1.80	77.00
Yongche	Yongche	25.00	4.60	0.80	75.00
Didi Chuxing	Kuaidi ONE	29.00	4.90	0.99	82.95
7 seater					
Yongche	Yongche	18.00	4.50	0.70	66.50
CAR	UCAR	20.00	4.50	0.70	68.50
Didi Chuxing	Didi Zhuanche	19.00	4.50	1.20	70.00
Didi Chuxing	Kuaidi ONE	25.00	4.90	0.84	78.20

Source: Company reports, Citi Research

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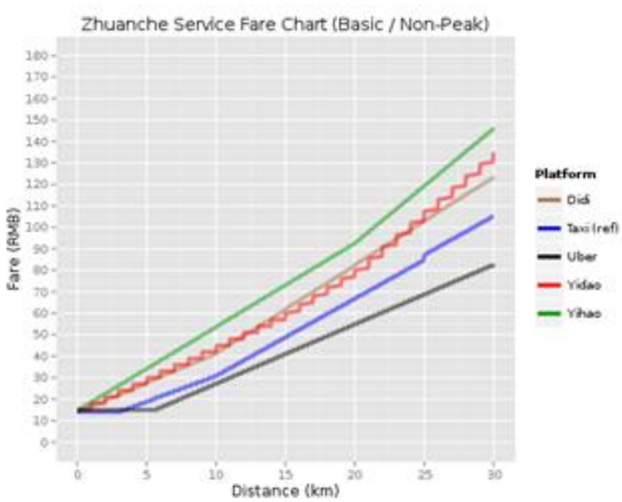
Didi Acquiring Uber China

Didi Chuxing, which was combined from Didi Dache and Kuaidi Tech, announced its acquisition of Uber China's brand, operation, and data on August 1, 2016. It was a non-cash deal with Uber Inc. receiving 5.89% voting shares of the combined company, or equivalent to 17.7% of economic interest. The founders of Didi and Uber will be on each other's board. The combined company will take up to 87% market share. After the merger, there are three major players left including Didi, UCAR and Yidao, while there are still newcomers squeezing into the market. Caocao Ride-hailing Service, backed by Chinese auto maker Geely Group, just began expanding its fleet with its own electric sedans.

Figure 51. China – Car Hailing Price (Non-Peak)



Source: Zhihu, Citi Research

Figure 52. China – Car Hailing Price (Peak)

Source: Zhihu, Citi Research

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Saving Lives in the *Car of the Future*

While the autonomous race garners much attention, we expect the vast majority of vehicles over the next 10-15 years to have forms of automation but not necessarily be fully autonomous. Ford, for example, expects 80% of vehicle in 2030s to still be non-automated vehicles (AV).

Yet even vehicles falling in the Level 1-3 category still have much to offer in the *Car of the Future* by way of safety & convenience.

Despite major advancements in automotive safety systems over the past two decades, road fatalities still claim over 1 million lives around the world each year. The outlook is unfortunately even grimmer considering the aging population and the increasingly connected driver. By 2030, road fatalities are poised to rank in the top 5 causes of death globally.

It is estimated that 93% of U.S. accidents are caused by human error, with Europe sporting a similar ratio. Alcohol remains a major U.S. contributor involving ~30% of fatal crashes. Speeding is also a major factor at ~30%, driver distraction ~20%, lane keeping ~14% and failure to yield ~11%. It is estimated that if a driver is afforded an extra ½ second of response time, roughly 60% of accidents could be avoided or mitigated.

Figure 53. U.S. Crash Stats

US Crashes per Year	5.5mln
% Human Error	93%
Fata Crashes per Year	**32,367**
% Involving Alcohol	31%
% Involving Speeding	30%
% Involving Distraction	21%
% Involving Lane Keeping	14%
% Involving Yielding	11%
% Involving Wet Road	11%
% Involving Fatigue	3%
% Involving Erratic Operation	9%
% Involving Inexperience Issues	8%

Source: IIHS, Citi Research

Besides the human toll, there's also a substantial economic toll. In the U.S. alone, the annual economic toll of car crashes is estimated at $300 billion, or ~2% of GDP. This is made up of several buckets including property damage, productivity loss, medical & legal costs, and congestion. So on top of the personal safety risk, drivers must also bear a direct operating cost (insurance) to cope with this economic toll.

Figure 54. Global Auto Fatality Stats

	Fatalities per 1,000 Vehicles
United States	15
Germany	7
Japan	7
South Korea	26
China	36
India	315
Thailand	119
Brazil	71

Source: IIHS, Citi Research

If that's not enough, the resulting traffic congestion and inefficient driving behavior diminishes the joy of the driving experience and contributes unnecessary tailpipe emissions. Bettering real-world driving behaviors may be equally as powerful in the quest to reduce tailpipe emissions.

The "ABCs" of ADAS

In the simplest defined form, a typical advanced drive assistance system (ADAS), or active safety, package uses onboard sensors, software, electronic controllers/architecture, and actuators to alert drivers to potential hazards and even temporarily take control of a vehicle to avoid dangerous situations. When we think about ADAS there are many unique features to consider, some of which include: blind spot detection, forward collision warning, lane departure warning, lane keeping assist, pedestrian detection, vehicle/object detection, autonomous emergency braking (AEB), traffic sign/light recognition, intelligent headlamp assist, adaptive cruise control (ACC) or even a more advanced feature like traffic jam assist (TJA). All of these features can be powered by different sensing modalities, which we go into a bit more detail below.

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Figure 55. ADAS Sensor Comparison by Cost, Distance, and Visibility

Sensor Comparison

Modality	Cost per Sensor	Detection Distance	Weather
Ultrasonic			
48 kHz	$15-$20	0 <= 6m	Great
Vision			
Vision - Mono	$75-$100	0 <= 150m	Good
Vision - Stereo	$115-$200	0 <= 40-50m	Good
Radar			
24-26 GHz	$50-$125	0 <= 50m	Excellent
76-81 GHz	$125-$165	0 <= 200m	Excellent
LiDAR			
64 channel	~$70k	0 <= 120m	Good
32 channel	~$30k	0 <= 80-100m	Good
16 channel	~$8k	0 <= 100m	Good

Source: Delphi, Mobileye, Velodyne, TI, Citi Research estimates

Radar

Radar (RAdio Detection And Ranging) uses emitted microwaves and reflected signals to detect objects. Automotive radar is typically classified by its range — long-range 77GHz and short-range 24GHz. Longer-range radars tend to have a narrower field of view while shorter-range a wider coverage. During the initial onset of ADAS in the early-2000s, radar was a natural first choice sensor because of its ability to detect metal objects in a manner that's unaffected by weather or lighting conditions. As a result, radar has been used extensively in side-facing applications like blind spot warnings where detection of metal objects in varying weather conditions is a requirement. Over the years, the industry also began using radar for forward-facing applications like forward-collision warning and adaptive cruise control. But this is where radar technology began to show its weaknesses. Radar is inherently less sensitive to non-metal (i.e. pedestrians, objects) and stationary objects — both critical in forward facing applications. And because radar cannot "see", it cannot perform core forward-facing tasks like lane-departure warning and traffic sign/light recognition. To be sure, radar has improved on these capabilities as well as on its cost proposition, so radar remains a key sensor both within ADAS and automated driving applications. We've seen innovative 3D radar technology and new ways to remove signal noise. So while radar is unlikely to become a "one-stop shop" sensor for all ADAS applications, it will likely serve as a key redundancy role in future ADAS and Level 2-4 autonomous systems, with the key advantage being all-weather and day/night functionality. In fully automated vehicles, 4-6 radars will likely be used for surround redundancy as costs continue to decline.

Camera & Machine Vision

Cameras, both mono and stereo, have the inherent advantage of processing extremely rich and dense amounts of data in the same way the human eye does. Of course, this is easier said than done in that "seeing" requires tremendous advances in software ingenuity (machine vision, deep learning), computing power, and the actual camera sensors themselves (dynamic range). This likely explains why the industry initially opted to utilize radar for forward-facing applications. However, even before the advances that occurred in vision software/computing power, cameras had the distinct advantage of having a technical monopoly on certain applications like lane-departure warning (LDW), traffic sign/light recognition (TSR/TLR) and object classification. So if an automaker wanted these features that meant that a

camera was a "must-have". So the industry was met with a challenge — what if you could develop a vision solution that could perform forward-collision and related applications that were typically done by radar? Doing that would enable a lower cost and weight single-sensor solution to meet ADAS demands. Within cameras there were also the options of directing resources to either stereo or monocular (mono) vision — two very distinct approaches. Initially, there was a thought that stereo — which uses two cameras to triangulate a good short-range 3D image — would provide better protection worthy of the added weight and cost. For an industry racing to gain an early mover ADAS advantage (mainly in luxury vehicles), stereo was an easier choice early on. Monocular, or a single camera, was initially seen as relevant but a much tougher engineering feat. Today, thanks to advancements in computer vision and deep learning, the monocular camera enjoys a far greater share of the ADAS vision market than stereo. The resurgence of deep learning for image recognition, as well as improvements in camera resolution and computing power is likely to maintain the camera's role as a dominant sensor. The future of sensing won't be limited to specific objects (a car that can warn/stop for cars and pedestrians but not for other objects) but rather all-encompassing scene interpretation that increasingly understands context as well. In 2016 we did see the industry's first camera-only Level-2 (with auto steer) feature with the Nissan ProPilot — essentially a vision-only semi-autonomous program. The ability of a mono camera to perform such complex tasks is good news to automakers who need to find optional features to sell as ADAS gravitates from optional to standard. For Level-3 and higher vehicles, some of the camera's traditional weakness in adverse weather and very low-light conditions will likely necessitate some form of fusion. Level-3 vehicles could see a combination of multiple monocular cameras (covering the front/side), four to five surround radars and possibly even LiDAR. Fully automated vehicles (Level-4+) will likely see as many as eight cameras, four to six radars, potentially multiple LiDARs and even a few ultrasonic sensors to cover the sides of a vehicle.

LiDAR

Figure 56. Short-Range LiDAR

Source: Continental

LiDAR stands for Laser Imaging Detection Ranging. As its name suggests, LiDAR emits laser light and analyzes the reflection in a similar concept as radar (through an emitter, receiver and signal processing). There are different types of LiDAR. In the past relatively simple short range 3-beam LiDAR sensors were used for autonomous braking at low-speeds, mainly in Europe. Perhaps the most well-known LiDAR system today is the Velodyne scanning beam technology that's used in the Google driverless testing cars and on Ford's test vehicles. The 64-beam 360 degree version is often used for HD mapping and onboard sensing but the sensor remains costly. Lower beam sensors (scanning LiDARs) and solid-state sensors are being developed at lower costs in the few/several hundred dollar range with targets for ~$100 per sensor over the coming years. Since mechanical LiDARs with moving parts might struggle to meet automotive grade standards, there's an increasing focus in the industry on solid-state sensors. LiDARs have some advantages when it comes to range (up to 250m), field-of-view (120-140 degrees), nighttime detection (versus vision), and distance measurement. LiDAR can also have higher resolution versus radars with very low false positive rates. Suppliers involved in LiDAR include Velodyne (puck), Quanergy, Ibeo (ScaLa), and LeddarTech. Tier-1 suppliers engaged in LIDAR include Valeo (ScaLa and Leddartech), Delphi (invested in Quanergy), and Continental (purchased ASCar and working on flash LiDAR technology). LiDAR is expected to have an increasing role in Level-3 and beyond. Cost, resolution and weather sensitivity remain drawbacks of LiDAR. LiDAR sensors are also used in non-auto applications like unmanned aerial vehicles (UAVs) and security.

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Drivers of ADAS Demand

Regulations

Figure 57. China C-NCAP 2018

C-NCAP 2018	
Active Safety	
AEB City	8
AEB VRU Ped	3
ESC	4
Max Pts	*15*
Weight	*15%*
Score	*(ESC + (AEB*K))*15%*

Source: C-NCAP, Citi Research

Much like successful technologies before it, ADAS is already seeing a gradual push by regulators to accelerate penetration. The European Union New Car Assessment Program (NCAP) is leading the way having tied the highly sought after 4- and 5-Star ratings to automatic emergency braking (AEB). By 2017, all newly-launched vehicles will essentially require ADAS to achieve a 4-Star rating thereby covering the vast majority of vehicles in the region. Camera-only applications like lane departure warning (LDW)/lane keeping assist (LKA) will gain NCAP point-share in 2017, making vision-based systems well-suited for automakers looking to meet these requirements. In the U.S. the NHTSA (National Highway Traffic Safety Agency) announced a commitment by 20 automakers (>99% of U.S. auto market) to make AEB a standard feature on virtually all new cars no later than 2023. Additionally, in late 2015, NTHSA announced a revamp to its 5-Star rating system to include crash-avoidance and advanced technology, such as lane-departure warning and forward collision warning. Besides the safety regulatory channel, it's not farfetched that automated might also play a role in future fuel economy regulations. Industry contacts have suggested that equipping 1 out of 4 vehicles with adaptive cruise control and related capabilities could yield a 3-4% fuel economy improvement.

Figure 58. China C-NCAP 2018

% of Active Safety Needed for 5 & 5+ Score			
Star	Active Safety		
	2018	2019	2020
5+	50%	55%	72%
5	26%	38%	55%

Points of Active Safety Needed for 5 & 5+ Score			
Star	Active Safety		
	2018	2019	2020
5+	7.5	8.3	10.8
5	3.9	5.7	8.3

Points Needed from AEB for 5 & 5+ Score			
Star	Active Safety		
	2018	2019	2020
5+	3.5	4.3	6.8
5	0.0	1.7	4.3

Source: C-NCAP, Citi Research

China has also taken increased interest in adopting regulation and recently provided some information of the C-NCAP 2018 plan where active safety will be required to achieve 5- and 5+ -tar ratings – continuing to leverage the Europe NCAP programs. Starting in 2018, In order to achieve a 5+-Star rating, an auto manufacturer must achieve at least 3.5 of the possible 11 points for AEB; in 2019 at least 4.25 of the possible 11 points for AEB; and in 2020 at least 6.8 of the possible 11 points for AEB. In order to achieve a 5-Star rating an auto manufacturer would merely need to deploy ESC in 2018; however, in 2019 and 2020 a manufacturer would need to achieve 1.7 and 4.25 of the possible 11pts for AEB, respectively. All-in, regulations appear increasingly headed towards mandating ADAS adoption and accelerating the pace of standardizing ADAS equipped vehicles.

Figure 59. Global NCAP Adoption Timeline

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
United States						AEB, FCW, LDW, BSD				AEB,FCW	
Europe		AEB Interurban & LDW		Occupant detection, LKA,SAS		AEB Ph2 Road departure		AEB Crossing, Junction, Head-on			
Japan		AEB - rear, LDW	Surround View Monitor	AEB - ped	LKA						
Korea	FCW, LDW				AEB - rear, ped ACC, LKA						
China						AEB - City, VRU					

Source: NHTSA, Euro NCAP, JNCAP, KNCAP, Global NCAP, C-NCAP, Citi Research

Looking at Past Safety Technology Adoption Curves

Back in March 2016, 20 automakers who collectively represent >99% of the U.S. auto market committed to making AEB standard on all cars no later than NHTSA's 2022 reporting year — or effectively no later than model year 2023 vehicles.

The question now is what the penetration cadence looks like in the ramp to MY 2023, since prior to that commitment ADAS can still be sold as optional equipment. To better understand the ramp we look at three recent safety technologies that have been effectively mandated: (1) rear backup cameras; (2) electronic stability control (ESC); and (3) side airbags (as a result of a changed vehicle side impact safety test).

The interesting thing with regards to these technologies is that they typical don't have a linear trend adoption technology, rather they more aptly take on a polynomial trend curve, a sixth order polynomial to be precise. As such we thought it'd be prudent to show AEB adoption using growth rates and the model year 2023 100% penetration target (though again, some puts and takes re: light trucks) leveraging each of these technologies penetration cadence.

Rear Backup Camera

In 2007 the U.S. Congress passed legislation requiring vehicles to have a backup camera; President George W. Bush subsequently signed the "Cameron Gulbransen Kids Transportation Safety Act" into law. This law required the NHTSA to have certain safety standards set by 2011. These standards were delayed numerous times leading to a marked delay in a set adoption curve. To auto manufacturers the writing was on the wall — at a certain point in the near-future, post the signing of the "Cameron Gulbransen Kids Transportation Safety Act", rear backup cameras would be a standard technology. The table below shows that multiple Notices of Proposed Rulemaking (NPRM) were put forth by NHTSA only to have the Final Ruling (FR) signed in late 2015. These NPRMs and the FR put forth an adoption curve for full compliance by model year 2019; however, after the second NPRM the adoption curve markedly spiked as it had set forth a cadence in advance of the final ruling.

Figure 60. Rear Backup Camera Timeline (Years are Model Years)

REAR CAM PENETRATION	1	2	3	4	5	6	7	8	9	10	11
	A	A	A	A	A	A	A	E	E	E	Mandate
Model Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
NHTSA Action	NPRM		NPRM #2			FR	FR; signed				
Domestic Car	0%	2%	3%	10%	34%	48%	68%				
Domestic Truck	19%	24%	31%	33%	48%	61%	76%				
Import Car	7%	8%	13%	16%	23%	34%	56%				
Import Truck	26%	24%	24%	22%	55%	84%	93%				
W. Avg Attach Rate	**11%**	**14%**	**19%**	**21%**	**40%**	**55%**	**73%**	**79%**	**85%**	**92%**	**100%**
Memo:											
initial rule phase-in schedule			*0%*	*0%*	*10%*	*40%*	*100%*				
final rule phase-in schedule								*0%*	*10%*	*40%*	*100%*

	x^6	x^5	x^4	x^3	x^2	x	B
6th Order Polynomial	-3E-05	0.001	-0.02	0.15	-0.53	0.85	-0.34

Source: NHTSA, Citi Research Estimates

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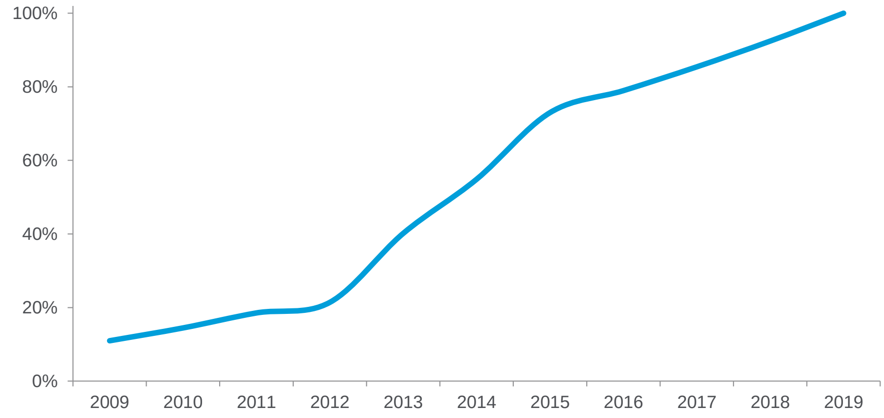
Figure 61. Rear Backup Camera Adoption Curve (Model Years)



Source: NHTSA, Citi Research Estimates

Electronic Stability Control (ESC)

In 2005 NHTSA passed a NPRM for the adoption of electronic stability control (ESC), due to the feature's widespread ability to prevent rollovers The initial NPRM set forth an adoption schedule of 30% of a given auto manufacturers production for model year 2009; 60% for model year 2010; 90% for model year 2011 and full penetration thereafter. The final ruling was put into effect in model year 2007 and increased the adoption curve markedly versus the NPRM. Under the FR, OEMs had to meet targets of 55% for model year 2009; 75% for model year 2010; and 95% for model year 2011 and full penetration thereafter.

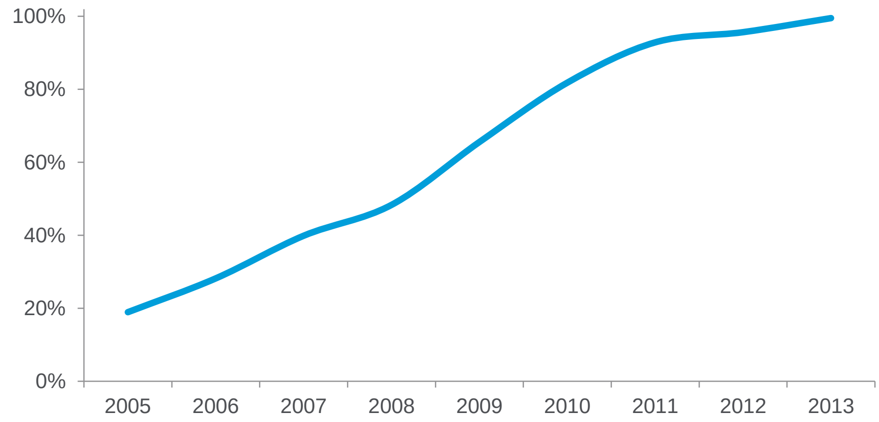
Figure 62. ESC Timeline (Years are Model Years)

ESC	1	2	3	4	5	6	7	8	9	10	11
	A	A	A	A	A	A	A	A	A	A	
Model Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
NHTSA Action	NPRM	⇨	FR	⇨							
Domestic Car	9%	14%	12%	17%	43%	78%	94%	100%	100%		
Domestic Truck	18%	31%	47%	66%	82%	86%	93%	95%	99%		
Import Car	31%	37%	50%	49%	56%	72%	87%	85%	100%		
Import Truck	50%	53%	94%	94%	97%	96%	98%	99%	100%		
W. Avg Attach Rate	**19%**	**28%**	**40%**	**48%**	**66%**	**82%**	**93%**	**96%**	**100%**		
Memo:											
initial rule phase-in schedule					***30%***	***60%***	***90%***	***all***			
final rule phase-in schedule					***55%***	***75%***	***95%***	***all***			

	x^6	x^5	x^4	x^3	x^2	x	B
6th Order Polynomial	1E-04	-0.003	0.03	-0.13	0.32	-0.28	0.25

Source: NHTSA, Citi Research Estimates

Figure 63. ESC Adoption Curve (Model Years)



Source: NHTSA, Citi Research Estimates

Side Airbags

In model year 2004 NHTSA issued a NPRM to upgrade the side impact protection standard. The NPRM consisted of two parts: (1) it required vehicles to protect front seat passengers against head, thoracic, abdominal, and pelvic injuries in a vehicle-to-pole test simulating a vehicle crashing sideways into a narrow fixed object; and (2) it upgraded current vehicle-to-vehicle tests that required protection of front and rear seat occupants against thoracic and pelvic injuries in testing to mimic a vehicle being struck in the side by another moving vehicle. These upgrades all but required some type of side impact protection feature. Thus, side airbags started to see a drastic uptick in penetration.

Figure 64. Side Airbag Timeline (Years are Model Years)

Side Airbags*	1	2	3	4	5	6	7	8	9	10	11	12
	A	A	A	A	A	A	A	A	A	A	A	A
Model Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
NHTSA Action	NPRM				FR							
Domestic Car	28%	34%	47%	63%	73%	89%	97%	99%	100%	100%	100%	100%
Domestic Truck	27%	20%	22%	32%	50%	51%	61%	71%	77%	73%	81%	73%
Import Car	78%	81%	75%	85%	92%	94%	100%	100%	100%	100%	100%	100%
Import Truck	59%	49%	70%	71%	87%	94%	97%	95%	94%	100%	100%	100%
W. Avg Attach Rate	**36%**	**35%**	**42%**	**53%**	**68%**	**75%**	**82%**	**86%**	**90%**	**89%**	**92%**	**87%**
Memo:												
initial rule phase-in schedule							***20%***	***50%***	***100%***			
final rule phase-in schedule							***20%***	***50%***	***75%***	***100%***		
	x^6	x^5	x^4	x^3	x^2	x	B					
6th Order Polynomial	-7E-05	0.002	-0.02	0.12	-0.27	0.24	0.29					

Source: NHTSA, Citi Research Estimates

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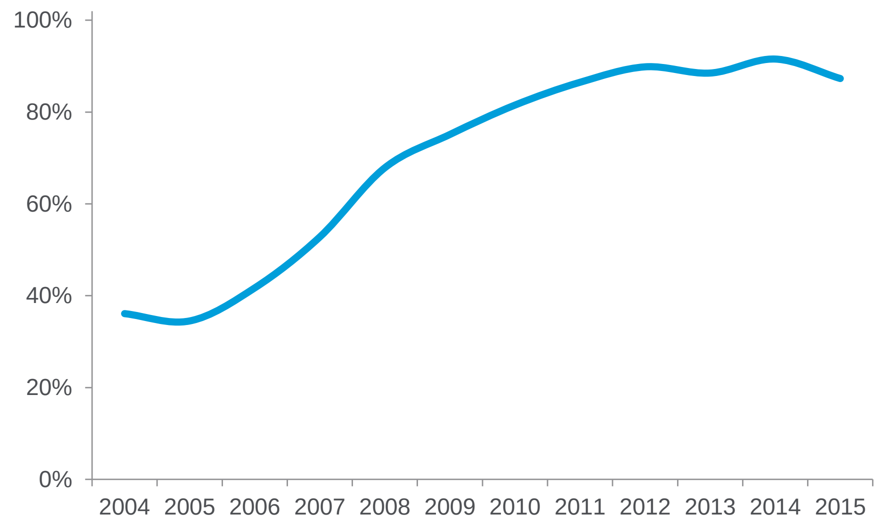
Figure 65. Side Airbag Adoption Curve (Model Years)



Source: NHTSA, Citi Research Estimates

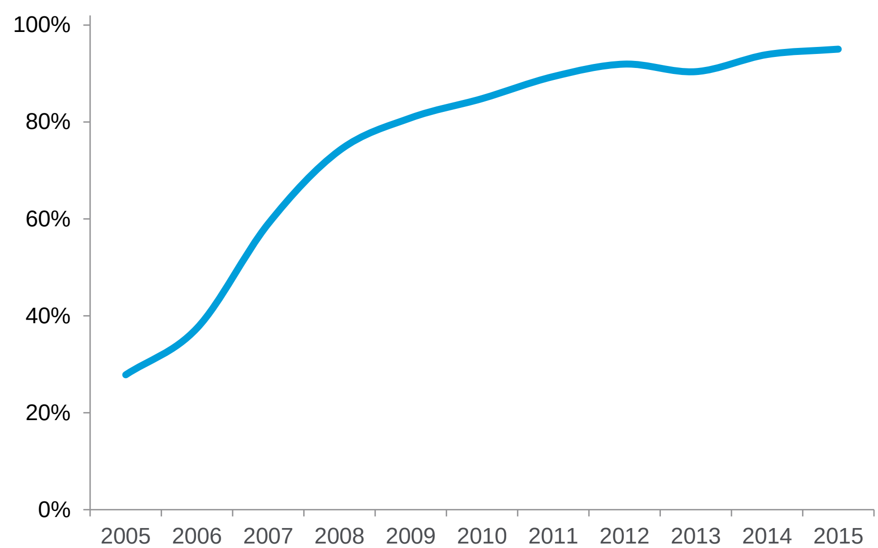
Figure 66. Side Curtain Airbag Timeline (Years are Model Years)

Side Curtain Airbags*	1	2	3	4	5	6	7	8	9	10	11	12
	A	A	A	A	A	A	A	A	A	A	A	A
Model Year	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
NHTSA Action	NPRM	→	→	→	FR	→	→	→	→	→	→	→
Domestic Car		25%	40%	66%	80%	92%	95%	98%	97%	99%	99%	99%
Domestic Truck		16%	23%	43%	58%	63%	71%	80%	85%	80%	89%	91%
Import Car		61%	56%	79%	88%	90%	96%	97%	100%	98%	97%	96%
Import Truck		64%	76%	83%	100%	100%	97%	97%	96%	93%	97%	100%
W. Avg Attach Rate		**28%**	**37%**	**59%**	**74%**	**81%**	**85%**	**89%**	**92%**	**90%**	**94%**	**95%**
Memo:												
initial rule phase-in schedule							***20%***	***50%***	***100%***			
final rule phase-in schedule							***20%***	***50%***	***75%***	***100%***		

	x^6	x^5	x^4	x^3	x^2	x	B
6th Order Polynomial	-3E-04	0.008	-0.10	0.57	-1.74	2.70	-1.45

Source: NHTSA, Citi Research Estimates

Figure 67. Side Curtain Airbag Adoption Curve (Model Years)

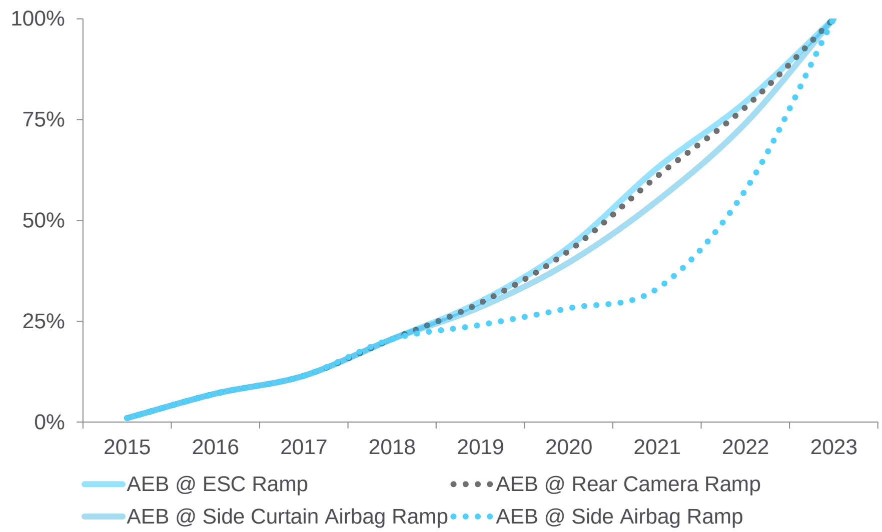


Source: NHTSA, Citi Research Estimates

AEB Penetration Using Other Safety Technologies' Cadence

We have an idea of land departure warning (LDW) (forward facing camera system) penetration going back to model year 2013, the first real year of meaningful penetration data. That said, LDW doesn't necessarily mean the vehicle has AEB as well. Thus we must leverage public studies, NHTSA releases and most importantly our Megatrends LIVE! ADAS Tracker to get an understanding of AEB penetration. We believe, using all resources at hand, that for model year 2015 AEB penetration was in the 1-2% range. Now, if we assume that growth for AEB will follow that of LDW penetration, then we have a credible ramp through model year 2018. After that we can grow each technology's NPRM to FR compound annual growth rate (CAGR) to arrive at a reasonable basis for the second leg of the story (assuming that with AEB the commitment from the auto manufacturers is effectively equal to a NHTSA NPRM). Then all we need to do is grow the remaining 2 years at a CAGR to reflect 100% penetration by model year 2023. In Figure 68 and Figure 69 we highlight potential paths for AEB penetration, based on the aforementioned technologies.

Figure 68. AEB Penetration at Ramps of Other Safety Technology



Source: Citi Research

Figure 69. AEB Penetration at Ramps of Other Safety Technology Timeline (Years are Model Years)

	A	A	A	E	E	E	E	E	E	E	E
Model Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
NHTSA Action				OEM Commit							
Domestic Car	3%	8%	15%								
Domestic Truck	7%	10%	19%								
Import Car	11%	16%	20%								
Import Truck	2%	6%	19%								
W. Avg Attach Rate	**6%**	**10%**	**18%**								
est. AEB	**0%**	**0%**	**1%**								

Source: NHTSA, Citi Research Estimates

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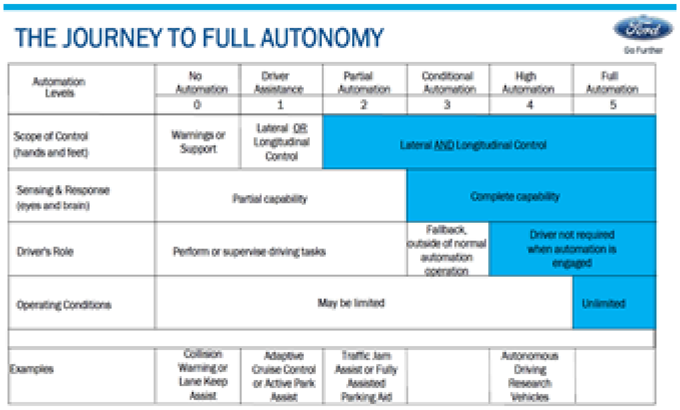
The ADAS-to-Autonomous Virtuous Loop

Autonomous vehicles tend to be grouped into categories depending on the level of automation and driver involvement. ADAS tends to be considered Level-1 where sensor/software provides assistance but the driver is driving as usual. Level-2 includes things like automated highway piloting where the driver is required to monitor the system as the primary operator of the vehicle even as the vehicle performs autonomous tasks. Level-3 is full automation where the driver does not have to monitor the system but must still be engaged enough to take control after a brief warning. Think of the car driver playing the role of an aircraft pilot. Level-3 is nearly upon us though some companies are deciding to skip this step.

The final levels — Levels 4 & 5 — are a fully autonomous driverless vehicle with level-4 confined to geo-fenced areas and level-5 is fully autonomous everywhere.

Figure 70. Levels of Autonomous Driving

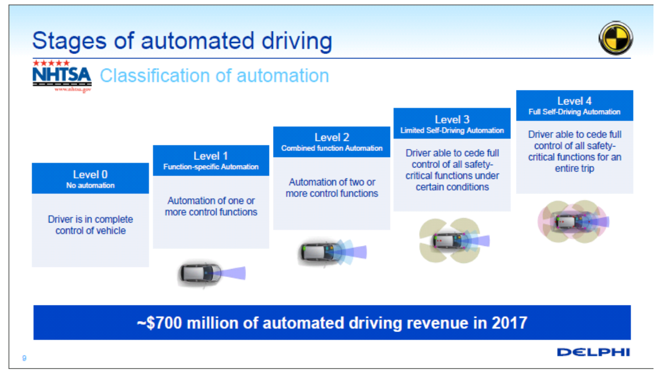


THE JOURNEY TO FULL AUTONOMY

Automation Levels	No Automation 0	Driver Assistance 1	Partial Automation 2	Conditional Automation 3	High Automation 4	Full Automation 5
Scope of Control (hands and feet)	Warnings or Support	Lateral OR Longitudinal Control	Lateral AND Longitudinal Control			
Sensing & Response (eyes and brain)	Partial capability			Complete capability		
Driver's Role	Perform or supervise driving tasks			Fallback, outside of normal automation operation	Driver not required when automation is engaged	
Operating Conditions	May be limited					Unlimited
Examples	Collision Warning or Lane Keep Assist	Adaptive Cruise Control or Active Park Assist	Traffic Jam Assist or Fully Assisted Parking Aid		Autonomous Driving Research Vehicles	

Source: Ford, Citi Research

Figure 71. Levels of Autonomous Driving



Source: Delphi, Citi Research

A key difference between ADAS and prior passive safety technologies is that the use case for ADAS can expand beyond safety to include various forms of automated driving — with relatively limited incremental costs. Regardless of an automaker's strategy for Level-2 or Level-3 automation, they all face a common problem — how do you replace current lucrative profit streams that will disappear as soon as ADAS becomes standard on all vehicles? Thankfully for the automakers, the same sensors performing ADAS functions (camera or camera/radar) can also perform adaptive cruise control, traffic jam assist, and even highway autonomous driving at a Level-2 engagement. Software and hardware improvements could conceivably stretch the performance of these sensors to one day include a Level-3 low-speed traffic jam assist.

Automakers can also leverage two other elements here. The first is connectivity. Automakers are increasingly installing embedded modems into the car to enable over-the-air (OTA) software updates, big data monetization, and consumer services. This opens up opportunities to sell convenience features (i.e. software) on the same hardware sensors performing ADAS functions. That means that the delivery of vehicle options no longer occurs solely at time of purchase, but throughout a car's entire life. The second element is the potential, at least in theory, for future insurance premium discounts for consumers. A modest insurance discount could go a long way into funding the cost of ADAS — perhaps even funding all of it.

Figure 72. Advanced ADAS Package Financing

Amount Financed	2,500
Rate	4.5%
Duration	66
Monthly Payment	(43)

Source: Citi Research

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Figure 73. Insurance Savings at 15%

Cost of Insurance/yr	1,700
per month	142
Advanced ADAS Discount	**15.0%**
Adjusted Annual Premium	1,445
Savings	255
Per month	21

Source: Citi Research

Figure 74. Insurance Savings at 30%

Cost of Insurance/yr	1,700
per month	142
Advanced ADAS Discount	**30.0%**
Adjusted Annual Premium	1,190
Savings	510
Per month	43

Source: Citi Research

This, in our view, creates something of a virtuous cycle. Equipping vehicles with more sensors naturally expands the safety envelop of the vehicle. Additional safety raises the future prospects of insurance discounts. More safety sensors also enabler more robust Level-2/3 automated driving features. And connectivity could enable a "freemium" model whereby automakers can sell the automated features through OTA updates unlocking the features during the car's lifetime.

Let's dig in a bit more into this.

Possible Future Insurance Savings

We believe that a 15%-30% discount to a customer's insurance premium is theoretically reasonable, using current plug-in solutions as a proxy. To help validate this we looked at some current programs offered by insurance providers that leverage a vehicles on-board diagnostics (OBD-II) port. These programs provide a piece of hardware that plugs into the OBD-II port and then monitors certain driving criteria to assess an individual's driving behavior. In some cases an insurer will offer an initial 5% discount just for enrolling in the program, which would then phase out after the consumer locks into their more permanent premium discount rate of up to 30%. Results vary by a plethora of factors, but discussions with insurance agents suggest the average discount rate falls between 12% and 18%. In order to obtain this discount a customer would generally have the OBD-II port product plugged in for a 30-180 day timeframe. We have also seen separate indications from safety organizations suggesting a potential 50% reduction in front-end crashes from installing AEB and FCF on all vehicles.

Figure 75. Insurance ODB-II Plug-In Discount Solution

	Liberty Mutual	Allstate	Progressive	Nationwide
Program Name	RightTrack	Drivewise	Snapshot	SmartRide
Plug-in Time	90d	Always	6mo	6mo
When Discount Starts/Refreshes	*x*	6mo disc. refresh	disc. starts after first 30d	*x*
Initial Discount*	5%	*x*	*x*	5%
Max Program Discount	<= 30%	<= 30%	<= 30%	<= 30%
Conditions Tracked				
Miles Driven	o	o	o	o
Nighttime Driving (12am-4am)	o	o	o	o
Rapid Acceleration/High Speed	o	o	*x*	o
Hard Braking	o	o	o	o

Source: Company data, Citi Research

The significance here is that insurance savings of say 15%-30% could fund the estimated cost of a semi-autonomous package on a vehicle. This would then leave the automaker open to realize profits through over-the-air subscriptions over the life of the car (not just making money at the point of sale).

Based on our modeling, we believe this offers a more lucrative profit stream versus today's go-to market approach.

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Connectivity Enabling Subscription Models

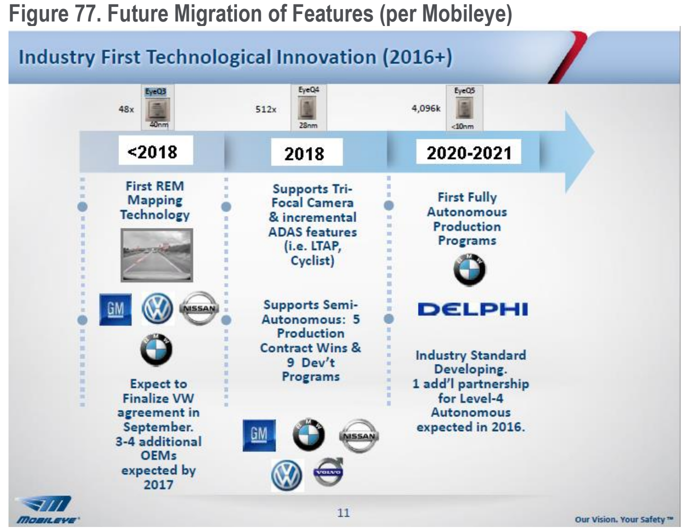
Today automakers are forced to guesstimate what features consumers want to buy, even though consumers themselves might not always know what they want at the point of sale. Unfortunately, under this model, after a car is sold both parties risk leaving something on the table. Yet there might just be a path that makes everyone happy, and it sits in two areas:

1. In the field of ADAS/automation, advances in computer vision/deep learning as well as camera detection are allowing high-functioning ADAS and partially automated driving to be performed off a single chip/camera. Nissan ProPilot serves as an example of the industry's first Level-2 system (with auto steer) being performed in a camera-only configuration. Advances in radar detection are also enhancing the combined power of vision/radar sensors. The future vision/radar system will likely cover a greater field of view with far better processing allowing detailed understanding of a scene. At the same time future crowdsourced map will add yet another layer of redundancy. The car buying experience in the 2018-2020 time frame could look something like this:
   a. Basic trim offers a camera-only solution or a camera/radar system performing ADAS and Level-2 convenience features like adaptive cruise control, highway auto steer (Nissan ProPilot) or traffic jam assist. It's possible that camera-only systems might eventually also perform Level-3 low-speed traffic jam assist;
   b. Mid/high-trim level using camera/radar/LIDAR fusion (including multi-focal) to offer Level-3 driving from low-speed applications like traffic jam assist to fully-speed highway driving at a level-3 engagement, with and without lane changes;
   c. High-trim features, albeit likely at low volume initially, offering Level-3 everywhere and perhaps select Level-4 operation under certain conditions such as pre-mapped highways. In such situations the driver would be able to totally disengage at least during a specific period of the drive. This, however, would not be a driverless car and would not offer Level-4 features everywhere.
2. Embedded connectivity platforms like OnStar/LTE could enable subscription-based models (on certain features) that reduce instances where automaker/customer leaves something on the table after the car is sold. That would mean automakers would equip more vehicles than normal with the required sensors (i.e. greater attach-rates) and would have the ability to sell the optional features over the ~15 year life of car.

Figure 76. Past Migration of Features (per Mobileye)

Source: Mobileye

Figure 77. Future Migration of Features (per Mobileye)



Source: Mobileye

Citi's ADAS Subscription Model

The basic concept behind Citi's ADAS subscription model is a selling approach whereby ADAS is sold standard and convenience applications (off the same sensors) are sold as optional equipment, either upfront (as is the case today) or through a subscription model offered throughout the life of the car. There are many permutations around such a model, but the one we'll describe entails the following (we'll use GM in this an example because of its OnStar/LTE platform, but this of course applies to all automakers):

- GM offers standard camera-only or camera/radar ADAS safety applications including lane/path departure warning, full-speed automatic emergency braking (vehicle/pedestrian/objects/cyclists), traffic sign/light — essentially all safety apps required under future regulations and even beyond. GM would still offer the more complex Level-3 autonomous driving features as optional equipment (i.e. Super Cruise), but consumers not opting for those features would still get standard vision-based ADAS.

- GM offers 1-year subscriptions for customer access to convenience applications including low-speed traffic jam assist, moderate-speed adaptive cruise control, intelligent headlight control, and road surface detection. The first two features would serve as very basic semi-autonomous driving packages (i.e. lower-speed, no lane changes or complex city/country roads, driver in the loop) that are serviceable with a mono camera or fusion configuration. Consumers would be able to purchase a subscription through GM's RemoteLink app or at any time in the car itself. The software package would be provided through an over-the-air update.

- As for costs, we assume a per vehicle cost of $220 including the mono camera (~$75-100), a radar (~$75-100) or perhaps a camera-only configuration with front/side facing ultrasonic sensors for short-range redundancy and close cut-in detection, as well as other components.

- We model an initial 3-month free trial period followed by a $199 annual subscription. The annual price would be similar to subscriptions offered by Sirius XM and the OnStar telematics service. Over time GM could offer its drivers a one-time use option during an actual traffic jam, complimentary periods for customers who might be close to a new vehicle purchase decision (in an effort to build loyalty) or even on special days (birthdays, etc.) and holidays.

- According to Polk data, new car buyers are holding their vehicles for just over six years, followed by a four year ownership period in the used market prior to the end of vehicle life at ~15 years. The turnover in ownership would allow GM to re-sell subscriptions to new owners.

Would People Want this Subscription Model?

We understandably enjoy focusing on the later development stage of automation (Level 4 & 5) as that represents the most exciting part of the *Car of the Future*. But over the next three to five years, the mass-market "killer-app" may be something simpler — hands-off and possibly eyes-off low-speed traffic jam assist. Traffic jams represent one of the most frustrating and tiring aspects of daily driving today, both mentally and physically. According to a Texas A&M study, each year we spend close to 40 hours stuck in traffic, which is up from 32 hours in 1990 and 16 in 1982. We believe consumers would find value with the ability to take a physical and mental break by allowing the car to take over during these jams. Hands-free is nice and doable, but eventually eyes-off (at least temporarily and in certain conditions) would

be ideal. At an annual subscription cost of $199, the average customer would be paying $5 per hour to be relieved of traffic jam driving. Those commuting in America's largest cities would be effectively paying only $4/hour. Now, assuming consumers place some value in the adaptive cruise control application (for when traffic is light), then one could say the effective traffic jam hourly cost is more like $2-$5. So next time you're stuck in traffic for one full hour, ask yourself: Would I pay $2-$5 to sit back and rest, relax, and be more productive? We think enough would think that's a reasonable price to justify the cost. Consider that outside surveys and consultants have shown a consumer willingness to pay $1,100 for traffic jam assist, or 5.5 years' worth of $199 annual payments.

Subscription Model – Running the Numbers

To explore this further we built a financial model outlining the costs and returns for an ADAS subscription model. We assume the year is 2018 and ADAS hardware penetration for GM vehicles is 100%. From there, we derive a base for our model using comparatives from Citi Media Analyst Jason Bazinet's Sirius XM model, but we make some tweaks to account for certain puts and takes. We chose to compare to Sirius XM as we believe this is one of the broadest, multi-manufacturer subscription platforms available in the automobile today.

The Ownership Cycle

We divided the life of the car into unique ownership periods based on historical average length of ownership data (6.0 years on a new vehicle; 4.3 years on a used vehicle):

- Period 1 – Initial Ownership, which spans from point of sale to year 6;
- Period 2 – 1st Used Ownership Cycle, which spans from year 6 to year 10;
- Period 3 – 2nd Used Ownership Cycle, which spans from year 11 to year 15 (scrap).

Figure 78. Citi's ADAS Subscription Model Cost Input Assumptions

GM U.S. Sales	2,596,000
ADAS penetration rate	*100%*
Mono Camera Cost	**$130**
Other Equipment Cost	**$90**
Avg. Length of Own - New (Yrs)	**6.0**
Avg. Length of Own - Used (Yrs)	**4.3**

Source: Citi Research

Cost Inputs

For costs, we assumed $130 for the primary sensing systems/controls and $90 for other costs including possibly ultrasonic sensors as well as other electronics including possibly driver monitoring sensors (touch or camera). We believe these costs are reasonable, particularly considering that this example entails a "bulk" purchase by one of the largest automakers in the world.

Profit Drivers

As mentioned, we looked at Sirius XM as a comparable for what auto consumers may be willing to pay for a subscription-based in-vehicle service. We used Sirius XM take rates for new vehicles as a base, but made some tweaks to account for hardware penetration. We were able to assess that with 100% hardware penetration the unpaid trial conversion rate would be closer to ~38%. There was little relationship between unpaid used vehicle conversion and used vehicle Sirius XM hardware penetration, so we used an 18% conversion rate on used vehicles with the embedded hardware. Additionally what we needed to analyze was the 2nd cycle of used vehicle ownership and for that we simply took ~50% off our 1st cycle used vehicle conversion rate. To account for cancelled subscriptions and potential reactivation we built in monthly churn and potential reactivation rates in line with Citi's Sirius XM model.

Figure 79. Citi's ADAS Subscription Model: Cost Input Assumptions

GM U.S. Sales	2,596,000
ADAS penetration rate	*100%*
ADAS Sub Cost Per Year	**$199**
memo: Siri All Access/yr	*$199*
New Vehicle Conversion Rate	**38.2%**
1st Used Ownership Convert Rate	**18.1%**
2nd Used Ownership Convert Rate	**9.1%**
Potential Reactivation Subs	**1.2%**
Monthly Churn	**-2.0%**

Source: Citi Research

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Financial Impact

After running all these variables through our model we are able to assess estimated lifetime revenue per vehicle subscription versus the total initial upfront OEM investment. This allows us to calculate an internal rate of return (IRR). Based on the assumptions above we calculate an IRR of ~15% over the life of the vehicle.

Figure 80. Citi's ADAS Subscription Model

Ownership Periods	Year	Price	Take Rate	Units	Monthly Churn	Pot'l React	Net Subs	Revenue	Notes		
POINT OF SALE	0	$199	38.2%	992,525	0.0%	0.0%	992,525	$148,134,298	*Assume 3 month Free Trial*	IRR	14.7%
	1	$199	38.2%	992,525	-2.0%	1.2%	772,759	$153,778,976			(571,120,000)
	2	$199	29.8%	772,759	-2.0%	1.2%	608,264	$121,044,509		0	148,134,298
	3	$199	23.4%	608,264	-2.0%	1.2%	485,140	$96,542,761		1	153,778,976
	4	$199	18.7%	485,140	-2.0%	1.2%	392,981	$78,203,203		2	121,044,509
	5	$199	15.1%	392,981	-2.0%	1.2%	324,000	$64,476,043		3	96,542,761
OWNERSHIP CHANGE	6	$199	18.1%	469,097	0.0%	0.0%	469,097	$70,012,757	*Assume 3 month Free Trial*	4	78,203,203
	7	$199	18.1%	469,097	-2.0%	1.2%	380,973	$75,813,678		5	64,476,043
	8	$199	14.7%	380,973	-2.0%	1.2%	315,012	$62,687,484		6	70,012,757
	9	$199	12.1%	315,012	-2.0%	1.2%	265,641	$52,862,528		7	75,813,678
	10	$199	10.2%	265,641	-2.0%	1.2%	228,686	$45,508,548		8	62,687,484
OWNERSHIP CHANGE	11	$199	9.1%	235,457	0.0%	0.0%	235,457	$35,141,987	*Assume 3 month Free Trial*	9	52,862,528
	12	$199	9.1%	235,457	-2.0%	1.2%	206,094	$41,012,649		10	45,508,548
	13	$199	7.9%	206,094	-2.0%	1.2%	184,115	$36,638,914		11	35,141,987
	14	$199	7.1%	184,115	-2.0%	1.2%	167,664	$33,365,173		12	41,012,649
	15	$199	6.5%	167,664	-2.0%	1.2%	155,351	$30,914,778		13	36,638,914
										14	33,365,173
										15	30,914,778

Source: Citi Research

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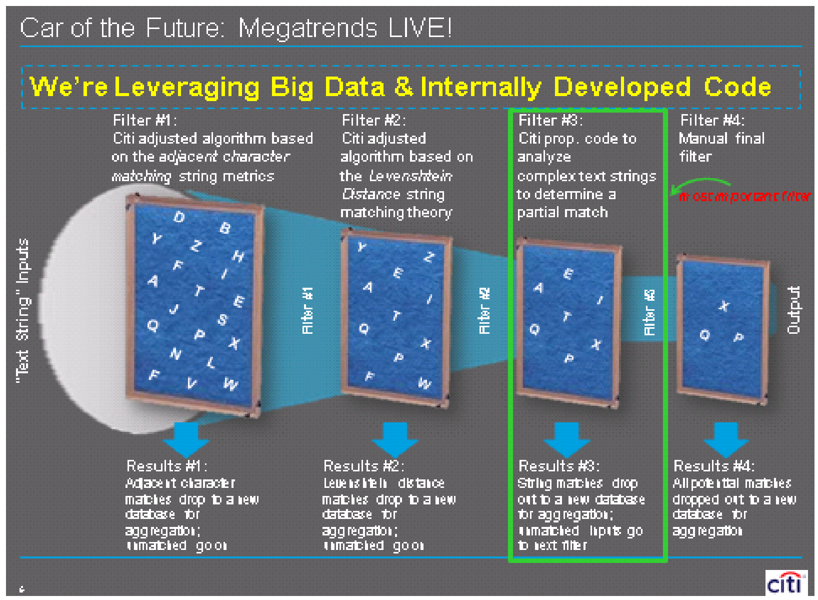
Enter, Megatrends LIVE!

Analyzing ADAS Trends with Proprietary Big Data Analysis and Algorithms

Whether you are investing in auto technology or auto manufacturers, there tends to be a lot of unknowns with regards to real-time penetration of certain key features, including: ADAS, infotainment, and powertrain technology, just to name a few. Analyst's consistently ask "take-rate" questions to suppliers and OEMs alike in order to glean just a few nuggets of wisdom; however, they are often only given a vague response or are told that the data just simply doesn't exist on a real-time basis.

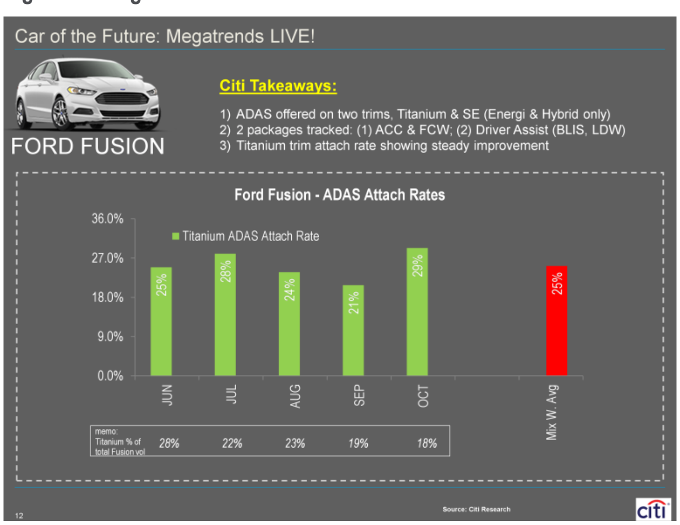
The Citi Autos Team has developed a method of tracking monthly tech options in >60,000 real vehicles recently produced, leveraging big data and internally developed algorithms. Our product can parse through >10 million features for an unprecedented look at take-rates.

Figure 81. Megatrends LIVE! Description Slide



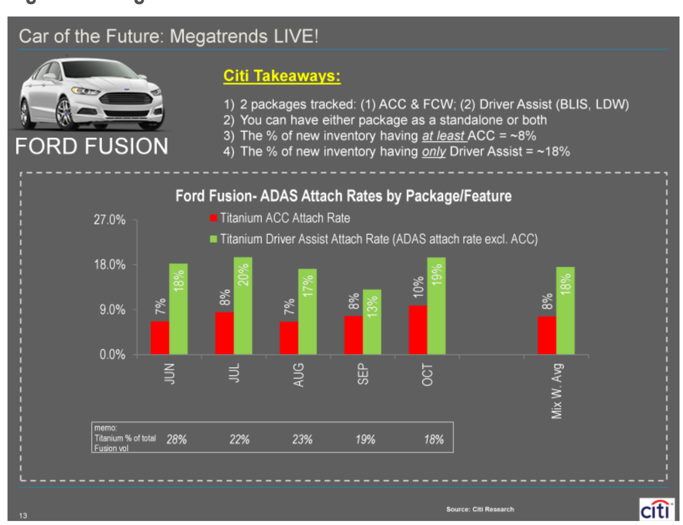
Source: Citi Research

Figure 82. MegaTrends LIVE! Ford Fusion ADAS Attach Rates



Source: Citi Research

Figure 83. Megatrends LIVE! Ford Fusion ACC/ADAS Attach Rates



Source: Citi Research

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Spotlight: Megatrends LIVE! What are my Options?

Besides just tracking ADAS, we launched a Big Data tool that we think can help solve one of the biggest challenges in auto supplier revenue modeling — content tracking. Take the Jeep Grand Cherokee —you can buy a Laredo trim starting at ~$30k or an SRT for ~$65k, a large ~$35k gap. In between this gap likely sits thousands of dollars of supplier revenue content. Popular industry data can tell you how many Grand Cherokee's were sold, but not necessarily which trims, so real-time changes in supplier content goes untraceable (infotainment, leather seats, electrical). How often have you heard companies asked about mix? How often have investors struggled to decipher revenue growth by backlog vs. content mix? What happens to content if macro slows? Our newest Megatrends LIVE! product seeks to solve this. We're tracking 25 high-volume U.S. vehicles to assess monthly trim penetration and related supplier content.

Figure 84. Megatrends LIVE! How Investors Can Apply Out Data to Supplier Stocks

Supplier	Trim Content Exposure
Valeo	Advanced headlights
GENTHERM	Heated Seats, Heated & Cooled/Vented Seats, Heated Steering Wheel, Electrical content on high trims
LEAR	Heated Seats, Heated & Cooled/Vented Seats, Power & Leather Seats, Electrical content high trims
Visteon	Advanced Instrument Clusters, Navigation (infotainment), Satellite Radio (connectivity component)
MAGNA	Heated Seats, Heated & Cooled/Vented Seats, Power & Leather Seats, Auto-dimming Rearview Mirrors
DELPHI	Electrical content on high-trims (wires, connectors & harness), Instrument Clusters, Infotainment
GENTEX	Auto-dimming Rearview Mirrors
HELLA Group	Advanced headlights

Source: Citi Research

Figure 85. Megatrends LIVE! Chevrolet Malibu

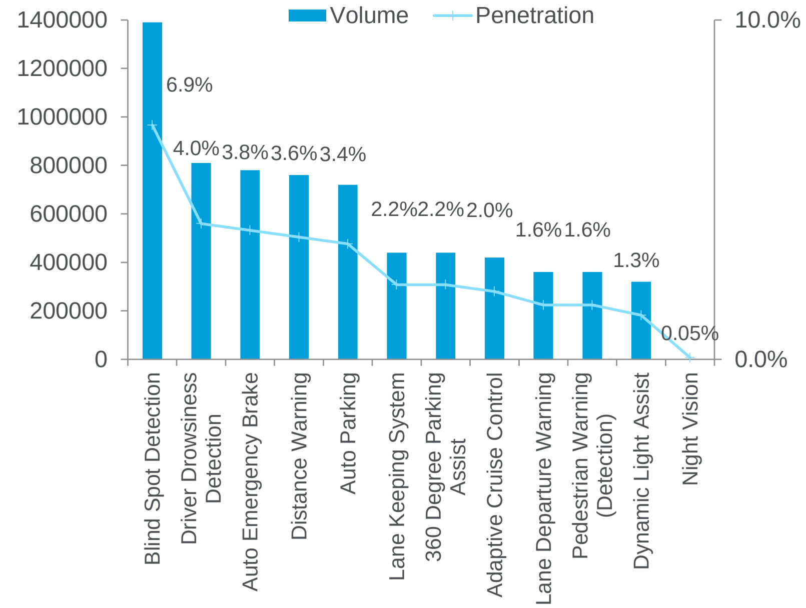
Source: Citi Research

ADAS & Autonomous Driving in China

ADAS Adoption Ratio

Per auto industry consulting firm Gasgoo, the latest ADAS adoption ratio in China remains at only 2-5%. Among all systems, blind spot detection has the highest penetration at 6.9%, followed by driver drowsiness detection at 4.0%. Auto emergency brake system, distance warning and auto parking also have small rates of adoption. Night vision and heads-up display currently remain the least adopted features among all. Relatively speaking, European and Japanese brands are more aggressive in adopting ADAS, while BYD is the leading auto manufacturer in ADAS adoption among Chinese brands.

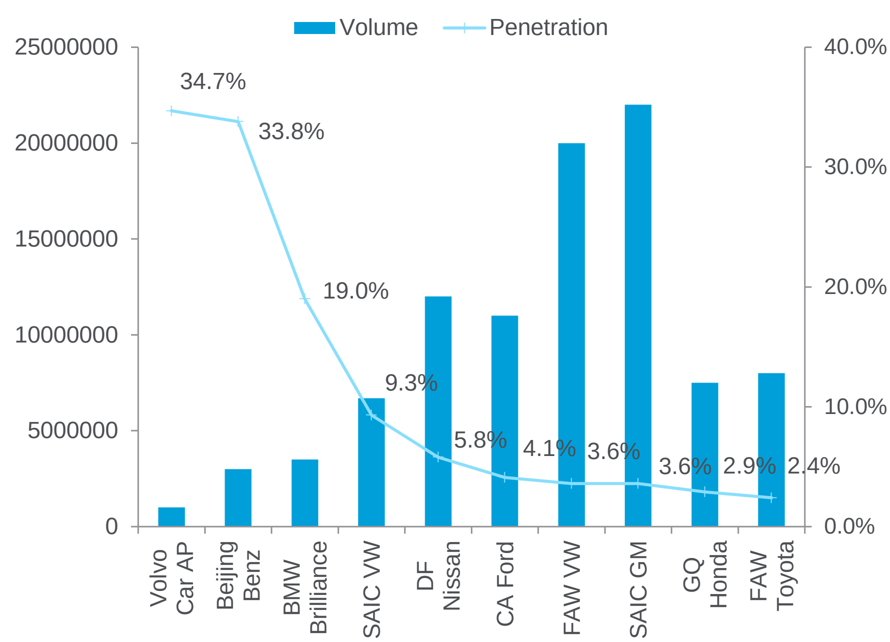
Figure 86. China – ADAS Penetration Rate and Volume (2015)



Source: Gasgoo, Citi Research

Among all Chinese auto manufacturers, Volvo Car AsiaPac, Beijing Benz, BMW Brilliance have the highest adoption ratios, while SAIC GM and FAW VW have the highest total adoption volume.

Figure 87. China – ADAS Penetration Rate and Volume (2015)



Source: Gasgoo, Citi Research

Local SUV Leader Great Wall Motor

Taking Chinese SUV leader Great Wall Motor as an example, their latest vehicles are equipped with Advanced Driver Assistance Systems (ADAS) such as Cruise Control System (CCS), Driver Drowsiness Detection (DDD), Hill Start Assist (HSA)/Hill Hold Control (HHC), Intelligent Parking Assist (IPA), as well as Active Safety Systems such as Anti-lock Braking System (ABS), Electronic Brake Distribution (EBD), Emergency Brake Assist (EBA), Anti-Slip Regulation (ASR), Electronic Stability Program (ESP), Tire Pressure Monitor System (TPMS), and Seat Belt Reminder (SBR).

Figure 88. Great Wall Motor – Safety Equipment Adoptions

	ADAS				Active Safety System							Passive Safety System			
Model	CCS	DDD	HSA/HHC	IPA	ABS	EBD/CBC	EBA	ASR	ESP	TPMS	SBR	Front airbag	Side airbag	Air curtain	ISOFIX
C20R					Standard	Standard	Standard	Optional	Optional		Standard	Standard			Standard
C30	Optional				Standard	Standard	Standard	Optional	Optional	Optional	Standard	Standard			Standard
C50	Standard		Optional		Standard	Standard	Optional	Optional	Optional	Optional	Standard	Standard	Optional	Optional	Standard
M2	Standard				Standard	Standard	Optional	Optional	Optional	Standard	Standard	Standard			Standard
M4	Standard		Optional		Standard	Standard	Standard	Optional	Optional		Standard	Standard			Standard
H1	Standard		Optional		Standard	Standard	Standard	Optional	Optional	Standard	Standard	Standard	Optional	Optional	Standard
H2	Standard				Standard	Standard	Standard			Standard	Standard	Standard	Optional	Optional	Standard
H5	Standard				Standard	Standard	Optional			Optional	Standard	Standard	Optional	Optional	Standard
H6	Optional		Optional		Standard	Standard	Standard	Standard	Standard	Optional	Standard	Standard	Optional	Optional	Standard
H8	Standard	Standard	Standard		Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
H9	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard

Source: Company data, Autohome, Fourin, Citi Research

Autonomous Driving

Many industry experts we interviewed think the biggest barrier to autonomous driving is not technology, but regulation. While Chinese companies may not be leading the autonomous driving technology race at this moment, they do enjoy arguably the most encouraging policy environment. Meanwhile, as a recently mobilized country, many Chinese people have more trust in machines than its large population of newly licensed drivers. During the past year, we have seen two Chinese companies – Chang'an Auto and Yutong Bus -- finish high profile highway autonomous driving programs.

Autonomous Bus by Yutong

Yutong Bus tested its autonomous bus on the open road on August 29, 2015. Its autonomous electric bus, developed together with a research institute under People's Liberation Army, passed 26 traffic lights and ran 32.6km, with a top speed of 68km/h and average speed of 36km/h. It stopped at a bus stop twice without human driver intervention. Per the company's disclosure, the bus was equipped two cameras, four laser radars, a millimeter-wave radar, and a navigation system. It is said to be first autonomous bus tested around the world, though not the first autonomous vehicle.

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Figure 89. China – Autonomous Driving Bus by Yutong

Source: Company website, Citi Research

Figure 90. China – Autonomous Driving Bus by Yutong

Source: Company website, Citi Research

2,000km Test by Chang'an

In mid-April 2016, Chang'an Auto finished a long distance (2000km) test of an autonomous driving vehicle, driving its Raeton medium-sized sedan from Chongqing to Beijing. With only limited intervention by humans (such as entering into a gas station) this test has fulfilled Level-3 conditional automation requirements according to the automated driving level definition. To date, this test is the longest autonomous driving test achieved by a Chinese carmaker.

Figure 91. China – Autonomous Driving Car by Chang'an

Source: Company website, Citi Research

Figure 92. China – Autonomous Driving Car by Chang'an

Source: Company website, Citi Research

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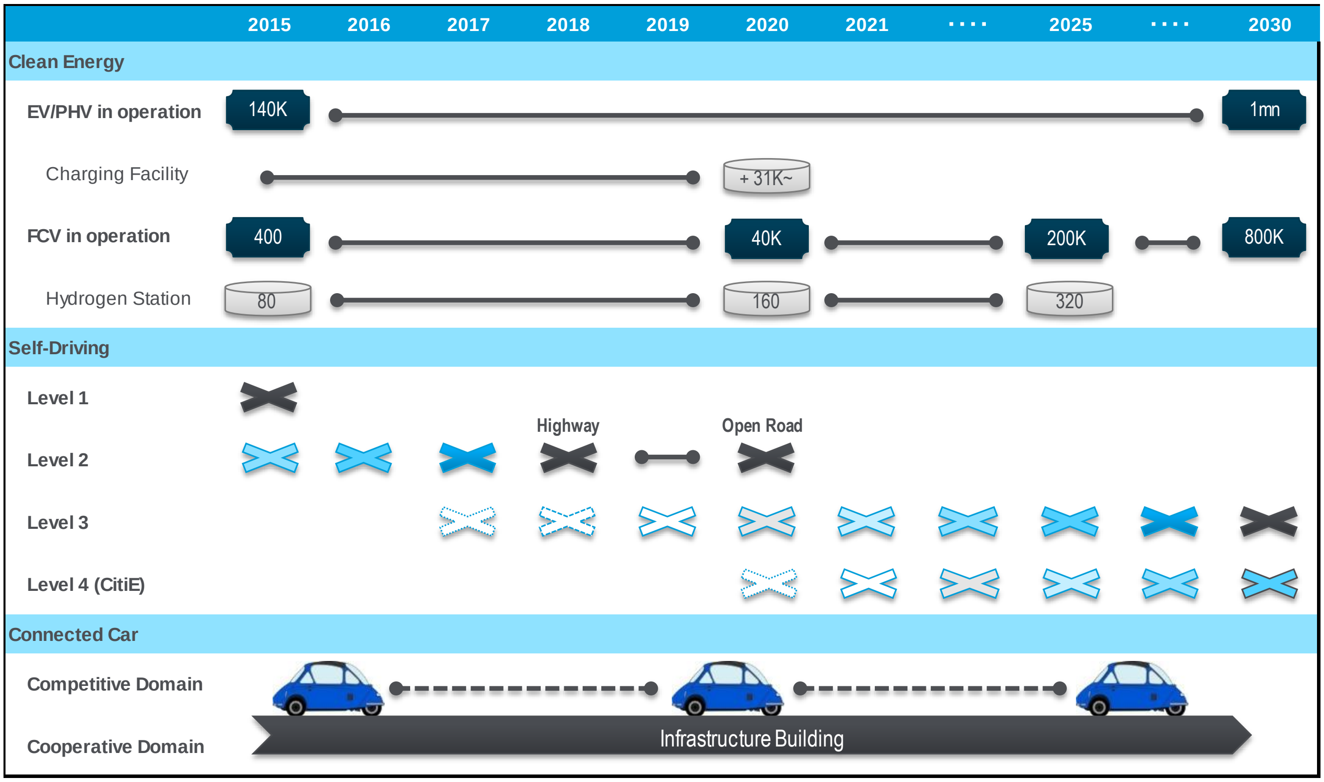
Automated Driving Systems in Japan

In Japan, automated driving systems are expected to help ease traffic congestion, and reduce the number of road accidents, with development of related technologies is advancing rapidly. The U.S. National Highway Traffic Safety Administration (NHTSA) divides automated driving into four levels based on the degree of human intervention (Figure 94.). Japan uses the same definitions. The automated driving business study group set up by the Ministry of Land, Infrastructure, Transport & Tourism (MLIT) and the Ministry of Economy, Trade & Industry (METI) envisages Level-3 automation for passenger cars and Level-2 automation for truck platoons (a convoy of three or more trucks in which only the lead truck is manned) between 2020 and 2030. The committee targets Level-4 automation for valet parking in dedicated (pedestrian-free) areas and for last-mile travel. The committee has also indicated it is actively considering Level-4 automation for general roads in addition to exclusive spaces.

Figure 93. Summary of Japanese Policy Targets



Source: METI, Citi Research

Level-1 automation systems independently perform one or more functions of acceleration, steering, and braking. Well-known examples include automatic braking to prevent collisions, adaptive cruise control (ACC), and lane keep assist (LKA). These technologies are rapidly being adopted in Japan as driver assistance systems, including Toyota Safety Sense, Honda Sensing, and Subaru EyeSight.

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Figure 94. Japan – Levels of Automatic Driving and Policy Targets for Passenger Cars

	Name	Description	Sysytem	Target
Level 1	Function-specific Automation	Perform one or more functions of steering, braking and acceleration	Driver Assistance	○
Level 2	Combined Function Automation	Perform at least two functions of steering, braking and acceleration	Partial Automation	2018
Level 3	Limited Self-Driving Automation	Perform full control functions under certain traffic condition (drivers are expected to be available for occasional control only)		2020s
Level 4	Full Self-Driving Automation	Perform all driving functions for an entire trip (drivers are not expected to be available for control)	Full Automation	2020s (Exclusive Space)

Source: Citi Research

In March 2016, Japan became the first country in the world to announce design guidelines for a driver abnormality response system. The guidelines outline a process for slowing a vehicle to a stop when the driver cannot operate it safely because of a sudden change in physical condition. This process starts with issuing an alert when a system detects that something is wrong with the driver. The guidelines include recommendations for vehicle control when the system is operating. We expect the development of driver abnormality response systems to advance and we forecast automakers will adopt more sophisticated control functions in driver assistance systems.

Level 2 automation systems perform at least two functions of steering, braking, and acceleration at the same time. The combined operation of ACC and LKA is an example. Simultaneous handling and pedal operation differentiates Level-2 automation from Level-1 automation, which basically still requires drivers to use either their hands or feet. Level-2 automation assumes the driver is constantly watching the road and requires the development of human machine interface (HMI) technology that makes it easier for the driver to monitor road conditions.

Level-3 automation systems fully control a vehicle under certain traffic conditions: for example, when cruising on a highway or in a traffic jam. Acceleration, braking, and steering are controlled entirely by vehicle systems. The driver does not have to watch the road and is only called upon by the system to operate the vehicle in an emergency. Level-3 automation thus realizes semi-autonomous vehicle operation. In an emergency, the system must give the driver sufficient warning to take control of the vehicle and avoid an accident. The timing and delivery of warnings are therefore of great importance and require the development of more precise recognition and decision-making technologies.

Many countries are targeting Level-3 automation. To accelerate the development of Level-2/3 automation technologies, the Japanese government has defined areas for cooperation and implemented policies to build a cooperative framework that transcends competitive relationships. Eight fields are identified for collaborative efforts: mapping, communications, social acceptance, ergonomics, functional safety, security, recognition technology, and decision-making technology. The development needed in these fields entails enormous cost and time, and cooperation is therefore expected to improve efficiency. For example, a database of driving video footage is being built to assist in the development of recognition technology. Plans call for the database to be made partially available in fiscal year 2016. Also, basic R&D on LIDAR, a surveying technology that can detect a vehicle up to 60 meters ahead, is advancing and development is expected to be completed by fiscal year 2018. In the field of decision-making technology, a drive recorder that collates driving behavior is being developed and initiatives to apply this in artificial intelligence software are being considered.

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The government aims to realize a market for Level-2 automation on highways as early as 2018 and on general roads by around 2020. The introduction of Level-3 automation is targeted for 2020s.

Figure 95. Action Plans in Eight Cooperative Domains

	Cooperative domain	Action plan
1	Maps	Expedite the analysis of the business model that will be needed for maps by around 2018. Consider the possibilities of maps as data platforms
2	Telecoms	Clarify the uses and specs that will be needed by around 2018. Consider further applications beyond 2018
3	Social acceptability	Promote the understanding of the Japanese people of the utility, functionality, and limits of automated driving. Shape societal agreement on accident responsibility and ethics
4	Ergonomics	Standardize the basic research and results necessary to investigate driver monitoring, human-machine interfaces, and the acceptable bounds of second-tasking
5	Safety	Respond to the international standardization of the development process for safety measures at times of accidents, performance limits, and driver error
6	Security	Build out test-beds for the assessment environment. Respond to the international standardization of the development process. Create a Japanese version of the Auto-ISAC
7	Recognition tech	Build out a driving image database. Develop innovative recognition technologies. Look into trial methods for performance standards
8	Decision-making tech	Build a database for the driving actions and accidents of normal drivers. Look into assessment methods for mechanical learning algorithms

Source: METi, Citi Research

Level-4 automation refers to fully-automated vehicle control that requires no human intervention. It is hoped that Level-4 technology will contribute to alleviating social issues in underpopulated regions as Japanese society ages by improving the provision of means of transport. However, ensuring safety using fully-automated vehicles alone is difficult. Therefore, alliances that extend beyond the auto industry, as well as system and infrastructure responses will be required. While the Japanese government eyes the possibility of Level-4 automation for passenger vehicles by 2025, at this time it is primarily being considered for valet parking in dedicated (pedestrian-free) areas and for last-mile (specialized vehicle) travel. Technology requirements for Level-4 automation in general traffic conditions have not yet been decided.

Ensuring safety using in-vehicle equipment alone is technologically challenging, so for the time being the government's plans call only for automated valet parking in specially adapted parking lots. The aim is to conduct tests from fiscal year 2017. Priority will be given to perfecting technology on the vehicle side, but at the same time specialized parking lots will be prepared. Plans call for the introduction of vehicles and specialized parking lots suitable for automated valet parking around 2020. Car rental businesses will likely be the first to begin offering automated valet parking services. Automated valet parking will be rolled out to general car parks once Level-4 automation has been more widely implemented.

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Automated last-mile travel refers to Level-4 automation of short journeys between the nearest rail station (or a main road) and the final destination (minor road). The aim includes reducing the walking burden in theme parks and shopping centers, and overcoming transport problems in underpopulated areas. The government aims to have the basic technologies and systems necessary for automated last-mile travel in place by around 2017 and to commence trials on test courses by 2018. New mobility services in underpopulated areas are slated for around 2020.

Robot Taxi, a joint venture between DeNA (66.6%) and ZMP (33.4%), is conducting trials on automated taxis with the aim of introducing a commercial service by 2020. ZMP and Park24 are conducting trials on automated parking in parking lots. Many others have been carrying out trials in this area like Softbank, Yamaha Motor, Tier IV (a Nagoya University venture), and automakers.

The formulation of a legal framework for automated driving is advancing. In April 2016, the National Police Agency published draft guidelines for measures needed to facilitate the commercialization of automated driving systems. The government has started full-scale studies into related topics, including responsibility in the event of an accident while testing automated vehicles on public roads, issues related to driver's licenses for automated vehicles, and security measures. The National Police Agency draft calls for a drive recorder to be installed to assist with investigations into the cause of accidents, and for drivers to be able to operate vehicle in cases of emergency, even in trials on Level 4 automated vehicles.

Actions of Automakers

Figure 99 and Figure 100 outline initiatives being undertaken by individual automakers. We believe Toyota, Nissan, and Fuji Heavy Industries (FHI) are particularly noteworthy. All Japanese automakers are actively investing in Cars of the Future but they are often reluctant to disclose information about these efforts, since monetization remains some way off. From the perspective of global appeal, we believe Toyota, Nissan, and FHI have the best technologies and approaches toward disclosure. Among suppliers, we highlight the overall strength of Denso. Material contributions to earnings are likely to take time at Denso, as at OEMs, but it is taking an aggressive attitude toward development, including the formation of alliances.

Toyota has released a succession of strategies for automated driving and connected cars, adding to its initiatives in clean energy vehicles — an area where it already has a long track record. Artificial intelligence (AI) is considered key to automated driving and Toyota has established a new company headed by Dr. Gill Pratt, a world leader in this field. Toyota is the world's largest automaker and has a reputation as a leader in environmental technologies and access to big data. The combination of Toyota's resources and Dr. Pratt's standing in the AI research community should attract top quality researchers. We expect Toyota to create a structure that can add value over the longer term as automated driving becomes more common. In the ride-haling space, it is forming tie-ups and alliances with other firms both within and outside of the automotive industry, investing in Uber and collaborating with the Japan Federation of Hire-Taxi Associations to develop a next-generation taxi for Japan. In the field of clean energy vehicles, the profitability of strong hybrid systems has already reached the same level as gasoline engine vehicles, putting Toyota in a superior position to respond to tighter environmental regulations. Toyota has an abundance of cash to invest in fuel cell vehicles (FCVs), electric vehicles (EVs), and other future technologies.

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Nissan is ahead of its peers on the automated driving technology roadmap. Nissan plans to install automated driving technology in several models for Japanese, European, US, and Chinese markets by 2020. It took its first step here in August 2016, when it launched the new Serena complete with technology that can control vehicles on single-lane highways. We believe Nissan's brand image could benefit because this cutting-edge technology has been made available not in a luxury model. One of the reasons FHI's EyeSight driver assistance system has been so well received is that it was adopted in the Impreza, providing adaptive cruise control and automatic braking in a mass-market model. We believe early introduction and adoption in mass-market models are crucial to the success of next-generation technologies. Nissan's automated driving systems technologies are supported by its close relationship with Mobileye, a leader in driver assistance technology. In the EV space, Nissan gained a jump on rivals with the release of the Leaf in 2010. However, we feel Nissan has failed to fully leverage its brand power. The Nissan IDS concept car, which was unveiled at the 2015 Tokyo Motor Show, has a 60kWh battery that can run for 550km (in NEDC mode) before it needs a recharge. While the schedule for the commercialization of this new technology is not known, we believe success will hinge on its ability to be a clear differentiating factor for new models.

FHI's EyeSight driver assistance system is based on proprietary stereo camera and image recognition technology, and it has received top ratings in NCAPs around the world. FHI aims to introduce an automated driving system (stereo camera) for vehicle-only single-lane roads in 2017 and an automated driving system for highways (stereo camera base with radar, digital maps, and other devices) that includes a lane-change function in 2020. FHI's position on the automated driving roadmap is similar to that of peers. The key point, in our view, is whether it will be able to use proprietary technologies to retain its current edge in 2020.

Figure 96. Real-World Reliability for Subaru EyeSight (Pass Rate Using Automatic Braking)

Pass Rate	NCAP Testing Course	FHI Actual Environment Testing Course			
Remote Sensing System	50km/h	30km/h	40km/h	50km/h	60km/h
*Stereo Camera (Distance and Object Discrimination)	100%	100%	100%	100%	100%
Millimeter-Wave Radar (Distance and Object Discrimination)	100%	64%	36%	56%	86%
Millimeter-Wave Radar (Distance) + Stereo Camera (Object)	100%	100%	100%	43%	0%

Note: * EyeSight System
Source: Company Data, Citi Research

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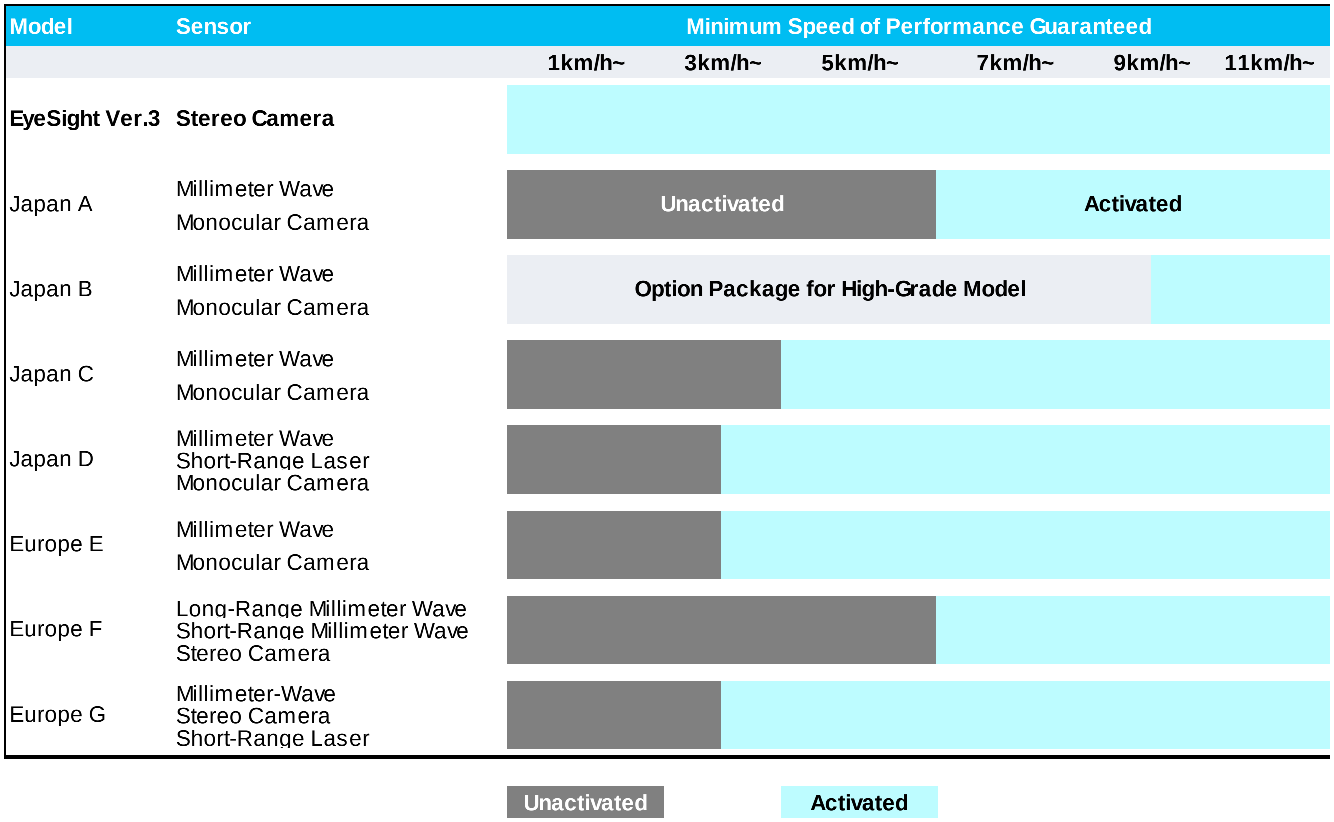
Figure 97. Subaru's Ultra-low Speed Braking functionality: EyeSight Also Prevents Low-Speed Collisions at Times When Cars are Creeping Forward After Stopping. Other Systems Generally Do Not Work at Speeds Below 4-5km/h



Source: Company data, Citi Research

Denso's development activities focus on the environment plus security and safety. Figure 98 shows the future configuration of advanced safety systems envisaged by Denso. In addition to enhancing preventive safety technology, Denso is developing general-purpose basic technologies premised on automated driving. Denso has a broad range of sensor technologies including: (1) sonar radar cameras for relatively short-distance sensing; (2) radio communication equipment and ADAS locator (vehicle position and general traffic information) technology for vehicle-to-vehicle and road-to-vehicle communications; and (3) driver status monitors (cameras that monitor the condition of the driver).

Denso has actively pursued alliances. Most recently, in December 2015 Denso announced a joint development agreement with Morpho. The agreement covers basic research on the application of deep learning-based image processing technology to auto systems. In February 2016, Denso and NTT DoCoMo agreed to jointly develop advanced driver assistance and automated driving systems. In April 2016, Denso established a joint venture with eSOL and NEC Communication Systems to develop cybersecurity software and other data communication technology needed to support advanced in-vehicle systems. In the area of emergency automatic braking, Denso lags rivals in terms of volume production but aims to increase sales to automakers other than Toyota, starting with Toyota Safety Sense P. While Denso is under heavy pressure from auto manufacturers to reduce the cost of air conditioning systems and other conventional products, we expect the development of next-generation technologies, particularly in the environmental and security/safety fields, to keep Denso's per-vehicle sales trending upward.

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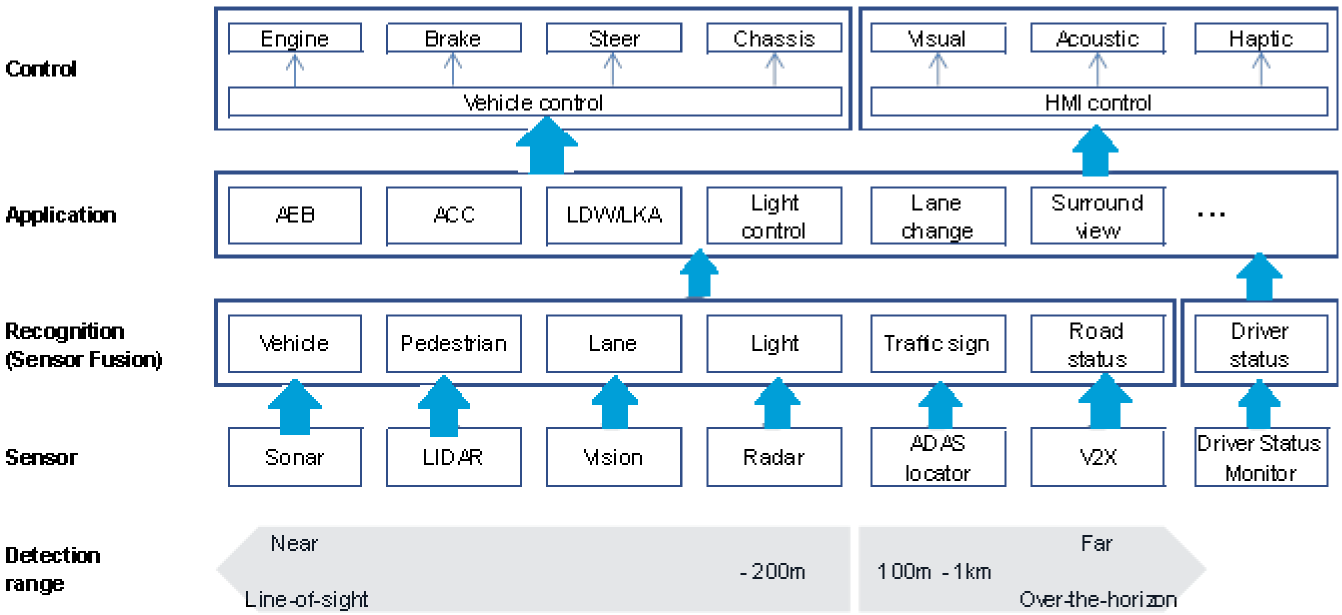
Figure 98. System Configuration for Advanced Safety System as Envisioned by Denso



*AEB: Autonomous Emergency Brake, ACC: Adaptive Cruise Control, LDW: Lane Departure Warning, LKA: Lane Keeping Assist

Source: Denso

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Figure 99. Japanese OE/Supplier Approach

Clean Energy Vehicles			Automated Driving		Others (Connected Car, etc.)	
Nissan	EV/PHV	At the Tokyo Motor Show, Nissan displayed the IDS Concept model, which can deliver a cruising distance of 550km (NEDC mode) on a single charge with a large-capacity 60kWh battery. The launch dates have not been set	ADAS	Introducing Traffic Jam Pilot in 2016, which will make vehicle control unnecessary when in traffic jams on expressways. Expects to deliver a completely automated parking assist system in the course of 2016. Plans to bring in danger avoidance and lane-control/changing technologies by end-2018	Telematics	Using Microsoft Azure on the platform afforded by the telematics systems that come with the Leaf and Infinitis for the European market. Shifting from exclusive use of its own data center to a hybrid cloud environment in which it will couple its data center with Azure. Remote control of the vehicle is possible, so users can switch the air-con on and off and recharge the battery remotely
	FCV	Development has been ongoing since 2013 in partnership with Daimler and Ford. The plan is to bring to the market a vehicle equipped with a jointly developed FCV system in around 2017	Automated driving	Due to launch vehicles equipped with automated driving functionality, limited to single lanes of expressways, in 2016. Plans to commercialize level-three automated driving for some ordinary roads by the end of 2020		
Toyota	HV/PHV	Toyota launched the new Prius, which is based on the TNGA design concept, in 2015, realizing 40km/l economy. The new Prius PHV is slated for launch in autumn 2016	ADAS	Aims to install Toyota Safety Sense in all vehicles developed in Japan, the US, and Europe by 2017. Automated braking is set to be standard on almost all vehicles in the US by end-2017	Telematics	Toyota aims to raise the ratio of vehicles equipped with data communication modules from 2017 and push for common global communication modules by 2019. The company is pushing the evolution of networked autos globally. Vehicles will increasingly come equipped with systems that notify the authorities of emergencies. It is building Toyota Big Data Centers so as to process the vast amounts of data being generated. It is using Microsoft Azure as a platform and has tied up with Microsoft over a wide range of areas. It is working with Ford in infotainment fields
	FCV	Toyota launched the Mirai, the world's first mass-produced FCV, in 2014. It is jointly developing a second-generation FCV with a target launch date of 2020	Automated Driving	Toyota plans to deliver automated driving for expressway on-ramps and off-ramps by around 2020. The company established an AI R&D facility in the US in 2015. It is researching completely automated driving, automated driving that is mainly geared to the support of humans, and deep learning at multiple facilities		
	Target	Toyota is targeting a 90% cut in new vehicle CO_2 emission volume versus 2010 by 2050, with internal-combustion engine vehicles to be virtually eliminated				
MMC	EV/PHV	MMC will launch a small SUV in FY3/18, a new Outlander in FY3/19, and a new RVR in 2019. the small SUV and the Outlander will be PHEVs and the RVR an EV. MMC is also developing an EV based on a minivehicle with Nissan	ADAS	MMC is mainly developing level-one automated driving technologies, such as adaptive cruise control and lane-keeping assist. It is aiming for a sales weighting of vehicles fitted with its e-Assist technologies of 50% or more		
	Target	MMC plans to raise its EV weighting to 20% in 2020, it announced in 2013	Automated Driving	MMC announced the development of an EV concept car capable of automated driving on expressways in October 2015. It is aiming to deliver automated driving on expressways in 2020		
Mazda	EV/PHV	Mazda plans to bring in a hybrid system from Toyota	ADAS	Mazda is deploying i-Activsense. Since 2015, it has been equipping vehicles with blind spot monitors, lane departure warning systems, and adaptive front-lighting systems, which project the shape of the road from the extent of the steering input and speed, illuminating the corner ahead		
	CDE	Mazda is slated to debut Skyactiv Generation 2 by FY3/19	Automated Driving	Mazda is aiming to create vehicles as precisely as humans can rather than deliver completely automated driving. It says it is prioritizing issues of driver support, such as accident reduction and protection of vehicle occupants in the event of a collision		
	Target	Mazda aims to improve average global fuel efficiency by 50% versus 2008 by 2020				

Source: Company reports, Citi Research

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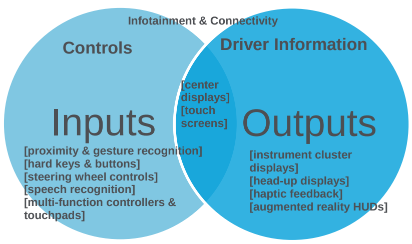
Figure 100. Japanese OE/Supplier Approach, Continued

	Clean Energy Vehicles		Automated Driving		Others (Connected Car, etc.)	
Honda	EV/PHV	Honda will launch new EV and PHV based on the same platform as new sedan FCV,Clarity Fuel Cell, in North America by 2018	ADAS	Started equipping the new Odyssey with Honda Sensing in 2015. It was the first company in the world to offer steering that reduces pedestrian accidents and the first in Japan to offer lane departure control functionality	Telematics	Honda was ahead of the global pack in 2003 in offering sophisticated traffic information services using probe data collected from vehicles. It increased the amount of data being collected dramatically with its free telecom services, which started in 2010. The societal role of the services is considerable, with maps offering information on which roads are navigable in the event of a disaster; they do not just offer sophisticated navigation functions. Honda is working together with Toyota on the trial operation of an automatic emergency notification system, D-Call Net
	FCV	Honda is launching a sedan FCV, Clarity, in 2016. it plans to debut next-generation FCV models around 2020 through joint development with GM	Automated Driving	Honda plans to equip vehicles generally available for sale with features such as automated overtaking and leading-vehicle pursuit control by 2020, making automated driving practical on expressways		
	Target	Honda plans to lift its clean-energy vehicle sales weighting to 2/3rds by 2030				
Suzuki	EV/PHV	Main near-term efforts are on a mild HV that combines a kinetic energy recovery system with an integrated starter generator	ADAS	Suzuki is working to evolve braking support systems via lasers and cameras and also plans to beef up routine driver support technologies such as automated parking. On the heels of Fuji Heavy, it is adopting standalone stereo camera systems		
	FCV	Developing a motorcycle FCV ahead of the pack in alliance with Intelligent Energy of the UK	Automated Driving	In the field of sophisticated automated driving, Suzuki is at the stage of amassing technologies. A timeframe for commercialization has not been set		
FHI	EV/PHV	Plans to debut a PHV using Toyota Motor technologies around 2017 in response to North American ZEV regulations. Expects to introduce next-generation electronic power technologies in 2020 and beyond	ADAS	Fuji Heavy equipped the Levorg with 3G EyeSight in 2014. It has enhanced visibility by shifting to CMOS cameras from CCD ones. It is adding active braking and lane departure warning functionality		
			Automated driving	Aims to deliver traffic-following features on a single expressway lane around 2017 and automated driving, including lane changing, on expressways in 2020		
Denso	GE/DE/EV/PHV	Denso handles direction injection control systems for gasoline engines, common rail systems for diesel engines, and motor, inverter, and battery monitoring units for HVs and EVs, etc. Its basic policy is to move forward on all environmental technology fronts	ADAS	Denso has positioned security and safety as its chosen focal fields, with a platform consisting of two core technologies, sensing and human-machine interfaces. In emergency automated braking, it has a supply track-record, such as for Toyota's Safety Sense P	Telematics	Denso has long had a presence in the field of auto telecommunications, dating back to car transceivers in the 1970s. In the arena of wide-field telecoms, Denso commercialized automotive data communication modules for Toyota's G-Book in 2002, a world first. We believe that it is currently, too, a main supplier to Toyota. In near-field (10m-100m) communication, the company handles vehicle-mounted electronic toll collection devices and dedicated short-range communication devices. In telematics, it announecd it had reached an agreement to cooperate with NTT DoCoMo in R&D into vehicle control systems that use LTE and 5G
			Automated Driving	In December 2015, Denso announced an alliance with Morpho, which has strengths in image recognition. Together they are conducting basic research into the application of image-recognition technologies in on-board devices (electric mirrors, etc.) via deep learning		
Aisin Seiki	HV/PHV	Aisin AW currently handles two-motor format HV systems for Toyota and Mazda and is developing one-motor format HV systems that are expected to target high-torque vehicles as a way of responding to environmental regulations, which will be toughened up moving forward. We believe it is also looking into making proposals for European and US customers	Automated Driving	Aisin Seiki is developing sophisticated driving support technologies, such as remote-control parking - automated parking technology using a smartphone without anyone present - and emergency roadside evacuation, which guides the vehicle to the side of the road in the event of the driver becoming unable to drive. We believe it intends to commercialize these technologies as early as 2017-2018	Telematics	Aisin Seiki is developing technologies for such goals as pedestrian protection at crossings using telematics, which capture the presence of pedestrians that have mobile phones with them via telecommunications from data centers, and route-change advisories that reflect accident conditions, which envisage intra-vehicle communications and road-vehicle communications

Source: Company reports, Citi Research

Connecting the *Car of the Future*

Figure 101. Cockpit Electronics Overlap



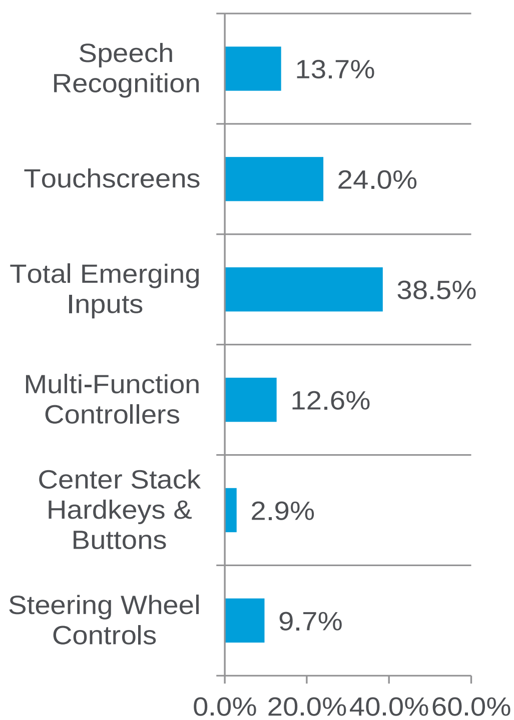
Source: Citi Research

In this section we focus on products that help to connect the driver to the vehicle (human machine interface (HMI)) as well as products that allow the consumer to remain connected to the outside world. Broadly speaking these products are based in the cockpit of a vehicle and contain items such as: the infotainment system, the center stack display, the instrument cluster, touch screens, heads-up displays, WiFi Hotspots, LTE connectivity, and other components. We think about these products in two specific buckets: (1) inputs and (2) outputs. Inputs are systems that allow you to influence change or get a desired outcome from an action you took (I hit a button and the radio changes channels). Outputs are display devices or actions that occur from the use of a specific input (new station loaded on the center stack display playing music). For example, an input device may be something like a camera focused on gesture recognition; the output would be the result of the gesture you made, like raising the volume on the stereo. The common denominator here is that these connectivity products ultimately allow the driver to better engage and react to their surroundings, inside and outside of the vehicle; effectively helping to create immersive, intuitive, fluid, and simple human machine interface to improve the driver's experience.

The Evolution of Cockpit Electronics

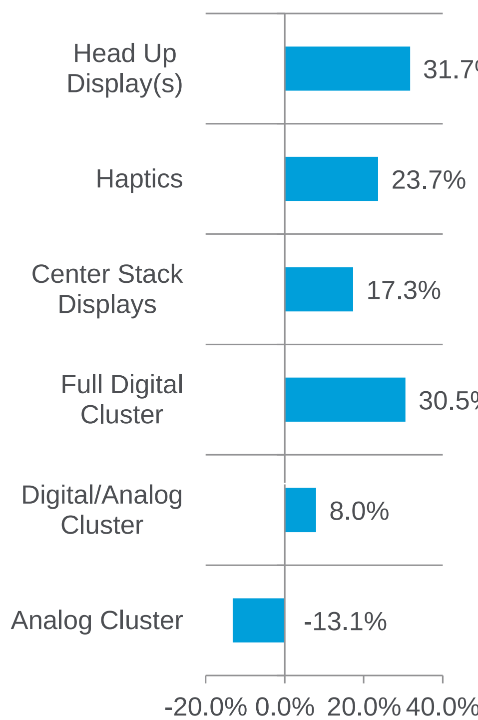
The cockpit electronics market is constantly evolving, similar to that of the consumer electronics market. The cockpit electronics market is expected to have a total addressable market of ~$50 billion by 2020. As mentioned above, the market can be bucketed into two categories: inputs and outputs. Segmenting the market into two buckets, allows us to see how certain technologies complement one another, helping drive adoption and increased penetration. We explore the 2015E-2020E unit CAGRs for varying technologies within these two buckets in the charts below.

Figure 102. Cockpit Electronics Input CAGRs (units, 2015E-2020E)



Source: IHS, Citi Research Estimates

Figure 103. Cockpit Electronics Output CAGRs (units, 2015E-2020E)



Source: IHS, Citi Research Estimates

Homage to the Human Machine Interface

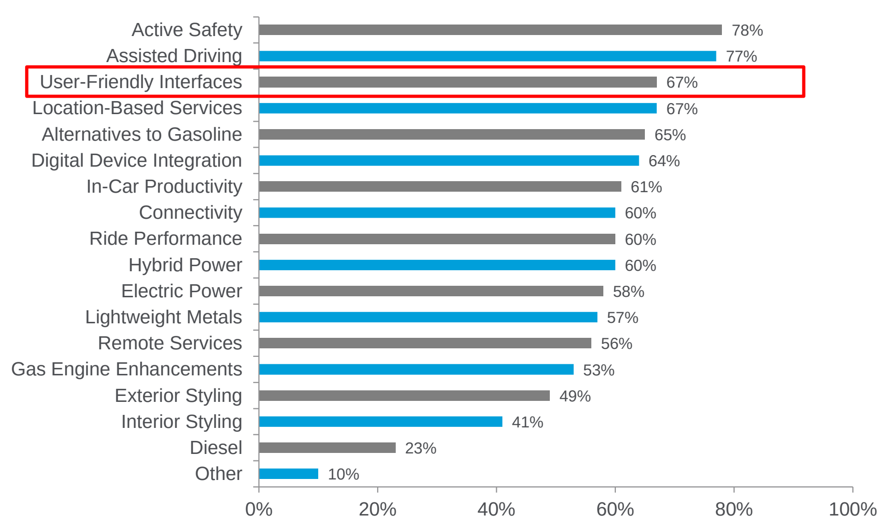
The role of cockpit electronics continues to be a key differentiator for OEMs. In a culture where the consumer always wants to be connected and plugged in, OEMs must evolve to help facilitate the transition from external-connectivity to in-vehicle-connectivity. So, how does an OEM reduce the complexity of modern machinery to expedite in-vehicle-connectivity? Through the human machine interface (HMI) for the *Car of the Future* – basically the solutions that help the consumer control the advanced electronic aspects of their new vehicles as intuitively as possible. Within this section we will focus on HMI outputs, which include: the evolution of center stack displays, instrument display clusters, heads-up displays, and augmented reality. We find these areas to be particularly interesting given their convergence with the autonomous car megatrend discussed earlier.

Why is the HMI so Important?

The human machine interface serves as a primary interaction point between person and machine. The importance of this interface stems from the fact that unlike other aspects of the vehicle, the consumer directly interacts with this system in order to perform driving-related tasks. Additionally, when shopping for a car the HMI outputs are one of the most innovative features that the consumer can view and test without stepping foot off the dealer lot. This makes the interface prime real estate for OEM differentiation.

Looking at a survey conducted by the Boston Consulting Group back in late 2013, 67% of those surveyed noted that user-friendly interfaces are extremely-/somewhat-innovative products. For an OEM, innovation is paramount as it can contribute either to the success or failure for any given launch. We note that a user-friendly interface ranks amongst the Top 3 innovations, as noted by consumers, and is not that far behind autonomous driving and advanced safety systems.

Figure 104. What Customers Find Innovative (% of Sample Who View the Choice as Either "Extremely" or "Somewhat" Innovative

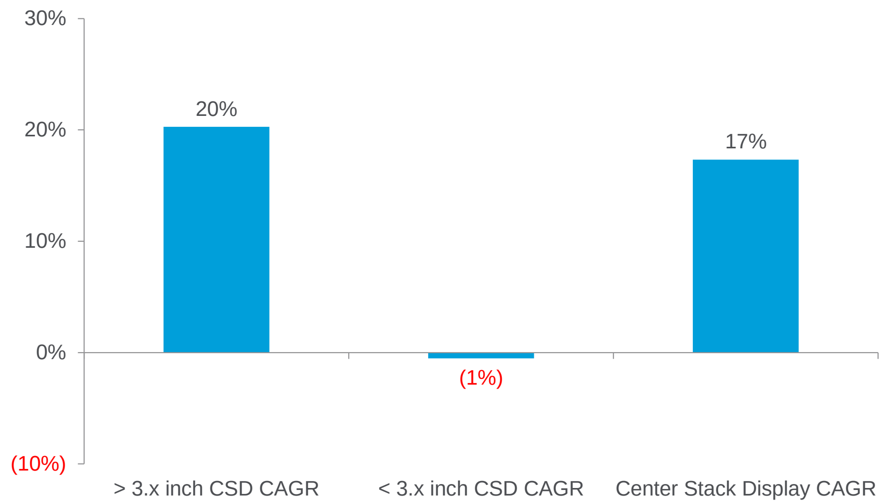


Source: Boston Consulting Group, Citi Research

Starting with the Center Stack

The center stack of the vehicle is defined as the control-laden console in the center of the front vehicle interior. This stack contains both HMI inputs and outputs. In more recent vehicles, this stack has become the home to a display screen, which is utilized for many different aspects of the automobile experience, including navigation, infotainment, and active safety. This center stack display is primarily liquid crystal display (LCD,) but light-emitting diodes (LEDs) and organic light emitting diodes (OLEDs) are also likely solutions. In our analysis, we note just one real prerequisite for the classification of a center stack display: the display must offer some sort of graphical functionality. If this condition is not met (i.e. <3.x inch display screens), we would classify the product as a discrete non-TFT (thin film transistor LCD) display. This would not meet our standards for a product that would be classified as of the *Car of the Future* "eligible" because we believe that generic product commoditization offers little value in the complex supplier/OEM relationship (where the supplier makes margin on innovative solutions vs. generic commoditized products).

Figure 105. 2015E to 2020E Center Stack Display Unit CAGRs



Source: IHS, Citi Research

Another important trend to keep an eye on is the shift in size of the center stack display. The general increase in size creates a more easily viewable and intractable graphical user interface (GUI), adding value to both consumer and auto manufacturer. At a certain size a manufacturer does hit a ceiling for what the center stack can hold, but an emerging trend is to flip the orientation of the display from landscape to portrait; this trend is currently utilized in the Volvo XC90.

Digitizing the Instrument Cluster

The instrument cluster remains a critical component of any automobile. This display shows many different aspects of vehicle performance, ultimately providing the driver with the necessary information to make informed decisions. The typical cluster displays can include a speedometer, tachometer, fuel gauge, temperature indicator, oil indicator, and many warning lights/indicators. The instrument cluster can be bucketed into essentially three distinct categories: (1) analog clusters – a cluster with no graphical TFT display (excl. LCD odometer); (2) Digital plus Analog (hybrid) clusters – some graphical TFT display with analog gauges; and (3) Full-digital clusters – a cluster where all analog displays have been replaced with a digital LCD.

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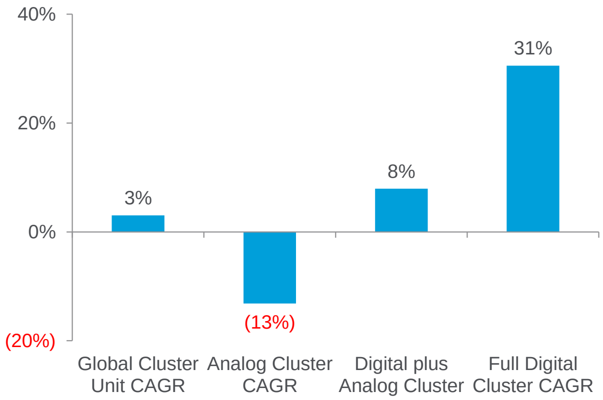
As vehicles continue to evolve and become more electrified (vs. mechatronic), more and more information should be able to be displayed on the instrument cluster – for example, active safety warning systems and tire pressure monitoring systems. The more information available, the more immersive the driving experience, which then becomes a catalyst to drive product differentiation and higher penetration of advanced cluster technology.

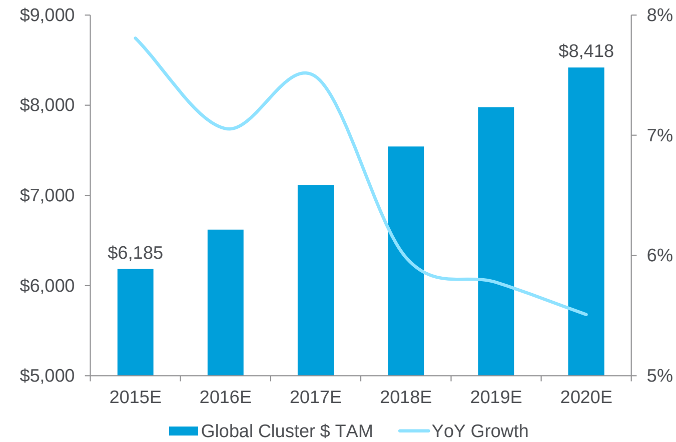
Continental, Visteon, Delphi, Denso, and Nippon are suppliers in this instrument cluster space.

Figure 106. 2015E-2020E Global Cluster Unit CAGR by Technology



Source: IHS, Citi Research

Figure 107. 2015E-2020E Global Cluster $ TAM and $ YoY Growth

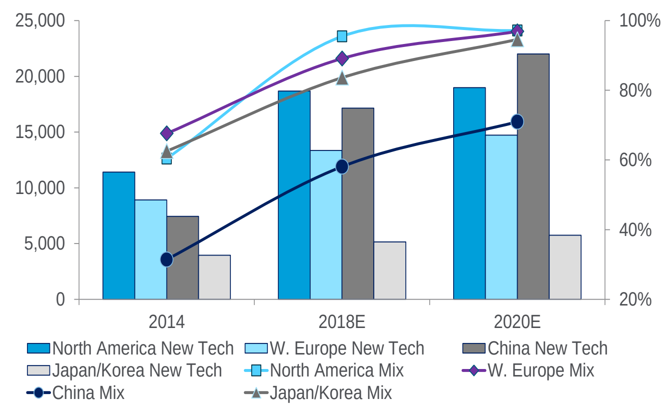


Source: IHS, Citi Research

Global and Regional Cluster Penetration by Technology

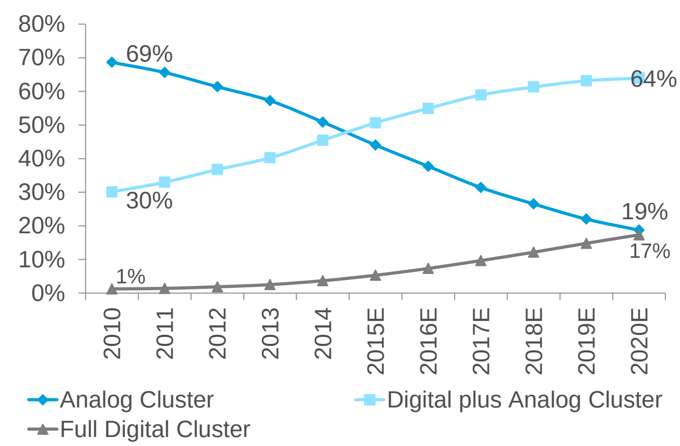
At the global level, there is a significant ramp up for digital plus analog AND full-digital display – as you shift to a more digitized display, suppliers can really provide a lot of value add at the software level. Take for example the full-digital cluster display in the new Lincoln Continental and the new Cadillac CT6.

Figure 108. New Tech Cluster Units and Penetration



Source: IHS, Citi Research

Figure 109. Global Technology Penetration – 1 Cluster per Vehicle



Source: IHS, Citi Research

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The decline of the typical analog cluster is consistent across both emerging and developed markets; however, the rate of adoption of the newer digital plus analog clusters and the full-digital clusters vary from region to region. North America, W. Europe, Japan/Korea and China remain important areas for adoption from a unit volume perspective. In North America and Europe, new cluster technology, as a percentage of the total mix will be ~97% for each region by 2020 (digital plus analog or full-digital); Japan/Korea with 95% of the mix; and China with 71% of the mix.

The Pricing Environment for Different Clusters

The cluster total addressable market (TAM) is estimated to grow to ~$8.5 billion by 2020. While the total CAGR may not look as promising as other technologies such as active safety, it is important to note that the total market growth rate is a bit deceptive because of the sheer volume of the commoditized analog cluster (hardware). If we look at unit and approximate revenue growth CAGRs by cluster technology we see that the more value-added software solutions like digital plus analog and full-digital clusters have higher growth profiles.

Using a trailing two year, three variable equation as a proxy for the current year (x = analog clusters, y = digital plus analog clusters and z = full-digital clusters) and assuming a 1% annual average selling price (ASP) decline in analog clusters, we can solve for technology specific ASPs, using IHS forecasted global aggregate ASP assumptions. Using this calculation we believe that mass market penetration ASPs (by 2018E-2021E) could be: ~$50-$55 for analog clusters; ~$75-$85 for digital plus analog clusters; and ~$150-$180 for full-digital clusters. In today's current environment, we believe that range could be the following: ~$55-$65 for analog clusters; ~$120-$185 for digital plus analog clusters; and ~$250-$290 for full-digital clusters – given that the cost to deploy may be elevated as the current demand environment may not yet drive volume efficiencies from the more advanced cluster technologies.

Sizing-Up the Instrument Cluster

As with center stack displays, the instrument cluster display comes in many different sizes. There are two caveats to cluster sizing: (1) cost constraints come into play given the cluster must be standard on every car, as such a larger screen size is more costly; and (2) the viewable real estate in the cluster display is much smaller as it is viewed through the steering wheel. It is important to note that only digital plus analog or full-digital clusters contain some type of graphical display, therefore the adoption cadence will increase as more regions convert over to one of the two from the typical analog displays, which could help drive costs lower.

In general much of the 2015E-2018E growth is seen in the 3.x inch and 7.x inch screen size. The 3.x inch screen growth can be attributed to increasing popularity and penetration of the digital plus analog cluster; the 7.x inch screen growth is likely a function of a higher adoption rate of option packages for full-digital instrument cluster displays (ICDs), which start at the 7.x inch size.

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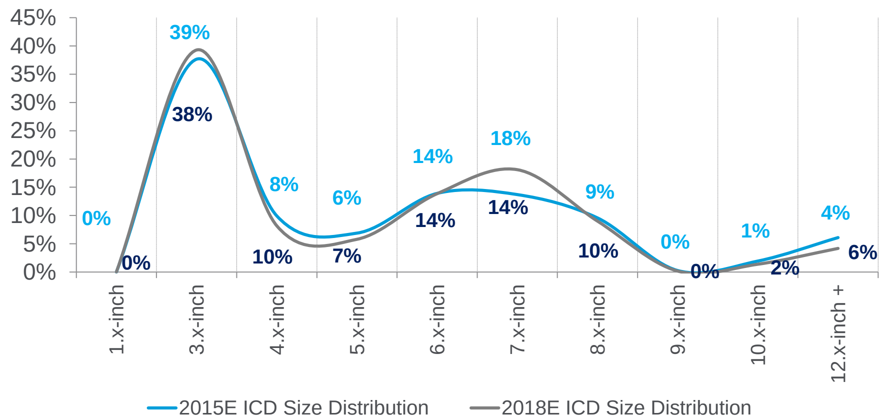
Figure 110. 2015E vs. 2018E ICD Size Distribution Curve



Source: IHS, Citi Research

Enhancing HMI: HUDs and Augmented Reality

The heads-up display (HUD) concept has been around for quite a while, in fact the first known automobile HUD went into production with GM in 1988. From that point forward HUDs have been a very niche product mainly due to size, cost, and benefit constraints. With recent trends of infotainment, a more focused effort to improve safety by helping to keep eyes on the road, the declining cost of components and the reduced size of components/end systems, this niche product is on track to become a more mainstream product which is widely accepted by many vehicles. Factor in the evolution of the HUD to encompass augmented reality and you have an explosive growth product within the global automobile industry. HUDs can either be in one of two fittings: (1) windscreen HUD (currently the only one with real production volume) – a HUD that projects information directly on the windscreen of the vehicles; and (2) a combiner HUD, which projects the information to a separate piece of glass or plastic – known as the combiner.

Windscreen HUDs, as shown below, project directly to the windscreen, with no combiner piece. The ASPs on windscreen HUDs (per IHS) carry a premium of ~2.3x combiner HUDs, even as the volume mix shifts from windscreen dominated to a more combiner dominated.

The Cadillac CT6, unveiled at the NYC Auto Show has a windscreen HUD

Figure 111. Evolution of Windscreen HUDs

Source: Continental, Citi Research

Combiner HUDs shown to the right – this feature can be added to a MINI Cooper for $500

Figure 112. Combiner HUD Display

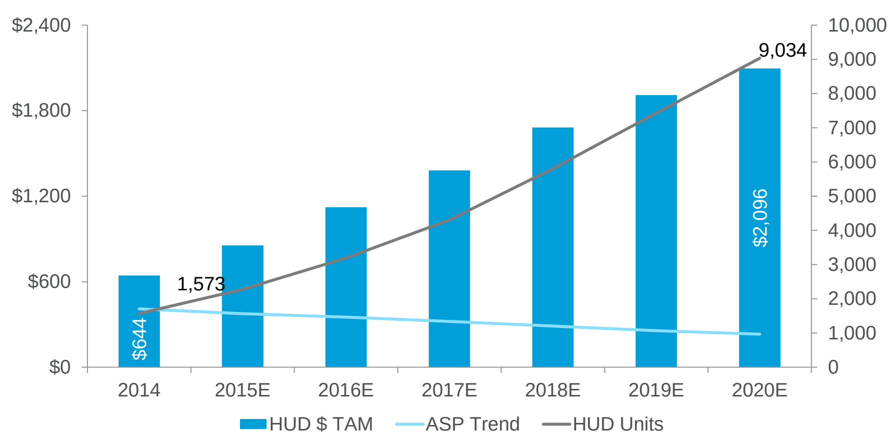
Source: MINI, Citi Research

Sizing Up the Markets - The Current and the Future

The overwhelming majority of HUDs currently produced are windscreen HUD. In sizing up the market we believe that units (1 unit per vehicle) are expected to grow at a 2015E-2020E CAGR of ~30%. At the same time, the revenue total addressable market is expected to grow to nearly $2.1 billion.

As expected, North America, China and Western Europe remain the most important regions for both unit TAM and revenue TAM – accounting for 75% of the total TAM in 2020E

Figure 113. HUD Market Overview – Revenue TAM, Unit Volume, and ASP Trend



Source: IHS, Citi Research

North America, China and Western Europe remain key regions for adoption of HUD technology

By 2020 it is estimated that overall HUD penetration will be ~9%. The major regions adopting this technology are no surprise – W. Europe, Japan/Korea and North America remain the highest regions by percentage of sales adoption.

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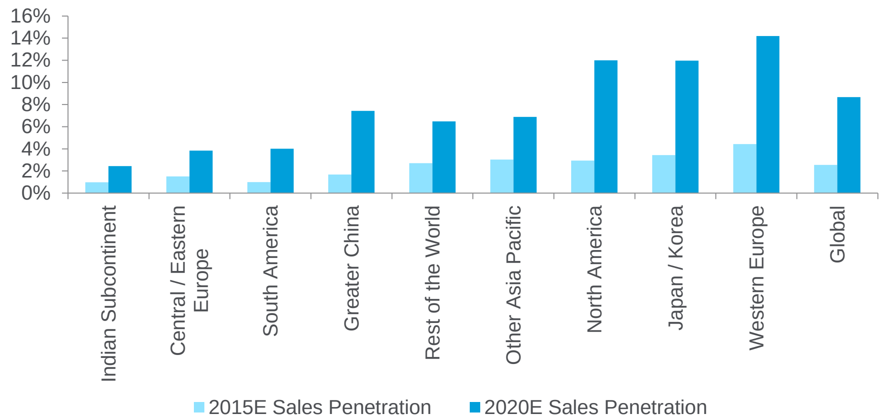
Figure 114. Global Sales Penetration of HUDs (Windscreen + Combined)

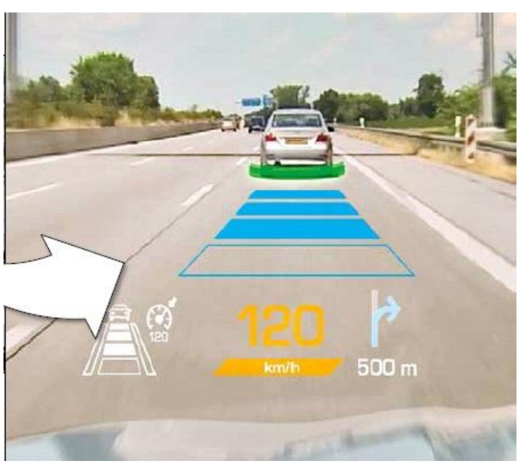


Source: IHS, Citi Research

A Further Step to the Future -- Augmenting Reality

The neat thing about HUDs is that the very nature of the product allows for OEMs to leverage it as an ideal platform for multi-modal technological convergence. What we mean by this is that as the infotainment and active safety mega-trends continue to develop, they will eventually converge where all information will be available and accessible in one place, allowing for faster adoption and increased penetration. For HUDs, this can be achieved by leveraging the prime real estate within a vehicle to not only display driver information, but also provide active safety cues to help the driver gauge potential troublesome situations, or provide navigation and other directions in one easy to view location. We already know the trajectory for both windscreen and combiner basic HUDs, but the next step in the evolution of the HUD is to augment the reality of the driver's viewpoint, allowing for 3D effects to cover the depth of the scene ahead. The 3D aspects of the augmented reality will not only help the driver minimize distractions and help keep them focused on the road, but it will also help to reduce the uncertainty of the road ahead. As seen in the images below, the augmented 3D reality is able to help enhance both infotainment (real time navigation becoming part of the road) and active safety technology (3D distance between cars to help prime AEB or ACC) into one easy to view GUI/HMI.

Figure 115. Augmented Reality HUD - ACC



Source: Continental, Citi Research

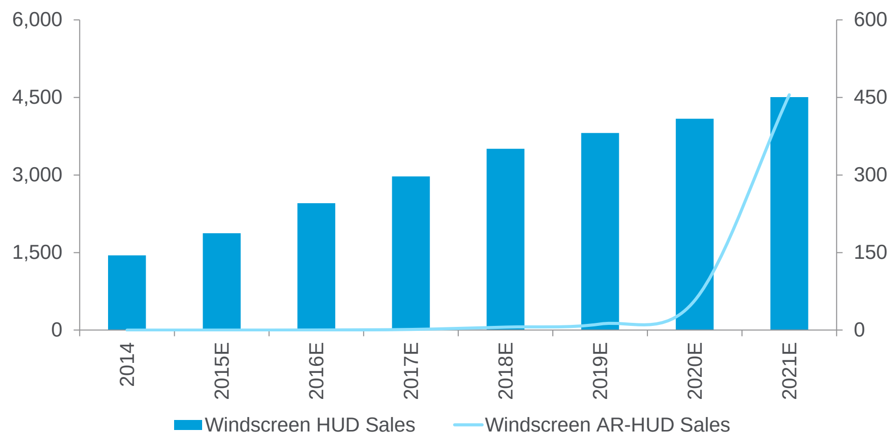
Figure 116. Augmented Reality HUD - NAV

Source: Continental, Citi Research

A Small, but High Growth Market

Augmented reality HUDs (AR-HUDs) will all start off as windscreen HUDs, and will be at a premium relative to the typical windscreen HUDs; the exact ASP of these AR-HUDs are currently unknown as only very limited shipments are expect to occur from 2015E to 2019E. From 2019E through 2021E unit shipments should ramp significantly, driven by increased penetration relative to standard windscreen HUD shipments, but will still remain a niche market. As the windscreen technology does carry a much higher ASP vs. combiner, we believe unit shipments will likely remain low as these costs could be a headwind to more mass market adoption, thus limiting this technology primarily to luxury vehicles, at first. By 2018E, we estimate that 3.5 million windscreen HUDs will be shipped, of which a mere ~5,800 units will have some type of augmented reality; this number of units could reach 455,000 by 2021E or ~10% of total windscreen HUD unit shipments or ~0.4% of global sales.

Figure 117. Windscreen HUD Sales (LHS) and Windscreen AR-HUD Sales (RHS) (Windscreen AR-HUD Sales are Included in the Total Windscreen HUD Sales)



Source: Bishop, Citi Research

As HUDs are very software-driven product platforms, we tend to favor this technology in our *Car of the Future* investment framework. As such, we prefer companies with reflection based technology (windscreen or combiner vs. light bars). Additionally, this software-heavy solution should allow for higher margins and higher ASPs on future iterations of these products – for example, any increased penetration of AR-windscreen HUDs in favor of typical windscreen HUDs will help expand the revenue total addressable market for total HUDs.

Connecting the *Car of the Future*, in Japan

Connected cars are always connected to the Internet and have communications capabilities similar to smartphones and PCs. This technology concept started in the field of information display equipment, such as car navigation systems, music playback devices, and news/e-mail services. Now sensors are able to monitor the condition of a vehicle as well as traffic conditions, and vehicles can communicate with other vehicles and with information infrastructure via networks.

In Japan, almost all connected car technology standards have been developed by automated driving and information technology (IT) strategy task forces rather than specialized connected car working groups. In June 2013, the Japanese Cabinet declared a target of making Japan the world's most advanced IT nation, including a plan to combine the development of in-vehicle systems with vehicle-to-vehicle and road-to-vehicle information exchange to enhance driver assistance technology. Systems will be tested on public roads with a view to commercialization. Connected cars require sensor technology to read information and communication technology to transmit information. The government will encourage competition in the private sector to advance sensor and other in-vehicle system technologies (General Motors' OnStar is a prime example), but promote alliances to develop infrastructure and other basic technologies.

Government efforts include the development of intelligent transport systems (ITS) that use vehicle-to-vehicle and road-to-vehicle communications to provide drivers with information ranging from traffic conditions to the presence of vehicles in blind spots or pedestrians at an approaching intersection. The government has already installed around 1,600 antennas (ITS spots), mainly along national highways, which are able to communicate with ITS-compatible car navigation systems. This allows drivers to choose optimal travel routes based on traffic data transmitted to the navigation system. In addition, the construction of a next-generation transportation management system (universal traffic management system: UTMS) that uses infrared beacons to realize two-way communications between vehicles and integrated traffic control (ITC) systems is advancing. The UTMS centers on ITS and has eight subsystems. These include the driving safety support system (DSSS), which provides drivers with visual and audio information about peripheral road conditions, and the help system for emergency life-saving and public safety (HELP), which transmits information to a dedicated reception center in the event of an accident or other emergency.

Based on results to date, the Japanese government aims to develop higher precision driver assistance systems by 2016—specifically, systems that reduce the risk of accidents on general roads and vehicle-only roads by using roadside milliwave radars to understand traffic conditions at intersections and identify peripheral vehicles and pedestrians, regardless of weather conditions. By 2017, the government aims to develop safe-driving support systems by using roadside sensors to detect peripheral pedestrians and vehicles and transit information to vehicles in real time via radio wave. Other functions are being considered to promote the diffusion of these systems. The government aims to reduce the unit cost of this roadside equipment to the same level as a traffic light or lower. The government has called on the auto industry to agree on technical specifications for the information obtained by in-vehicle safety support systems and for the methods by which it is transmitted. Related ministries have indicated support for the commercialization of new systems by around 2018. For example, MIC has indicated plans to open up the 77.5-78GHz bandwidth, previously used for amateur radio, and use the 71-81GHz bandwidth for auto milliwave radar.

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Elsewhere, Europe has decided to make automated emergency warning systems mandatory. Certified non-profit organization HEM-NET (Emergency Medical Network of Helicopter and Hospital), Toyota, and Honda have started trialing an automated emergency warning system called D-Call Net. Full-scale operation is planned for 2018. Also, the auto industry is considering including automated emergency warning systems in the Japan New Car Assessment Program (JNCAP). This could accelerate the installation of data communication modules (DCM).

Japan does not allow the owners of private vehicles to carry passengers for a fee, except in special circumstance like for welfare purposes. Although efforts are being made to steadily enhance transport options in sparsely populated parts of the country with a relaxation of the ban on ride-hailing services in Japan's experimental policy zones, we think ride-hailing services face high regulatory hurdles.

Connectors/Sensors a Major Beneficiary of Vehicle Electrification

We forecast annual average connector volume growth of 4%-6% per vehicle in addition to annual auto production growth of 2-3% less average price declines of 0-2% resulting in organic connector growth of 6-8% without aggressive assumptions

As cars become electrified, connected, and autonomous, the electrical architectures will grow and become increasingly complex. By 2020+ and as compared to 2015, Delphi expects to see a 67% increase in cabling — up 2.5 miles. About 100,000 pieces of data will be exchanged in a blink of an eye versus ~15,000 today. And architecture complexity will increase 15 times by 2025 as compared to 2010.

Connectors are another product that will benefit from vehicle electrification. As the installation of electronic systems advances, the number of electronic circuits that exchange information and hence the number of connectors will increase. As the increase in electronic circuits will be exponential to system installation, we forecast annual average volume growth of 4%-6% versus just over 2% for engine control units (ECUs). We forecast auto volume growth and an increase in the number of connectors per vehicle will result in the connector market expanding from $11.8 billion in 2015 to $12.5 billion in 2016, and $16.5 billion in 2021 (Figure 118 and Figure 119). We note our assumption of ~2% global automotive production growth is roughly in-line with major OEMs and third party estimates.

We estimate connector content has grown with weighted CAGR of +6.2% from 2003 to 2015 (assuming Europe cars have twice the content vs. N. America cars; Asia half the content vs. N. America). We note content growth was negative during recession time (2008-2009), demonstrating a scale back of electronic content per vehicle when end market demand is highly uncertain. In addition, we highlight the currency headwind to the connector industry in 2015 which caused the industry to decline -6.1% in U.S. dollar terms (or down -0.5% on constant currency basis). We note automotive connector industry was down -6.4% in 2015 and believe the constant currency growth rate is at flat to up low single digit given that higher connector content value in European autos. Recall, TE Connectivity's automotive segment was up +3% organically vs. -8% decline of reported revenue in fiscal year 2015 primarily due to currency impact. (However, we note TE Connectivity faces significant headwinds in its industrial segment which represents 26% of their sales and the company's industrial segment was down -4% year-over-year in June 2-16 organically as oil price declined and major oil and material exploration activities significantly have slowed down).

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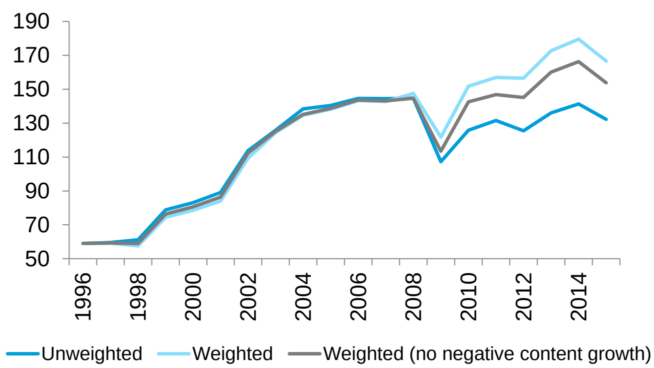
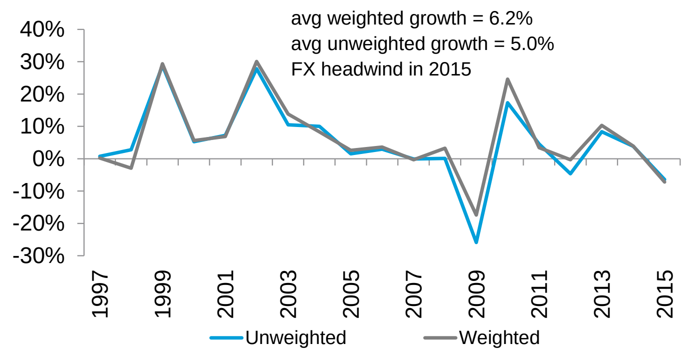
Figure 118. Connector Content Per Vehicle (2003-2015)



Source: Bishop, Citi Research

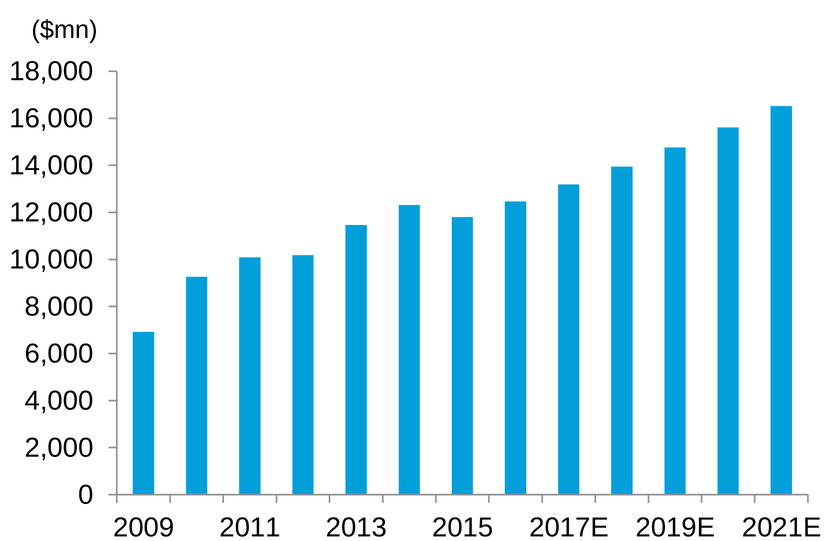
Figure 119. Connector Content YoY Growth



Note: We believe automotive connectors were flat to up low single digit in 2015 on a constant currency basis vs. -6.4% in US% due to Euro depreciation
Source: Bishop, Citi Research

Major auto-use connector makers include Yazaki, Sumitomo Wiring Systems, Japan Aviation Electronics, Hirose Electric, Iriso Electronics, and JST (Japan), TE Connectivity, Delphi, Molex, and Amphenol. The number of suppliers is large because the type of connector used differs by application. Even so, we estimate TE Connectivity has a market share of 30%-40% and is the dominant player.

Figure 120. We Forecast Connectors Will be One of the Biggest Beneficiaries of Vehicle Electrification (Revenue, $ Million)



Source: Bishop, Citi Research Estimates

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Figure 121. Top 30 Connector Manufacturers, 2010-2015

Rank	Manufacturer ($ Millions)	2009	2010	2011	2012	2013	2014	2015	2011 Y/Y Change	2012 Y/Y Change	2013 Y/Y Change	2014 Y/Y Change	2015 Y/Y Change	2011 Market Share	2012 Market Share	2013 Market Share	2014 Market Share	2015 Market Share
1	TE Connectivity	$6,005	$7,865	$8,476	$8,482	$8,719	$8,943	$8,211	8%	0%	3%	3%	-8%	17.3%	17.8%	17.0%	16.1%	15.8%
2	Amphenol Corporation	$2,820	$3,293	$3,676	$4,015	$4,290	$4,993	$5,238	12%	9%	7%	16%	5%	7.5%	8.4%	8.4%	9.0%	10.1%
3	Molex Incorporated	$2,480	$3,403	$3,582	$3,580	$3,617	$3,911	$4,169	5%	0%	1%	8%	7%	7.3%	7.5%	7.1%	7.1%	8.0%
4	Delphi Connection Systems	$726	$1,228	$2,522	$2,589	$2,953	$2,701	$2,736	105%	3%	14%	-9%	1%	5.2%	5.4%	5.8%	4.9%	5.3%
5	Yazaki	$1,260	$1,777	$2,176	$2,278	$2,382	$2,409	$2,459	22%	5%	5%	1%	2%	4.4%	4.8%	4.7%	4.3%	4.7%
6	Foxconn (Hon Hai)	$1,146	$1,547	$2,718	$2,683	$2,704	$2,482	$2,328	76%	-1%	1%	-8%	-6%	5.6%	5.6%	5.3%	4.5%	4.5%
7	JAE	$786	$976	$1,083	$1,311	$1,311	$1,503	$1,428	11%	21%	0%	15%	-5%	2.2%	2.8%	2.6%	2.7%	2.7%
8	JST	$1,364	$1,602	$1,509	$1,357	$1,445	$1,394	$1,321	-6%	-10%	6%	-4%	-5%	3.1%	2.9%	2.8%	2.5%	2.5%
9	LuxShare	N/A	N/A	N/A	N/A	$595	$942	$1,139				58%	21%			1.2%	1.7%	2.2%
10	Hirose	$939	$1,155	$1,160	$948	$1,087	$1,065	$1,017	0%	-18%	15%	-2%	-5%	2.4%	2.0%	2.1%	1.9%	2.0%
11	Rosenberger	$343	$453	$630	$625	$720	$900	$920	39%	-1%	15%	25%	2%	1.3%	1.3%	1.4%	1.6%	1.8%
12	Sumitomo Wiring Systems	$726	$816	$859	$1,006	$976	$992	$902	5%	17%	-3%	2%	-9%	1.8%	2.1%	1.9%	1.8%	1.7%
13	China Aviation Optical-Electrical	N/A	N/A	N/A	N/A	$427	$467	$639				10%	37%			0.8%	0.8%	1.2%
14	HARTING	$426	$553	$668	$616	$662	$726	$629	21%	-8%	7%	10%	-13%	1.4%	1.3%	1.3%	1.3%	1.2%
15	Samtec	$320	$466	$489	$515	$565	$613	$625	5%	5%	10%	8%	2%	1.0%	1.1%	1.1%	1.1%	1.2%
16	3M Electronic Solutions Division	$469	$624	$607	$576	$610	$920	$597	-3%	-5%	6%	51%	-35%	1.2%	1.2%	1.2%	1.7%	1.1%
17	Phoenix Contact	$164	$177	$211	$399	$436	$470	$467	19%	89%	9%	8%	0%	0.4%	0.8%	0.9%	0.8%	0.9%
18	Korea Electric Terminal Co	$190	$293	$303	$320	$424	$470	$457	3%	6%	33%	11%	-3%	0.6%	0.7%	0.8%	0.8%	0.9%
19	Belden	$100	$139	$300	$463	$468	$428	$401	115%	54%	1%	-9%	-6%	0.6%	1.0%	0.9%	0.8%	0.8%
20	CommScope	N/A	N/A	N/A	N/A	$432	$468	$400				9%	-15%			0.8%	0.8%	0.8%
21	Carlisle						$336	$373				N/A	11%				0.6%	0.7%
22	AVX/Elco	$397	$448	$461	$481	$501	$449	$356	3%	4%	4%	-10%	-21%	0.9%	1.0%	1.0%	0.8%	0.7%
23	Bel Connectivity						$310	$339				N/A	9%				0.6%	0.7%
24	Radiall	$222	$245	$283	$283	$312	$365	$333	15%	0%	10%	17%	-9%	0.6%	0.6%	0.6%	0.7%	0.6%
25	ITT Interconnect Solutions	$346	$415	$415	$377	$397	$399	$328	0%	-9%	5%	0%	-18%	0.8%	0.8%	0.8%	0.7%	0.6%
26	IRISO Electronics	$226	$268	$297	$311	$336	$352	$316	11%	4%	8%	5%	-10%	0.6%	0.7%	0.7%	0.6%	0.6%
27	Shenzhen Deren Eletr. Co						$352	$316				N/A	-10%				0.6%	0.6%
28	Glenair						$300	$303				N/A	1%				0.5%	0.6%
29	Huber+Suhnei	$233	$283	$327	$298	$311	$336	$301	15%	-9%	4%	8%	-10%	0.7%	0.6%	0.6%	0.6%	0.6%
30	Souriau	$301	$315	$353	$376	$364	$324	$299	12%	6%	-3%	-11%	-8%	0.7%	0.8%	0.7%	0.6%	0.6%
	Total Top 30	$22,956	$29,611	$34,595	$35,517	$38,737	$42,210	$41,168	17%	3%	9%	9%	-2%	71%	75%	76%	76%	79%
	All Others	$11,434	$16,287	$14,328	$12,093	$12,446	$13,192	$10,882	-12%	-16%	3%	6%	-18%	29%	25%	24%	24%	21%
	Total Market	$34,390	$45,898	$48,923	$47,610	$51,183	$55,402	$52,050	7%	-3%	8%	8%	-6%	100%	100%	100%	100%	100%

Note: We highlight the currency headwind to the connector industry in 2015 which caused the industry to decline 6.1% in US$ (or down 0.5% on a constant currency basis). We note automotive connector industry was down 6.4% in 2015 and believe the constant currency growth rate is at flat to up low-single digit given the higher connector content value in European autos.
Source: Bishop, Citi Research

Figure 122. Top 10 Connector Manufacturers Segment Rankings (2015)

World Rank	Computers and Peripherals	Consumer Electronics	Business Retail Education	Telecom Datacom Equipment	Instruments	Industrial Equipment	Transportation Equipment	Automotive Equipment	Medical Equipment	Military Aerospace	Other
1	Foxconn	Molex	Molex	Amphenol	LuxShare	TE Connectivity	TE Connectivity	TE Connectivity	Molex	Amphenol	TE Connectivity
2	Molex	TE Connectivity	JST	TE Connectivity	Rosenberger	Amphenol	Delphi	Yazaki	TE Connectivity	China Aviation	Sumitomo
3	LuxShare	JST	Foxconn	Molex	Molex	Molex	Amphenol	Delphi	Amphenol	TE Connectivity	Hirose
4	Amphenol	CommScope	TE Connectivity	JAE	LEMO SA	HARTING	Molex	JAE	LEMO SA	Glenair	Delphi
5	Foxlink	LuxShare	IRISRO	LuxShare	Samtec	JST	Carlisle	Sumitomo	3M	Carlisle	Multi-Contact
6	LOTES Co. Ltd	IRISO	3M	Rosenberger	Foxconn	Phoenix Contact	Yazaki	JST	ODU	ITT	Amphenol
7	TE Connectivity	Delphi	Smiths	Hirose	TE Connectivity	Belden	Sumitomo	Rosenberger	Samtec	Radiall	Foxconn
8	Shenzhen Deren	Foxconn	Luxshare	CommScope	Radiall	3M	Korea Electric	AVX	LuxShare	Delphi	Korea Electric
9	Hirose	JAE	Hirose	Foxconn	Hosiden	Weidmuller	ITT	Korea Electric	Radiall	Souriau	3M
10	Samtec	Hirose	I-PEX	Bel	IRISO	Samtec	Souriau	Amphenol	Delphi	AMETEK	Molex

Source: Bishop, Citi Research. Note: 2016 data not yet available.

Figure 123. Top 30 Connector Manufacturers – Regional Ranking (2015)

World Rank	Manufacturer	North America	Europe	Japan	China	Asia Pacific	ROW
1	TE Connectivity	1	1	1	1	1	3
2	Amphenol	2	2	9	2	3	2
3	Molex	4	4	4	4	2	89
4	Delphi Connection Systems	3	3	53	8	11	5
5	Yazaki	5	7	2	9	4	1
6	Foxconn (Hon Hai)	13	26	21	3	5	8
7	JAE	15	34	6	6	13	13
8	JST	8	23	3	11	7	62
9	LuxShare	82	62	19	5	23	22
10	Hirose	31	38	7	10	6	26
11	Rosenberger	11	6	35	15	10	7
12	Sumitomo Wiring Systems	33	40	5	16	9	4
13	China Aviation Optical Electric	80	66	85	7	79	88
14	HARTING	29	5	25	22	49	19
15	Samtec	7	9	34	17	15	66
16	3M Electronic Solutions Division	19	24	8	20	16	25
17	Phoenix Contact	22	8	66	21	24	28
18	Korea Electric Terminal Co	83	85	29	14	8	6
19	Belden	14	19	28	28	33	9
20	CommScope	9	41	39	23	22	48
21	Carlisle	6	32	54	73	47	24
22	AVX/Elco	26	18	11	25	60	90
23	Bel Connectivity	18	35	57	70	14	91
24	Radiall	17	16	36	40	54	33
25	ITT Interconnect Solutions	12	31	31	69	31	10
26	IRISO Electronics	40	39	14	34	18	15
27	Shenzhen Deren	84	86	86	12	19	39
28	Glenair	10	27	58	96	63	18
29	HUBER+SUNHNER	35	11	44	46	21	17
30	Souriau	16	17	22	81	78	38

Source: Bishop, Citi Research

We forecast annual average sensor volume growth of 6%-8% per vehicle in addition to annual auto production growth of 2-3% less average price declines of 0-2% resulting in organic sensor growth of high single digits without aggressive assumptions.

Auto-use sensors are the eyes of electronic systems, monitoring information inside and outside the vehicle. There are more than 20 types of sensors, including oxygen sensors and knock sensors for engines, current sensors for xEVs, angular velocity sensors for ESC, and radar sensors and ultrasonic sensors for ADAS. Fuel economy and emission regulations have already led to engine oxygen and nitrogen oxide sensors becoming commonplace.

We estimate total sensor content has grown with weighted CAGR of +8.5% from 2009 to 2015 (assuming Europe cars have 2x content vs. N. America cars; Asia 0.5x content vs. N. America) and forecast long term annual average sensor content growth of mid to high single digits versus just over 2% for ECUs. In the near term, we believe the Volkswagen diesel defect device issue remains a headwind to sensor content growth (diesel vehicles have 1.5x sensor content vs. combustion vehicles).

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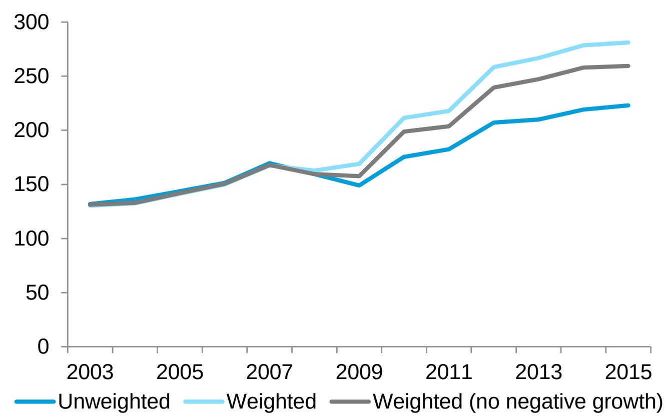
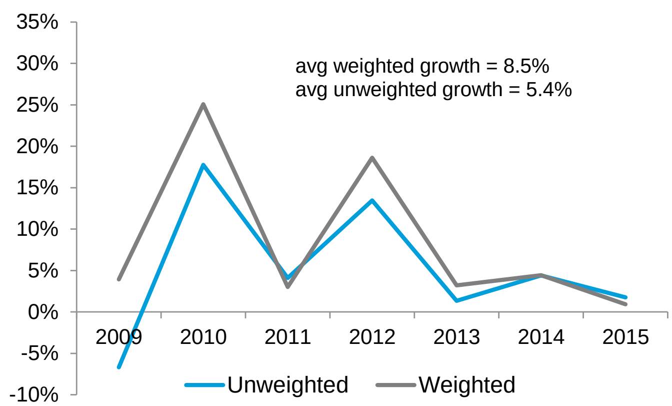
One noticeable trend in the sensor industry is that connector companies are acquiring sensor companies for vertical acquisition. (i.e., Amphenol acquired GE Advanced Sensor business and Casco and TE Connectivity acquired Measurement Specialty). We believe connector companies could benefit from automotive sensor acquisitions as connector companies leverage existing relationship with auto OEMs to expand sensor product offerings. In addition, we expect continuous M&A activities within automotive sensor industry given the low market concentration. (i.e., Sensata making horizontal acquisition of Schrader for TPMS sensor business). We believe big companies can create synergies from sensor industry consolidation by leveraging their global manufacturing footprint, design capabilities and sales channels with major auto manufacturers.

Figure 124. Sensor Content Per Vehicle



Source: Company Reports, Citi Research

Figure 125. Sensor Content Year-Over-Year Growth



Source: Company Reports, Citi Research

Figure 126. Outline of Major Automotive Sensors

Sensor	Application	Outline
Oxygen sensor	Engine	Monitors oxygen concentration in the engine. Penetration almost complete.
A/F Sensor	Engine	Monitors the engine air-tp-fuel ratio. Penetration almost complete.
NOx sensor	Engine	Monitors NOx concentration in the exhaust. Penetration almost complete.
Knock sensor	Engine	Monitors knocking caused by an increase in engine pressure. Penetration almost complete.
Air flow meter/ Vacuum sensor	Engine	Measure the quantity of air going into the engine.
Pressure sensor	Engine	Monitors engine intake pressure, turbo pressure, and common rail pressure.
Magnetic sensor	Engine/Body	Monitors vehicle angle and position.
Temperature sensor	Engine/xEVs	Monitors temperature changes in the engine. Used for batteries and motors.
Current sensor	xEVs/Lead batteries	Measures the electric current used by electrified vehicles.
Air Pressure sensor	TPMS	Monitors tire pressure.
Torque sensor	EPS	Monitors power steering torque.
Rudder Angle sensor	ESC	Monitors vehicle steering direction.
Yaw rate sensor	ESC	Monitors the rate of vehicle rotational angle change.
Gyro sensor	ESC/Car navigation	Monitors the change in vehicle angular velocity; used by ESC and car navigation (positional information).
Acceleration sensor	ESC/Air bag	Monitors vehicle acceleration; used by ESC and airbag collision detection systems.
Ultrasound sensor	ADAS	Used by parking assistant and internal detection systems.
Auto camera sensor	ADAS	Used by preventative safety technologies (automatic braking, LDW, ACC, automated parking, etc.)
Radar sensor	ADAS	Used by obstacle detection systems (automatic braking, ACC, etc.)

Source: Company data, Denso, Citi Research

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Enhanced Mobile Communications

IT Hardware analyst Jim Suva notes the importance of enhanced mobile data communications to help enable the *Car of the Future*. Current mobile data networks do not have sufficient bandwidth to enable mass automobile machine-to-machine (M2M) communication especially in highly populated areas. Therefore the technology is looking ahead at future network developments.

A key enabler to facilitate the massive data transmissions associated with fully autonomous vehicles is the roll out of continued enhancements of the current LTE networks and even more so the 5G network which is slated to roll out in 2020. Enhancements to the current LTE network occur on a regular basis and help via compression and throughput accelerators but do not appear sufficient to support a fully autonomous vehicle community. Therefore this constraint is likely met via the planned 5G roll out which is slated for implementation for 2020.

In late October 2016 we attended an industry 5G summit. We were surprised at the packed attendance and note from that event that while the roll out of the 5G networks in 2020 is very encouraging we note there are still several challenges all of which we believe will be eventually worked out but perhaps not without lots of press, media and political fanfare. Governments will play an essential role in the legalization and deployment of spectrum as well as the physical implementation of the networks and one major concern is government intervention could potentially delay the planned 2020 implementation timeframe. A few examples include:

- Governments may try to regulate and monetize the 5G deployment more than anticipated or simple act slowly to certify and approve regulations.
- 5G may need more cell or antenna sites and it is common for residents to not want a base station or cell site near their residence.
- The manual labor need to upgrade the base stations and cell sites is enormous and no one wants to implement technology that could become obsolete.
- Finally there is the concern about security and trying to ensure the 5G network is secure. Imagine the havoc and potential danger if the 5G network gets hacked by terrorists and a community of fully-autonomous vehicles becomes compromised.

While these indeed are great questions we do believe like in times past such questions and issues will eventually be addressed and resolved although there could be some “speed bumps”.

Connected Automakers: Finding $1 billion in the U.S. Aftermarket

As we’ve described in past reports, the connected car stands to open new revenue and efficiency streams for automakers & suppliers outside of ride sharing. To name a few:

- Reducing warranty costs through OTA updates—an opportunity we’ve previously quantified as a few to several hundred million dollars.
- Usage-based insurance
- Big data opportunities
- Advertising / coupons
- Aftermarket

In recognition that not every opportunity will necessarily net to the bottom line (automakers do, after all, face regulatory cost headwinds), we tend to focus on those that appear sizable and relatively easier to execute.

To that, the aftermarket comes back to us as being more sizable than perhaps is currently understood, fairly straightforward to execute, and faster to implement (vs. driverless cars).

We believe U.S. automakers' aftermarket divisions currently generate most of their revenue within their 0-7 year old vehicle pools, a relatively small portion of the total vehicle population. Since the majority of a car's repair work occurs in the 8+ year time span, it appears that automakers are under-represented in a big chunk of the aftermarket. Historically this has made sense, since expiring warranties and ownership changes tended to cause the aftermarket to gravitate to areas like do-it-yourself (DIY) and other non-auto dealer distribution channels. In GM's case, we've estimated that AC Delco (GM's aftermarket division) generates roughly $2 billion in revenue representing a very modest implied share of GM's vehicle population.

Connected cars bring rise to services like advanced predictive diagnostics and automatic rolling service appointments that consumers can seamlessly select to save time, hassle, and money. Connectivity would allow the automakers (assuming customer sign-off) to gain critical data intelligence throughout the life of the vehicle. This isn't really breaking news as automakers including GM have already begun pursuing these channels in small steps. But the size of this P&L opportunity may be overlooked by investors relative to the risk of pursuing this channel.

As we see it there are two potential opportunities to tap into here:

- **Commission Model:** Here GM would contract with DIY & DIFM (do-it-for-me) retailers to provide them early intelligence on the aftermarket needs of consumers living and driving throughout their area. Consumers requiring parts/service would then be recommended to participating dealers on the basis of convenience (best appointments on top because consumer satisfaction come first), price, or simply the consumers' own preference of retailers/service channels. The consumer would gain convenience at all levels and possibly a lower price while retailers would value from better inventory management thanks to predicted demand. We've attempted to roughly size up GM's potential opportunity here as follows: (1) DIY market size at $50 billion; (2) DIFM at $90 billion (retail dollars); and (3) Tires at $33 billion — so a total of $173 billion market. Assuming GM's future share of this market resembles its current U.S. SAAR share of ~18%, at a 35% hit rate (reflecting % of retailers opting in and % of consumers accepting offers) and 5% commission fee, GM's revenue would amount to over $500 million. At a 70% variable margin (asset light) this would add roughly $400 million of earnings before interest and tax (EBIT).

- **Gaining Parts Share:** At its 2015 Investor Day, GM somewhat surprised people when it sized up its global aftermarket EBIT exposure at a higher-than-thought "in the billions" bucket. Regardless of the Connected Car discussion we think GM's aftermarket division is poised to grow in the coming years as the population of vehicles in the sweet spot (<7yrs) should rise both in the U.S. and China. But what about older vehicles? If we go back to the markets described above and express them at a wholesale level (parts), we roughly estimate that Delco's market share of GM vehicles sits below 15% — an under-penetration, in our view. GM's share gain opportunity is probably going to be limited to some extent by competition from robust aftermarket brands and GM's own willingness to add capacity.

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But one has to believe that having the intelligence stemming from predictive diagnostics could allow GM to gain some share by offering discounts and encouraging retail partners to sell its own parts where it makes sense. We estimate every 10 points of share gain at a 50% variable margin nets roughly $600 million of EBIT. We use this as the base case for the opportunity. If GM describes its current aftermarket profit contribution as “measured in the billions” and this is concentrated at the 0-7 year old vehicles (so roughly half of a car’s life with older cars needing more service), by order of magnitude a $1 billion incremental EBIT opportunity would seem reasonable to us from a high-level vantage point. The aftermarket opportunity should be common to Ford as well as other automakers over time. Running similar math on Ford suggests an $800+ million EBIT opportunity.

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Propelling the *Car of the Future*

Over the past few years, the convergence of regulatory and consumer demands across geographies have compelled automakers to pursue development strategies that focus on improved fuel economy, reduced emissions, and the pursuit of energy independence at the state level. These sweeping global regulatory updates are generally firmly in place through the latter part of this decade and into next decade.

That said, even considering the significant strides already taken in developing emerging technologies, much of the high-volume growth opportunities will likely come from "workhorse" powertrain technologies built around the internal combustion engine. Despite this fact, however, this near-future period may also prove transformative in the sense that non-conventional technologies (i.e. EVs, fuel cells) could make sufficient strides to gaining acceptance and leading to a market tipping point.

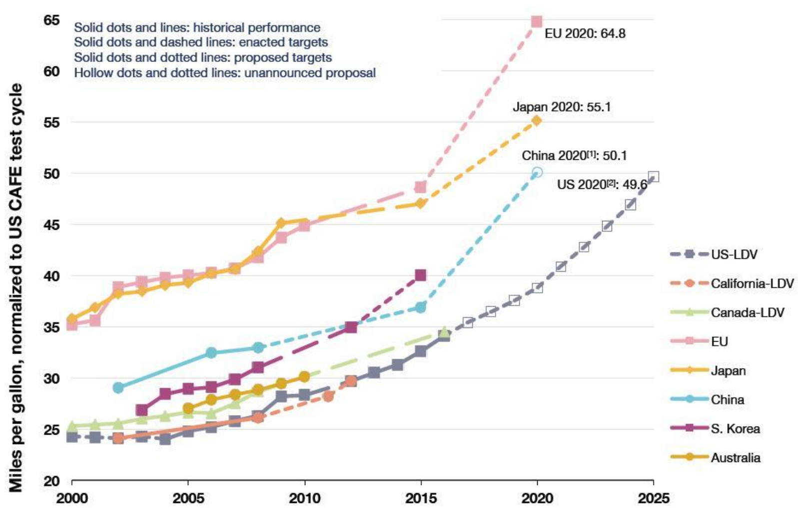
A wrinkle to the story has been the recent dramatic decline in global energy costs. Lower energy costs have spurred vehicle mix shifts, particularly in the US, and raised debate around the need for such stringent fuel economy standards. Another topic to add to this discussion concerns the implications to propulsion from autonomous vehicles. For the first time we're contemplating the removal of vehicles on the road (particularly in cities) as a form of reducing emissions reduction.

For an automaker, the choice regarding propulsion technology strategy might be its most important — a decision driven both by regulations and by consumer willingness to pay for premium technologies, desired brand perceptions, and expectations around the trajectory of energy prices.

The Drivers

- **Fuel efficiency** – As CO_2 regulations become more stringent (including a mandatory reduction of emissions to 95g/km in 2021 in Europe and potentially 68-78g/km in 2025), powertrains will have to become more efficient.
- **Fewer pollutants** – Aside from CO_2, regulators are increasingly looking at other pollutants, including Nitrogen Oxides (NOx) and particulates (PM10).
- **More power** – With increased regulation, consumers are still looking for at least the same amount of or, indeed, more power from their powertrains.

Figure 127. Emissions Regulations: Gram CO_2 per Kilometer to 2025



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be higher.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

Source: International Council on Clean Transportation, Citi Research

U.S. Focus: Discussing CAFE “Mid-term Review’ in 2017

With oil prices down significantly, average gas at the pump still below $3 per gallon and vehicle mix clearly moving back in favor of larger trucks and SUVs, now seems like a good time to discuss the U.S. CAFE requirements are being re-examined as part of the looming “mid-term” CAFE review. The purpose of the mandated review, set to take place in 2017 with a final decision by April 1, 2018, will be to evaluate the feasibility of current fuel economy/emissions plans from 2022-2025, updating rules put in place in 2012 by the EPA and NHTSA. Industry observers wonder whether stricter standards that ultimately lead to 54.5 MPG by 2025 may be lowered or even pushed farther out along the timeline if lower energy prices persist. The EPA, NHTSA, and California Air Resources Board released their draft Technical Assessment Report earlier this year, which analyzed cost, technology and other items to help lower gas emissions. U.S. regulators believe that auto manufacturers may have a challenge in reaching the 2025 54.5 MPG target, due to the current mix of vehicles sold in the U.S. The Government now estimates that the overall fleet average fuel economy will be 50-52.6 MPG by the 2025 timeframe — this accounts for a move even split in car vs. truck.

Looking Toward the 2022-2025 Timeframe

One matter that appears widely agreed upon is that the next immediate phase of the program, from 2017-2021, will likely not change much as multi-year product cycle lead times allow for minimal flexibility. We’ve heard comments echoing this from suppliers. It appears to us that the substance of the debate remains focused on the out-years (2022-2025) of the program, with OEMs expressing that excessive regulatory costs may impact both consumers as well as the employees who produce these vehicles. Of course, a new U.S. presidential administration will be in place during the time of the mid-term review. At this point, the situation remains fluid and is sure to gain wider attention as we move through the process.

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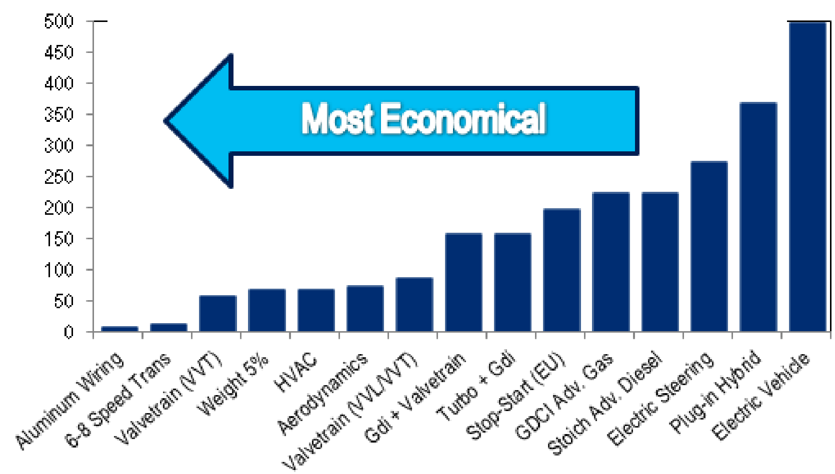
How to Meet the Requirements

In order to fulfill the stricter of these proposals, automakers will likely need to rely on a larger mix of non-conventional technologies including various forms of electrification.

But, it's Not a Winner-Take-All Game, Yet…

Figure 128. Cost/Benefit of Select Fuel Saving Technologies (Retail $ per MPG Improvement)



Source: Citi Research

For automakers, the decision to focus on one particular technology over others is complex and includes many variables. Choosing a technology package to achieve a specific goal (for instance, improving fuel economy) may not necessarily correspond best with achieving others (like improving well-to-wheel emissions). Also, automakers must consider what consumers want to buy, as demand for fuel efficiency historically tends to rise and fall with gasoline prices (at least in the short term). With this in mind, the affordability (payback) of newer technologies becomes a point of consideration.

Thus far, there is no surefire approach to tackling fuel economy, and automakers are adopting varying strategies for satisfying regulatory and consumer demands. This stems in part from specific automaker competitive advantages and in part from divergent thinking around consumer acceptance. What does seem clear is that a successful technology package must meet the following criteria:

1. **Reasonable Costs & Payback:** Historically, the majority of U.S. consumers purchasing new and used vehicles plan to keep that vehicle for less than 5 years, though the trend is on the upswing. Outside surveys have shown that, while consumers are willing to pay a premium for fuel economy, they also tend to require a ~3-year payback. This attitude is unlikely to shift dramatically anytime soon in light of lower energy prices and consumer distrust around "real-world" vs. "rated" miles-per-gallon labels. For this reason, affordable packages such as GDI/turbo, engine timing, stop-start, advanced transmissions, aerodynamics, and weight reduction have proven to be the most popular solutions thus far. Advances in these technologies should allow for continued market penetration for the foreseeable future, though at some point automakers will likely need more advanced combinations to satisfy 2025+ standards.

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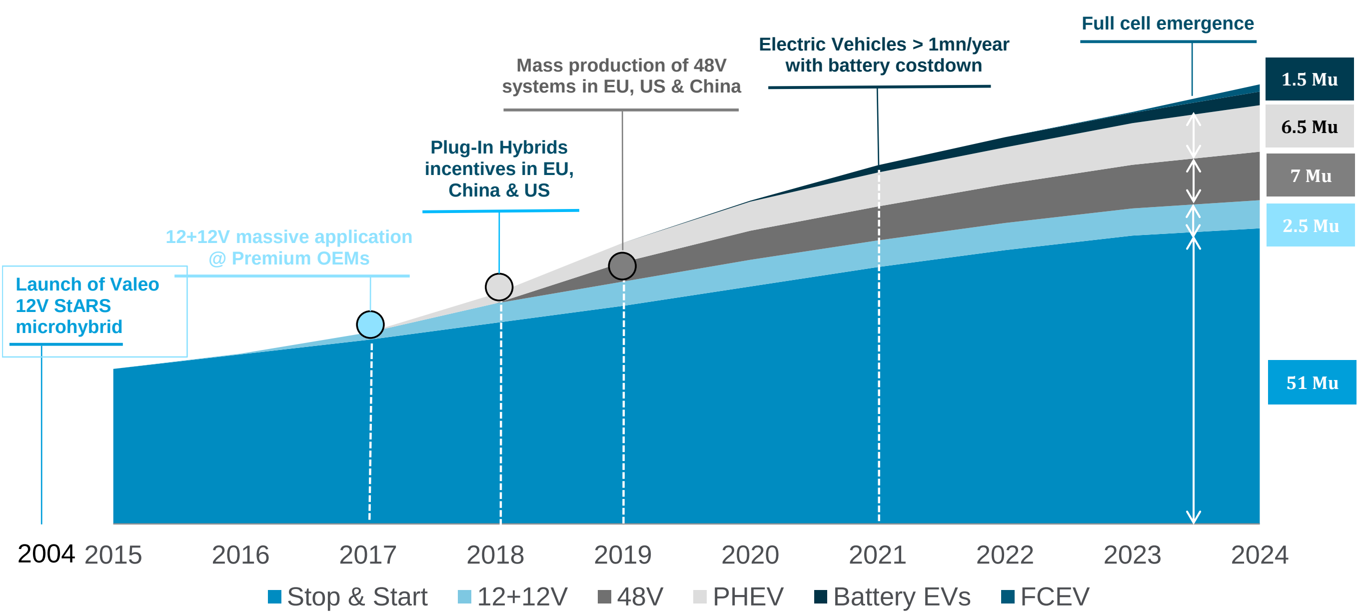
2. **Preserve (or Enhance) Performance:** The success of engines like the Ford EcoBoost can be attributed to their ability not only to improve fuel efficiency, but also to enhance vehicle performance. Providing a boost to performance greatly enhances the consumer value proposition and helps ensure the automaker earns a reasonable variable margin on sale. This is also a key advantage for electric vehicles.

3. **Strong Branding:** The best example to illustrate here is the painfully slow pace of diesel acceptance in the U.S. Traditional cost-benefit analysis often points to diesels as ranking among the more compelling technologies for the U.S. market — mainly because of appealing payback, compelling performance and the greater mix of U.S. highway driving (hybrids, for instance, tend to return best in city driving). However, diesel technology didn't have a strong reputation in the U.S. even prior to the VW diesel issue. Branding counts. But will diesels make a reputational comeback in the U.S? GM's recent product unveilings—including a diesel option on the 2018 high-volume Equinox crossover—suggests the automaker is investing in diesel when perhaps others aren't. It will be interesting to track in 2017.

A Look at the Different Technologies Propelling Change

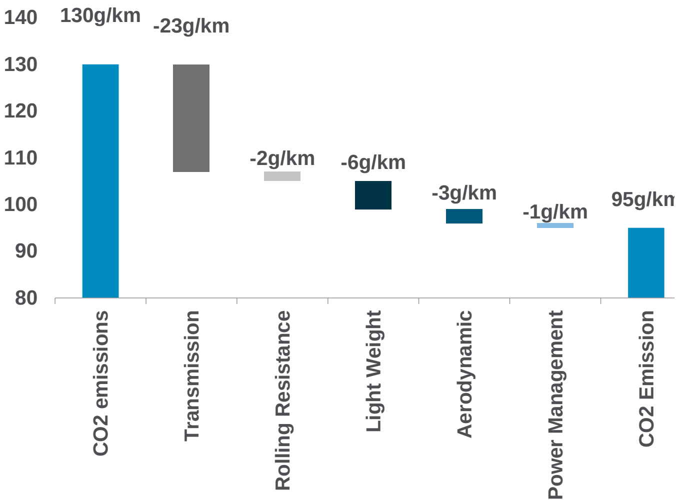
Figure 129. Growth in Engine Technologies



Source: Valeo

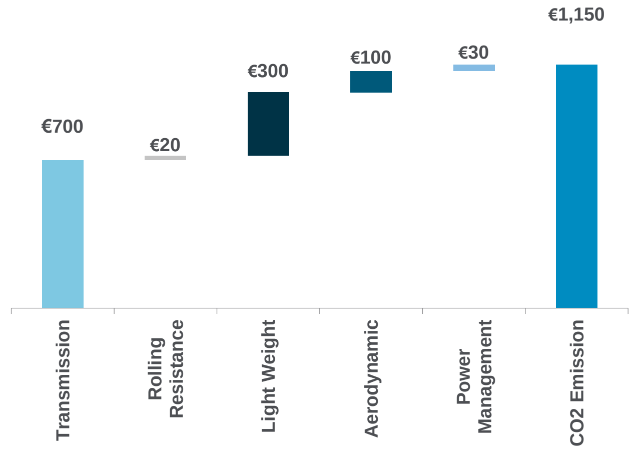
European auto supplier Continental provides numerous solutions below that will help OEMs reach their 2020-21 targets, which we highlight in the charts below. What is evident is that improvements will come from various areas, particularly more efficient engines/transmissions and higher electrification.

Figure 130. Meeting Emissions Reductions



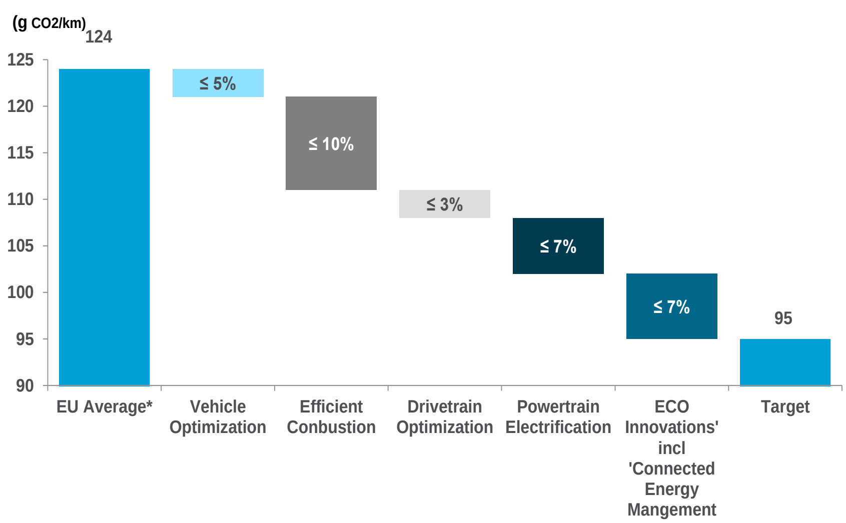
Source: Plastic Omnium Alphatech, Citi Research

Figure 131. Cost of Meeting Emissions Reductions



Source: Plastic Omnium Alphatech, Citi Research

Figure 132. How to Reach CO_2 Targets



Note: * EU Market Average in 2013
Source: Continental

Valeo categorizes solutions into two distinct areas: (1) efficient engines and (2) efficient transmissions, which we detail below.

1) Efficient Engines

- **Direct Injection:** Direct injection systems allow fuel to be injected into the engine combustion chamber at a very pressurized level and, as a result, the amount and timing of fuel directed into the engine can be controlled. This means that the air and fuel is mixed directly in the combustion chamber to the optimal level, rendering the engine more efficient. Also, direct injection can also increase the compression, thereby improving engine power. As such, this often works in parallel with turbochargers, reducing CO2 emissions by an extra 10-20%. Valeo believes Gasoline Direct Injection will have a CAGR of about 9% to 2024. Penetration rates are currently around 30-35% in Europe and 31% in North America.

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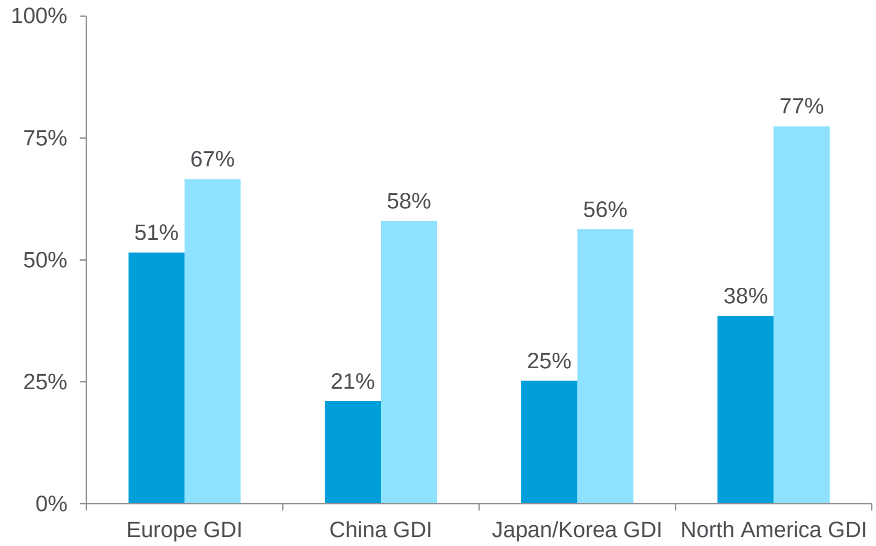
Figure 133. Gasoline Direct Injection Systems Installation Rate of Gasoline Engines



Source: IHS, Citi Research

Direct Injection, in turn, is often found with Variable valve Timing that can contribution to a 1-5% saving in fuel

- **Variable Valve Timing:** Direct Injection, in turn, is often found with Variable Valve Timing that can contribute to a 1-5% saving in fuel. This allows the valves (which let air both in and out of the combustion chamber) to be more regulated, including when they open in the combustion cycle, how long they are open for in order to let air in or out, and how far they open. The result is that the flow of air to and from the engine can be optimized depending on required speed and load, rather than having the same valve operation for all conditions. The Variable Valve Timing market should grow 8% each year to 2024, according to Valeo.

Thermal Management has the potential to be one of the fastest growing areas for powertrains, according to Valeo, growing at a CAGR of 27% over the next ten years

- **Thermal management:** Monitoring and influencing the heat of the engine can contribute significantly to the efficiency of the dynamics and, as a result, this has the potential to be one of the fastest growing areas for powertrains, according to Valeo, growing at a CAGR of 27% over the next ten years. Products include Charge Air Coolers, which cool the air used within turbochargers so that, as the air flows into the combustion cylinder and heats up again, its density increases and the energy produced is greater. Engine radiators also regulate the temperature of the engine to make sure it runs at the most efficient operational temperature. The heat of cars' interior can also be regulated more effectively, for instance by insulation, decreasing the need for more intensive air conditioning.

Exhaust Gas Recirculation can increase fuel efficiency by ~2%

- **Exhaust gas recirculation:** This helps reduce NOx through recirculating part of the engine's exhaust back into the engine, which takes up some of the room in the combustion cylinder with inert gas. Since there is less oxygen to combust, the temperature is lowered below what is necessary to produce NOx (~ 2,500°C).

- **Start-Stop:** Start-stop systems enable the car engine to switch off automatically when the car is stationary. Start Stop systems, which already have high penetration in Europe at >50% in new cars, are not credited by the U.S. EPA's fuel economy testing system given the limited idle time in the test and therefore this technology could see slower uptake in the U.S., where penetration rates are currently less than 10%. In any case, Valeo believes that this technology, which can save up to 7% of CO_2 emissions, could grow by 11% per year in the ten years to 2024.

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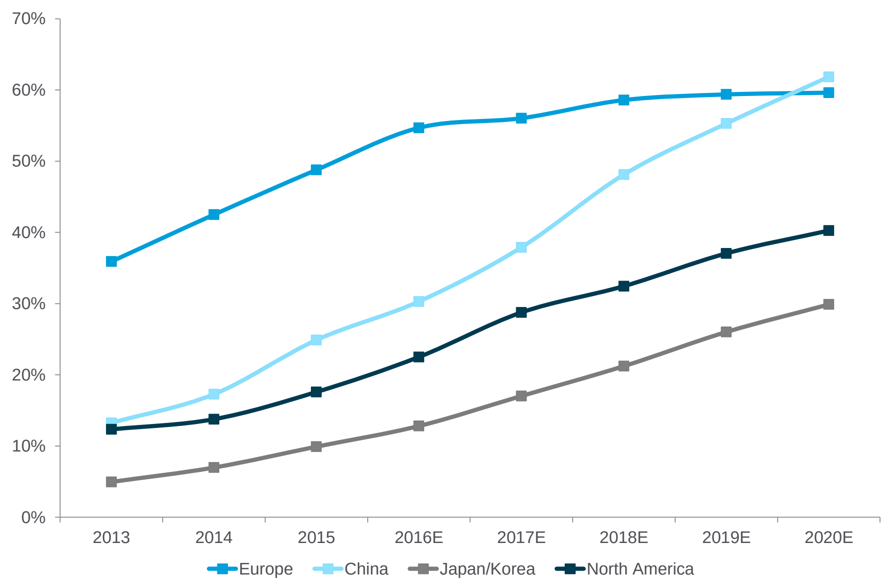
- **Turbochargers:** Turbochargers increase the quantity of air delivered to the combustion chambers, which increases the density of air in the cylinder, thereby allowing for greater combustion after the air has been compressed. This allows engines to be downsized, which also helps offset incremental cost of the turbocharger. Turbochargers can reduce CO_2 emissions by 10%. According to Honeywell, global turbo penetration stood at 33% in 2015 and is expected to rise to 47% by 2020 before reaching ~70% around the 2030 timeframe.

Figure 134. Overview of Turbocharger Technology

	Turbochargers	Superchargers	Electric Superchargers
Operating Principle	Turbine driven	Connected to engines by belt	Powered by electric motor
Mechanical load	No Mechanical load	Created mechanical load as connected to engine via crankshaft	No Mechanical load
Adiabatic process	Less heated flow of air	Raised up temperature;	Raised up temperature;
Horsepower gains	Least	Moderate	Maximum
Air density	Moderate	Least	Maximum
Cost	Expensive	Moderate	Cheap
Engine dependency	Dependent	Dependent	Independent
Intercoolers requirement	Yes	Yes	No

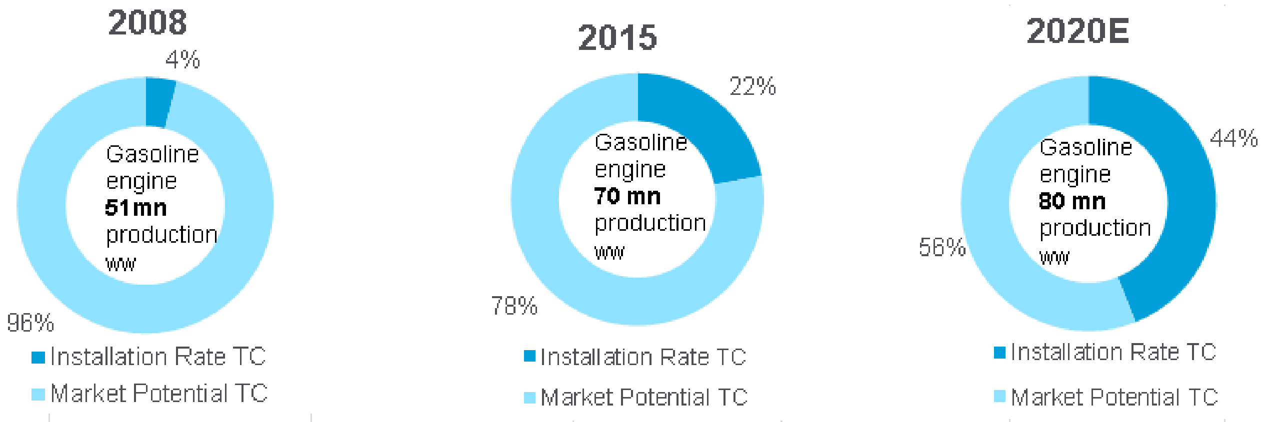
Source: Citi Research

Figure 135. Installation Rates of Turbochargers in Gasoline Engines



Source: IHS, Citi Research

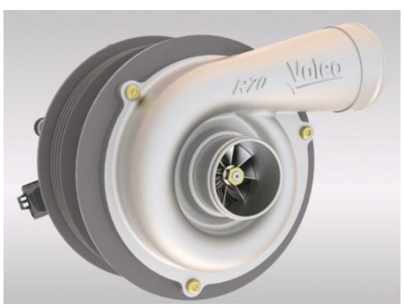
Figure 136. Installation Rates of Gasoline Turbo Chargers and Market Potential



Source: Continental, IHS

- **Electric Supercharger:** An interesting innovation that could impact turbocharger demand is the Electric Supercharger, which uses an electric motor to force air into the combustion chamber, rather than having a turbine which is powered by the engines exhaust, as is the case for a turbocharger. Although these use additional power, rather than what is being produced by the engine already, they are significantly more effective than turbocharges and strengthen engine torque at low revolutions, helping the vehicles acceleration, and puts less pressure on the engine. Electric Superchargers should come onto the market in 2016 for premium cars and be in the mass market by 2019, according to Valeo.

Figure 137. Electric Supercharger



Source: Valeo

Advantages of electric superchargers:

- Easily fitted into new or existing vehicles;
- Less intrusive on the engine architecture;
- Less pressure on the engine; and
- Improved performance compared to turbochargers.

Disadvantages:

- Less efficient use of energy; and
- Increased temperature, decreasing the density of the air compared to turbochargers.

2) Efficient transmissions

DCT can increase fuel efficiency by up to 10% and could grow by a CAGR of 12% to 2024

- **Dual Clutch Transmissions (DCT):** In a normal transmission, the driver will use a clutch pedal to disconnect the engine from the gear box and therefore change a gear. This interrupts power to the transmission. A dual clutch transmission uses two clutches, with one clutch operating the odd gears and one operating the even. As a result, gears can be changed without interrupting power to the transmission, increasing fuel efficiency by up to 10%. There are two types of DCT — wet and dry; wet DCTs are surrounded by lubricated with oil, unlike dry, this makes dry less able to dissipate heat, although they are more effective at lower speeds. According to Valeo, DCT has potential to grow by a CAGR of 12% to 2024.

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AMT has the potential to grow up 8% pa to 2020 and can reduce emissions by up to 7%

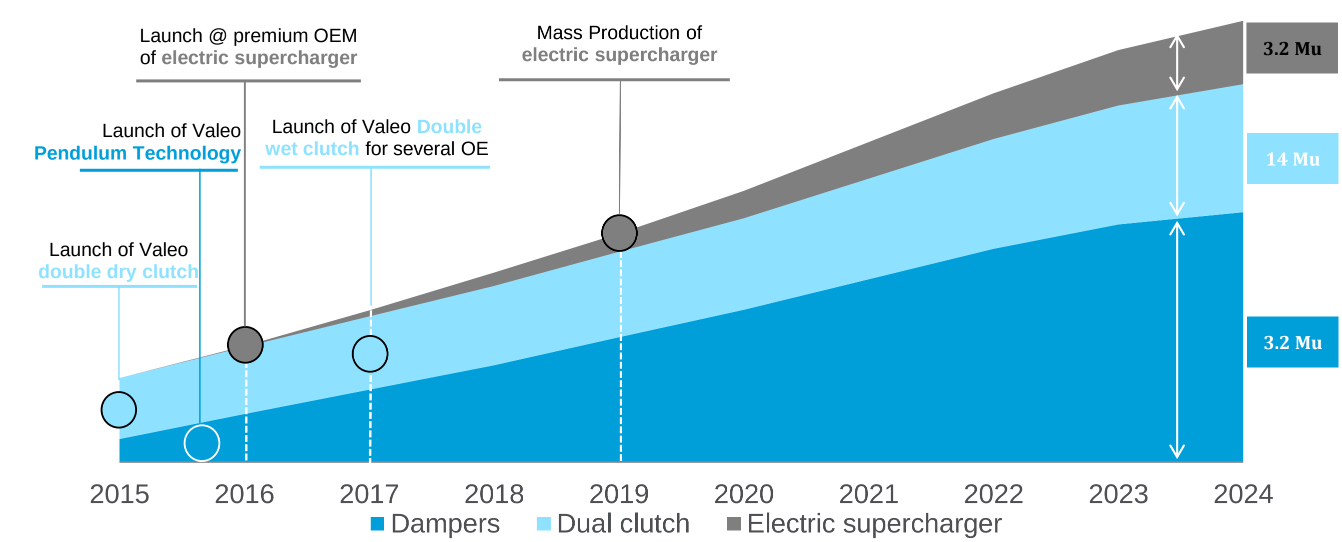
- **Automated Manual Transmission:** Growing at a slower pace than DCT (8% per year to 2024, according to Valeo) are automated manual transmissions, which have been in use since the mid-1980s. AMT use the same gear system as manual, but are changed automatically through a hydraulic system. These reduce emissions by up to 7%.

- **Continuous Variable Transmissions (CVT):** CVT use a different system altogether from other transmissions. Indeed CVT involve a system of belts and clutches that can contract and expand to give effectively different gears by adjusting the ratios. Already with significant penetration in some markets (>30% in Japan), CVTs could grow by 4% per year.

- **Pendulum Damper:** Pendulum Dampers help balance out the vibrations from the engine, by vibrating in the opposite direction to the engine. This is especially helpful at low speeds when in higher gears, encouraging drivers not to lower gears at lower speeds, where the engine is less fuel efficient.

  Valeo believes that these technologies have the potential to grow at a significant pace, which we highlight in the chart below. This chart shows how dampers should grow by 30% between 2015 and 2024, while, according to Valeo, electric super chargers should grow at >70%, entering the market in 2016 for the first time.

Figure 138. Growth in Dampers, Dual Clutch, and Electric Superchargers



Source: Valeo

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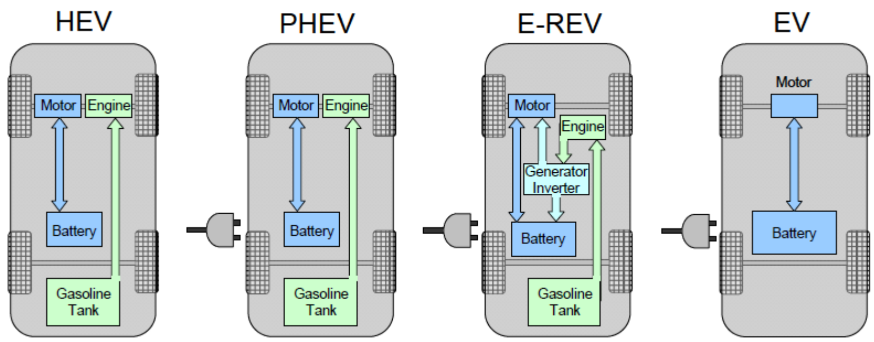
Electrification of the Powertrain

Electric vehicles can broadly be split into four categories, as shown in Figure 139. Hybrid Electric Vehicles (HEVs), Plug In Hybrid Electric Vehicles (PHEV) and Electric Range Extended Vehicles (E-REV) all include internal combustion engines that are supplemented (usually at low speeds, in urban areas) by electric batteries. Battery Electric Vehicles (BEVs) however are entirely powered by electricity from the grid. The distinction between HEVs and PHEVs is that the batteries for the HEVs are charged from energy recuperation, whilst PHEVs, like EVs are charged from the mains. In this report we will refer to BEVs and PHEVs collectively as EVs.

Figure 139. Structure of HEVs, PHEVs, E-REVs, and EVs



Source: Citi Research

Figure 140. Fuel Economy Improvement by Electric Powertrain Type

Electric Powertrain Type	Fuel Improvement	Field	Outline
Fuel Cell Vehicle (FCV)	100%	Electric engine	Uses electrical energy generated from hydrogen using a fuel cell stack to power the vehicle
Electric Vehicle (EV)	100%	Electric engine	Uses electrical energy stored in a battery to power the vehicle
Plug-in Hybrid Electric Vehicle (PHEV)	70%	Electric engine	Uses electrical energy stored in a rechargeable battery to power the vehicle, but also has an internal combustion engine
Hybrid Electric Vehicle (HEV)	25-40%	Electric engine	Uses electrical energy stored in a battery to assist an ICE engine with vehicle acceleration

Source: Company data, METI, and Citi ResearchEstimates

Spotlight on 48V

We have written substantially on the electrification of the vehicle in our previous *Car of the Future* report and one product that we think if of particular note is the 48V battery. This technology uses energy from deceleration to recharge a 48V battery, which is used to power the vehicles electronics. At the same time, the battery serves as a complement to the current 12V, which, in many cases, is coming under strain from the increasing electrification of vehicles. Using regenerative power and a higher voltage battery helps lower emissions by 10-20%. In Figure 125, we show the potential savings from the electrification of the powertrain, highlighting the effectiveness of the 48V battery compared with the 12V as well as its wide availability in all vehicles segments, which should facilitate its use.

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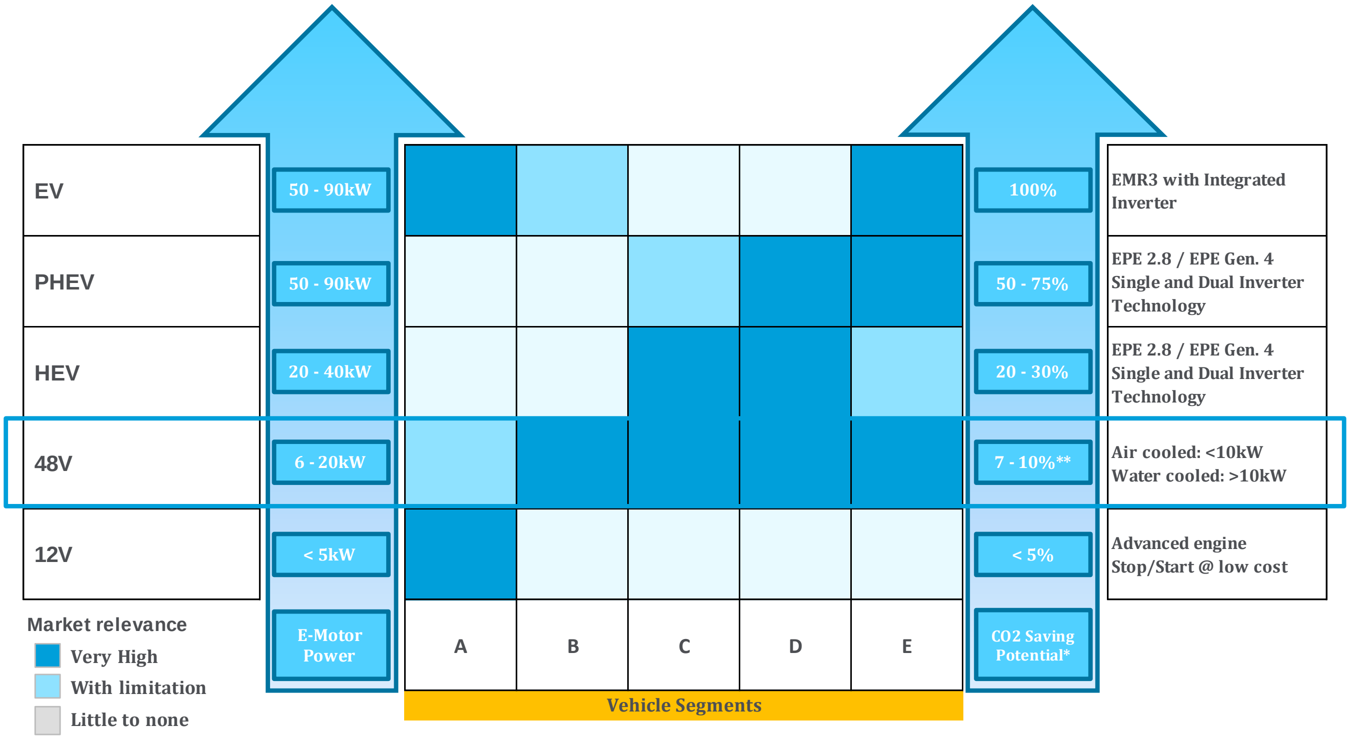
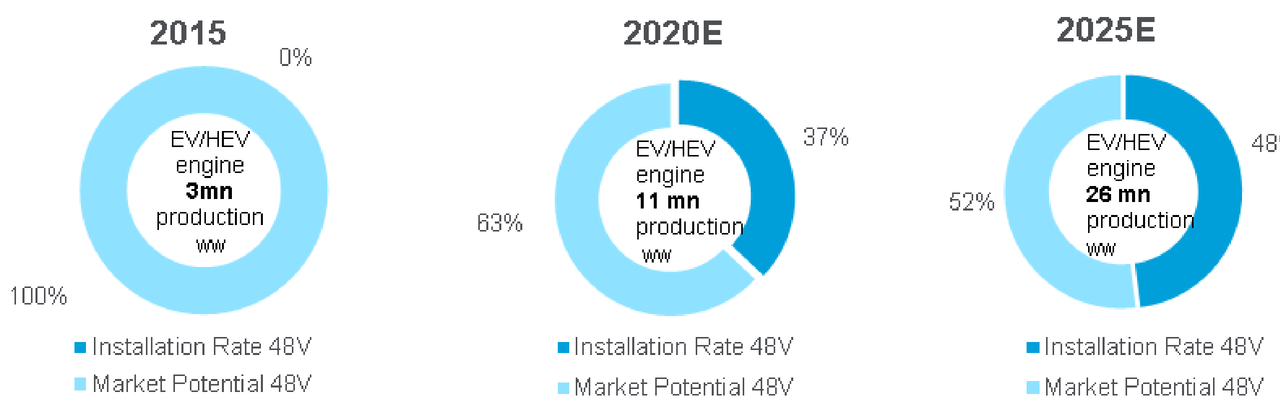
Figure 141. Electrification of the Vehicle



Source: Continental

Below we also highlight the market potential for 48V batteries in xEVs, which, according to Continental, could reach almost 50% by 2025.

Figure 142. Installation Rates of 48V Systems and Market Potential



Source: Continental

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Current State of EV Adoption

EVs: Why Now?

The economics of electric vehicles, namely higher battery costs, have historically limited them to premium segments. This remains the case today and is likely to remain so in the near future, though “premium” is no longer $60k+ cars but rather $35k+. BorgWarner recently estimated that the all-in cost (around 2020) of an internal combustion engine — including transmission, treatment, battery, alternator—at $4.0-4.5k. The cost of an EV was estimated closer to $18k.

Yet what makes EVs so intriguing is that — battery costs aside — they have inherent advantages in performance, operating cost-per-mile, lower maintenance, and zero emissions. While EVs aren’t necessarily “disrupting” the internal combustion market anytime too soon, a lot can start to change over the next 10-15 years.

Declining battery costs, growing infrastructure, and greater consumer interest are setting-up EVs well into next decade. Whereas full range EVs have historically been high-end luxury products, upcoming vehicles like the Chevy Bolt EV are already migrating towards low luxury prices in the high-$30 thousand range before incentives. While this might still one or two generations from being competitive with internal combustion engines (ICE) on initial vehicle cost and range (unadjusted for lower operating costs, which favors EVs), it’s moving in the right direction and the industry appears to see this inevitability.

Depending on the forecast, pure EVs are expected to reach 3-7 million units in volume by 2025 — or still a fairly small percentage of global auto production. But a major inflection might occur around that point. In September 2016 Daimler noted that by 2025 EV costs are expected to intersect with conventional powertrains before becoming cost advantaged by 2030. Ford’s recent projection showed a roughly one-third global EV penetration by 2030, though this also includes plug-in EVs.

The potential long-term disruption from EVs is also drawing new players into the auto industry. Since EV powertrains are arguably less complex than traditional ICEs, and somewhat more software dependent (power electronics), the tech industry may be seeing an opportunity to enter. Companies like Faraday Future, Lucid Motors (formerly known as Atieva), and others have all discussed entering the EV market in the coming years. To the extent such companies focus on premium segments and urban shared autonomous mobility, then the barrier to enter (volume wise) might indeed be lower from a volume standpoint. Traditional auto companies counter that the increasing complexity of the car requires unprecedented systems integration know-how that auto companies are best experienced to handle. They also point to areas like vehicle financing, servicing, and cash intensity as elements that will remain important.

How the EV race shapes up could have major consequences for industry players late this decade and into the next. We’re entering an era where technological breakthroughs from one company could have profound implications on others and in high volume segments.

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Figure 143. Select OEM Electrification Plans

OEM Electrification Plans			
Company	Year	Powertrain Type	Sales Plan / Model Plans
D3			
Ford	by 2020	Electric/ Hybrid	13 new models, >40% of nameplates to be electrified
General Motors	CY16-CY17	Electric	Bolt, Ampera-e
J3			
Honda	2030	Electric/ Hybrid	Global Sales: PHEV/HEVs ~50%, EVs ~15% in 2030
G3			
BMW	CY19-CY20	Electric	Mini, BMW x3
Mercedes	by CY2025	Electric	>10 models, 15-25% of sales
VW	by CY2025	Electric	>30 EVs, 20-25% of annual total sales
Others			
Hyundai/Kia	2020	Electric/ Hybrid/ FCV	12 HEVs, 6 PHEVs, 2 EVs, 2 FCVs
Volvo	by CY2025	Electric/ Hybrid	Total sales of up to 1mln electrified vehicles by 2025; "a range of PHEVs"; 1 EV by 2019

Source: Various media reports, Company reports, Citi Research

Figure 144. Select OEM Electric Vehicle Plans

Electric Vehicle Plans					
Company	Brand	Model Name / Type	Launch Year	MSRP	Range
D3					
Ford	Ford	New 2017 Ford Focus EV	MY2012	n/a[1]	Company est: 100 mi
General Motors	Chevrolet	Bolt	CY2016	$37,495	EPA: 238 mi
General Motors	Opel	Ampera-e	CY2017	n/a	NEDC[2]: >310.7 mi[3]
J3					
Honda	Honda	Clarity	CY2017	n/a	n/a
G3					
BMW	BMW	x3	CY2020	n/a	n/a
BMW	Mini	n/a	CY2019	n/a	n/a
Daimler	Mercedes	EQ Electric SUV (concept)	CY2019	Starting at ~$39,000	Company est: <=310mi
VW	Audi	Electric SUV	CY2018	n/a	Company est: >250mi
VW	VW	I.D. (concept)	CY2020	~ Golf price	Company est: 249-373mi
Others					
Hyundai/Kia	Hyundai	Ioniq Electric	CY2016	n/a	Company est: 110 mi
Geely	Volvo	"all-electric car"	CY2019	n/a	n/a
Renault-Nissan	Renault	New 2017 ZOE	CY2012	n/a[4]	NEDC[2]: 248.5 mi[5]

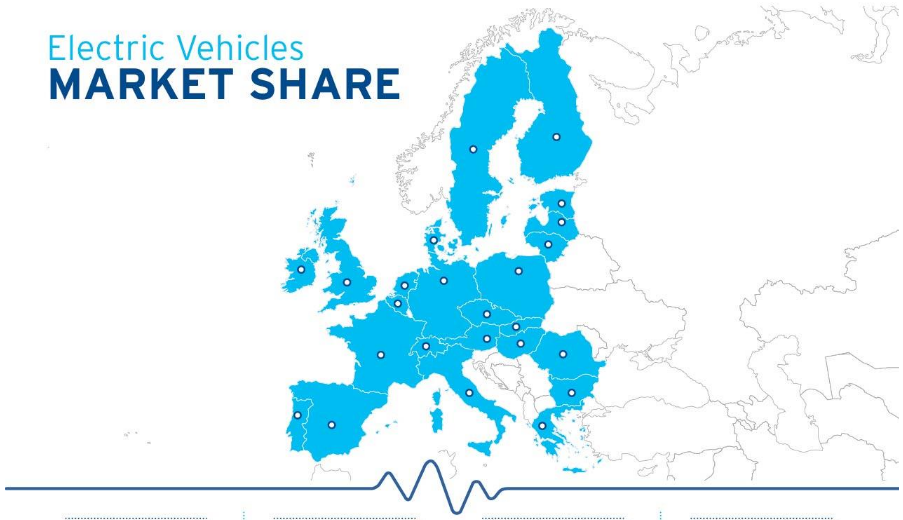
Source: Various media reports, Company reports, Citi Research

Europe EV Focus

Market share today of new car registrations

The market share for EVs in most European markets is negligible in 2014/2015. With the exception of Norway and the Netherlands, no other European country had a market share of greater than 2.5%.

Figure 145. Market Share of EV/PHEV New Sales



	2014	2015
Austria	0.5%	0.7%
Belgium	0.4%	0.8%
Bulgaria	0.0%	0.1%
Czech Republic	0.1%	0.1%
Denmark	0.9%	2.2%
Estonia	1.6%	0.2%
Finland	0.4%	0.6%
France	0.7%	1.2%
Germany	0.4%	0.7%
Greece	0.1%	0.1%
Hungary	0.1%	0.2%
Ireland	0.3%	0.5%
Italy	0.1%	0.1%
Latvia	1.4%	0.2%
Lithuania	0.1%	0.2%
Netherlands	3.8%	9.0%
Poland	0.0%	0.1%
Portugal	0.2%	0.6%
Romania	0.0%	0.0%
Slovakia	0.2%	0.1%
Spain	0.2%	0.2%
Sweden	1.5%	2.5%
United Kingdom	0.6%	1.1%
European Union	0.6%	1.0%
EU 15	0.6%	1.1%
Norway	13.3%	22.4%
Switzerland	0.9%	2.0%
Western Europe	0.7%	1.4%

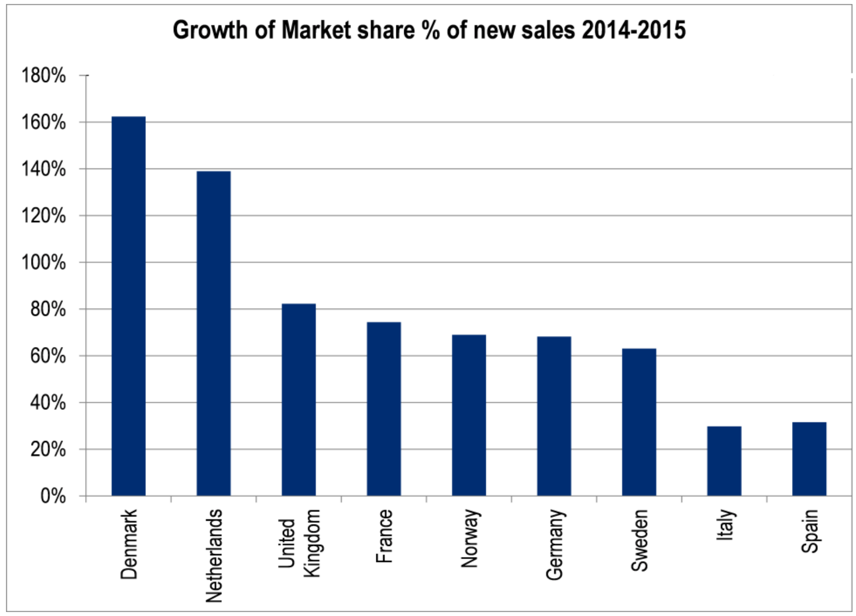
2014 2015

© Citi Research 2016

Source: ACEA, Citi Research

However, what is interesting is the growth in market share between 2014 and 2015. If we take the key markets, which we define as such either due to significance of the volume of total cars sold or due to the market share of EVs as a result of government subsidies, we see that there is significant growth in market share taking place shown in Figure 146.

Figure 146. Global Market Share of BEV/PHEV

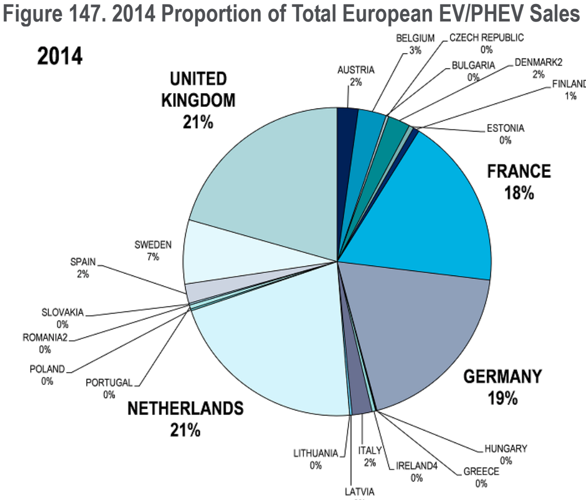


Source: ACEA, Citi Research

The market share growth in all major markets is strong year on year. For the Netherlands and Denmark, this is explained to some extent by recent changes to taxation that reduces the value of benefits to PHEV cars (but not EVs) in 2016; a rush to take advantage of the favorable tax rules is likely to have been a factor in the large market share growth. However, considering that the UK, France and Germany (in fact Germany has introduced new incentives) have not announced any planned cuts to the level of subsidy/tax benefit entitlement for EVs, the market share growth is still impressively strong.

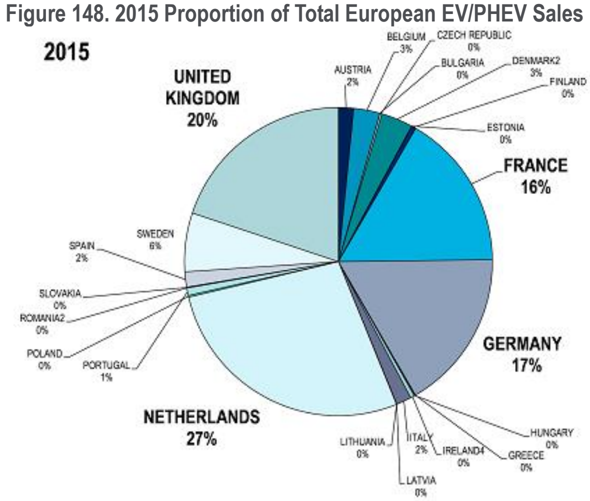
From an OEM perspective, if we consider total actual sales, Figure 147 and Figure 148 show that European sales are dominated by Netherlands, UK, Germany and France respectively. These markets have attractive incentives in place for EV/PHEV and there are no current indications that these incentives will be withdrawn at a faster rate than the impact of the reduction of battery costs.

Figure 147. 2014 Proportion of Total European EV/PHEV Sales



Source: ACEA, Citi Research

Figure 148. 2015 Proportion of Total European EV/PHEV Sales



Source: ACEA, Citi Research

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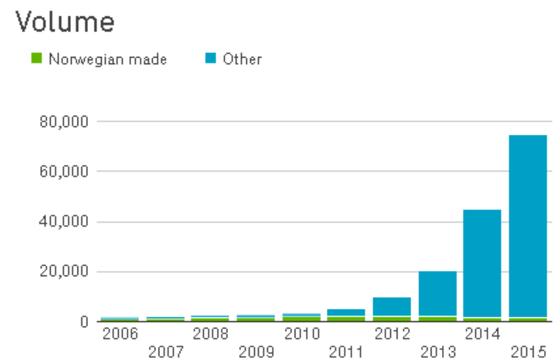
Incentives: Norway…The Wheel Deal

Norway has seen the number of EV/PHEVs grow dramatically and is the widely acknowledged electric vehicle capital of the world. From barely a few thousand in 2006, Norway now has well in excess of 75,000 electric vehicles registered.

Figure 149. Norway EV/PHEV Stock



Source: evnorway.no

This explosive growth has been aided by very favorable subsidies/tax reliefs and other benefits offered by the government, include those summarized below:

- No purchase tax – this is a considerable benefit as Norway has one of the highest vehicle purchase taxes in Europe
- Exemption from 25% value-added tax (VAT) on purchase
- No charges on toll roads
- Free municipal parking
- Free access to bus lanes

These benefits are enshrined until 2017 after which new measures will be introduced. However, all major political parties in Norway reached an agreement in 2015 that will result in the following changes:

- Road tax will be due at 50% from 2018 and 100% from 2020
- VAT exemption replaced by a direct subsidy – which is expected to reduce as battery costs decline.
- Local authorities will be able to decide whether to offer free parking, exemption from tolls and free bus lane use.

Despite the changes to the very generous subsidies on offer until 2017, electric vehicle users still benefit greatly from favorable government policy. Given the penetration electric vehicles have achieved in Norway, interesting insights can be gained from the experience of owners.

A survey by the Norwegian Electric Vehicle Association found that EV users believed the most significant EV incentives were the zero taxation on purchase and the free use of toll roads. The Norwegian experience points to the reality: the cost of running an electric vehicle is the most important factor for owners.

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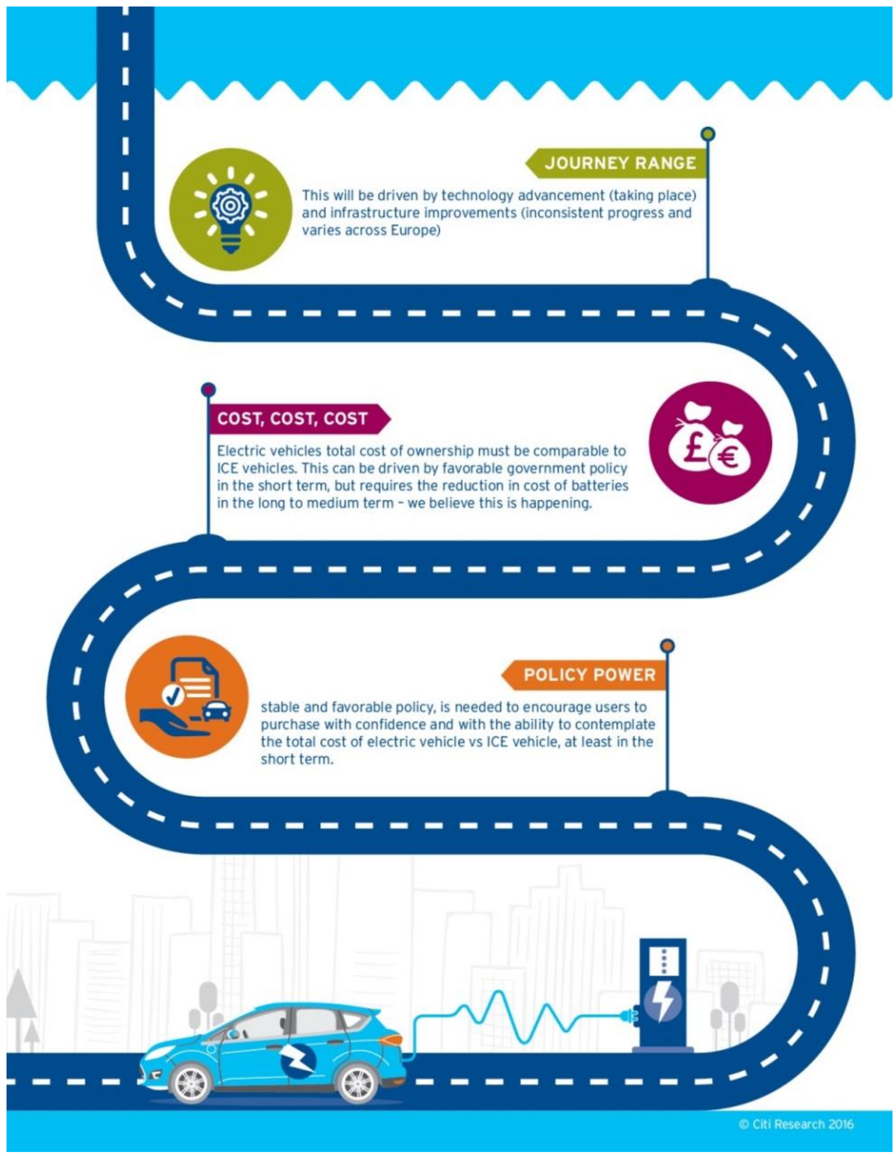
When the same survey asked users what they considered most important to get more people to purchase electric vehicles, the two largest results were predictable electric vehicle policy and longer range on vehicles (22% and 29% respectively).

The range of vehicles will be extended either through increased efficiencies in cars, or more likely, through the use of batteries with larger capacities. Infrastructure will also need to play a part in range extension, as the increased availability of charging points would also serve to increase range.

Three key themes emerge from the Norwegian experience for successful mass market electric vehicle adoption, as noted in the figure below:

Figure 150. Three Key Themes Emerge from the Norwegian Experience for Successful Mass Market Electric Vehicle Adoption



Source: Citi Research

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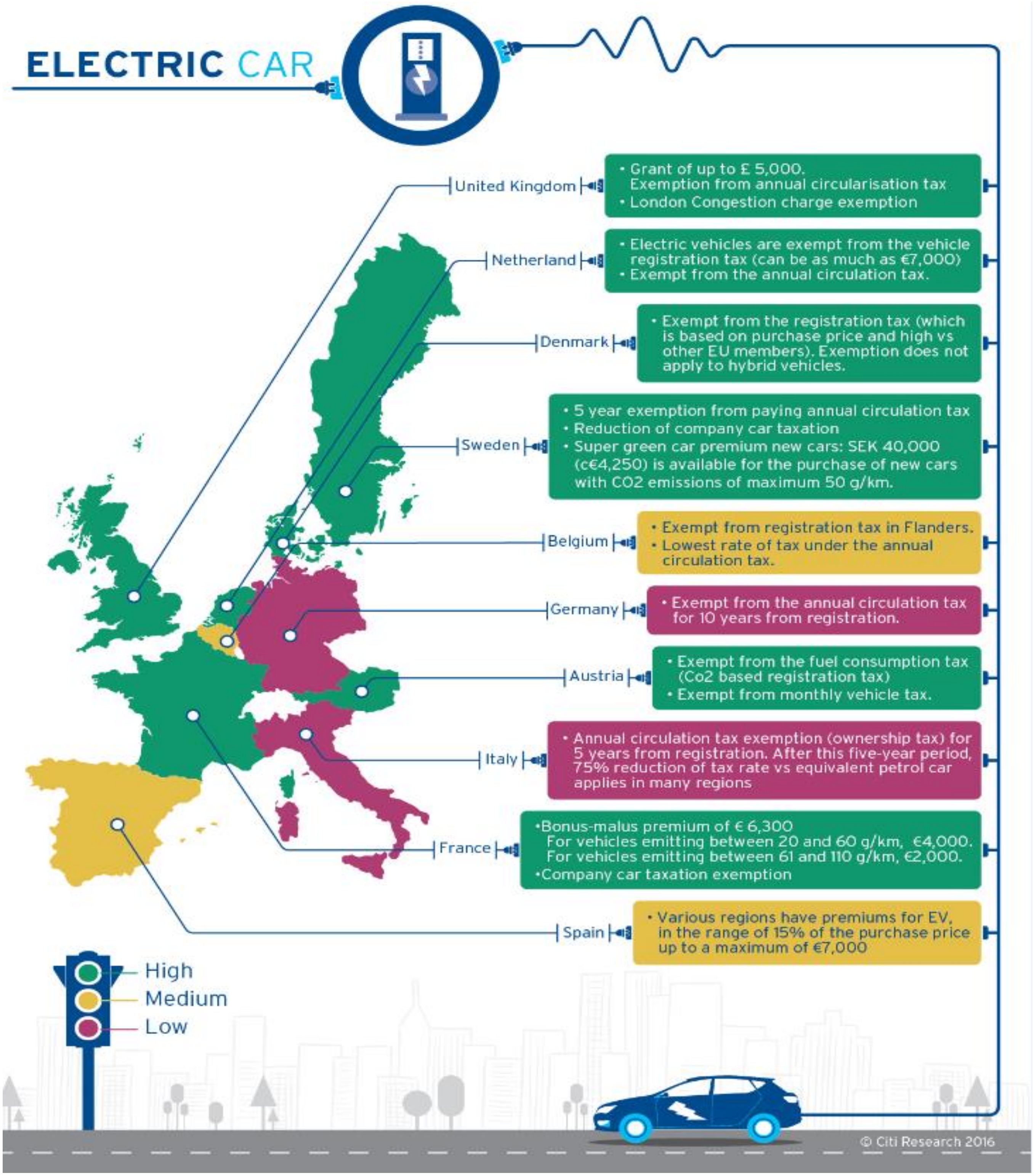
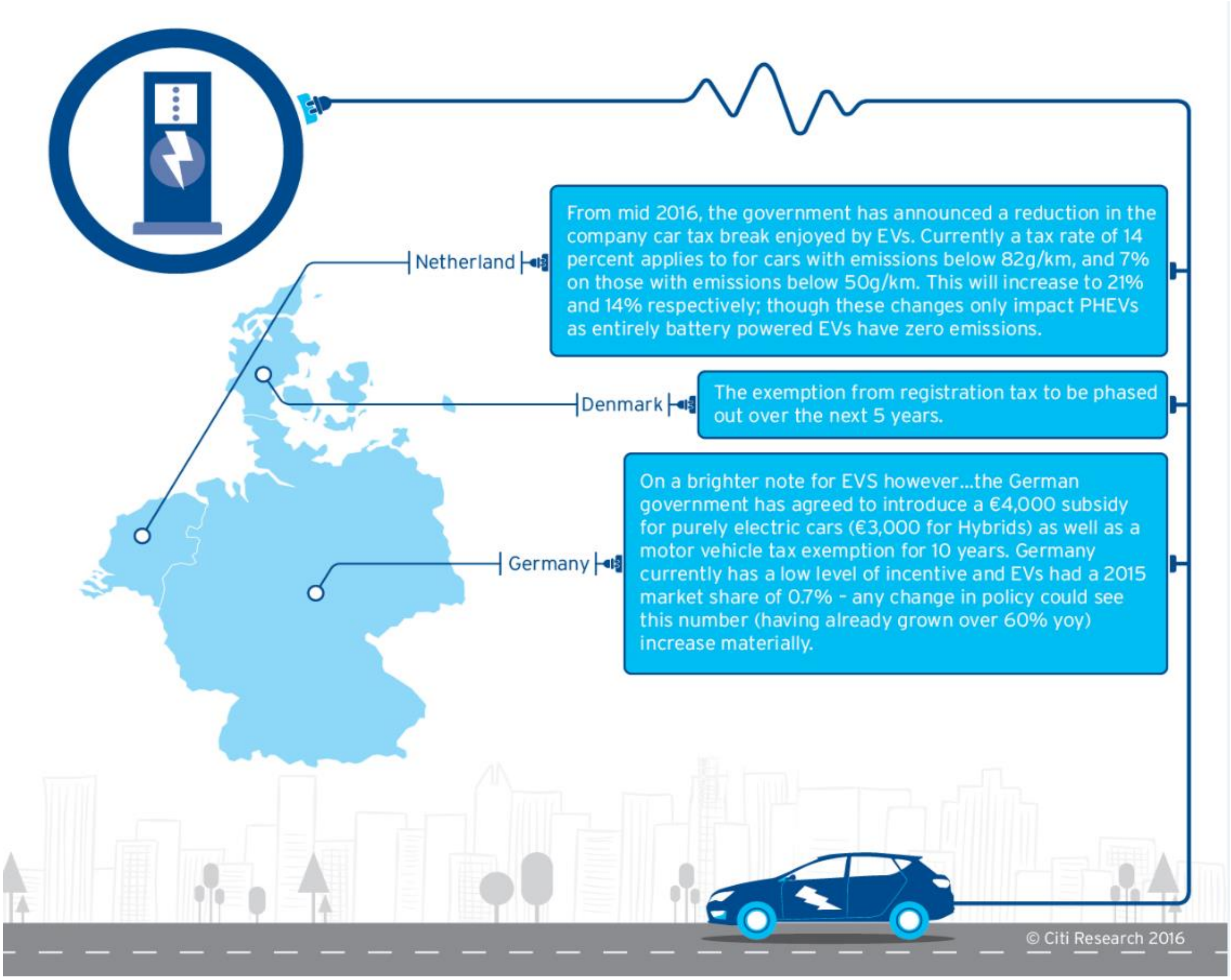
…and the Situation in Rest of Europe

Figure 151. Summary of EV Incentives



Source: Citi Research

Figure 152. Recent Changes



Source: Citi Research

Powered by Lithium-Ion

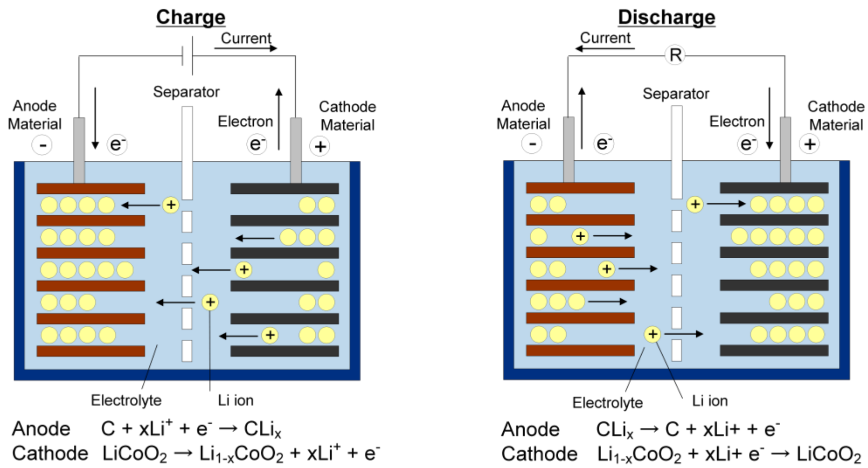
What is a Lithium-ion battery?

A lithium-ion battery is an electric device capable of charging and discharging. It consists of three main components:

- **Electrodes:** One positively charged and one negatively charged. The cathode is typically a lithium compound.
- **Separator:** Is a thin film with many small holes that provide a passageway for lithium ions between the anode and the cathode during charging or discharging.
- **Electrolytic Solution:** Typically an organic electrolyte of LiPF6 dissolved in an organic solvent is used to carry the lithium ions between electrodes. An aqueous solution cannot be used as it would react with the lithium-ions and form lithium hydroxide.

The basic working theory of a lithium-ion battery is demonstrated below in Figure 153. During discharge a chemical reaction takes place where lithium ions (Li+) are extracted from the negative anode releasing an electron, the Li+ flows through the separator and is inserted into the cathode. The electron flows through the external circuit generating a current.

Figure 153. Lithium-Ion Battery Basic Working Theory (Positive Electrode, Lithium Cobalt Oxide, Negative Electrode, Carbon)

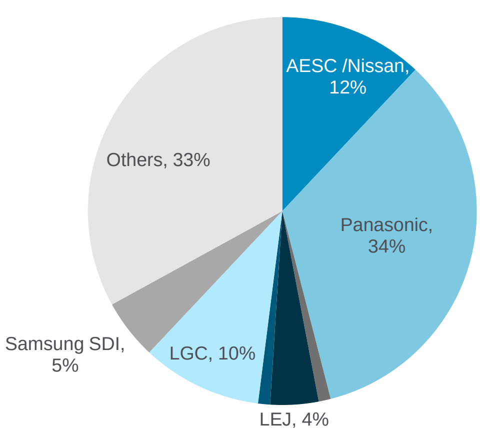


Source: Citi Research

History

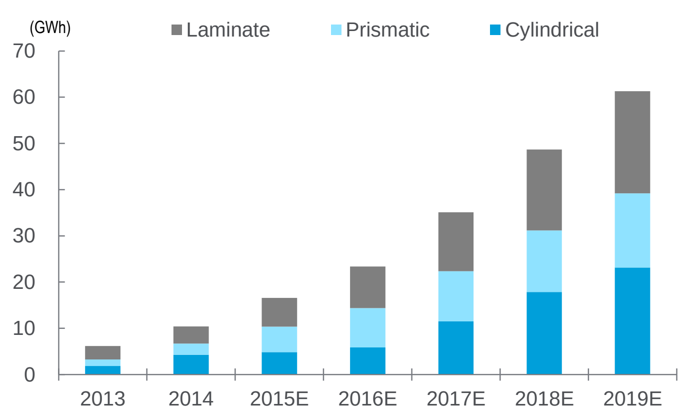
Lithium-ion batteries were first commercially introduced by Sony in 1991. We have seen their price in consumer goods steadily fall from over $3,000/kWh to less than $300/kWh today. They have a number of characteristics that make them attractive not only for their initial intended purpose of consumer goods but also for auto use. The cost profile for lithium-ion batteries in auto applications has followed a similar profile to that of consumer goods in the decades before. Costs have dropped from $1,500/kWh in 2009 to less than $500/kWh today; Citi expects this trend to continue.

Figure 154. Lithium-Ion Battery Market Share (2015)



Source: TSR, Citi Research

Figure 155. Market Volume for Automotive Lithium-Ion Batteries



Source: Citi Research

Electric Vehicles in China

Chinese Ambition in Electric Cars

The Chinese government has a strong incentive to push technology development and physical deployment of electric vehicles, especially on pure electric vehicles and plug-in hybrid electric vehicles. Key considerations include:

- 60% of China's oil consumption relies on imports, and this ratio will rise to 75% by 2030 according to the IEA. Though oil prices have experienced a plunge recently, the Chinese government still hopes to build energy independence for strategic and safety reasons.

- Despite strong government support, China's traditional car technologies still lag far behind European and Japanese leaders, and China's streets are still mostly running foreign brand cars.

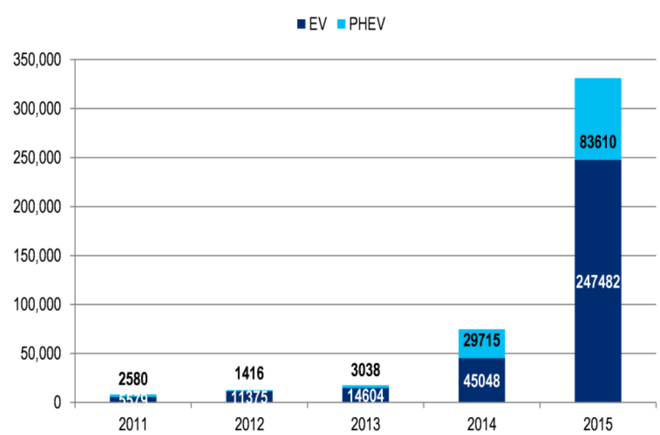
- China is also one of the most ambitious countries in manufacturing industry, with success in high-speed rail, telecom equipment, and power equipment sectors. The auto industry is a notable laggard and efforts are being made to raise its profile and success. Without having dominance in internal combustion autos, the Chinese government hopes to catch up along the curve and build a leadership in electric cars.

Figure 156. China – Central Government Subsidy on EV

Rmb per unit	2013	2014	2015	2016	2017	2018
Pure electric PV						
80km <= R < 150km	35,000	33,250	31,500	25,000	20,000	20,000
150km <= R < 250km	50,000	47,500	45,000	45,000	36,000	36,000
R >= 250km	60,000	57,000	54,000	55,000	44,000	44,000
Plug-in hybrid PV						
R >= 50km	35,000	33,250	31,500	30,000	24,000	24,000
Pure electric bus						
6<L≤8	300,000	300,000	300,000	250,000	200,000	200,000
8<L≤10	400,000	400,000	400,000	400,000	320,000	320,000
10<L≤12	500,000	500,000	500,000	500,000	400,000	400,000
L>12	500,000	500,000	500,000	600,000	480,000	480,000
Plug-in hybrid bus						
6<L≤8	n.a	n.a	n.a	125,000	100,000	100,000
8<L≤10	n.a	n.a	n.a	200,000	160,000	160,000
10<L≤12	n.a	n.a	n.a	250,000	200,000	200,000
L>12	250,000	250,000	250,000	300,000	240,000	240,000

Source: Government website, Citi Research

Figure 157. China – Pure EV & PHEV Sales Volume



Source: CAAM, Citi Research

Side Effect of Government Subsidy

However, despite the governments ambition in the electric vehicle industry and >300% volume growth in 2015, we are hearing more and more reviews on such policies recently. The high subsidies standard has triggered some to pursue short-term profit rather than make long-term technology investment. For example, in 2015, the central government subsidy on pure electric buses of 6-8 meters long was Rmb300K ($44k). Together with local government subsidy, which could be same as central government one in some developed regions, the total subsidies of Rmb600K ($88k) could cover the entire cost of building such as bus. Therefore, some manufacturers were not focused on quality and technology, but just building such buses in large volumes and selling them to leasing companies which they owned. This made the entire revenue from the sale of the bus wholly from government subsidies.

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In the passenger vehicle segment, a similar situation also happened. For cars with a driving range of more than 150km, central and local government subsidies could add up to Rmb90K ($13k), while building such a vehicle with the lowest technology, such as a DC motor and ~20kWh lithium batteries, could cost far less than the subsidy. The generous government subsidies have actually triggered more arbitrage activities by some manufacturers.

Figure 158. New Energy Vehicles – China Brand New Energy Vehicles Comparison

Model	MSPR (Rmb)	Total subsidy (Rmb)	OEM	Level	Max speed (km/h)	Max Power (Ps)	Battery capacity (kWh)	Electric motor total torque (Nm)	Driving Mileage (km)	Weight (t)	L*W*H (mm)
Denza	369-399K	54K	BYD Daimler	Medium sedan	150	117	47.5	290	300	2.1	4642*1850*1642
e6	309.8-369.8K	54K	BYD	MPV	140	122	57	450	300	2.4	4560*1822*1645
Emgrand EV	228.8-249.8K	54K	Geely	Compact sedan	140	129	45.3	240	253	1.6	4631*1789*1495
iEV5	169.8-180.8K	45K	Jianghuai motor	Small sedan	120	68	23	215	240	1.3	4320*1710*1515
ES210	346.9K	45K	BAIC New Energy	Medium sedan	135	109	38	255	210	1.8	4861*1820*1462
Eado EV	234.9-249.9K	45K	Changan Auto	Compact sedan	140	61	NA	280	200	1.6	4620*1820*1515
EV-series	188.9-246.9K	45K	BAIC New Energy	Small sedan	125	72	25.6	180	200	1.3	4025*1720*1503
eQ	159.9-164.9K	45K	Chery	Mini sedan	100	57	22.3	150	200	1.1	3564*1620*1527
ZD D2	158.8K	45K	ZD EVcar	Mini sedan	88	24	NA	85	180	0.7	2808*1540*1555
Chenfeng	267.8-281.8K	45K	DF Nissan	Compact sedan	144	109	24	254	175	1.5	4467*1771*1549
620EV	233.8-249.8K	45K	Lifan	Compact sedan	120	82	24	213	155	1.4	4550*1705*1495
Cloud100	158.9K	45K	Zotye	Mini sedan	85	24	18	120	150	1.0	3559*1620*1476
Kandi K11	150.8-152.8K	45K	Kandi	Mini sedan	80	27	NA	103	150	1.2	3598*1630*1595
Kandi K10	150.8K	45K	Kandi	Mini sedan	80	27	20	103	150	1.0	2900*1545*1590
ZD D1	108.8K	31.5K	ZD EVcar	Mini sedan	80	24	NA	82	120	0.7	2765*1540*1555
Roewe E50	234.9K	31.5K	SAIC	Mini sedan	130	71	18	155	120	1.1	3569*1551*1540
GA5 Extended Range EV	199.3-219.3K	31.5K	GAC	Medium sedan	150	128	13	225	80	1.7	4800*1819*1484
Tang PHEV	251.3-518.8K	31.5K	BYD	Medium SUV	180	2.0T/205	NA	500	80	2.2	4815*1855*1720
Qin PHEV	209.8-219.8K	31.5K	BYD	Compact sedan	185	1.5T/154	13	250	70	NA	4740*1770*1480
Roewe550 Plug-in	248.8-259.8K	31.5K	SAIC	Compact sedan	200	1.5L/109	11.8	464	58	NA	4648*1827*1479

Source: Autohome.com, Citi Research

Local Electric Car Leader BYD

So far the most devoted Chinese new energy vehicle manufacturer is BYD, who sold 64K new energy vehicles in 2015, including 50K plug-in hybrid sedans and SUVs, 8K pure electric cars, and 5K pure electric buses. Its latest electric and hybrid cars are named after Chinese dynasties, and the most popular medium plug-in hybrid SUV Tang claims to accelerate from 0-100km/h in 4.9 seconds.

Figure 159. BYD – Tang Plug-In Hybrid SUV

Source: Company website, Citi Research

Figure 160. BYD – Qin Plug-In Hybrid SUV

Source: Company website, Citi Research

Electric Vehicles (EVs) and Plug-In Hybrids (PHVs) in Japan

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In March 2016, METI announced a roadmap to promote the spread of EVs and PHVs. The roadmap calls for an increase in EV/PHV ownership to one million units by 2020 and an increase in the EV/PHV weighting of new car sales to 20%-30% by 2030. In addition, it includes measures to overcome obstacles to EV/PHV diffusion, including range (distance per charge) and battery charging infrastructure.

Figure 161. Clean Energy Vehicle Sales Weightings and Targets

	2015 actual	2030 target
Gasoline vehicles	**73.5%**	**30%-50%**
Clean energy vehicles	**26.5%**	**50%-70%**
Hybrid	22.2%	30%-40%
Electric	**0.27%**	**20%-30%**
Plug-in hybrid	**0.34%**	
Fuel cell	0.01%	~3%
Clean diesel	3.6%	5%-10%

Source: METI, Citi Research

Nissan released the Leaf, a mass-produced EV, in 2009. In the six years since, EV/PHV sales in Japan have totaled around 140,000 units. While this is a faster rate of growth than that achieved by HVs, EV/PHV sales still accounted for less than 1% of new car sales in 2015. Numerous obstacles will have to be overcome to get this ratio up to the target of 20%-30%.

The first problem is high sales prices. EV/PHVs have lower running costs than gasoline engine cars but cost a lot more to buy. Subsidies for clean energy vehicle purchases, eco-car tax reductions, and other measures have been introduced to reduce the initial burden for buyers, but the reduction in costs still lags initial expectations. On reflection, the government has decided that measures to increase vehicle range and promote the development of the EV/PHV market are necessary. A new scheme that incentivizes automakers to reduce prices, including via subsidies paid in line with battery capacity, is expected to be introduced as part of a revamped subsidy system.

The second problem is vehicle range. Support to develop better rechargeable batteries is crucial to increasing driving distances. Currently, the government is promoting development projects to (1) improve the performance of lithium-ion batteries and (2) create innovative storage batteries that exceed the performance limits of lithium-ion batteries. The aims of these projects are to (1) realize commercial production of lithium-ion batteries with a specific energy of 200-250Wh/kg — roughly double the current level — by the first half of the 2020s and (2) develop a new storage battery with a specific energy five times that of existing lithium-ion batteries by 2030. The government aims to increase the distance an EV/PHV can travel on a single charge to 700km by 2030, compared with 120km-200km as of 2012.

The third obstacle is battery charging infrastructure. Infrastructure is broadly divided into public charging facilities (located in highway service areas, shopping center parking lots, etc.) and non-public charging facilities (at private homes, workplaces, etc.). The government estimates Japan will need 6,100 charging stations along national and prefectural highways. There are already 5,971, meaning this demand is almost fully met. The priority now is to build charging stations in areas where infrastructure is still lacking and improve the quality of charging services. Meanwhile, the government is targeting an installed base of 20,000 public charging stations by 2020, mainly (target of 9,000) at large retail facilities with parking space for at least 100 cars. As for non-public facilities, the roadmap targets 2,000 charging

stations at apartment buildings and 9,000 at large office buildings by 2020. To improve convenience, the government aims to have infrastructure that supports remote charging in place by 2020. This would allow vehicle owners to charge their vehicle simply by parking in a designated space.

Fuel (hydrogen) cell vehicles

Fuel cell vehicles (FCVs) are powered by electricity generated through a chemical reaction between hydrogen and oxygen. FCVs do not emit CO2 and have advantages over EVs: their range is significantly longer, at c500km, and they only take three minutes to refuel. In recent years FCVs have attracted increasing attention as a clean energy technology. Toyota and Honda have released FCV models — the Mirai and the Clarity, respectively — but both cost more than ¥7 million ($66k) and there are considerable technology, cost, and infrastructure hurdles to overcome before FCVs can become a mass-market product. In March 2016, METI published a strategic roadmap for hydrogen and fuel cells that includes measures to overcome these hurdles and realize a hydrogen society.

The roadmap promotes cost reductions and volume production effects. Specifically, it targets (1) a 50% reduction in the cost of fuel cell systems used in second-generation FCVs (likely to hit the market ~2020) compared with first-generation FCVs (those released in 2015) and (2) making third-generation FCVs (c2025) cost competitive with HVs of the same class. Measures to support cost reductions include (1) subsidies and tax breaks to stimulate initial demand and (2) support for development of low-cost fuel cell system technologies through 2020. Efforts to reduce fuel cell system costs will focus on electrolyte membranes in the initial stage and catalysts and separators in the diffusion stage.

Just as charging stations are crucial to EV/PHV diffusion, hydrogen fueling station infrastructure is critical to FCV market formation. Plans to build 100 hydrogen stations in Japan's five major metropolitan areas by end-FY2016 (March 2017) are advancing. The roadmap targets 160 stations by FY2020 and 320 stations by FY2025. Thereafter, it calls for the expansion of hydrogen fueling station infrastructure in step with hydrogen demand; that is, for hydrogen supply capacity growth to track FCV diffusion from the second half of the 2020s. Assuming capacity of 300Nm3/hour per station, METI estimates Japan will need 900 hydrogen fueling stations by 2030. By reducing FCV costs and expanding hydrogen infrastructure, the government aims to grow the FCV market to 40,000 units by 2020, 200,000 units by 2025, and 800,000 units by 2030.

Figure 162. FCV Diffusion Targets

	2015 actual	2020 target	2025 target	2030 target
Fuel Cell Vehicle				
FCV sales volume	400	40,000	200,000	800,000
Fuel cell system cost	100%	50%	25% Same level as HV	NA
Hydrogen fueling stations	80	160	320	NA

Source: METI, Citi Research

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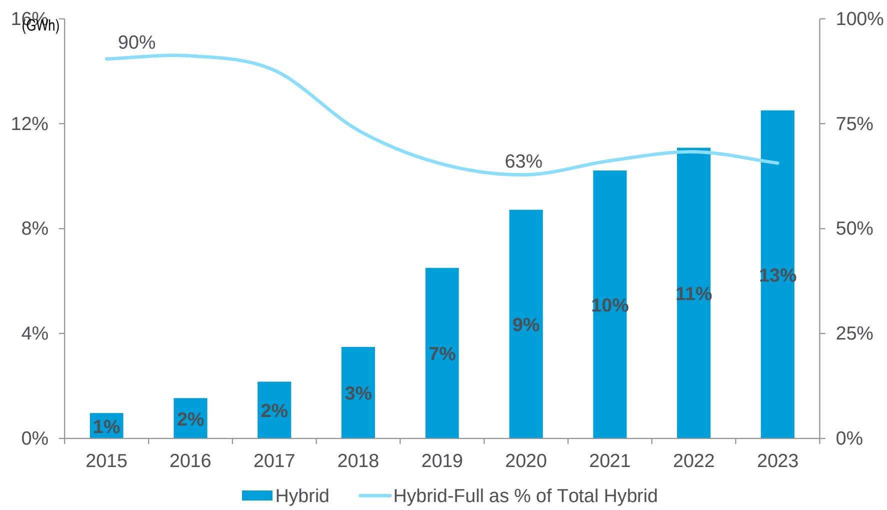
A Quick Trip around the World: Propulsion

North America

The North America propulsion landscape through 2020 will continue to be dominated by the internal combustion engine and its variants. We expect gasoline turbocharging penetration (of ICE gas production) to rise from the ~20% today to almost double that by 2020E. As shown in the charts below, this will be supplemented by stop-start systems and more advanced transmissions and driveline systems.

Figure 163. North American Full-Hybrid as Percent of Total Hybrids



Source: IHS, Citi Research

Focusing on stop-start in particular, in North America this system was a mere 11% of total ICE production in 2015 (ICE accounted for 99% if total production); by 2020E stop-start as a percent of ICE is estimated at ~77% of all ICE (ICE estimated at ~89% of total production). EV penetration on the other hand should continue to gain momentum, particularly as GM's Chevy Bolt hits its stride. EV penetration is expected to rise to ~2.5% of North American production by 2020 (vs. <1% in 2015). The other major propulsion system to account for is the hybrid vehicle. There are two classifications of hybrids that need to be discussed: (1) a full-hybrid is a vehicle that can drive using only the electric motor (low speeds & launch), but shifts to combustion at higher speeds – i.e. Chevy Volt; and (2) a mild-hybrid a vehicle with a large enough electric motor and battery pack to aid the combustion engine in acceleration, but cannot power the vehicle (at low speeds) using solely the electric motor and battery pack – i.e. Honda Civic Hybrid. The full-hybrid is expected to remain the dominant hybrid production platform in North America, but its ~90% share of the whole hybrid market is expected to drop to ~63% by 2020, as hybrid-mild gains share. The aggregate hybrid category is estimated to grow to ~9% of all North American production by 2020 (vs. 1% in 2015).

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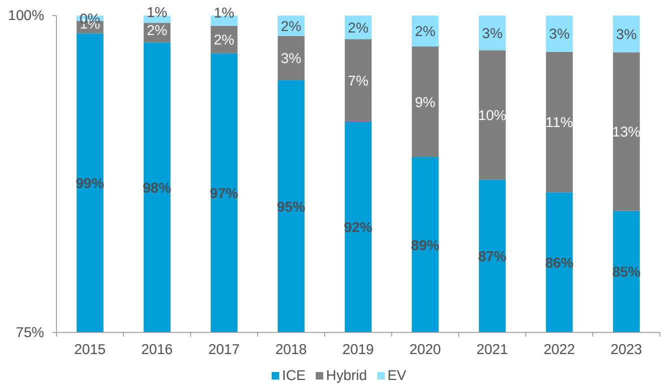
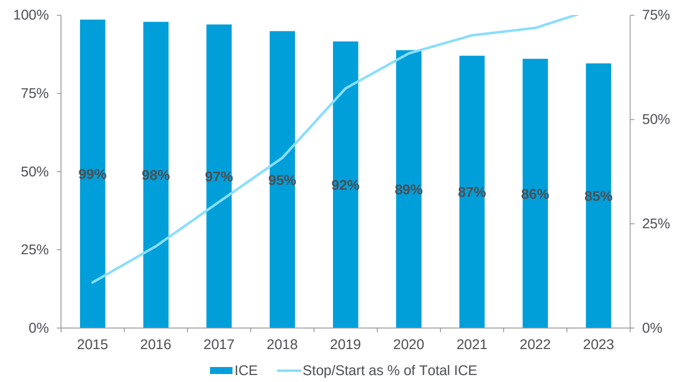
Figure 164. North American Propulsion Penetration Outlook



Source: IHS, Citi Research

Figure 165. North American Stop-Start Penetration % of ICE



Source: IHS ,Citi Research

Europe

Over the past year, Diesel propulsion technology has suffered quite a bit of negative press due to a large Diesel scandal with VW. Despite the negative press it doesn't appear that there was a marked revision in Europe with regards to the end-of-decade CAGR for diesel penetration as a percentage of total European ICE production. To this point, forecasts from the beginning of 2015 had Europe's '15-'20 Diesel penetration as a percentage of total European ICE at a CAGR of -1.1%; more recent forecasts have this CAGR at -1.8%, a more rapid deceleration, but not a substantial movement. Looking at recent forecasts, Diesel penetration as a % of total ICE production in Europe appears to be moving from ~48% in 2015 to ~44% by 2020. With respect to emerging propulsion technology penetration, Europe stands out as the clear winner, relative to North America. Stop-start penetration in 2015 stood at ~70% of ICE production (ICE was ~98% of European production) vs. ~11% for North America; by 2020E Europe stop-start penetration is estimated to be ~87% of ICE production (ICE estimated at ~90% of European production) vs. ~77% for North America. EV penetration is a bit slower than the North American cadence, but is estimated to be ~2% of total European production by 2020. Hybrid penetration also is a bit slower than that of North America. Additionally, the decline in full-hybrid penetration (in favor of mild-hybrid penetration) is much more severe – this could be a result of a smaller presence of Japan-based automakers. Another item worth noting is gasoline turbo penetration in the European gasoline ICE market. As of 2015 penetration was ~49% the gasoline ICE market; by 2020 gas turbo penetration is estimated to be ~60% of the gasoline ICE market.

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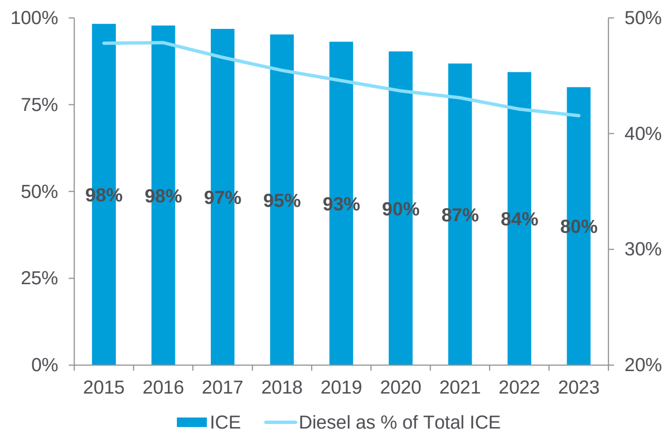
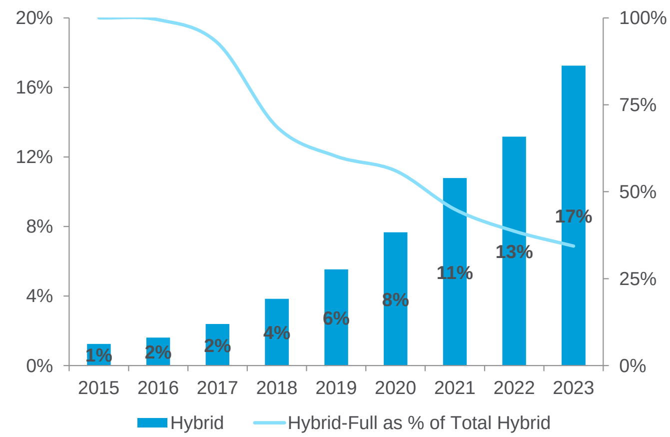
Figure 166. Europe – Diesel Penetration, % ICE



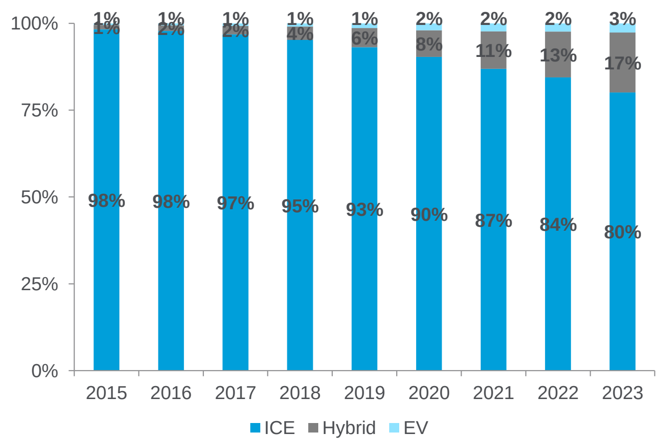
Source: IHS, Citi Research

Figure 167. Europe – Hybrid Full as % of Total Hybrid



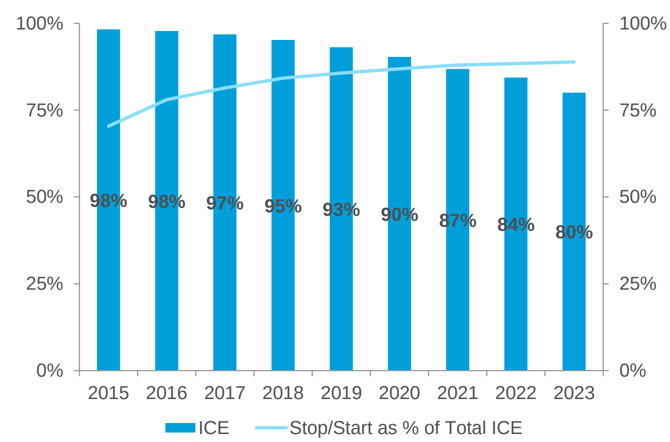
Source: IHS, Citi Research

Figure 168. Europe – Emerging Propulsion Penetration Outlook



Source: IHS, Citi Research

Figure 169. Europe – Stop-Start Penetration % of ICE



Source: IHS, Citi Research

China

We touched upon the EV environment in the section above, but we find it prudent to discuss the other forms of propulsion technology in this section. Advanced powertrain technologies are expected to rapidly increase penetration in the coming years. Gasoline turbocharger penetration, currently around 25% (of gasoline ICE production), is estimated to grow to ~62% of gasoline ICE production by 2020E. Stop-Start penetration as a percent of total ICE production in China is estimated to grow to ~58% in 2020E (vs. the ~13% in 2015). Additionally, the aggregate hybrid market is estimated to grow to ~7% of total China production by 2020 (vs. the <1% in 2015); again, similar to other regions, hybrid-full penetration (as a percent of the total hybrid market) is estimated to decline in favor of mild-hybrid. In fact, mild-hybrid is estimated to become the dominant hybrid technology by 2021.

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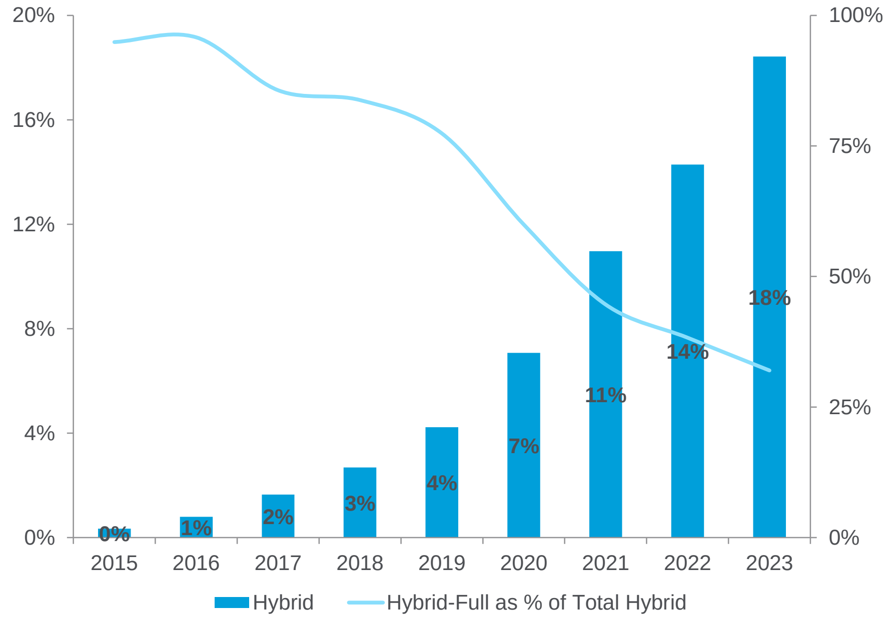
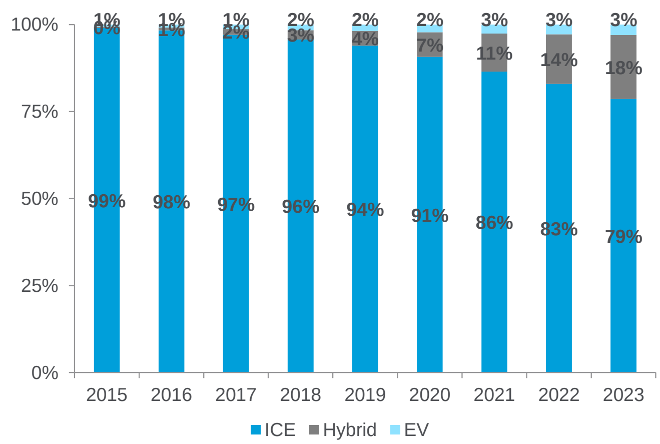
Figure 170. China – Hybrid Full as % Hybrid



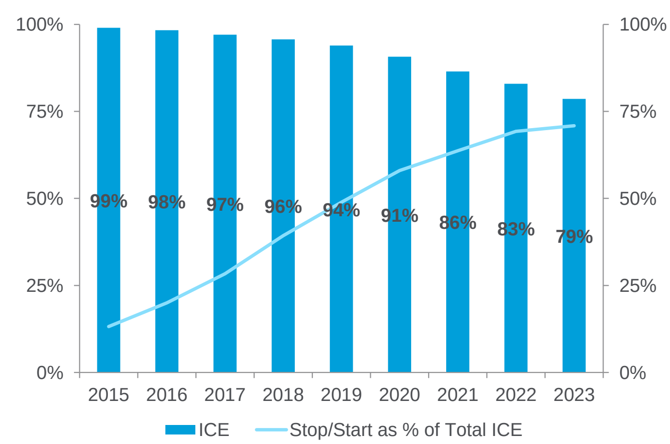
Source: IHS, Citi Research

Figure 171. China – Propulsion Penetration Outlook



Source: IHS, Citi Research

Figure 172. China – Stop-Start Penetration % of ICE



Source: IHS, Citi Research

Japan/Korea

The Japanese market is unique in its strength around hybrid adoption rates. Hybrids made up ~12% of 2015 production; that penetration rate is nearly 6 times that of Europe and North American hybrid production penetration, combined. As with other geographies, ICE engines will continue to comprise the bulk of new vehicle production, with performance enhancers like Stop-Start systems and a ramping of mild-hybrids showing outsized growth.

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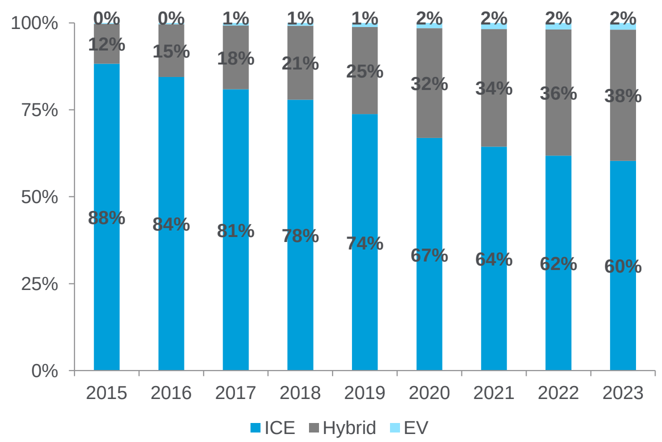
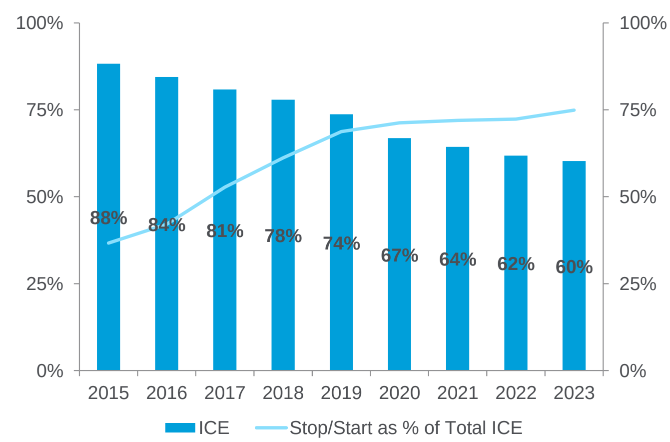
Figure 173. Japan/Korea – Propulsion Penetration Outlook



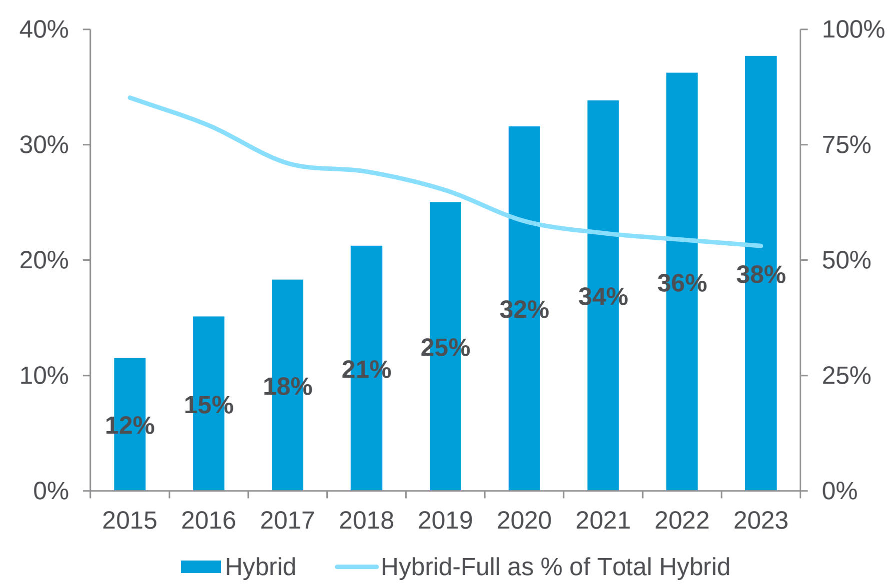
Source: IHS, Citi Research

Figure 174. Japan/Korea – Stop-Start Penetration % of ICE



Source: IHS, Citi Research

Figure 175. Japan/Korea – Hybrid Full as % of Hybrid



Source: IHS, Citi Research

Lightweighting

Reducing vehicle weight is another path towards achieving CO_2 reductions. According to Magna, every 10% of mass saved can achieve a 3% CO_2 reduction — without the benefits of engine downsizing. With engine downsizing included that number jumps to 7% CO_2 savings for every 10% mass saved.

For automakers, lightweighting is an exercise in maximizing weight savings at the lowest possible cost to both content and production complexity. Advanced materials such as high-strength steel, aluminum, magnesium and others all play a role in future weight savings and each appear to have pros and cons.

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Aluminum in particular received much attention after Ford's launch of the F-150 pickup truck. Today aluminum is found in engine components, transmissions, heat exchangers and wheels. Ford's embrace of aluminum for the F-150 was followed by the 2017 Super Duty launch and plans for future SUVs. The Cadillac CT6 also utilized aluminum to achieve a similar final weight as the smaller CTS vehicle.

Aluminum usage is expected to gain further share over the next decade. Steel has advantages in strength, cost (including repair), familiarity, density, and design flexibility. Several recently launched vehicles have used advanced high strength steel to contribute to mass reduction.

Ultimately we expect to see a combination of advanced materials in the *Car of the Future*. Suppliers like Magna have discussed their own Multi Material Lightweight Vehicle projects that achieved over a 20% mass reduction leveraging a holistic approach to the vehicle and a mixture of aluminum and steel.

The industry is also expected to see a rise in composite materials and aerodynamic designs. Earlier this year Magna showed a composite liftgate for the Nissan Rouge that achieved a 30% weight reduction compared to the prior steel liftgate. This contributed to a 10% increase in the Rogue fuel economy.

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Appendix A: Driverless Cars in "New Frontiers"

Figure 176. Top 10 Populated Countries & Density

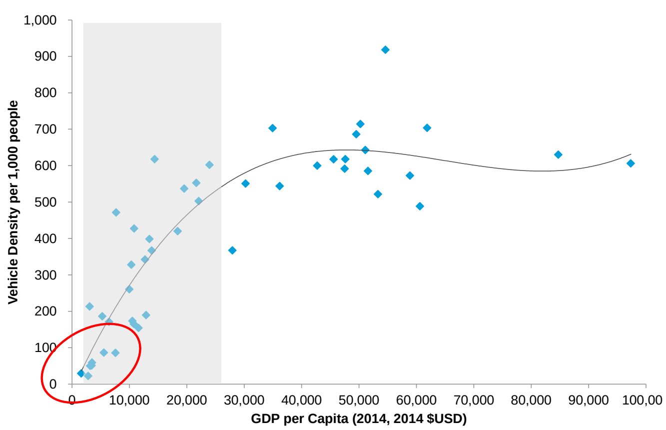
	Population	Car Density
1 China	1,367,485	86
2 India	1,251,695	29
3 U.S.	321,368	918
4 Indonesia	255,993	59
5 Brazil	204,259	154
6 Pakistan	199,085	nm
7 Nigeria	181,562	nm
8 Bangladesh	168,957	nm
9 Russia	142,423	342
10 Japan	126,919	544

Source: Census, LMC, Citi Research

Today's automotive industry is largely characterized by the sale of personal cars indirectly or directly to consumers. It's a business model that requires consumers who can generally afford big ticket items (particularly when auto financing is less prevalent), dealers to distribute & service them, and infrastructure to support the system.

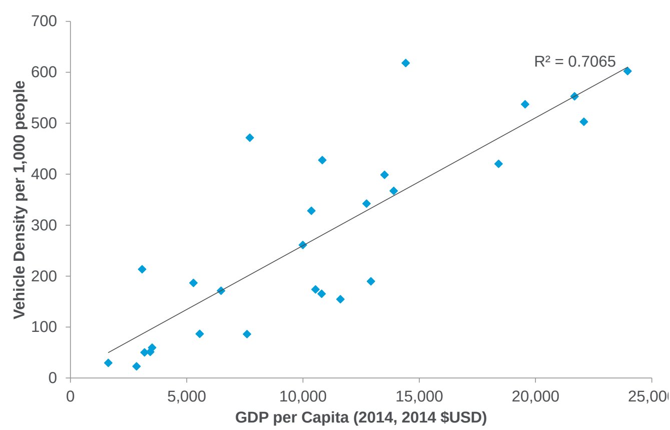
For these reasons, economies have historically faced high economic hurdles to achieve meaningful car density. The Figures below show today's global GDP/capita thresholds necessary to achieve meaningful levels of car density. You'll notice a category of countries that are just on the cusp of entering the typical GDP/capita zone that accommodates meaningfully higher density. The existence of these often large on-the-cusp countries has occasionally led to what we regard as "false-start" auto markets, that is, growing economies that near GDP/capita thresholds only to fall short and disappoint on SAAR. When these happen it's often a bad moment for auto manufacturers; in fact most regions outside of North America and China are still loss making for GM and Ford.

Figure 177. GDP per Capita in Relation to Vehicles per 1,000 People



Source: LMC, World Bank, Citi Research Estimates

Figure 178. Linear Relationship for Frontier Country "Sweet Spot"



Source: LMC, World Bank, Citi Research Estimates

What if classic thresholds were lowered? Enter driverless cars and new mobility sharing networks. These networks can change the equation at many levels including proving direct and easy access to consumer mobility at a substantially lower per-mile cost vs. car ownership. In prior sections we estimated that driverless networks operating in dense markets could roughly halve the per-mile cost to consumers (and this assumed auto financing in place) prior to accounting for non-mile revenue. These services would likely prove far more convenient vs. public transport/motorcycles. For the auto industry, pursuing driverless networks in these markets would likely be less risky than trying to break through too far with personal cars. Less of a need to have established consumer auto financing, less need for dedicated dealers (outside of service centers), less inventory management, fewer costly product cycles and not having to make a big call on how many consumers will abandon their personal cars. For governments, it better ensures a safe and efficient transportation system with less of an infrastructure requirement. At the extreme you don't need traffic lights or signs. While this long-term thought piece focuses mainly on driverless concepts, we note that a driver-based car sharing network could also be economically compelling in certain markets. Thus the concepts discussed aren't necessarily just limited to driverless models.

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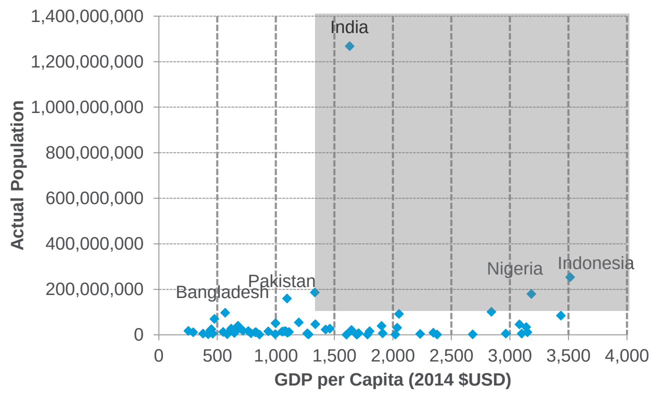
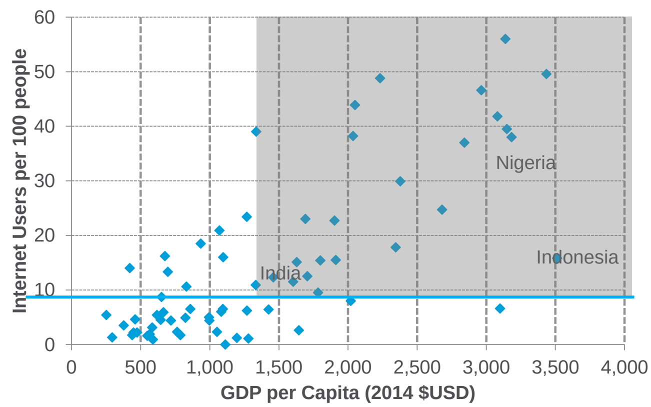
So who's on the cusp now? To assess candidates for unlocking we sought out ideal on-the-cusp countries to assess whether there will be a need for mobility services and whether such services would offer an affordable alternative to current methods of mobility. To determine if there's a need we looked for countries with vehicle density on the cusp of inflection, as this suggests an underlying desire to shift from that country's traditional form of local mobility. We defined the inflection point as the year where the year-over-year change in density (for the 2003-2014 time frame) is >1 standard deviation from the average; we then made note of this point in time. For the affordability aspect, we believe that GDP per capita provides a decent proxy for personal income. So we overlaid GDP per capita and the density point of inflection to come up with a range for potential inflection. For Frontier Markets we found this to be a GDP per capita of $3,000-$11,000. So we ended up filtering for: (1) GDP per capita countries just below or just north of $3,000; (2) high populations; (3) growing urban regions; and (4) Internet access availability.

Figure 179. "Sweet Spot" GDP per Capita by Country and Population



Source: LMC, World Bank, Citi Research Estimates

Figure 180. "Sweet Spot" GDP/Capita & Internet Users per 100 People



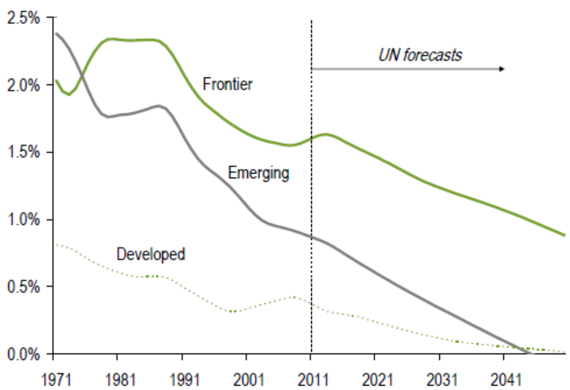
Source: LMC, World Bank, Citi Research Estimate

We found the "best fit" countries to be India, Indonesia and Nigeria.

As shown, these "best fits" are deemed to be "frontier" or "emerging" by nature and have GDP growth profiles well in excess of global GDP, as forecasted by Citi Economists. India has a population that's not far below China's. Indonesia's plus Nigeria's populations exceed that of the U.S. Some of these countries are growing. Maybe not through classic economic thresholds required for meaningful car ownership, but they are growing. And they're becoming more connected too.

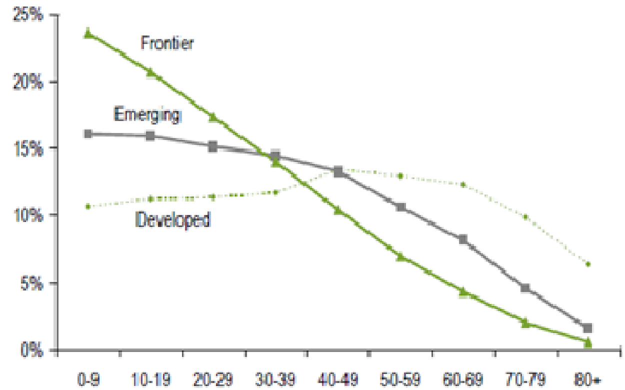
Also, they're not on everybody's radars. Third party forecasting firms predict that India, Indonesia, and Nigeria will contribute less than 20% of global light vehicle sales growth through 2020. That would leave India's and Indonesia's car densities significantly below average. This tells us the consensus view doesn't incorporate these three countries breaking out in a meaningful way, and that's probably right unless economic thresholds were lowered. Driverless & new mobility networks have the potential to do just that over the next 10-30 years.

Figure 181. Annual Population Growth, 1971-2050E



Source: UN Population Division

Figure 182. Population Profile in 2013, by Age Cohort (% of Total)



Source: UN Population Division

So let's play with some numbers.

New Mobility Could Add ~8 million "SAAR"

We roughly estimate that over the next 10-30 years, new mobility networks, including driverless, could add ~8 million "SAAR" units alone in India, Indonesia and Nigeria. This number would likely be additive to third party sales forecasts in these regions. Unlike our analysis in developed regions, here we do count FLEET-AVs as "SAAR" because they unlikely come at the expense of personally owned cars.

Our analysis is based on the potential that these countries possess the characteristics for an inflection in vehicle density and ultimately a change of the status quo for currently available transportation methods. These are also countries that are expected to grow but stay "on the cusp" of levels required for meaningful increases in personal car density. In other words the ~8 million SAAR would not happen if not for driverless car networks so they would truly be incremental from an investment perspective. While the analysis is of course highly theoretical and long-term, we have attempted to apply a consistent method using available information.

Figure 183. India – Urban Driverless Proxy

LOGIC: Delhi Proxy for Urban	
Population -	18,126,142
Vehicle Density per 1000 -	487
Total Vehicles -	8,827,431
Cars & Jeeps	2,790,566
Motorcyles & Scooters	5,681,265
Taxis	79,606
Auto Rickshaws	81,633
Delhi Transport Bus Fleet -	4,712
Passengers Moved Daily	3,680,576
km Moved Daily	744,030
Est. People Moved by Bus TOTAL -	6,134,293
Delhi Transports % of People Moved*	60.0%
Total People Transporting	15,915,717
% drivers commuting	87.8%

Taxis	79,606
# of trips per person per day	2
# of trips per taxi per day	24
# of people per taxi	1.2
Total People Moved	1,146,326
Auto Rickshaws	81,633
# of people per Rickshaw	2
Total Moved Daily	163,266

Source: Govt of NCT of Delhi, Citi Research Estimates

India

Method: India is a highly populated country, boasting close to 1.3 billion inhabitants. We estimate that ~70% are adults. Our working assumption is that the majority of demand or driverless mobility will take place in major urban cities. The majority of the country is deemed to be rural (~65% of the population), but urban population growth has shown a healthy increase – rising from ~26% in 2003 to ~35% in 2014. In our analysis, we assumed a mere 3% of the rural population requiring driverless mobility. In our view, it is more important to nail down the urban population that may require driverless mobility. So we use Delhi as a proxy for urban cities in India and build out our analysis using economic data provided by the region, particularly on transportation. Our analysis led us to believe that ~88% of the urban population commutes on a daily basis and would therefore serve as the basis for consideration of driverless mobility. So we applied 88% to our best estimate of the adult urban population. We also made other assumptions including the number of trips/person/day (2) and the number of trips/day/vehicle.

Results: Our analysis suggests that India would require ~24 million "FLEET-AVs" to meet demand. Assuming a 4.5 year vehicle life with no residual value, this implies a SAAR of ~5.4 million vehicles. Sensitivities to key assumptions are shown below.

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Figure 184. India FLEET-AVs Sensitivity

2020 Sensitivity

			# of taxi trips/day			
1.2	Urban	8	16	24	32	40
trips PP/D	1	32.4	16.2	10.8	8.1	6.5
	2	64.8	32.4	21.6	16.2	13.0
	3	97.1	48.6	32.4	24.3	19.4
	4	129.5	64.8	43.2	32.4	25.9

			# of taxi trips/day			
1.2	Rural	2	6	10	14	18
trips PP/D	1	6.3	2.1	1.3	0.9	0.7
	2	12.6	4.2	2.5	1.8	1.4
	3	19.0	6.3	3.8	2.7	2.1
	4	25.3	8.4	5.1	3.6	2.8

TOTAL		# of taxi trips/day			
trips PP/D	38.7	18.3	12.1	9.0	7.2
	77.4	36.6	24.1	18.0	14.4
	116.1	54.9	36.2	27.0	21.5
	154.8	73.2	48.2	36.0	28.7

Source: Citi Research

Figure 185. India Driverless Car SAAR Potential

INDIA	2020 Urban	2020 Rural	2020 Total
Adult Population	354	607	961
% drivers /commuters	88%	3%	34%
Total Traveling Adult Pop	311	15	326
# of trips per person per day	2	2	
# of trips per taxi per day	24	10	
# ppl per taxi per trip	1.2	1.2	
People moved per taxi	14.4	6	
Amnt. Of Robo Taxi Needed (mlns)	**21.6**	**2.5**	**24.1**
Current PARC (mln)			56.8
TOTAL PF DENSITY (cars per 1,000 adults)			84.3
Average Life of Robo Taxi (yrs)			4.5
Robo Taxis Needed per Year (mln)			**5.4**

Source: Govt. of NCT of Delhi, LMC, World Bank, Citi Research

Indonesia

Method: While Indonesia is not as heavily populated as India, it still has quite a sizeable population in the 250+ million range. Again, we choose to focus on the adult population/driving population, which we believe represents ~70% of the total population. We then drill down just a bit further to the rural vs. urban population split. Indonesia's urban population appears significantly higher than that of India, coming in at the low-/mid- 50% range. As rural remains difficult to assess, we carry over our estimate of a mere 3% of the rural population requiring/considering driverless mobility. We use Jakarta as a proxy for urban cities in Indonesia and build out our analysis using third party reports and some economic data from the densely populated city. Our analysis leads us to believe that ~97% of the urban population commutes on a daily basis and would therefore serve as the basis for consideration of driverless mobility.

Results: Our analysis suggests that Indonesia would require ~8 million "FLEET-AVs" to meet demand. Assuming a 4.5 year vehicle life with no residual value, this implies a SAAR of ~1.7 million vehicles.

Figure 186. Indonesia – Urban Driverless Proxy

LOGIC: Jakarta Proxy for Urban	
Population -	9,200,000
Commuters from Bodetabek region	2,000,000
Total Population in Jakarta per day	11,200,000
Vehicle Density per 1000 -	598
Total Private Vehicles	6,608,918
Cars & Jeeps	1,048,856
Motorcycles & Scooters	5,560,062
Total Public Vehicles -	91,082
Taxis	24,529
Auto Rickshaws	14,424
Bus	24,015
Total Daily Trips	20,700,000
trips per person	1.85
Private Vehicles Service 44% of Trips	9,108,000
Public Vehicles Service 56% of Trips	11,592,000
Private Vehicles:	
Motorcycles & Scooters	5,560,062
people per vehicle	1.00
Daily use rate for commuting	62%
Total Amount People Moved per Day	3,447,239
Total Trips	6,894,477
Cars & Jeeps	1,048,856
people per vehicle	1.2
Daily use rate for commuting	85%
Total Amount People Moved per Day	1,106,762
Total Trips	2,213,523
Private People Moved	4,554,000
Public Vehicles:	
Trips	11,592,000
trips per person	1.85
Public People Moved	6,272,000
Total People Transporting	10,826,000
% drivers commuting	**96.7%**

Source: Eria.org, Third Party Estimates, Citi Research Estimates

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Figure 187. Indonesia Driverless Car SAAR Potential

INDONESIA	2020	2020	2020
	Urban	Rural	Total
Adult Population	107	84	191
% drivers /commuters	97%	3%	55%
Total Traveling Adult Pop	104	2	106
# of trips per person per day	2	2	
# of trips per taxi per day	24	10	
# ppl per taxi per trip	1.2	1.2	
People moved per taxi	14.4	6	
Amnt. Of Robo Taxi Needed (mlns)	**7.2**	**0.3**	**7.6**
Current PARC (mln)			16.9
TOTAL PF DENSITY (cars per 1,000 adults)			127.8
Average Life of Robo Taxi (mln)			4.5
Robo Taxis Needed per Year (mln)			**1.7**

Source: Eria.org, Third Party Estimates, LMC, World Bank, Citi Research estimates

Nigeria

Method: Nigeria was a bit more difficult to assess than India or Indonesia, but given the population size and relatively high penetration of internet access we ran some simple calculations to figure out the potential demand for driverless new mobility. We know that population is in the high-180 million to 200 million range. While we cannot determine for sure, we estimate the vehicle density in Nigeria to be in the 30-50 per 1,000 people range. We estimate the adult population at ~70%. Based on World Bank data we know that the rural vs. urban population split is nearly at parity. Again, we maintain our estimate of a mere 3% of the rural population requiring/considering driverless mobility. We use Lagos as a proxy for urban cities in Nigeria and build out our analysis using educated estimates derived from Olukayode Taiwo, Lagos Metropolitan Area Transport Authority's (LAMATA) Deputy Director Safeguards. It was estimated that on an 18 million Lagos population there were 7 million passenger movements per day (we assume 1.85 movements per passenger); we estimate that at the current ~21mln population there are 10-12 million passenger movements per day. Our analysis leads us to believe that ~30-40% of the urban population commute on a daily basis. Given expected economic growth, we modeled the forward percentage at 70%.

Figure 188. Nigeria – Urban Driverless Proxy

LOGIC:	
Lagos Proxy for Urban	LAMATA
Population	18,000,000
People Movement per Day	7,000,000
movements per passenger	1.9
Total People Moved	3,783,784
% people moved	21.0%

Source: LAMATA, Citi Research Estimates

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Figure 189. Nigeria FLEET-AVs Sensitivity

2020 Sensitivity				# of taxi trips/day		
1.2	Urban	8	16	24	32	40
trips PP/D	1	6.1	3.0	2.0	1.5	1.2
	2	12.1	6.1	4.0	3.0	2.4
	3	18.2	9.1	6.1	4.5	3.6
	4	24.2	12.1	8.1	6.1	4.8

				# of taxi trips/day		
1.2	Rural	2	6	10	14	18
trips PP/D	1	0.7	0.2	0.1	0.1	0.1
	2	1.5	0.5	0.3	0.2	0.2
	3	2.2	0.7	0.4	0.3	0.2
	4	2.9	1.0	0.6	0.4	0.3

TOTAL		# of taxi trips/day			
trips PP/D	6.8	3.3	2.2	1.6	1.3
	13.6	6.5	4.3	3.2	2.6
	20.4	9.8	6.5	4.9	3.9
	27.2	13.1	8.7	6.5	5.2

Source: Citi Research

Results: Our analysis suggests that Nigeria would require ~4.3 million "FLEET-AVs" to meet demand. Assuming a 4.5 year vehicle life with no residual value, this implies a SAAR of ~1.0 million vehicles.

Figure 190. Nigeria Driverless Car SAAR Potential

NIGERIA	2020	2020	2020
	Urban	Rural	Total
Adult Population	83	70	153
% drivers /commuters	70%	3%	39%
Total Traveling Adult Pop	58	2	60
# of trips per person per day	2	2	
# of trips per taxi per day	24	10	
# ppl per taxi per trip	1.2	1.2	
People moved per taxi	14.4	6	
Amnt. Of Robo Taxi Needed (mlns)	**4.0**	**0.3**	**4.3**
Average Life of Robo Taxi (mln)			4.5
Robo Taxis Needed per Year (mln)			**1.0**

Source: LAMATA, LMC, World Bank, Citi Research Estimates

Who Else Might One Day Fit?

We ran some back of the envelope math on a few other countries that broadly fit our definitions above. The countries include Pakistan, Bangladesh and the Philippines. We ran some population analytics (using historical 5-year CAGRs) on World Bank data and assumed ~70% of the population to be adults. Our rough analysis leads us to believe that these three countries, in aggregate, could provide an additional ~1mln SAAR. This is not included in the base case.

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How Does China Fit Into All of This?

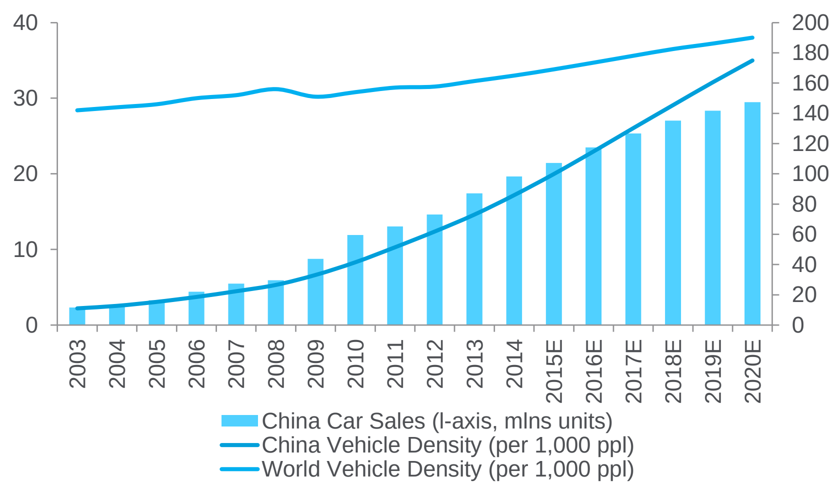
So the U.S. is about as straightforward as an analysis like this can be — a society that's oversaturated but accustomed to personal car ownership. Density likely does decline by 2030+ so the task is to assess how fast and how much.

Europe is similar to the U.S. in some ways but is less oversaturated. The analytical framework is similar in that you're determining how fast and how much density might decline while keeping in mind that the region has a lower starting point than the U.S. and somewhat different segmentation and regional traits. This too is a classic "Do They Want to Drive?" question.

The New Frontier markets introduced in this report are also straightforward in the sense that consumers aren't widely accustomed to owning personal cars — so you're not making a call on a behavioral shift but rather about roughly identifying an addressable market and other demand characteristics.

China is the tricky one. Here's a market that's undergoing a secular growth phase from a very low car density starting point but with megacity population centers and a society that isn't as accustomed to personal mobility as much as the U.S. and Europe. So it's part "Do They Want to Drive?" and part New Frontier.

Figure 191. China car Sales, China Car Density, and World Car Density



Source: LMC Estimates, Citi Research

Approaching China from an Equilibrium Perspective: Because of the uncertainties in modeling China from a bottom-up method, we approach the market conceptually by calculating an equilibrium level of personal car density in a hypothetical market where driverless and new mobility networks are available in major cities. We assume that once China fully matures (broad time frame here is 10-30years), rural households settle at an average personal car density of 1 times, well below that of the U.S. The urban households are assumed to settle at 0.5 times, also below that of some major U.S. cities. The 0.5 times assumes that the largest China cities see growth in mobility networks with personal cars being mostly owned by high income brackets. Based on China household population forecasts, we estimate a normalized personal car population (aka "parc" or "VIO") of 328 million vehicles. This 328 million would compare with the U.S. VIO at ~257 million, and China's current personal vehicle VIO of ~100 million. According to LMC, China's personal vehicle VIO is expected to grow to >200 million by 2020 and 290

million by 2025. Both would be below the 328 million equilibrium calculated. For sensitivity, if we were to assume an Urban density of 0.2-0.3 times (vs. 0.5 times base), it would take down the equilibrium population to 233-265 million, still above the LMC 2020 forecast (What is LMC?) and not far below 2025. Beyond 2025 it's conceivable that FLEET-AVs might eliminate remaining secular growth in personal car SAAR, but the sales runway before reaching equilibrium is so seemingly large that the potential for slow/limited growth beyond that is currently an afterthought from an investing perspective, in our view.

Figure 192. Calculating Density "Equilibrium" in China

	2025E	Notes
China Households	486,341,816	// based on implied 2014-2020 CAGR, LMC Population Growth
Population	1,468,886,800	// based on implied 2014-2020 CAGR, LMC Population Growth
Rural % Pop.	35%	// based on CAGR of hist. China rural declines, World Bank Rural
Urban % Pop.	65%	// based on implied CAGR of hist. China urban improvment, World Bank Total Population
Rural Household Est.	170,032,163	
Urban Population	316,309,653	
Rural Vehicle/HH Mult.	1.00x	// Citi inputs for "ideal" rural veh/HH mult.
Urban Vehicle/HH Mult	0.50x	// Citi inputs for "ideal" urban veh/HH mult.
Rural Car PARC	170,032,164	
Urban Car PARC	158,154,827	
Total Car PARC	328,186,990	

Source: Citi Research

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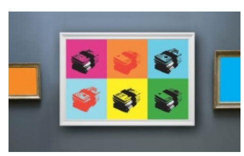

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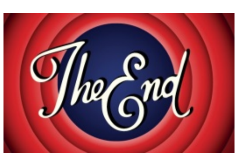

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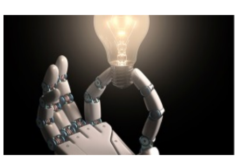

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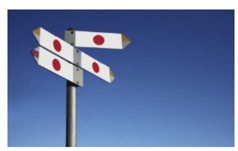

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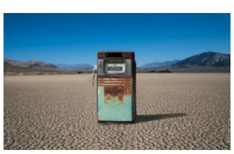

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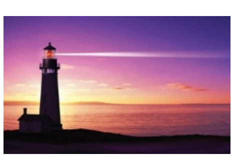

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Key Insights regarding the future of Mobility

TECHNOLOGY

Consumers are just starting to see the very first phases of ADAS focused on safety. / As the industry races towards advancing autonomous capabilities and driverless cars, the three paths to driverless include: (1) building capability, testing and validating; (2) validating, certifying and launching geo-fenced autonomous on-demand rideshare networks; and (3) expanding beyond geo-fence and the entry of personal driverless cars and integrated mobility networks.

REGULATION

Launching a driverless car service isn't straightforward, given prevailing regulations that mandate a human driver be inside the car. / A number of U.S. states have offered legislation that's seemingly friendly to self-driving cars but there are calls for federal government leadership to avoid having a patchwork of state laws and regulations.

INNOVATION

The biggest innovations to date have been in the technology of the car itself. / All aspects of mobility model may change with automated vehicles – on-demand driverless networks could be introduced to urban environments, auto peer-to-peer timeshare models can be developed as well as automaker subscription models.

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