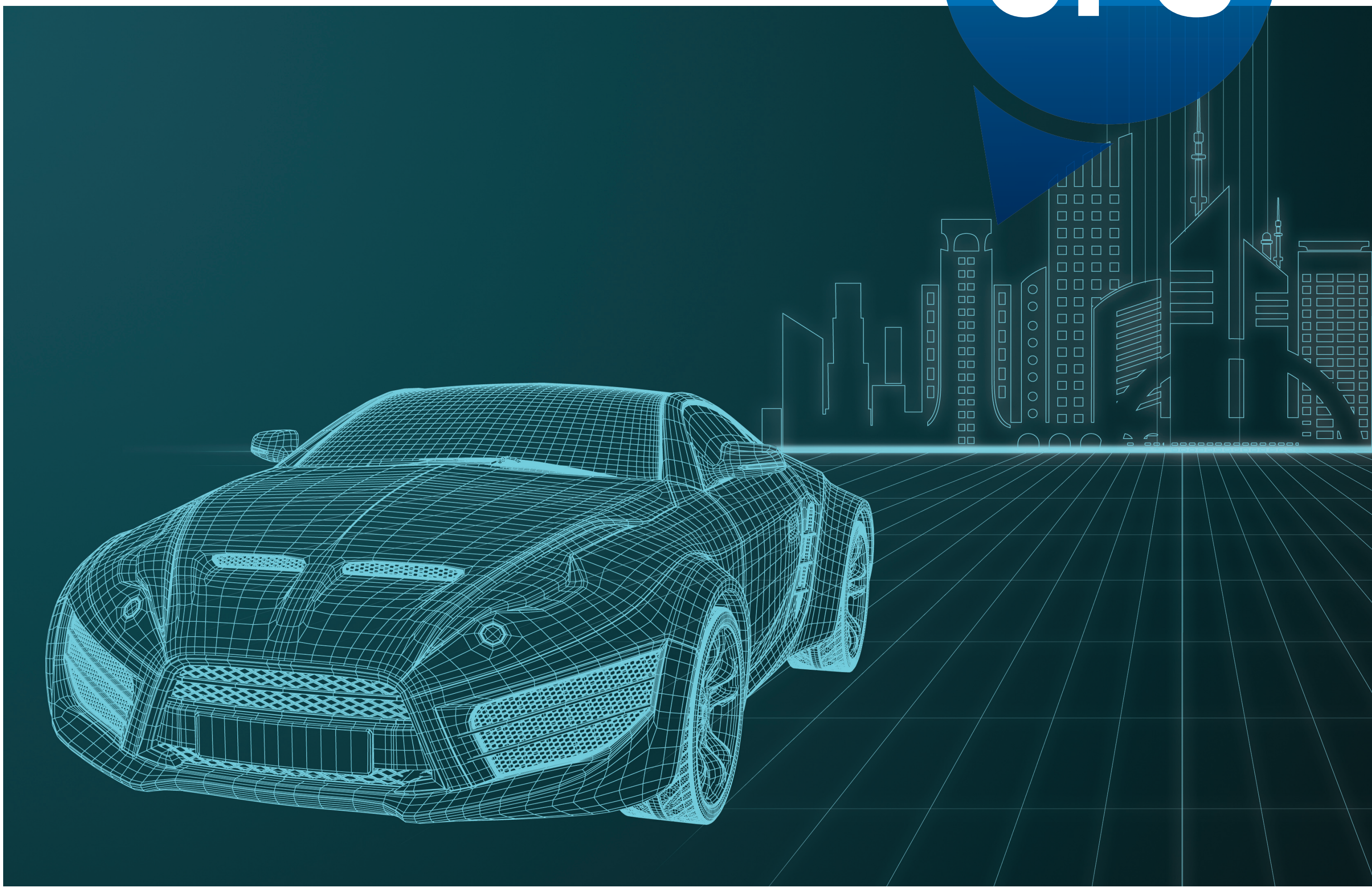
Citi GPS



THE CAR OF THE FUTURE v2.0

Mobility Transformation: Full Steam Ahead

Citi GPS: Global Perspectives & Solutions

May 2015

citi

Itay Michaeli
Jamshed Dadabhoy
Christopher Reenock
Jim Suva, CPA
Philip Watkins
Paul Gong
Michael Rollins, CFA
TimothyThein, CFA
Todd Bault
Manabu Hagiwara
Tsubasa Sasaki
Kenneth Wong, CFA
Justin Barell
Atushi Ikeda
Ashwin Shirvaikar, CFA
Arifumi Yoshida

Itay Michaeli
US Auto & Auto Parts Analyst

+1-212-816-4557 | itay.michaeli@citi.com

Todd Bault
US P&C Insurance Analyst

+1-212-816-4673 | todd.bault@citi.com

Jamshed Dadabhoy
Asia Auto Transportation Analyst

+65-6657-1146 | jamshed.dadabhoy@citi.com

Manabu Hagiwara
Japan Auto Parts and Truck Analyst

+81-3-6270-4805 | manabu.hagiwara@citi.com

Christopher Reenock
US Auto & Auto Parts Senior Associate

+1-212-816-4235 | christopher.reenock@citi.com

Tsubasa Sasaki
Japan Technology Thematic Research

+81-3-6270-4817 | tsubasa.sasaki@citi.com

Jim Suva, CPA
US IT Hardware & Technology Supply Chain Analyst

+1-415-951-1703 | jim.suva@citi.com

Kenneth Wong, CFA
US IT Hardware & Software Analyst

+1-415-951-1776 | kenneth.wong@citi.com

Philip Watkins
Europe Auto Analyst

+44-20-7986-3949 | philip.watkins@citi.com

Justin Barell
US Auto Parts Senior Associate

+1-212-816-7815 | justin.barell@citi.com

Paul Gong
China Auto Analyst

+852-2501-2787 | paul.gong@citi.com

Atsushi Ikeda
Japan Chemical & Synthetic Fiber Analyst

+81-3-6270-4777 | atsushi.ikeda@citi.com

Michael Rollins, CFA
US Telecommunications Analyst

+1-212-816-1116 | michael.rollins@citi.com

Ashwin Shirvaikar, CFA
US Computer Services & IT Consulting Analyst

+1-212-816-0822 | ashwin.shirvaikar@citi.com

Timothy Thein, CFA
US Machinery Analyst

+1-212-816-6706 | timothy.thein@citi.com

Arifumi Yoshida
Japan Auto, Tire & Rubber Analyst

+81-3-6270-4725 | arifumi.yoshida@citi.com

Contributors

Saree Boroditsky

Alex Glasner

Andrew Jaskowiak

THE CAR OF THE FUTURE v2.0

Mobility Transformation: Full Steam Ahead

Itay Michaeli
US Auto & Auto Parts Analyst

It has been quite a year for the Car of the Future theme! Discussions that were deemed theoretical only a few years ago have become reality. Silicon Valley companies have taken increasing interest in selling into and perhaps even building cars. New mobility services have gained rapid momentum. Technology events like the Consumer Electronics Show (CES) have increasingly begun to look like auto shows. And to think...it's only the beginning.

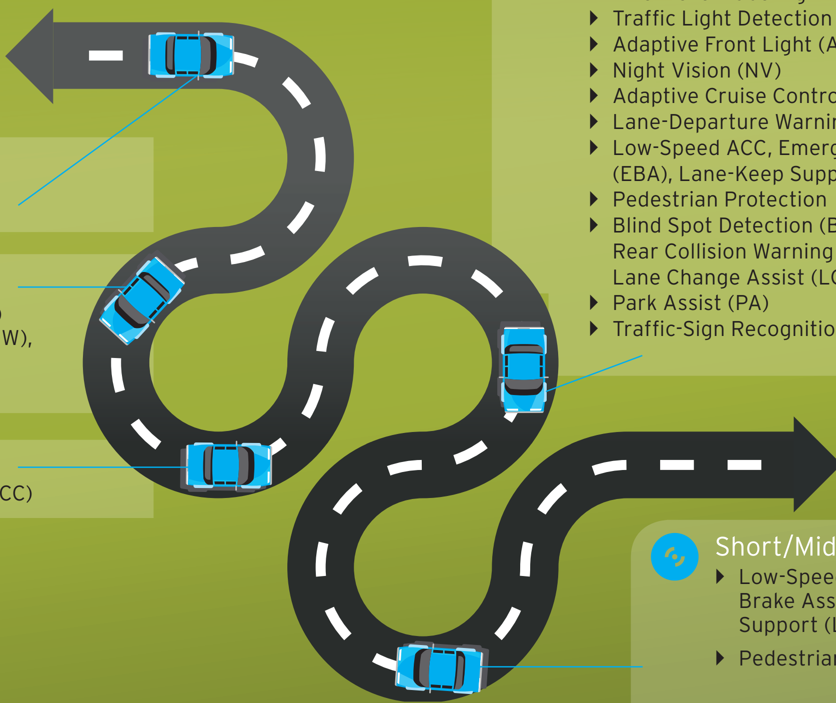
Our latest Car of the Future report (v 2.0) aims to offer a one-stop shop to understanding and evaluating global automotive technologies that will shape tomorrow's cars — how they are built, powered, equipped and serviced. By 'future', we generally aim to focus on the next 5-10 years in order to keep the topics both interesting and investable. The report features both new contributions and themes from several Citi analyst teams around the world as well as the integration and updates of recently published thematic reports by Citi's global analysts.

Besides integrating and updating all past discussions, Car of the Future v2.0 delves into some new "outside the box" discussions, such as: (1) ADAS as the most powerful trend in the history of the automobile, in which we highlight options for further penetration via insurance savings (Citi's Autonomous Driving Subscription Model) and game-changing potential in subscription-based automated driving offerings (Citi's ADAS Subscription Model); (2) A deep dive into the human machine interface (HMI), an increasingly critical frontier that might shape how automakers differentiate their automated driving offerings — full digital clusters, head-up displays and even augmented reality; (3) An updated thought-provoking view on the future of "new mobility" and mobility-as-a-service; and (4) A deeper look into the consumer demand for the ideal driving range of electric vehicles (EV).

As we continue to research and explore deeper into the world of futuristic and emerging automotive technologies, it is easy to fall under the seduction of these "sexy" technologies and forget entirely to connect the dots to an investable framework. As such, we aim to tie our Car of the Future report to the investable areas of future automotive technology by focusing on both Tier-1 and Tier-2 auto suppliers that play into the most compelling trends of our Car of the Future thematic report.

Moving towards autonomous driving

ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS) HAVE ADVANCED DRIVEN BY REGULATION, POSSIBLE INSURANCE SAVINGS AND CONSUMER VALUE.



Infrared
- Night Vision (NV)

Ultrasound
- Blind-Spot Detection (BSD) Rear Collision Warning (RCW), Lane Change Assist (LCA)
- Park Assist (PA)

Long Range Radar
- Adaptive Cruise Control (ACC)

Video
- Deep Learning Networks
- Pixel Level Labeling
- Traffic Light Detection
- Adaptive Front Light (AFL)
- Night Vision (NV)
- Adaptive Cruise Control (ACC)
- Lane-Departure Warning (LDW)
- Low-Speed ACC, Emergency Brake Assist, (EBA), Lane-Keep Support (LKS)
- Pedestrian Protection
- Blind Spot Detection (BSD) Rear Collision Warning (RCW), Lane Change Assist (LCA)
- Park Assist (PA)
- Traffic-Sign Recognition (TSR)

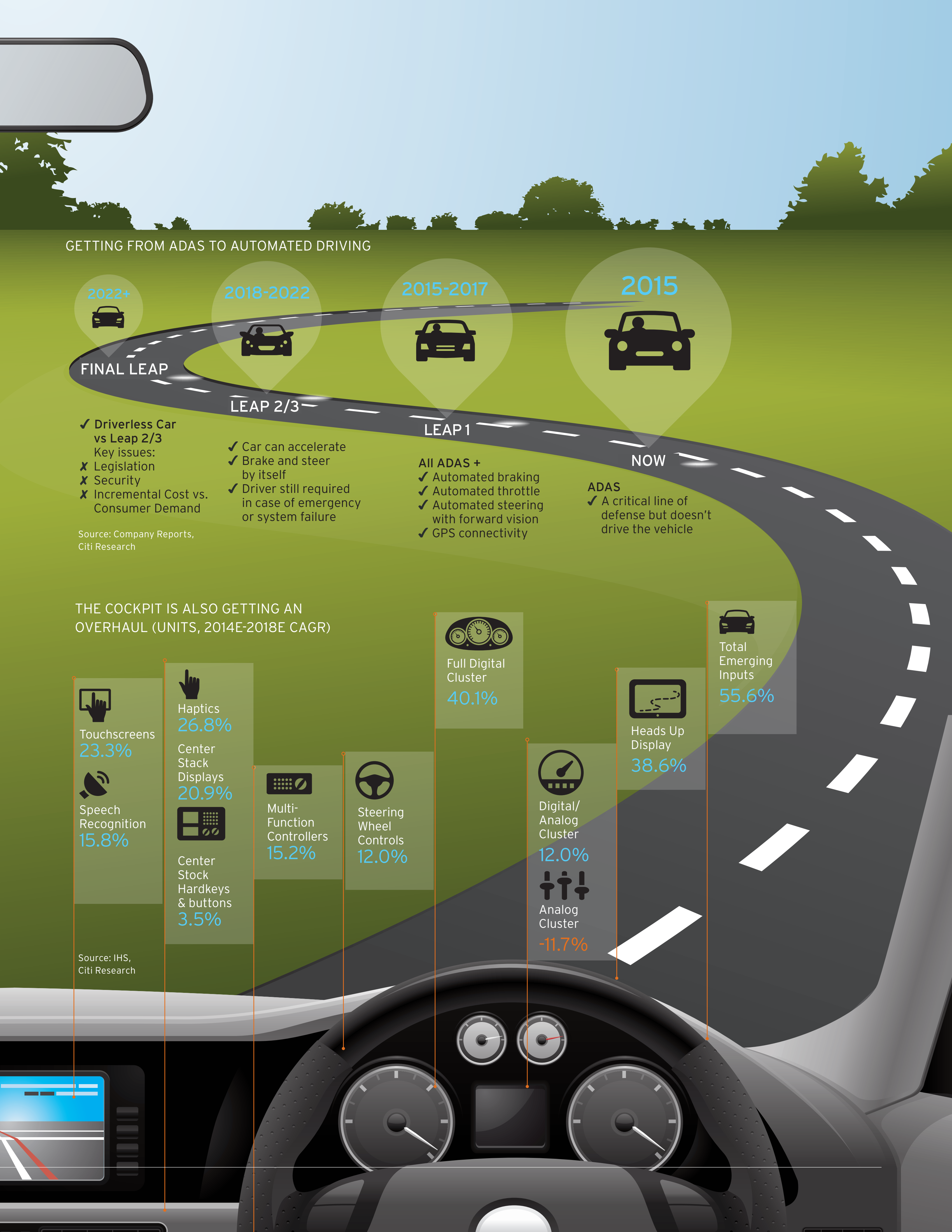
Short/Mid Range Radar
- Low-Speed ACC, Emergency Brake Assist, (EBA), Lane-Keep Support (LKS)
- Pedestrian Protection

Source: Texas Instruments

CAMERAS ARE AN IMPORTANT PART OF ADAS GROWTH

	2013	2017	2021	2025
Global Light Vehicle Sales	84	102	116	122
Forward Facing Camera ADAS Penetration Rate	2%	14%	47%	67%

Source: Company Reports, Citi Research



GETTING FROM ADAS TO AUTOMATED DRIVING
2022+
2018-2022
2015-2017
2015
FINAL LEAP
LEAP 2/3
LEAP 1
NOW
✓ Driverless Car vs Leap 2/3
Key issues:
✗ Legislation
✗ Security
✗ Incremental Cost vs. Consumer Demand
✓ Car can accelerate
✓ Brake and steer by itself
✓ Driver still required in case of emergency or system failure
All ADAS +
✓ Automated braking
✓ Automated throttle
✓ Automated steering with forward vision
✓ GPS connectivity
ADAS
✓ A critical line of defense but doesn't drive the vehicle
Source: Company Reports, Citi Research
THE COCKPIT IS ALSO GETTING AN OVERHAUL (UNITS, 2014E-2018E CAGR)
Touchscreens 23.3%
Speech Recognition 15.8%
Haptics 26.8%
Center Stack Displays 20.9%
Center Stack Hardkeys & buttons 3.5%
Multi-Function Controllers 15.2%
Steering Wheel Controls 12.0%
Full Digital Cluster 40.1%
Digital/ Analog Cluster 12.0%
Analog Cluster -11.7%
Heads Up Display 38.6%
Total Emerging Inputs 55.6%
Source: IHS, Citi Research

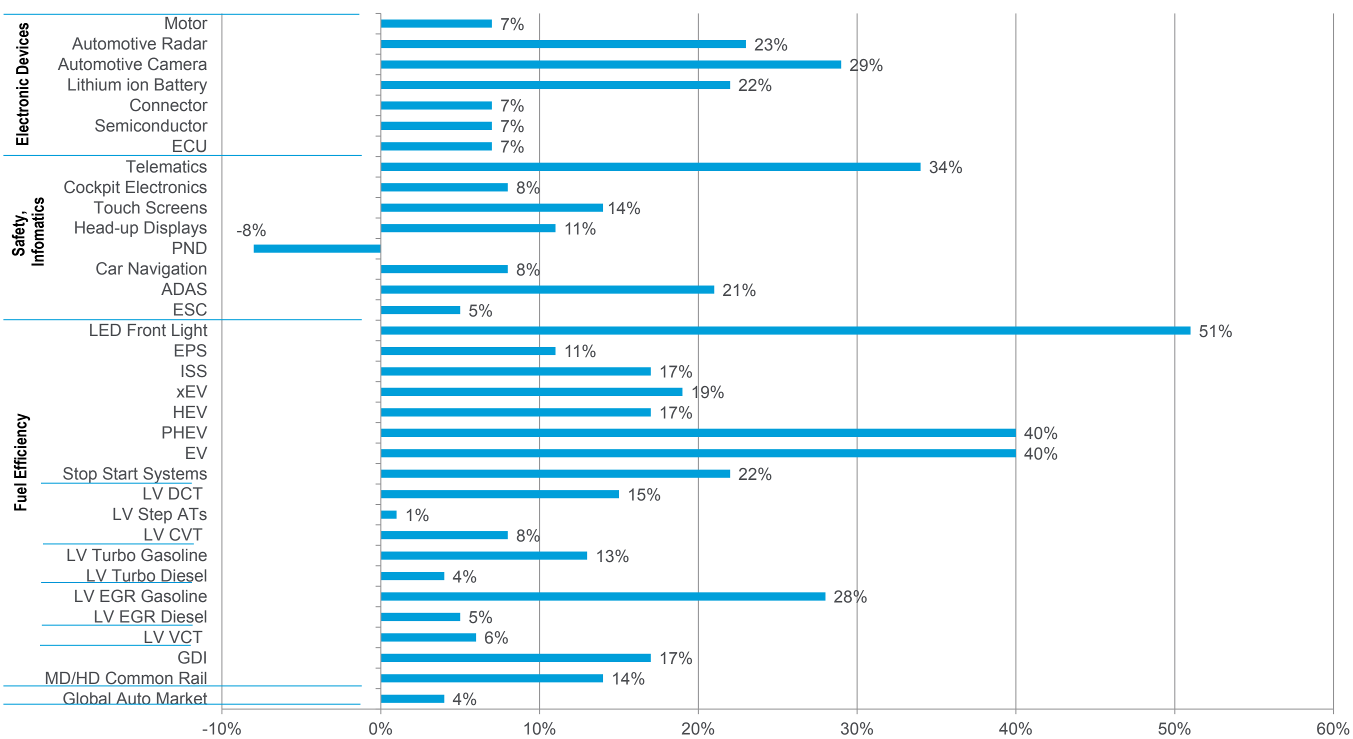
Contents

Investing in the Car of the Future 7
Saving Lives with the Car of the Future 12
The History of Active Safety 12
The "ABCs" of ADAS 13
Drivers of ADAS Demand 18
Defining the Market and 3rd Party Forecasts 20
The ADAS Evolution: A Subscription Model 22
The Path from ADAS to Automated 27
Can the "Autonomous Car" Be a "Free" Option? 29
New Mobility—Why Now? 34
Spotlight on Commercial Vehicles 39
Connecting the Car of the Future 41
The Evolution of Cockpit Electronics 41
Connectors/Sensors a major beneficiary of vehicle electrification 52
IT Services Enable the Car of the Future 55
Bridging Connectivity via Automotive Motors 59
A Quick Trip around the World: Infotainment 60
Ways to Connect, Lots of Players 61
The Rise of the Touch Screen 70
Telematics 73
Propelling the Car of the Future 80
The Drivers 80
How to Meet the Requirements 82
Electrification of the Powertrain 89
The Keys to the Car: Powertrain Systems 91
A Quick Trip around the World: Propulsion 98
Spotlight on Commercial Vehicles 107
Building the Car of the Future 109
Lighting 109
Additive Manufacturing 114
Carbon Fiber: Automotive Uses Expanding 114
China: Building and Distributing 117
India: Light Weighting Initiatives 120
Spotlight on Commercial Vehicles 123

Investing in the Car of the Future

What's Already Worked, and Why? Had we built a Car of the Future Index say 6-7 years ago, we would have seen a fair share of successes & failures. Some were great ideas with flawed business models, others were ideas that simply didn't pan out, some panned out but not entirely to plan, and a few worked remarkably well. When it comes to success stories, there's perhaps no better example than BorgWarner, whose stock valuation migrated from an "auto" multiple to "industrial" since 2008. Interestingly, the BorgWarner technology story was never really that complex; in fact today's turbocharger and dual-clutch transmission (DCT) discussions aren't fundamentally different than what they were in 2008. Rather, the key to the BorgWarner success, in our view, was in the company's ability to: 1) provide automakers with a superior *fuel savings-per-dollar* proposition, including the ability to remove content elsewhere (engine downsizing); 2) provide consumers with a similar value proposition around fuel economy *and* enhanced performance, resulting in high take rates and profit/brand gains for the original equipment manufacturers (OEMs); 3) play in technologies that are difficult to replicate (so-called tribal knowledge) leading to finite competitors and industry price discipline; and 4) offer globally scalable products.

Figure 1. Market Growth of Major Applications and Products (Estimated CAGR between 2013 and 2020)



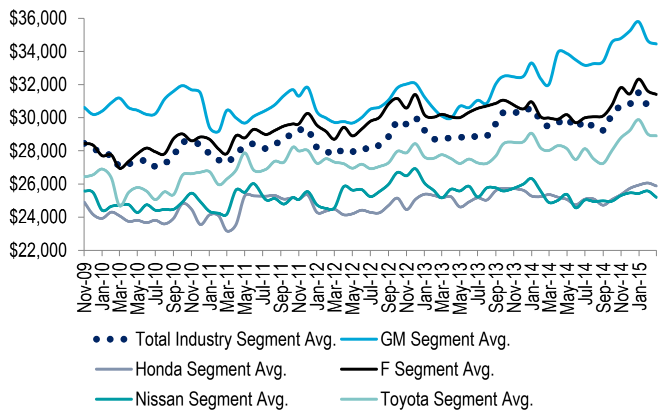
Note : Market units for fuel efficiency, safety, informatics applications and ECU. Market value for electronic devices such as semiconductors or connectors.

Source: Company data, Wards, Anfavea, AEB, JAMA, JAPA, CAAM, SIAM, GAIKINDO, TMT, TSR, Marklines, WSTS, JEITA, Bishop, BWA, DLPH Citi Research estimate

What Goes Up Must Come Down — The Variable Cost Tug of War: The average car in the US carries a variable cost of ~$20,000. 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, automakers must seek efficiencies (global platforms), supplier price-downs and de-contenting opportunities where possible. Given these

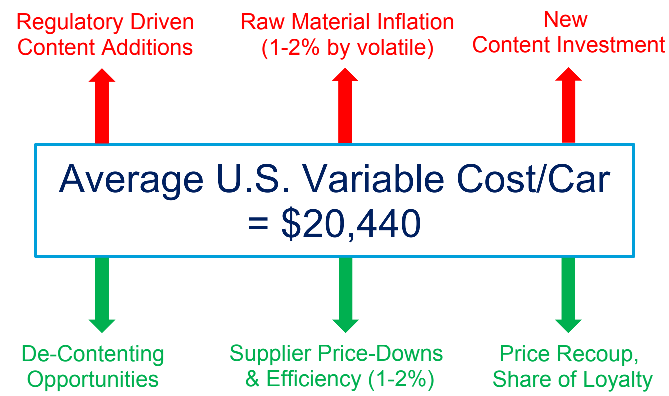
industry challenges, the appetite to load non-mandated content naturally becomes more dependent on the ability to earn an acceptable variable margin, market share or brand equity support. So when thinking about penetration stories, it's also important to keep de-contenting in mind. If lithium-ion battery costs decline significantly over the next 5-10 years, might EVs become less costly than plug-in hybrid EVs (PHEVs)? If semi and fully autonomous cars go mainstream over the next 10-15 years, will passive safety, mirrors and certain materials be less emphasized? How will Connected Car revenue streams impact automaker technology selection? Will wearable devices de-emphasize in-car displays? Engine downsizing in exchange for gasoline direct injection (GDI)/turbo occurs every day, eliminating passive safety and powertrain technology in exchange for an autonomous car could take decades — during which all might enjoy a period of higher penetration! So timing is a critical consideration here even for long-term investors. Thankfully, the next 5-10 years might see relatively less de-contenting than subsequent periods. But eventually, what goes up does need to come down.

Figure 2. US Vehicle Transaction Prices



Source: Company reports, Citi Research

Figure 3. Basic OEM Variable Cost Matrix



Source: Citi Research

It's All About the End Consumer: Most tier-1 auto suppliers claim their products save weight, improve safety, reduce noise, vibration & harshness (NVH) and so on. Certain technologies even have regulations on their side, such as passive safety and certain emissions systems. But what ultimately differentiates good technologies from great ones is whether consumers actually demand and pay for them. This is a function of capability and price.

Margin comparisons across the supplier group seem to support this view. Consider passive safety and emissions systems — good technologies with regulatory tailwinds but with arguably less direct consumer pull demand — EBIT margins for exposed suppliers (TRW, Tenneco, Autoliv) tend to run in the 7-10% range. Good, not great. In Europe, Faurecia, with its focus on more commoditized seating, interiors and exteriors, has a margin of only ~3%. Now consider GDI/turbo and electronics companies like BorgWarner, which generate 11-13% EBIT margins and command premium valuation multiples. Also consider companies in this category such as Harman (scalable infotainment EBITDA margin 12-14%, per company reports).

So Ask Yourself: Is a car company using supplier's XYZ technology to sell you a car? Think Ford EcoBoost, active safety commercials and various GDI offerings. If so, what does the competitive landscape look like? What value do suppliers add, what are their R&D requirements and how scalable is this technology? And can the automaker "fund" the content add by taking costs elsewhere in the vehicle or by clearly improving the cost of ownership to the end user (insurance, fuel)?

But It Also Goes Beyond Autos: Future technology suggests that changes may affect not only OEMs and suppliers but other industries too. It could affect the way we work such as adding an extra hour to work/communicate that would normally be an inefficient part of our commute. The ramifications for congested roads and advertisers, for insurance companies and oil companies, for technology companies vying for consumer attention could be significant. Some innovations can help both automakers and suppliers, though many are exclusive to suppliers.

Citi's Car of the Future Supplier Investing Framework: So as a first step in evaluating the investment worthiness of automotive technologies, we ask many of the questions posed in the above section. 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 turbocharging, ADAS and stop/start, followed by broader electronics/infotainment.

Figure 4. Auto Technology Investing Framework — Select Examples

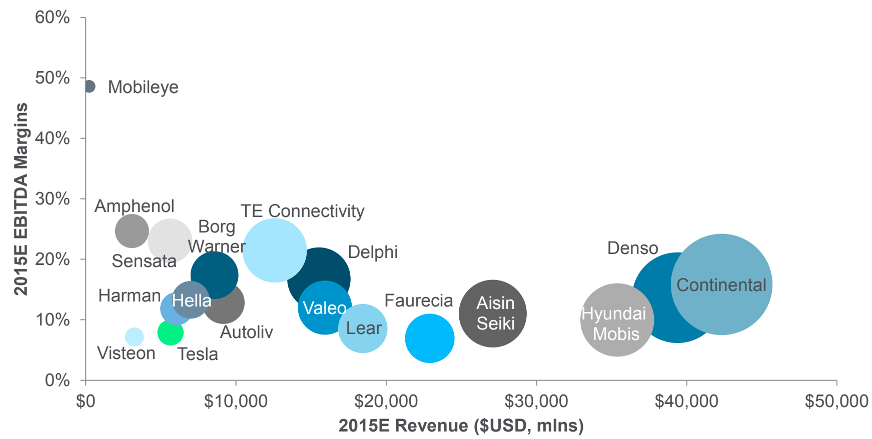
	ADAS	Turbos	Stop/Start	Weight Reduction	Embedded Infotainment	GDI	Connectors	EV	Clusters Displays	Emissions Systems	Embedded Telematics	LED Lighting
Is There a Specific Regulatory Driver?	Green	Green	Green	Green	Red	Green	Yellow	Green	Red	Green	Red	Green
Consumer Value (Perform, Safe, Connect)?	Green	Green	Yellow	Red	Green	Yellow	Yellow	Green	Green	Red	Green	Green
Do OEMs Use This As a Selling Point?	Green	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Red	Green	Yellow
Is It Reasonably Affordable to Consumers?	Green	Green	Green	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow
Is it Globally Scalable?	Green	Green	Green	Yellow	Green	Green	Green	Yellow	Green	Yellow	Yellow	Green
How is the Competitive Landscape?	Yellow	Green	Green	Yellow	Yellow	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow
Can It Be Funded By Content Reductions?	Red	Yellow	Red	Yellow	Red	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Yellow
Applicable to OEM Investing?	Yes	Yes	No	Yes	Yes	No	No	Yes	No	No	Yes	Yes

Source: Citi Research.

Updating the Car of the Future Index: In order to more easily depict the benefit of exposure to key secular trends in the automotive industry, we compiled a group of public companies to represent a sample of those well exposed to our auto technology investing framework criteria. We then take this group and weight it based on forward year 1 and forward year 2 revenue forecasts in order to create a weighted price performance index. In addition to price performance, we also look at valuation multiples. This index is not meant to serve as a recommendation of stocks, but rather meant to highlight historical price performance and historical valuation multiples.

We considered many different options for weighting the index, ultimately settling on revenue as the final criteria. The reason for utilizing revenue was that it allowed for more normalized multiple comparisons, especially when paralleled to our initial run at the index using traditional market cap weighted methodology. While revenue may not be a perfect metric for weighting given that only a portion of a certain company's total revenue may be applicable to these secular trends, we believe that revenue is more easily compared to expected emerging technology CAGRs and serves as a fair proxy. In our analysis, focusing purely on the supplier sample set, the correlation of market cap to 2014E revenue was a respectable .83; including the entire basket it drops to .69 (due to Tesla valuations).

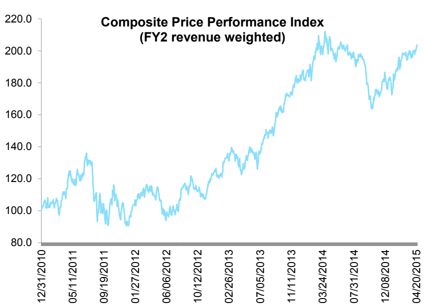
Figure 5. 2015E Revenue & EBITDA Margin



Note: Circle means the size of FY1 EBITDA

Source: Consensus Estimates, FirstCall, IBES, FactSet

Figure 6. Car of the Future Index = Price Performance



Source: Factset, Citi Research

Global Auto Stock Screen: As an added tool to the Car of the Future Index, the Citi Global Autos Team broke out the revenue exposure of key Tier-1/Tier-2 auto suppliers by various degree of attractiveness based on the investment framework described above. The four categories looked at were: 1) truly exceptional businesses exposed to secular trends in a concentrated competitive environment allowing for strong growth and margin expansion; 2) solid assets growth and expanding margins, but with a more competitive landscape suggesting margins will remain good, but short of top notch; 3) more commoditized assets growing at or slightly above market with average margins. Not bad assets; and 4) either poor assets or other special situations such as non-auto or divestiture candidate.

Figure 7. Global Auto Suppliers — Select Revenue Exposure Breakdowns

Legend:
- (Light blue) Truly exceptional LT secular growth outlook, concentrated competitive landscape (pricing power), scalable. Expect strong growth AND steady margin expansion
- (Green) Solid above market growth and margin expansion outlook but, perhaps more competitive with good, but not outstanding, margin prospects
- (Yellow) More commoditized businesses growing at or slightly above market with mean profit and return profiles. Not bad assets.
- (Red) Either poor assets or some other special situation (Non-Auto, Divestiture candidate, etc.)

	Summary Stats			Key Technology Exposures (Estimated Revenue % Exposures & Detail)			
	Market Cap ($, USD)	2015E Revenue* ($, USD)	2015E EBIT Margin*	(Light blue)	(Green)	(Yellow)	(Red)
United States							
BorgWarner	$13,861	$8,570	13.3%	70% Engine Segment + DCT		30% Torque Transfer Systems	
Delphi	$24,060	$15,522	13.1%	100% Powertrain | E&S | E&EA (GDI/Diesel & connectors)			
Visteon	$4,574	$3,235	4.6%	100% Cockpit Electronics			
Autoliv	$10,642	$9,161	9.3%	7% Active Safety		93% Passive Safety	
Johnson Controls	$34,054	$38,045	7.6%	19% Battery Business (Stop/Start)		44% Automotive Seats	37% Building Efficiency
Lear	$8,753	$18,440	6.5%	23% Electrical Business (Wire harness/connectors)		77% Automotive Seats	
Mobileye	$10,237	$218	47.3%	100% Active Safety			
Europe							
Continental	$48,254	$42,324	11.3%	61% :hassis & Safety; Powertrain; Interior, ContiTec (Includes ADAS, Infotainment)	11% Contitech	28% Tire Division	
Valeo	$12,832	$15,920	7.4%	63% Visibility; CDA; Powertrain	25% Thermal		12% Aftermarket
Hella	$5,106	$6,976	7.6%	74% Lighting (LED) & Electronics	6% Special Applications		20% Aftermarket
Faurecia	$5,875	$22,902	4.1%		25% Emissions	47% Automotive Seats & Exteriors	28% Interiors
Japan							
Denso**	$40,438	$37,875	9.9%	50% Powertrain, Info & Safety, Electronic systems	20% Engine electric systems, etc.	28% Thermal	2% Non-Auto Biz
Aisin Seiki**	$12,317	$26,133	7.1%	43% Drivetrain (Transmission)	20% Brake + Chassis	33% Engine related, Body, Info	4% Non-Auto Biz

** consensus estimates*
***FY 2016 estimates to reflect CY 2015 metrics*
% may now add due to rounding

Source: Citi Research, Company Reports, Bloomberg, First Call

Saving Lives with the Car of the Future

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. In the US alone, annual fatalities top 30,000. The outlook is unfortunately even grimmer considering the aging population and the increasingly connected (i.e. distracted) driver. By 2030, road fatalities are poised to rank in the top 5 causes of death globally.

It is estimated that 93% of US accidents are caused by human error, with Europe sporting a similar ratio. Alcohol remains a major US 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. Of all incidents, lane departure is often most fatal.

Figure 8. US Crash Stats

US Crashes per Year	**5.5 mln**
% Human Error	93%
Fatal 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: Citi Research

Besides the human toll, there's also a substantial economic toll. In the US 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 9. Global Auto Fatality Stats

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

Source: 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. In some of the largest US cities the average commuter spends 60+ hours-per-year stuck in traffic. And as much as regulators have focused on fuel-saving solutions in the car, bettering real-world driving patterns/behaviors may be equally as powerful in the quest to reduce tailpipe emissions.

Active Safety/ADAS/Autonomous driving, whatever vernacular you want to use to describe this mega-trend in the automotive space will help to solve the issues above and ultimately SAVE LIVES.

The History of Active Safety

It wasn't until the 1990s/early-2000s when Active Safety systems began to enter the equation. Electronic Stability Control (ESC) was perhaps the first form of an Active Safety system. ESC is an advanced computing technology that uses automatic braking of individual wheels to maintain vehicle stability/traction in potential skidding situations. A classic high-return at a reasonable cost solution—one of the tenants of our "Car of the Future" Investor Framework.

Let's examine the penetration ramp/outlook of ESC:

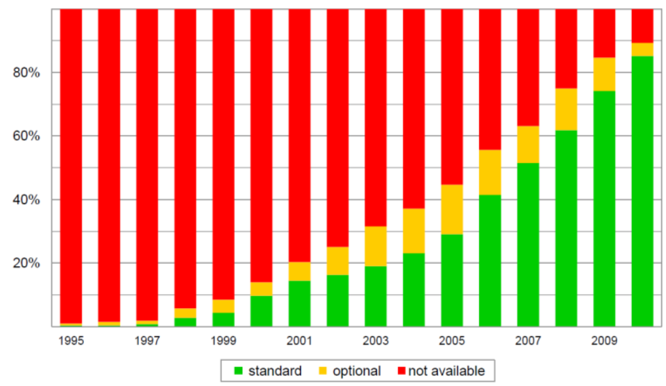
- ESC entered the market in the mid-1990s.
- By 2007, ESC global penetration stood at ~31% of light vehicles.
- By 2013, ESC global penetration grew to ~55% of light vehicles. Within that, North America was at nearly 100%, Europe at ~78% and Asia ~39%.
- By 2018, ESC penetration is estimated to grow to ~67% of light vehicles led by Asia and Europe, partially on approved legislation. It is worth noting, however, that automakers have adopted ESC well in advance of legislation.

Passive safety and ESC both serve as good guideposts for modeling the path of auto technologies that add tangible value to the consumer at an affordable price.

But as successful as they were in terms of adoption, neither ESC nor passive safety addressed the core of the problem—accident avoidance and mitigation. They also didn't necessarily appeal directly to consumer desires for fun and convenient driving.

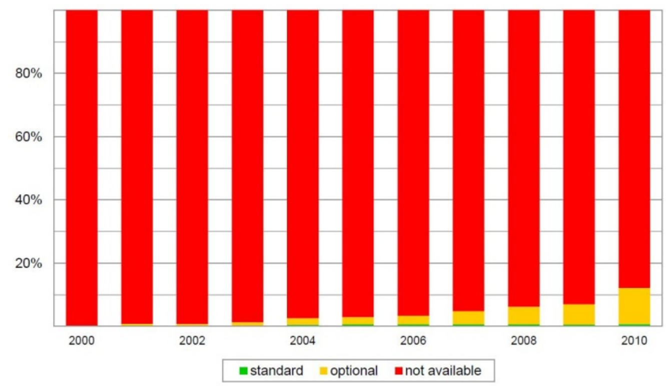
Enter Advanced Driver Assistance Systems (ADAS) and autonomous driving.

Figure 10. New Vehicle Sales with ESC



Source: IIHS

Figure 11. New Vehicle Sales with Forward Collision Warning



Source: IIHS

The "ABCs" of ADAS

While autonomous driving may not be commercially available for at least a decade, many of the foundation components involved are already in place with Advanced Driving Assistance Systems (ADAS). In the simplest defined form, a typical ADAS 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, we like to break the market down in two buckets: (a) Si*de-facing*/360 degree applications that perform blind-spot-warnings and related features; and (b) *Forward facing* applications that perform forward-collision warnings (FCW) with or without automatic emergency braking (AEB), lane-departure warning, adaptive cruise control (ACC), traffic jam assist, intelligent headlamp monitoring, turning assistance and more. These two buckets have differing technology options to help drive active safety forward.

Figure 12. ADAS Basics

Application/ Sensor Type	Video	Infrared	Long range radar 76-81 MHz	Short/ Mid range radar 24-26 / 76-81 GHz	Ultrasound
Adaptive Front Light (AFL)	X				
Night Vision (NV)	X	X			
Adaptive Cruise Control (ACC)	X	X	X		
Lane-Departure Warning (LDW)	X				
Low-Speed ACC, Emergency Brake Assist (EBA), Lane-Keep Support (LKS)	X	X		X	
Pedestrian Detection	X	X		X	
Blind-Spot Detection (BSD), Rear Collision Warning (RCW), Lane-Change Assist (LCA)	X	X		X	X
Park Assist (PA)	X			X	X
Traffic-Sign Recognition (TSR)	X				

Source: Texas Instruments

Some of the technologies used in ADAS include:

1. **Radar** (Radio Angle 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. 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. 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 like ACC stop/go and

Figure 13. Forward Looking Radar

Source: Delphi

traffic jam assist. 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, but the inherent challenges still exist. As a result, radar is: (a) unable to become a "one-stop shop" sensor for all ADAS applications and particularly those which emphasize lane/path departure; and (b) has experienced false braking scenarios that led to a number of recalls. In our view, radar will continue serving as the primary sensor for side-facing ADAS applications like blind-spot detection (this too, however, could eventually be challenged by LIDAR) but not for forward-facing applications where radar will likely be used mainly for redundancy purposes in a camera-radar fusion configuration—particularly as more advanced camera solutions and related applications emerge in the coming years. In automated vehicles, multiple radars will likely be used for surround redundancy as costs continue to decline.

2. **Camera** (mono/stereo) **& Machine Vision** applications have the inherent advantage of processing extremely rich data in much the same way the human eye does—in the sense that they can "see". Of course, this is easier said than done in that "seeing" requires tremendous advances in software ingenuity (machine vision) and computing power. 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), intelligent headlamp control (IHC), traffic sign/light recognition (TSR/TLR) and object classification. That meant that a camera was a "must-have" sensor for these applications regardless of its role in other ADAS applications. And since cameras didn't suffer from the same shortfalls as radar when it came to pedestrian/static object detection, the industry was faced with a key question — what if you could develop a vision solution that could perform forward-collision and related applications better than radar while still offering the core camera-exclusive bundles (LDW, IHC, etc.)? That, of course, would be disruptive to radar's dominance in forward-facing applications. But that wasn't the only puzzle to solve. Within cameras there were 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—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. Mono was initially seen as relevant but a much tougher engineering feat.

Technology Spotlight: Mono vs. Stereo Cameras

What is Stereo? The first key to understanding the stereo vs. mono debate is that stereo isn't a doubling-up of two monocular cameras. Rather, stereo uses two cameras in tandem to provide a good short-range depth/3D map of the environment. The 3D map is used for foreground/background segmenting, object detection/separation and range/range-rate estimation. The approach works well at close range and in good weather conditions. However, stereo camera systems possess a number of flaws. Range is a particular issue as stereo can best analyze a 40-50 meter field (vs. 150 for mono). But perhaps more severe is that the rate of error rises quadratically with distance based on the formulaic relationships tying disparity error to range error. Indeed, NHTSA studies comparing mono to stereo systems (Subaru Outback study) confirmed superior time-to-contact performance for mono. So why were/are stereo cameras used? In the initial ADAS range, we believe stereo was a less daunting engineering task for providing effective short-range capabilities. And since luxury vehicles are often the first to adopt new technology, stereo's higher cost (50-100% greater than mono) and bulkier packaging was likely considered secondary issues. Indeed, some of the OEMs that prominently feature stereo today include Daimler (Mercedes) and Jaguar/Land Rover. Of course, as ADAS mass adoption starts to occur, these are likely to become key limitations. As discussed further below in our new Europe ADAS Dealer Surveys section, price remains a key dealer feedback point around ADAS consideration.

Why Mono Wins: The early challenge for mono cameras was tied to their lack of depth cues which is required for target segmentation and therefore they was seen as a far more complex sensor to achieve adequate software capabilities. The software solution, pioneered by Mobileye, focused on using the laws of perspective by leveraging road geometry under the principle that the camera sits at a known height from a planar surface (road) and the objects of interest (cars, pedestrians) operate on that plane. Changes in the size of the image (similar to the human eye processing) were used to compute time to contact. By tracking certain features of an object in the individual frame (license plate, taillights), rates of change in size relative to the actual size enabled an estimate of the time to contact. This concept didn't only enable forward-collision applications but also adaptive cruise control and traffic jam assistance. Innovations in pedestrian detection using multiple classifier stages allowed for more robust pedestrian detection.

The result was a system that could perform ADAS tasks better than competing sensors for less. So let's review where we believe mono stands versus competing sensors:

- Radar only: From a cost perspective, we believe radar is generally comparably priced to cameras, though the range is quite wide depending on the radar's capability. But as discussed earlier, radar cannot perform the camera-exclusive ADAS functions (LDW, TSR etc.), so the capabilities are arguably insufficient to perform all tasks from a radar-only configuration.
- Stereo only: From a cost perspective, stereo carries an estimated ~50% price differential due to the need for two cameras and the associated processing power.
- Fusion: Combining two sensors will likely yield a cost differential vs. mono in the range of 50-200%, the low-end being a mono/LIDAR configuration and high-end being stereo/radar. For OEMs that insist on radar fusion, mono stands out as the most cost effective fusion solution.

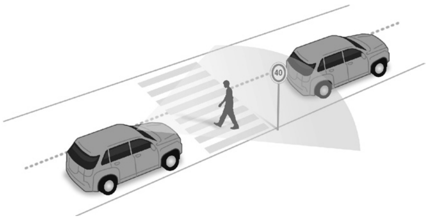
What's the Counter Point to Mono? We've had the opportunity to discuss the sensor debate with proponents of both radar and stereo vision. The counterpoint to mono by various proponents was fairly common—that improvements in radar and stereo were making great strides in both capability and cost. We have no reason to doubt these points. But some challenges were also acknowledged — stereo proponents noted that reducing size/weight was important but that doing so also entailed challenges in reducing the range of object detection upon narrowing the distance between the right/left cameras (i.e. the baseline length). What we didn't hear was a compelling argument for why radar and/or stereo were capably *superior* to mono with the exception of radar's claim to be less weather sensitive — valid but not a major swing factor, in our view. So even, for arguments sake, if we were to accept that all three sensors can reach a point of similar capabilities, mono still wins by virtue of its lower costs (one less camera than stereo + bundling efficiency with camera-only applications) and packaging (smaller than stereo, and internal placement vs. radar's external placement might be an advantage from an insurance perspective). To us, mono appears to be the most logical choice for mass global ADAS adoption. For luxury automakers who might be less sensitive to price, we would think that a solution like Mobileye's future tri-focal camera (discussed below) would also be more appealing than stereo due to its ability to perform automated driving tasks with 0% targeted error for AEB—likely worth the modest premium that tri-focal might carry vs. stereo.

Figure 14. Short-Range LIDAR

Source: Continental

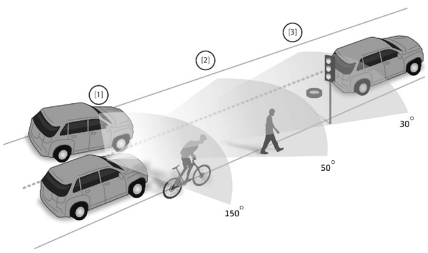
3. **Laser/LIDAR Sensors:** LIDAR stands for Laser Imaging Detection Ranging. As its name suggests, LIDAR emits laser light and analyzes the reflection in a similar concept as radar. There are different types of LIDAR. A relatively simple short range 3-beam LIDAR sensor has been used for autonomous braking at low-speeds, mainly in Europe. While effective for its designed mission and price point, the 3-beam LIDAR is unlikely to be competitive with camera solutions and therefore is unlikely to maintain its dominant position in low-speed emergency braking. Perhaps the most well-known LIDAR system today is the Velodyne scanning beam technology used in the Google driverless testing cars. The 64-beam 360 degree version used by Google has a reported cost of $70k and clearly isn't production ready at the moment. Similar systems using 8-lasers still carry a reported cost of ~$8-9k. However, low-cost scanning-beam applications covering a smaller field of view (145 degrees) are currently in development for commercial use. Auto supplier Valeo is developing (with LIDAR maker Ibeo) such a system that could be priced for mass adoption at what we estimate is a $200-300 range. Still, such systems, as we understand it, suffer from limitations in the vertical field of view and are not as rich in processing as cameras. Another company, Quanergy Systems, has also shown promisingly affordable LIDAR solutions for the coming years. "Flash" LIDARs are also worth watching as emerging technologies. ASCar Inc. is one of the leaders in this vertical. Flash LIDARs consist of an array of fixed laser beams that collect incoming data with an image sensor. The system promises lightweight 3D imaging with a single laser pulse and direct range calculation that doesn't rely on complex lens disparity as in stereo cameras. Cost remains a major issue as we understand it, and while major reductions are expected, the path and magnitude isn't entirely clear. Lower resolution versus cameras (e.g., 3x order of magnitude) is also an issue. That said, flash LIDARs do offer some promise and could play a role in automated vehicles particularly in side-facing applications where cameras can't be positioned as robustly. Industry forecasts suggest commercial availability perhaps by 2020. For this reason, in our market modeling (discussed later), we have not incorporated any side-facing share for camera applications. At the same time, we also have not assumed that scanning LIDARs will take any meaningful share as primary forward-facing sensors, but rather will serve as redundancy sensors in automated vehicles.

Figure 15. Mobileye Mono Camera



Source: Mobileye Company Reports

Figure 16. Mobileye Tri-focal Camera



Source: Mobileye Company Reports

Spotlight – Mobileye Takes Mono Further for Semi-/Full- Autonomous Driving: In our view, monocular vision will be the winner in mass ADAS adoption and early stage autonomous features like adaptive cruise control and traffic jam assist. However, more profound autonomous features will likely require a more robust sensor package. Mobileye's solution is the tri-focal camera, where design wins have already been achieved with two OEMs, expected to launch hands-free highway driving and congested traffic in 2016, and several others potentially launching in 2017/2018. The tri-focal camera covers a wider field of view for close vehicle cut-ins with a longer range for hazard detection. A wider field-of-view is critical for automated driving, particularly in complex scenes like country roads and cities. The system also possesses a "stereo-assist" function for redundancy — though the cameras do not work in traditional stereo. Initially, the tri-focal camera will be powered by multiple EyeQ3 chips before shifting to a single EyeQ4 in 2018. Although more expensive than mono, a case can be made that tri-focal might not only serve a role in autonomous driving, but also as a next-generation ADAS sensor due to its superior (albeit, more expensive) capabilities. This could particularly be true once the evolution of Connected Cars allows automakers to sell automated driving applications as subscriptions through OTA or "over-the-air" updates — a win-win for providing consumers both choice and superior safety and providing automakers a recurring profit stream through the ~15 year life of the car.

Over time, the camera(s) in the car could start being used for more than just safety and automated driving. Sparse recording could allow cameras to collect (a) critical intelligence in the scene; (b) road changes that mapping companies would find useful; (c) license plate or even facial recognition that law enforcement might find useful; (d) navigational intelligence; (e) real-time parking space intelligence, etc. When thinking about future advances in machine learning coupled with hardware and connectivity, it becomes apparent that we are in the early stages of the innovation pathway.

Figure 17. Comparison of Cameras, Radar and Ultrasound Sensors

	Cost ($)	Short range	Long range	Detection distance (m)	directivity	Weather	Outline
Cameras	Good	Good	5-20	Good	Poor	Good	Applications include AEB, ACC, LDW, and automated parking
Laser radar	Good	Bad	30-150	Poor	Bad	Good	Applications include AEB and ACC
Miliwave radar	Poor	Excellent	Excellent	Good	Good	Poor	Applications include AEB and ACC
Ultrasound sensor	Excellent	Poor	0.3-7	Good	Good	Excellent	Applications include automatic braking, parking assist, and theft protection

Source: Company data, TSR, Citi Research

Drivers of ADAS Demand

- **Regulations:** Much like successful technologies before it, ADAS is already seeing a gradual push by regulators to accelerate penetration. The EU NCAP (New Car Assessment Program) is leading the way having tied the highly sought after 4 and 5 star ratings to automatic emergency braking (AEB). By 2017, all 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 US, the NHTSA (National Highway Traffic Safety Agency) is reviewing adding AEB applications to their list of recommended features and commentary by key officials has generally been very supportive of ADAS. We expect US regulation to become solidified over the next few years, most likely in 2016-17. Besides the safety regulatory channel, it's not farfetched that ADAS might also play a role in future fuel economy regulations, particularly in the US where a mid-term Corporate Average Fuel Economy (CAFE) review is due to begin in 2017. Recent conversations with industry contacts touched upon data suggesting that equipping 1 out of 4 vehicles with adaptive cruise control and related capabilities could yield a 3-4% fuel economy improvement. Something to keep an eye on. The US Insurance Institute for Highway Safety (IIHS) has also been quite supportive of promoting ADAS through "Top Safety Pick+" recognition. China has also taken increased interest in adopting regulation and China NCAP was upgraded in 2013 benchmarking the Europe NCAP. All-in, regulations appear increasingly headed towards mandating ADAS adoption and accelerating the pace of standardizing ADAS equipped vehicles. For investors, ADAS regulations are of course very important, but we believe the "arms race" that's occurring in automotive coupled with the era of the Connected Car can push up adoption even without regulation. In addition to the regulations themselves, the specific safety applications being regulated are also important as this could have implications in the automaker sensor decision process.

Figure 18. ADAS Regulatory Timeline

Specification	Current Status	2013	2014	2015	2016	2017	2018
EuroNCAP	AEB City		Start rating AEB City				
	AEB Inter-Urban		Start rating AEB Inter-Urban				
	AEB Pedestrian				Start rating AEB Pedestrian		Night performance
	LDW/LKA		Start rating LDW/LKA				
	Speed Assist	Start rating SAS				Upgrade with regards to LKA	
JNCAP	Crash avoidance technologies		Low AEB for vehicles	Blind Spot (BS), Rear Crossing Traffic Alert (RCTA)	LKA; AEB Pedestrian	Night-time pedestrian warning	
KNCAP	Crash avoidance technologies	FCW/LDW			AEB Inter-Urban	AEB Pedestrian, AEB City, LKA, BSD, RCTA, ACC	
NHTSA/IIHS	Crash avoidance technologies		FCW, LDW	AEB Inter-Urban			

Legend: Current Version (grey); Decided or probable changes (yellow); Potential Changes based on what we know today (light blue)

Source: Autoliv Company Reports

Figure 19. Review of Global Safety Regulation Events

Year	Region	Outline
2013	North America	US NCAP adds points for LDW and FCW
2013	Europe	LDP and AEB made compulsory for large vehicles
2014	Europe	ECS made compulsory for all new vehicles
2014	Europe	Euro NCAP adds points for LDW and AEB
2014	Japan, Korea, Europe	ECS made compulsory for all new vehicles
2014	Japan	LDP and AEB made compulsory for large vehicles
2014	Japan	Regulations accelerate installation of LDW and AEB in commercial vehicles
2015	North America	Camera installation could be made compulsory under the Kids
2015	Europe	Euro modifies side camera ISO regulations
2016	Europe	Euro NCAP adds points for PD (Pedestrian Detection) and AEB
2016	Japan	Japan could approve side mirrors
2017	North America	North America approves side mirror cameras
2017	North America	US NCAP adds points for PD and AEB
2018	Japan	Japan could approve the use of autonomous parking assist
2018	Europe	Euro NCAP adds points for night-use PD and AEB
2018	EM Countries	EM country NCAP considers adding points for PD and AEB

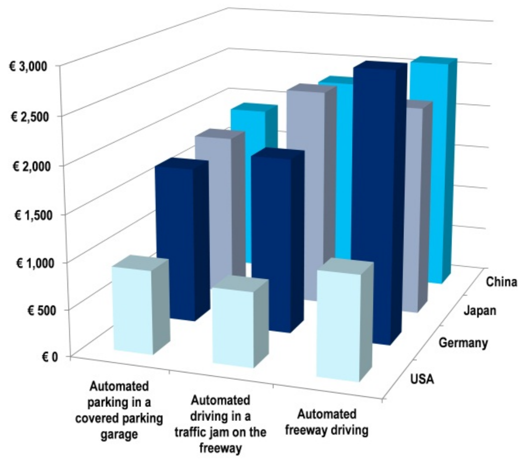
Source: Citi Research

- **Possible Future Insurance Savings (see our [Can the "Autonomous Car" Be a "Free" Option?] section below):** We discussed the economic toll of car crashes a little earlier and the toll drivers must bear with expensive insurance premiums. As ADAS penetration rises and begins to prove out in real-world reductions in claim frequency/severity, the potential for lower insurance premiums might also accelerate ADAS demand. To that, we were encouraged by an April 2014 study from the IIHS on the Honda Accord crash avoidance system (forward-collision + lane departure). In what was the first real-world US ADAS study on a high-volume/non-luxury vehicle, the results were quite impressive for reductions in claim frequency: 14% on property damage liability, 40% for bodily injury liability and 27% for medical payments. Importantly, the report also noted a significant reduction in collision claim severity for camera-based systems due to their placement inside the vehicle, in contrast to the externally mounted radar that's exposed to expensive replacement costs in minor accidents. This is indeed an exciting proposition, though Citi's Insurance Analysts remind us that such a scenario could take some time to play out as insurance companies must first gather and apply real-world data to actuarial models. But the opportunity is very real. Interestingly, unlike the fuel economy payback proposition that tends to vary with driving styles and gaps between rated vs. real-world miles-per-gallon, insurance savings are more set in stone and arguably more trustable for a prospective customer.

- **Consumer Value:** Of course, besides the potential insurance cost proposition there is the value ascribed by the consumers themselves. One can debate the "value" ascribed by consumers to pure safety attributes, but we do know that safety ranks highly in consumer preference surveys. A recent 2015 *JD Power US Tech Choice Study* showed clear preference for ADAS technologies over other offerings. Evidence does exist that consumers are willing to pay a premium for these. Studies presented by Continental, including as recently as July 2014, puts the consumers' expected price premium at >$1,000, which sounds reasonable to us considering the value versus similarly priced optional equipment. The *JD Power Study* suggested a willingness to pay in the range or $2,400-$3,700, depending on age group. This suggests, conservatively in our view, that the total consumer ADAS/automated package could be valued at around $2,400. Today, we believe the cost to an OEM (from the Tier-1 supplier) of a camera/radar fusion ADAS system ranges from $200-$300. If we also include side-sensors like blind spot detection, the cost rises closer to an estimated $650. Later we discuss autonomous vehicle sensor packaging, which we estimate will cost the OEMs ~$1,500. Even at this higher cost, the consumer value proposition matches up very well. It's no surprise that ADAS is showing up in advertisements at several of the OEMs.

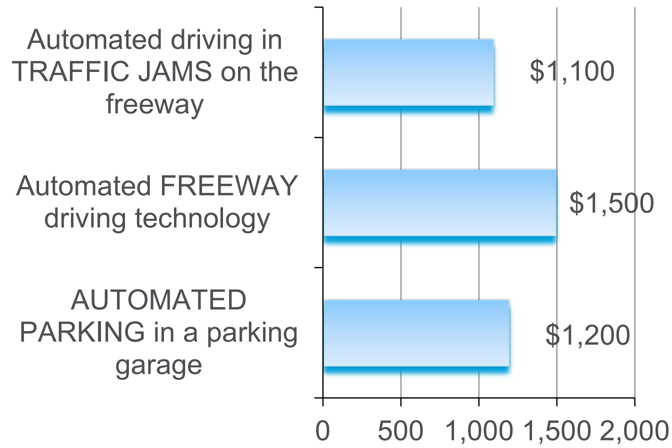
For these three reasons, ADAS continues to rank amongst the most attractive auto technologies under our "Car of the Future" investment framework.

Figure 20. Reasonable Price Survey on Autonomous Cars



Source: Continental, Citi Research

Figure 21. Consumer Price Survey on Autonomous Features



Source: Continental, Citi Research

Defining the Market and 3rd Party Forecasts

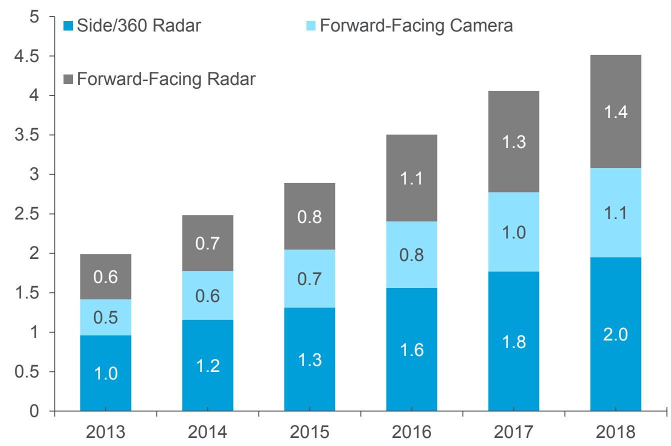
What exactly makes up the ADAS market isn't always consistently defined in the industry. This can sometimes lead to confusion around growth rates and company market share calculations. A key swing factor revolves around whether one includes/excludes park assist (i.e. ultrasonic) and rear-view backup cameras. We exclude these from our definition and instead focus on three core sensor buckets providing active driver assistance functionality: (a) side/360 radar; (b) forward-facing cameras; (c) forward-facing radar.

Below we provide industry forecasts for the ADAS market. Importantly, these are not Citi forecasts (which are discussed later), but rather a depiction of the "consensus" industry thinking around market growth. Per our definition of the ADAS market, we estimate the market today stands at roughly $2.5 billion, which is split fairly evenly between side-radar and forward-facing applications (radar + camera).

Most 3rd party forecasts peg ADAS market growth at 20-35% annually through the end of the decade. Within this, forward cameras/radar are forecast to outgrow side/360 radar due to regulations. As described above, we believe that forward camera (mono) will likely grow much faster than this industry rate, based on Mobileye's booked business through 2017 implying a CAGR closer to 60%.

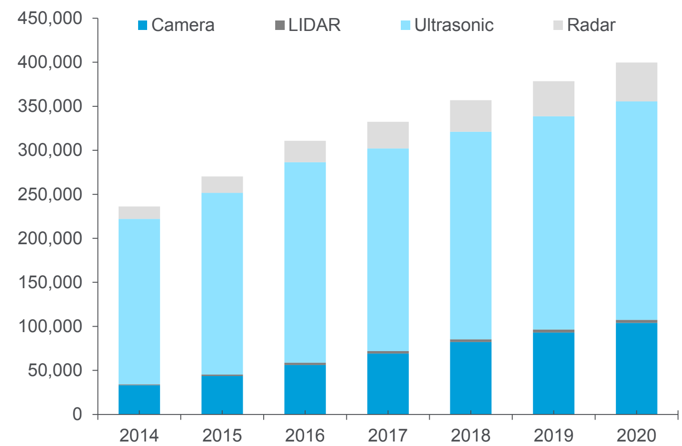
It is also important to note that a sharper inflection may actually occur in the latter part of the decade based on currently known and expected regulation.

Figure 22. ADAS Market Split & Consensus Outlook (Not Citi) ($bln)



Source: Strategy Analytics, Company Reports and Citi Research

Figure 23. ADAS Market Split & Consensus Outlook (Not Citi) (k Units)



Source: Strategy Analytics, Company Reports and Citi Research

Citi Market Outlook

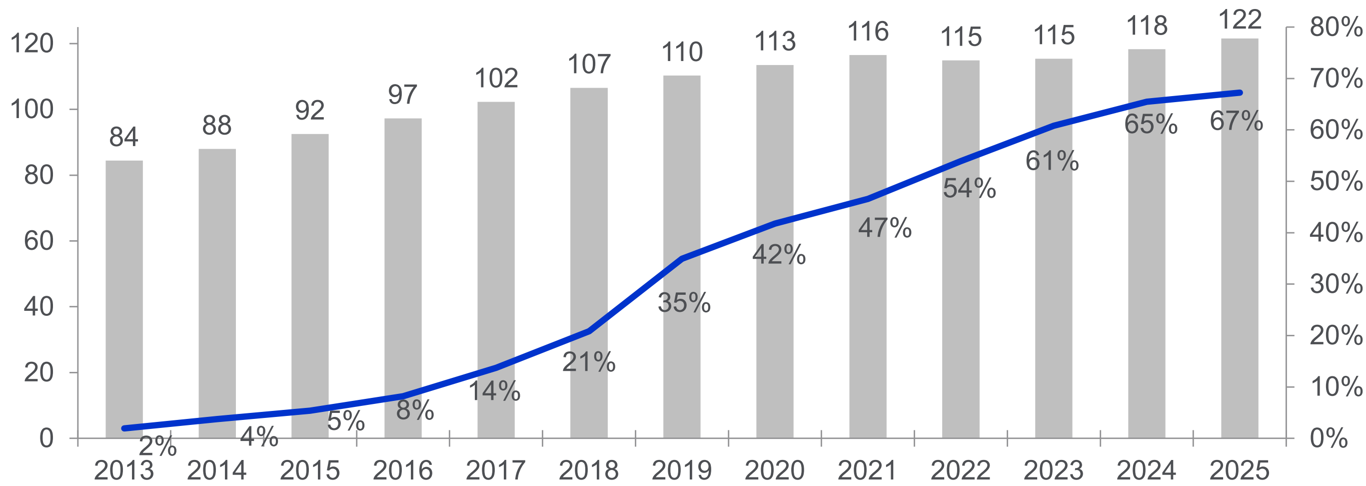
Within the broad ADAS market, our focus for present purposes is the outlook for forward-facing sensors. And since it is our belief that cameras have to be included (thanks to regulations and mono's disruptive capability), our market forecast is essentially a forward-facing vision penetration outlook. The mix between camera-only and fusion is less relevant for the penetration discussion, but we expect an initially balanced mix. Automakers with mono experience are expected to pursue a camera-only strategy — GM (including Opel), Audi, Nissan — while others are initially expected to stick with mono/radar fusion — BMW, Renault, Volvo.

Figure 24 models Citi's forecast for forward-facing camera ADAS penetration out to 2025. Our methodology first segments the global auto production market into an "ADAS likely" sub-market, separating typically high technology penetration regions (Europe, North America, Japan, Korea) from mid-penetration (Asia) and low-penetration (S. America, ROW) regions. We believe our visibility for bookings is fairly good through 2017 but beyond 2017, our modeling is based on a trajectory approach leaning on the ESC expansion as one guidepost. Our ADAS trajectory is therefore similar to ESC but somewhat faster to account for what we view as stronger consumer demand.

Our 2025 global ADAS penetration forecast of 67% remains below today's passive safety penetration rate and could still have some room for upside as prices decline.

Also, our market outlook presently does not include potential surround-view and rear-facing camera end markets. Surround-view, often utilizing "fish eye" cameras, provides drivers with 360 degree viewing for manual parking assistance but does not engage in much visual processing. This is an area of opportunity that we are not incorporating presently but are keeping an eye on.

Figure 24. Citi Forward-Facing Camera ADAS Outlook (Global Industry Light Vehicle Sales in Gray Bar vs. Penetration Rates in Blue Line)



Source: Citi Research, Company Reports

The ADAS Evolution: A Subscription Model

Convergence and Change Breeds Opportunity…: With Euro NCAP in place and the NHTSA recently endorsing AEB (automatic emergency braking), the question of regulation has become a matter of when, not if. The good news is that consumers are finding ADAS appealing and that appeal likely won't swing with the direction of oil prices, unlike in the field of propulsion. The other good news lies in the rapid advancements brought on by vision processing technology and embedded car connectivity, both of which are rapidly changing "old auto" economics. But the question remains whether automakers should wait for ADAS regulations to dictate adoption or "pull an F-150"[1] by leading the industry in an even more important part of the car—safety. And as they ponder this, automakers today must also contemplate the reportedly rising interest from tech companies in the automotive field. "Car of the Future" can and likely will become an arms race of sorts over the next three to five years. This tends to be good news for suppliers but also provides opportunities for automakers who can gain early mover advantages in areas where others cannot or will not lead.

…but Embracing the Opportunity Is a lot Easier Said than Done: Taking the leap to standardize highly profitable optional equipment (like ADAS) is bound to upset margin-loving analysts. Historically this has been true, but a lot is about to change. Think about it. 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, after a car is sold both parties risk leaving something on the table and this has consequences for both car economics and product strategy. Yet there might just be a path that makes everyone happy, and it sits in two areas:

1. In the field of ADAS/automation, recent advances in machine vision are allowing high-functioning ADAS and partially automated driving to be performed off a single chip/camera (i.e., Mobileye EyeQ3 & 4 solutions). This is a disruption that is only a few years in the making;

[1] "Pulling an F-150" refers to Ford Motor Company's decision to produce a fuel efficient aluminum truck years ahead of regulation. This has made Ford the de facto automotive leaders in that category.

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. And thanks to innovation, there's plenty left over to continue selling high-margin optional equipment at point-of-sale.

Let's touch upon these a bit more:

On ADAS and partially automated features…

- It is increasingly likely that advances in machine vision/learning and camera sensors will allow automakers to meet future regulatory requirements with lower-cost camera-only solutions. Applications most likely to be regulated include automatic emergency braking (cars, animals, pedestrians, cyclists, objects) and lane/path departure warning. The increasing role of camera-only sensors began in 2010-11 when automakers, including GM, began using Mobileye's EyeQ2 chip for camera-only forward collision warning applications. In 2013, BMW utilized an EyeQ2 for camera-only traffic jam assist and ACC applications. The recent launch of Mobileye's EyeQ3 chip is further extending this reach. In 2018, Mobileye is expected to launch an even more powerful EyeQ4 chip with increased procession power which is expected to support a much higher camera resolution with improved range, field of view and low-light detection. The EyeQ4 chip should also support multiple cameras thereby allowing automakers to leverage rear-backup cameras (mandatory in the US for 2018) for ADAS features.

- These improvements are increasingly making the mono camera a solution both for ADAS and basic partial automation. The former is likely to be regulated but the latter isn't. Non-regulated applications would include traffic jam automation (car takes over during low-speed jams), adaptive cruise control (ACC), rear-enhanced safety applications, high-beam control and road surface detection (dynamic suspension).

- Innovations in autonomous driving sensors (i.e. Mobileye tri-focal cameras) as well as redundancy sensors like radar/LIDAR will enable advanced semi-autonomous driving in the next few years. So automakers will have plenty of high-margin optional equipment to sell above-and-beyond the basic features referenced in the last bullet. Consumers wanting advanced automation will likely purchase it as an option while others could receive standard ADAS with subscriptions to basic traffic jam assist and ACC convenience applications. Seeing the far superior capabilities of advanced semi-autonomous driving (lane changes, exit-to-exit highway driving, city/country automation, 1st in traffic light, etc.), we do not believe a subscription model would create any cannibalization between advanced and basic feature sets.

On embedded connectivity…

- Today, automakers offer wholesale vehicles with option packages that can be thought of as guesstimates as to what consumers want. Sometimes the consumers themselves aren't sure what they want at the time of sale. This is a recipe that naturally leaves a lot on the table for both parties. Embedded connectivity allows the car to be "alive" 24 hours a day thereby allowing certain services to be sold throughout a car's life with software updates occurring as warranted. Once customers are given the option to purchase options at any time after the point-of-sale, the economics for adding certain standard features starts to make sense. ADAS is one of those features because: (a) both safety and convenience applications can run off the same software/hardware configuration;

and (b) there's a high value-add from being able to do sparse recording and over-the-air updating.

Putting it all together, we believe the innovations within vision-processing and embedded connectivity turn a normally risky standardization decision into one that can actually produce a respectable internal rate of return (IRR) and reap major branding benefits.

As for timing, we think a lot of this can occur in the coming two or so years, if not even earlier.

Introducing Citi's ADAS Subscription Model:

The basic concept behind Citi's ADAS subscription model is a business model where ADAS is sold standard and convenience applications (off the same sensor) 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:

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

- **(2)** GM offers 1-year subscriptions for customer access to convenience applications including low-speed hands-free traffic jam assist; moderate-speed adaptive cruise control, intelligent headlight control and road surface detection. With Mobileye's EyeQ4, chip GM could also package enhanced rear safety features on backup cameras (i.e. FCW in the rear using brake lights and seatbelt prep). 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. 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;

- **(3)** A key advantage with an embedded connection is the ability to do sparse recording that can actually help update/improve ADAS software periodically throughout the car's life. For GM, the ability to claim that its cars are constantly learning and adapting to a driver's common routes could become a powerful marketing tool and brand differentiator, not to mention a potential residual value boost versus unconnected peers. It could also support GM's efforts with usage-based insurance, lending itself to possible opportunities to offer customers insurance discounts.

- **(4)** As for costs, we assume a per vehicle cost of $220 including the mono camera ($130), possibly front/side facing ultrasonic sensors for short-range redundancy and close cut-in detection, as well as other components;

- **(5)** 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.

- **(6)** According to Polk data, new car buyers are holding their vehicles for just over 6 years, followed by 4 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 3&4) 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.

Citi's ADAS Subscription Model – Running with 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%, giving GM a 1st mover advantage by stepping in front of NCAP standards and the recommendation timeline – essentially "pulling an F-150". 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-OEM subscription platforms available in the automobile today; by this we mean that multiple global OEMs have Sirius XM useable hardware embedded in their vehicles versus OEM-specific hardware with subscriptions, such as GM's OnStar, Ford's Sync & MyFord Touch or BMW's ConnectedDrive.

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 25. 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

Figure 26. Citi's ADAS Subscription Model: Profit Driver 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	0.0%
2nd Used Ownership Convert Rate	-9.0%
Potential Reactivation Subs	0.0%
Monthly Churn	0.0%

Source: Citi Research

Cost Inputs: For costs, we assumed $130 for the mono camera system and $90 for other costs including possibly ultrasonic sensors for side/front short-range redundancy and close cut-in detection, 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 make 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.

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 IRR. **Based on the assumptions above we calculate an IRR of ~15% over the life of the vehicle**. This value excludes the likely 1st mover advantage benefit of offering standard ADAS equipment—branding, market share, etc.

Figure 27. 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

Should GM Do this? Pros & Cons (We Think Pros Win)

Pros:

- GM could leverage its early mover advantage in embedded connectivity to become the first OEM to standardize ADAS and do so with a profitable subscription-based model for convenience applications;

- Competitors lacking embedded connectivity would be unable, or at least less seamlessly able, to offer over-the-air software updates (making GM's cars smarter particularly as sparse recording starts to play in). If that means competitors cannot economically justify standardizing ADAS to match GM, then GM's early mover advantage could become meaningful for its brand and overall business.

- The benefits of being first to standardize ADAS clearly span the "brand, product, innovation perception," residual values and possibly even insurance considerations (OnStar recently announced a usage-based insurance product).
- The auto industry is evolving more rapidly these days with tech companies showing increasing interest in participating in one form or another. Every auto company must ask themselves whether they are truly pushing the limits of innovation. Yes, there are risks but every bold decision carries some risk. If there's ever a time, this is it.

Cons:

- **What if take-rates are poor?:** An investment of this size means GM is adding an estimated $500-$600 million in variable costs to North America, or ~50bp of EBIT[2] margin. The gap may be even wider considering that GM is likely earning healthy mark-ups on ADAS at the moment. However, with plenty of more advanced autonomous features coming in the next 1-3 years (highway w/lane change, country/city), GM would have no shortage of high-margin optional equipment to slot into product offerings. The basic automation features (traffic jam, ACC) would then slot in as either lower-price options or subscriptions as discussed above. So while standardizing ADAS would likely dilute margins initially, we believe it could be more than made up (IRR calculated at ~15%) over the life of the car thereby providing a small margin boost post-sale. Net-net this could be margin positive. And again, if ADAS is going to be regulated anyway regardless of macro conditions (I.e. oil price), why not lead?
- **Security:** By placing more product and brand reliance in connectivity, GM would be taking reputational risk in the event that security issues were to arise. This is clearly a major issue for the automotive industry. We don't claim to be experts here but our discussions with industry contacts and companies lead us to believe that the industry, including GM, is devoting significant resources to address this issue. In fact, one could argue this could actually become a competitive advantage for GM to the extent it can gain experience now on security thanks to its early lead with OnStar/LTE.
- **Privacy:** If GM was to aim for hands-free/eyes-off traffic jam assist and ACC, it might want to have some form of driver monitoring. A camera inside the car (which we believe is GM's intent with Super Cruise) could easily work, but would customers who opt-out of the subscription model be offended in seeing or knowing about a camera inside their car? That's indeed possible, but could be addressed with simple solutions such as designing an aesthetic cover to ensure customers that the camera is always disabled when the car isn't in automated mode. If not a camera, another option could be a touch sensor either on the steering wheel or gear shifter. We do note that industry surveys have shown an increasing willingness by consumers to share data if they are provided a value-add service in exchange (in this case free ADAS + 3 month free trial).

The Path from ADAS to Automated

Like the mixed definitions that exist for ADAS, autonomous or automated vehicles tend to sometimes be confused with driverless cars. Note that references to "self-driving" or "autonomous" cars do not imply "driverless" cars, which is an important distinction for thinking about this migration.

[2] EBIT – Earnings before interest and tax

Autonomous vehicles tend to be grouped into categories depending on the level of automation and driver involvement. ADAS tends to be considered Level 1 — 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. This next stage is likely to sweep the industry over the next 1-3 years. 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 (maybe 10 seconds). Think of the car driver playing the role of an airplane pilot. Level 3 is likely 4-8 years away but is currently deep into the development process.

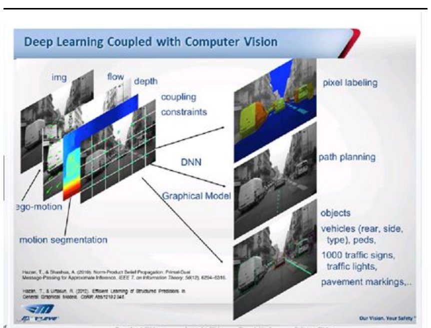
The final level — Level 4 — is a fully autonomous driverless vehicle. Most expectations peg this becoming reality in the early/mid-2020s. Beyond technical and cost hurdles, driverless vehicles pose challenges from regulatory, legal and security perspectives. There is a healthy debate around Level 3 versus Level 4 vehicles — will drivers even want to give up the joy or driving? But what about mobility models like driverless taxi-speeds (particularly at a safer low-speed) or mileage efficiencies in the fleet as cars start operating without occupants? And what is the cost premium for going from Level 3 to Level 4? It is clearly too early to fully tackle all of these questions, but we do believe there are some compelling use cases for an eventual driverless vehicle, particularly in fleets and 2nd/3rd car replacements. Google's efforts in this area will undoubtedly be monitored closely and in doing so likely establish greater consumer awareness of ADAS and autonomous vehicles.

Figure 28. Company Activities Related to Automated Driving Technology

Now	ADAS: A critical line of defense but doesn't drive the vehicle. (FCW, LDW, ACC, TSR etc.)
Leap 1: 1-3yrs **(2015-2017)**	All ADAS + Automated braking, Automated throttle, Automated steering with forward vision and GPS connectivity Key App = Auto Highway Piloting. Mobileye expecting to launch with tri-focal with 2 OEMS in 2016/17 with 6 others potentially in 2017/2018, likely using EyeQ3 chips initially until the 2018E launch of EyeQ4
Leap 2/3: 4-8yrs **(2018-2022)**	Car can accelerate/brake/steer by itself through transitions, lane changes, intersections, country roads and cities. Driver operates like today's pilots do; standing by to take over in case of emergency or system failure We believe this will be the key leap that Mobileye will pioneer with EyeQ4 in 2018.
Final Leap **(2022+)**	Driverless car. Versus Leap 2/3, key issues relate to legislation, security and incremental cost vs. consumer demand. We see a strong case for low-speed applications like taxis and car pooling, but mass adoption case unclear yet. Google's strategy appears geared towards reaching directly for this leap

Source: Company Reports and Citi Research

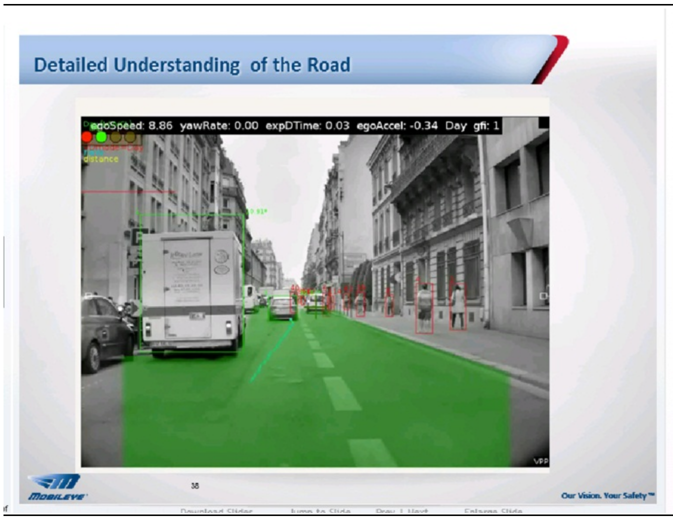
Figure 29. Mobileye: Deep Learning w/ Computer Vision



Source: Mobileye

ADAS to Automated Requires Environmental Modeling & Path Planning: What makes Mobileye unique is that its DNA has always been rooted in machine vision, a field that's undergoing major advancements specifically in the area of machine learning. By "learning" the purpose is to interpret representations holistically in much the way humans do (related architectures include convolutional networks). We believe Mobileye has developed algorithms for compact deep layer networks that consume limited chip capacity —with expected availability in 2015, not out there in the future. Just as Mobileye pioneered machine-vision algorithms for mono (leading to ~80% share), it appears to be doing the same in the emerging field of deep layer networks. Mobileye's Deep networks are responsible for: (a) free space pixel labeling; (b) holistic path planning; (c) general objects; (d) 1000 traffic signs; and (e) pavement markings.

Figure 30. Road Detail



Source: Mobileye

Figure 31. Free Space Pixel Labeling

Source: Mobileye

Convergence between ADAS and Connectivity Helps as Well: Today, ADAS is sold and marketed as an on-board system that alerts drivers to potential dangers and provides select driver-assist capabilities. Meanwhile, the topic of "connectivity" is mostly referenced in infotainment discussions. Clearly, a Connected Car also brings plenty of game-changing elements to the safety table. For example, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2X) communication is winning early regulatory and consumer support. Using DSRC — Dedicated Short Range Communication (similar to WiFi) — cars can quickly share critical safety information with each other before onboard ADAS systems can detect them. DSRC capabilities could also be enhanced by cellular connections such as GM's OnStar 4G LTE rollout. According to the US Department of Transportation (DOT), connected vehicle technology addresses ~80% of crash scenarios involving non-impaired drivers. The application would be useful in many scenarios, but particularly in intersections, traffic lights and school zones. In August 2012, the DOT launched a Connected Vehicle Safety Pilot deployment in nearly 3,000 vehicles in Michigan. The NHTSA has already noted that it will soon begin working on a regulatory proposal to require V2V devices in future years. It should be noted that the NHTSA's work to date has focused solely on light vehicles; we are not aware of similar test studies yet undertaken for commercial vehicles.

Can the "Autonomous Car" Be a "Free" Option?

We do believe that "autonomous car" highly advanced active safety solutions can in fact be a "free" option. The key is to remember that ADAS isn't just a regulatory-driven content story, but also a value-add for consumers. However, for the "self-driving" multiple sensor-vehicle, the cost to consumers can be pretty high. Currently ADAS systems retail at $600-$900 for basic capabilities (blind-spot detection, cross-traffic alerts) and $1,000-$3,500 for additional forward-collision, adaptive cruise control, lane departure capabilities and advanced displays such as heads-up. Today, the market is utilizing just a few sensors such as vision, fusion, radar fusion, ultrasonic and LIDAR, but when looking at what will be required for a "self-driving" vehicle we believe more emphasis will be put on redundancy (tech overlap to eliminate false positives or false negatives), as such creating the need for more sensors. Looking out to the future — the 2020-2025 period — we believe the cost to

an OEM for a "self-driving" sensor package may run ~$1,500. Typically an OEM would mark this up and sell it for >$2,700 to the consumer, but we believe there is another way: a subscription based model where an OEM offers the package at cost, essentially allowing the consumer's insurance savings from increased active safety content in their vehicle (assuming a ~15% premium reduction) to fund the option purchase price.

What if these OEMs offered these highly advanced "autonomous car" systems at cost? The recent Volvo "Drive Me" program got us thinking about how the subscription-based model would apply to highly advanced vehicles, say, in the 2020-2025 period. The most likely 2020-25 industry condition sees ADAS offered as standard equipment and "autonomous car" packages slotted as optional equipment. Note that we're not referring to driverless cars but rather cars with fully automated features. In today's automotive business model, automakers sell such optional equipment at a healthy mark-up; yielding a lucrative profit stream but often combined with low consumer take-rates. We believe this go-to-market strategy will change meaningfully for anything software related, as over-the-air updates will become a means of selling services to consumers throughout the life of car (and that life is getting longer each year). ADAS and autonomous driving fit perfectly into this. At the same time, the potential for consumers to qualify for insurance discounts could materialize sometime next decade once sufficient data is accumulated; this is based on discussions with our Citi Research Insurance colleagues. Autonomous cars are often described in the context of convenience and new mobility concepts. However, their foremost value still lies in significant safety gains. Indeed, Tesla CEO Elon Musk recently noted that "it's going to be the default thing, and it will save a lot of lives".

The significance here is that even modest insurance savings of say 15% could fund the estimated cost of an autonomous car package. Where the automaker would then realize profit would be through over-the-air subscriptions over the life of the car. Based on our modeling, we believe this offers a more lucrative profit stream versus today's go-to market approach.

The Insurance Dynamic

When it comes to insurance and ADAS, our discussions with colleagues and industry contacts yield two observations: (1) some form of future discounts are quite feasible; and (2) it will take time, a lot of time, for the insurance portion of this to play out since much data needs to be collected and analysis must still be performed. This suggests to us that insurance discounts likely won't play a major role in the near-term ADAS adoption story but could become more instrumental in the next decade particularly once more advanced autonomous cars (not driverless) start to gain in penetration. The other key consideration that could conceivably further this along is that Connected Cars could allow for safety software improvements throughout the car's life, thereby ensuring the latest safety updates are always on the car.

Figure 32. Insurance Savings Summary

Cost of Insurance/yr	1,700
per month	142
Adv. ADAS Discount	15.0%
Adj. Annual Premium	1,445
savings	255
per month	21

Source: Citi Research

We believe that a 15% discount to a customer's insurance premium is theoretically reasonable. To help validate this we looked at some current programs offered by insurance providers that leverage a vehicles 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, which is a mere 1.4%-8.2% of total initial vehicle ownership, assuming 6 years of initial ownership.

Figure 33. Insurance OBD-II Plug-In Discount Solutions

	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

**initial discount typically phased out after you lock into your final program discount*

Source: Citi Research

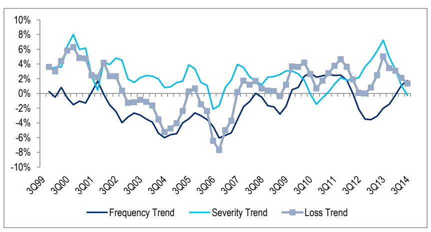
Figure 34. Adv. ADAS Package Financing

Amnt Financed	*1,500*
Rate	*4.5%*
Duration (m)	*66*
Monthly Pmt	*(26)*
Annualized	(309)

Source: Citi Research

The 15% discount we assume in our 2025 autonomous adoption model is in line with the average savings for customers making use of these insurance plug-in products.

Figure 35. Auto Frequency is Already Mostly Negative (-1.6% Avg.), Offset by 2.6% Severity



Source: ISO Fast Track, Citi Research

Further Validation of our 15% Discount

Directly from Citi's Insurance Analyst

Before we address the longer-term more subjective scenarios about driverless cars, we need to think about the more realistic situation over the next 5-10 years, where we are likely to see the introduction to driverless cars, but more importantly, see the continued rollout and penetration of *semi-autonomous vehicles*. These vehicles will incorporate even more safety features than we see today, including self-braking and object avoidance. So we should examine these more likely changes. To do so, we must recall that declining auto frequency from greater "safety" is already something that most observers believe is occurring. Since 2000, personal auto frequency has averaged -1.6% per ISO Fast Track, with considerable volatility. But severity has been higher than this at about 2.6% on average, and again quite volatile, driven in part by more expensive technology going into automobiles. So in the early days, it could be quite difficult to even know whether additional changes to loss trend are happening.

We estimate the cost of a (semi-)autonomous car insurance policy would be 10-15% lower than a standard policy. We make a number of assumptions, which have been laid out below. Keep in mind that we are still in early days here, where autonomous, semi-, and manual will all still be sharing the roads.

Cost of autonomous car assumption: First off, we assume consumers will simply wait until the new technology becomes affordable to the masses, implying no change to the $25,000 cost of the average new vehicle. In other words, we assume a luxury consumer would rather spend $100,000 on a high-end vehicle and drive it themselves, than spend $100,000 on an economy car that can drive itself. This is why the semi-autonomous assumption is more important near-term.

Frequency decline assumption: We assume an eventual 30% average decline in frequency from our (semi-)autonomous car. There are a few things to remember when considering the impact on insurance pricing from this decline. Liability coverage, which protects the other driver and their property when you cause an accident, will never be $0, even if the driverless car can't cause an accident. We estimate there is about a 15% administrative fee baked into liability coverage.

Secondly, no insurer will write a policy and assume zero chance of its driver causing an accident, even with a (semi-)autonomous car. Plus, many people will want to maintain control of the wheel and override the capability of their autonomous car, and this feature will likely be required for a considerable period. Third, there are pieces of individual policies that will be unaffected by reduced frequency such as Personal Injury Protection (which covers the driver and passenger's medical bills, plus those of any involved pedestrians upfront) and Comprehensive Coverage (protects your car in the event of theft, fire, flood, hail, deer etc.)

Severity increase assumption: We assume a 10% increase in severity from our (semi-)autonomous car. As previously stated, we don't think the average price of the car will change all that much, since there are limits to what consumers can afford. Instead, we assume the cost of repair of the (semi-)autonomous car will be 10% higher, since ordinary parts will now include sensors that are the crux of the (semi-)autonomous car technology. Moreover, repairing this technology may require special training and equipment, which will also drive up costs. As with frequency, we assume there are components of the cost of an individual policy that will be unaffected by the higher cost to repair the drivers own autonomous car, such as Liability, Uninsured Motorist, and Personal Injury Protection, which largely protect the other driver and pedestrians.

Citi's Subscription Model for Autonomous Driving

Methodology: We've expanded our previously discussed ADAS subscription model into autonomous cars, assumed for the 2020-2025 period. We simulate a go-to-market model that sees OEMs offer autonomous packages essentially at cost ("free" to consumers when factoring in insurance savings) while deriving profit from subscriptions to autonomous driving services such as traffic jam assist, hands-free highway driving, and complex city/country road applications. This would be a car that could drive itself but still requires the presence of a driver in the event of a required takeover. Because of the car's sophistication, human-machine interface (HMI) applications like augmented reality would presumably enable consumers to take on other tasks during the drive under certain conditions (i.e. hands- and eyes-off traffic jam assist and non-complex highway driving conditions).

Figure 36. Vehicle Ownership Cycle

Ownership Periods	Year
POINT OF SALE	0
↓	1
	2
	3
	4
	5
OWNERSHIP CHANGE	6
↓	7
	8
	9
	10
OWNERSHIP CHANGE	11
↓	12
	13
	14
	15

Source: Citi Research

Figure 37. Citi's ADAS Subscription Model: Profit Driver Input Assumptions

Inputs				
GM U.S. Sales	2,596,000			
Advanced ADAS penetration rate	*44%*			
GM U.S. Sales w/ Advanced ADAS	1,142,240			
Avg. Length of Own - New (Yrs)	6.0			
Avg. Length of Own - Used (Yrs)	4.3			
Adv. ADAS Sub Cost Per Year	$281			
memo: Siri All Access/yr	*$199*	*New Rate*	*Used 1 Rate*	*Used 2 rate*
High - All Features	$399	*9.9%*	*5.0%*	*2.5%*
Mid - Highway Auto Driving	$259	*12.4%*	*6.2%*	*3.1%*
Low - Traffic Jam Asssit	$199	*11.0%*	*5.5%*	*2.7%*
New Vehicle Conversion Rate	33.3%			
1st Used Ownership Convert Rate	16.6%			
2nd Used Ownership Convert Rate	8.3%			
Potential Reactivation Subs	1.2%			
Monthly Churn	-2.0%			

Source: Citi Research

The Model Inputs: To assess potential penetration for these vehicles we utilized a *Boston Consulting Group*[3] survey and comparisons of other optional equipment such as heated/cooled seats, rear-view cameras and navigation. Using these inputs we estimated an autonomous car "attach-rate" of 44% — meaning that 44% of the automaker's volume opts-in for this feature while the rest receive ADAS as a standard fit. For the 44% opting in, we assumed that the automaker would offer three subscription packages in low, mid and high price points, after some free-trial period: (1) a highly autonomous solution (all self-driving features); (2) a mid-level autonomous solution (hand-free highway driving, no lane change); and (3) a low-level autonomous driving solution (traffic jam assist). In order to assess take-rates on these features, we went back to *Boston Consulting* surveys covering willingness to pay. We concluded that 33% (of the 44%) was a reasonable estimate for those opting into subscriptions for their newly purchased vehicles. Those not opting-in might still enjoy basic features like surround-view and self-parking plus enhanced safety benefits, while leaving themselves the option of subscribing later on. Similar to our ADAS model we marked down the subscription rates for the 2nd ownership cycle by 50% (to 16.6%) and the 3rd ownership cycle by another 50% (to 8.3%). For cancellations and reactivations, we utilized rates in-line with Citi's Sirius XM subscription model. For price points we also used surveys measuring consumer willingness to pay — leading us to assume a $199 annual subscription for the lower-end service (traffic jam assist), $259 for the mid-level (hands-free highway) and $399 for full-automation. Of the 33% assumed to initially opt for subscriptions, we assumed 12 percentage points (ppts) opt for mid-level, 11ppts for higher-end and 10ppts for low. We view our assumptions to be prudent.

The Model Outputs: We ran this particular model on GM's US business, although clearly by 2025 most if not all automakers will likely be capable of this, if not sooner. The model suggests that the total subscription revenue stream over the life of the car (15 years) would approach $740 million. Under today's approach of doing large mark-ups at point of sale, the automaker could earn a $1,200 profit per vehicle but then settle for low-take rates of 10-20%, and that's probably optimistic. This would suggest a profit potential of $300-$600 million, or $450 million at the mid-point. The subscription approach suggests a profit pool roughly 50% greater. Of course, the consumer could be offered both—those adamant about wanting the features without being bothered by subscriptions could pay up front, while others could do so later. Either way, for the automaker the optionality of future earnings rises rapidly, while the ability to get more vehicles on the road would be beneficial both for data collection (to improve the fleet), as well as fuel economy and safety.

[3] Boston Consulting Group. Xavier Mosquet, "Trends in Automotive, October 10, 2014.

New Mobility—Why Now?

Many of the megatrends discussed in this report will occur gradually and in a series of steps. The timing for some trends like ADAS and automated driving could surprise to the upside, while other trends like electric vehicles (EVs) will naturally be constrained by required lengthy capital investment. However, we believe all will eventually culminate into three industry inevitabilities that will redefine the auto industry:

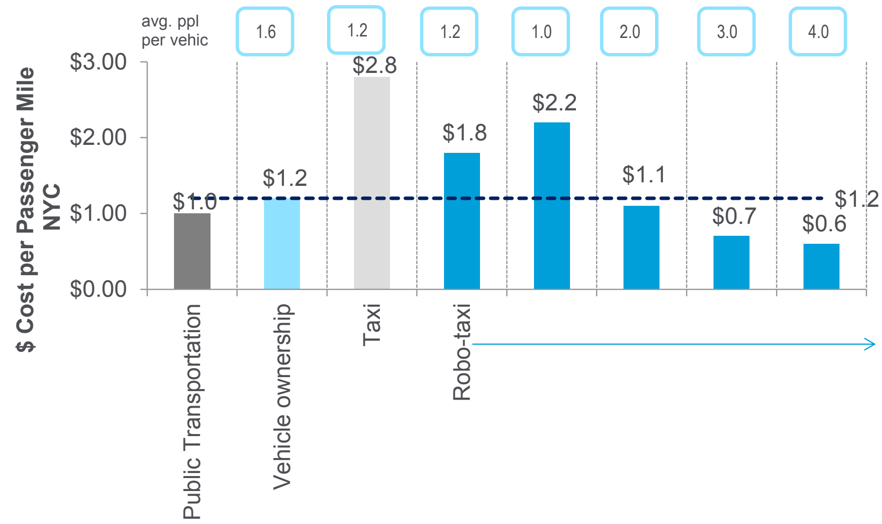
1. The vast majority of developed market vehicles will have automated features in some form. The term "automated" doesn't necessarily mean driverless though both can coexist. Vehicles with nearly full automation capability are only a few years away from production. Driverless cars are probably several years away but the technical path should become apparent soon. The fully automated and eventually driverless economics will likely redefine how we think about cars and segmentation. Vehicle segments could become broadly defined by personal mobility vehicles (like today), pure mobility vehicles and dual personal/mobility vehicles. Personal mobility cars would allow on-demand access to automated driving, mobility cars could come in the form of driverless low-speed taxi pods offering mobility-as-a-service and dual personal/mobility vehicles could allow consumers to own cars but at times rent out miles in exchange for a fee.

2. The economics of EVs will become competitive or even disruptive to internal combustion engines, as battery costs likely decline to $100-150 per kWh sometime next decade. High capital intensity will dictate the shift to be more linear than exponential.

3. The economic value of the car will shift from mostly exchanging dollars at point of sale to extracting value from the car throughout its life — from pay-per-mile services, autonomous driving features sold as subscriptions (that we've previously written about) to advertising and data collection.

Said differently, cars are poised to slowly but surely become more profitable both from a top-line sense (Connected Car), a consumer proposition sense (lower fuel & insurance outlays) and costs (software vs. hardware). For investors, this provides both opportunity and risk — some of which are more obvious than others.

Figure 38. NYC Case Study on Robo-Taxis



Source: BCG, Citi Research

*https://www.bcgperspectives.com/content/articles/automotive_consumer_insight_robo-taxis_new_mobility/

Mobility as a Service

Mobility services are such as Uber and Lyft are already growing rapidly and changing certain industry norms by providing simpler and less expensive access to miles. The impact has been wide-ranging in shifting the way consumers plan on getting from A to B. The near-term impact to the automotive industry from this is positive, in our view, because at some level these services shift car demand from low-margin fleets (i.e. taxis) into the retail channel, allowing for "taxis" to compete on the basis of the car and driver experience — something we've already observed amongst Uber drivers. Also, in major cities where car density is below the national average, these services can increase mobility consumption amongst those who wouldn't have otherwise consumed it — whereas before a trip outside a city might have meant public transport or time consuming rental cars, mobility services are providing new & affordable options. That's a good thing.

How about the long-term? Can mobility-as-a-service alter car ownership dynamics as know it? What about once we enter the era of driverless low-speed taxis? And if so, what are the implications to the automotive industry?

On the first point, in the US a case can easily be made that mobility vehicles could result in lower car/household density. This is a topic we've long documented in our proprietary survey work, where we've documented US density declines and their related causes. Already we've seen 34-44 year-old households increasingly reluctant to add a second car, and this anxiety, which we feel is largely confidence driven, can to some extent be addressed by mobility services. While Uber/Lyft have not specifically come up in our survey work as causes for this reluctance, there's no question to us that these services can lower the sense of urgency to buy a second car. As for the 18-34 year-old group, our view tends to be different than what is often described in media channels. Our published surveys have shown that 18-34 year-olds actually seem quite intent on adding a personal mobility vehicle (most likely their first) when economic conditions are improving, as first car ownership still offers the appeal of instant freedom of mobility.

Of course, neither our surveys nor consumers have yet contemplated a future of driverless, presumably low-speed and electric, taxi pods. Our working assumption is

that such vehicles could start making their way into major cities sometime next decade. While driverless driving in cities is more complex versus other theaters, it is a more natural low-speed environment offering high utilization and a rich opportunity from Connected Car services. Driverless vehicles could also serve in suburbs located close to cities particularly as services that can transport people to public transportation stations, eliminating the need for a certain commuter cars. Incidentally, while such vehicles might indeed be driverless, they do not have to be human-less; as competition could differentiate on a number of levels from the car/pod itself to a person serving refreshments etc. From a cost-per-mile perspective these vehicles could be game-changers in how consumers contemplate personal vehicles versus mobility service.

So how do we quantify this and what are the implications to the auto industry? As noted above, new mobility vehicles could eventually call into question the need for a second or third commuter car as well as car ownership in densely populated areas. There's little question that the net result will be some degree of pressure on cars per household. But the difficult part in these exercises is to determine whether consumers will actually act rationally. In the US, for example, we already own more cars than we probably "need", and the recent uptick in miles-driven suggests that the demise of the love of driving was a premature narrative. While density has declined from the pre-recession peak, American consumers have not yet been willing to return to 1980s/90s levels, suggesting that multiple car per household ownership, while at some levels economically irrational, has remained a priority for many. And it is key to note that some of the automotive megatrends discussed in this report make cars more fun to drive (EVs, turbos), safer (ADAS) and cheaper to operate (MPG, EVs, autonomous)—all of which might inspire increased personal ownership. So there's a real arm wrestle that will unfold here.

Back to the numbers: Precisely assessing how many personal use vehicles can be classified as "commuter cars" is far from straightforward, though understanding exposures to cities is a little more straightforward. For example we estimate that US vehicle density in major cities is roughly 70-80% that of the national average. The top 30 US cities sport a population of 39 million people, suggesting that ~23 million vehicles reside in them, or ~9% of the total US light vehicle population. That is not insignificant. However, at the same time it can be argued that owning personal cars in some major US cities is an economically irrational decision to begin with, so is mobility-as-a-service enough to change that? Our working assumption is that the density disruption will first be felt by taxi fleets themselves followed by non-luxury segments within personal use vehicles.

But it does not end there. Mobility-as-a-service also naturally increases society's access to miles. And since the car business is ultimately about selling finite miles and a user experience, both the addressable market plus transportation share (vs. other modes) could gain here. Of the ~316 million people in the US, ~251 million are of driving age, of which ~212 million have driver's licenses. So that leaves ~39 million driving-age folks who might not be consuming as many miles as they'd like either because of age, disability, location or other factors. So if 40% of the ~39 million people who are arguably under-consuming miles began consuming 2,000 miles each year, US auto demand would stand to benefit by about 173,000 units, in rough terms. Then there is the share gain from public transportation and even carpooling, which still combine for ~15% share of a typical US commute. If mobility-as-a-service proves to have a lower per-mile cost and an added convenience feature (with automated/connected vehicles minimizing traffic jams), this too could yield some share gain for mobility-as-a-service.

Ultimately the simplest way to quickly estimate normalized light vehicle demand is to consider miles-driven and the average life (in miles) of a car. In the US, for

example, the last-twelve-months vehicle-miles-driven is approaching 3.1 trillion miles. At an assumed vehicle life of 180,000 miles (a 15 year life at 12k miles driven/year), annual normal demand should amount to 17 million units. Miles-as-a-service promises to take vehicles off the road and better utilize the fleet, and that will likely happen. But at the same time we have argued that these services could increase total miles driven. What you end up with is a smaller fleet of vehicles on the road but a fleet that is being utilized much faster and therefore being replaced faster. Modeling the velocity of this path remains premature and fraught with uncertainty, but like many disruptive trends in automotive it won't happen overnight. If the end result is an increase in miles-driven, vehicle demand would still rise versus today's normalized rate (5% miles driven increase = 16.9 million units).

Implications to the Traditional Automakers

The three inevitabilities described above suggest both good and bad news to global automakers. The good news is that over the next 10 years the car business stands to arguably become more profitable for the reasons described above —connected car revenue, self-funding ADAS/automated cars, lower EV costs etc. The bad news is that the shift from hardware to software will also reduce historically high barriers to entry. To be sure, mass producing cars is something no Silicon Valley company has yet threatened to do; in fact recent comments from Tesla CEO Elon Musk (Q4 earnings call) seemingly acknowledged the increasingly complex risk profile that comes alongside higher production rates. As we see it, the automotive market could become distinguished by three broad categories:

1. **Personal Use (and Staying There):** Segments including pickup trucks, SUVs, vans, large crossovers, large cars and luxury are most likely to remain primarily personal use vehicles. These are essentially vehicles that inherently provide utility to the end-user (larger families, towing) or luxury that consumers will irrationally refuse to abandon. Larger vehicles also tend to be more overweight in US regions that are arguably not first in line to widely adopt mobility-as-a-service.

2. **Personal Use (at Risk):** Traditional mass market vehicles like small cars, midsize cars and crossovers. While most are likely to stay as personal use, here you would have those commuter cars and non-utility cars where the main purpose is getting from A to B.

3. **Mobility Vehicles:** Fleets of vehicles offering a miles-as-a-service concept run by driver operators like Uber, eventually morphing towards low-speed driverless pods run by fleet managers including traditional automotive players, companies like Uber, other Silicon Valley players or even partnerships across all. Each side arguably needs the other so we do not view this as a winner-take-all setup at this point. For instance, software and branding could be done by tech companies while manufacturing, fleet management and service by automotive companies. This is where dealer real estate also becomes more valuable — even driverless vehicles need tire rotations. Since competition will likely intensify rapidly, there will be plenty of optionality in partnerships, collaborations and differentiation.

It's also possible to have a mixture between these segments. For instance, in theory a driverless-capable personal use vehicle could be loaned to a fleet company (like Uber) during certain hours of the day in exchange for a fee. That would leave the service burden at the hands of the personal owner while allowing the fleet service company to manage supply and demand. Profits earned by the personal owner could help fund the cost of the more advanced technology.

For the US automakers, mobility-as-a-service doesn't currently appear to be a threat since our current working assumption is that profit-critical trucks/luxury segments likely will not foreseeably be impacted. But other segments could be, and as such, it is important that traditional automakers explore partnerships to leverage this trend. Automakers have a large seat at the table as expert manufacturers with large dealer networks — mass auto production is a venture many outside of automotive would probably like to avoid. The challenge is to accept newer players and achieve buy-in from all stakeholders. Connected autonomous vehicles (driverless or not) naturally lend themselves to a fleet network approach and there are some compelling long-term reasons for removing excess vehicles from the road in order to drive higher fleet utilization.

Implications to Suppliers

Much like the three segments described above, we believe investors will increasingly distinguish long-term suppliers into the following broad categories:

1. **Leading autonomous/connected car software providers and integrators:** This would include companies at the core of enabling automated driving including V2V, connectivity management, human-machine interface (HMI), infotainment and related areas in sensors, connectors. This of course might also include fleet managers in partnership with automakers.

2. **Leading propulsion hardware & software providers:** We've previously written about the disruptive forces of electrification of the vehicle, but the capital intensive and slow-moving nature of the auto industry will continue to allow for many years of multi-class propulsion innovation.

3. **Those with some risk for de-contenting**: We first wrote about de-contenting risk in last year's Car of the Future report. To be sure, this is something that takes considerable time to play out. Areas at risk might include passive safety, mirrors, certain materials and to a lesser extent steering systems.

4. **Business as usual:** Some things won't go away and that's a good thing in an industry undergoing slow but disruptive change. Seats, tires, manufacturing-related, HVAC, interiors etc. As we pointed out last year, these often thought of "commoditized" group could become better appreciated for the lack of disruption risk.

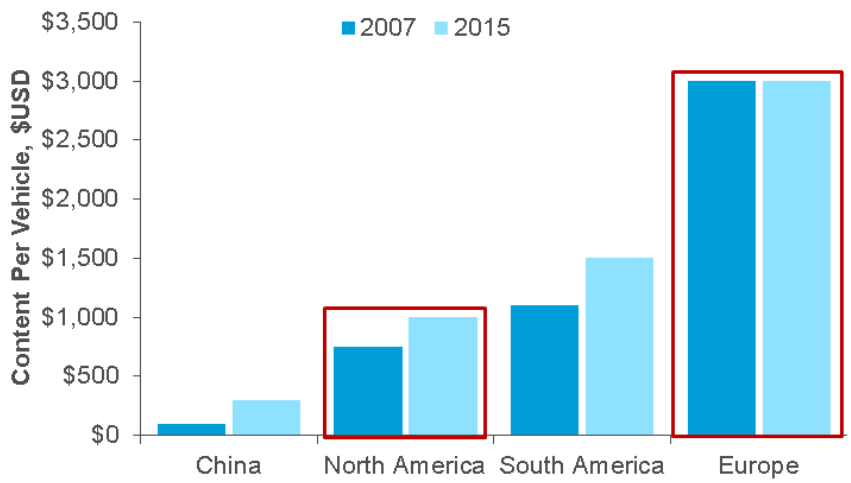
Spotlight on Commercial Vehicles

It has not just been the automakers (some of which, of course, also produce commercial vehicles) that have pushed hard on change and technology upgrades in recent years. The global truck and engine industries have also responded to meet regulatory requirements and operator demands by developing products that improve fuel economy and help to lower emissions. The next wave of requirements will focus on reducing greenhouse gas emissions, though this will evolve on a global basis. In a nutshell, advancements in truck technology center around three key secular trends: improving safety standards, driver retention, and fuel efficiency.

"There is a channel shift to higher technological standards for trucks worldwide. In the triad, it's very clear. And very important, the demand for high-tech trucks will increase step by step in Russia and China and India as well." ~Andreas Renschler, Daimler AG

These developments have resulted in thousands of dollars of both compulsory and optional technology content per vehicle. Not surprisingly, implementation of these advanced technologies has not been uniform across the globe. Thus far, Europe has been the undisputed leader in technology adoption, largely because regulators mandate the world's most stringent safety and efficiency performance. However, as regional legislation, driver retention issues, and the drive for improved fuel economy take hold, we expect other regions of the world to continue to "catch up" to Europe.

Figure 39. Global Trucks - Europe is the Leader in Global Technology Content Adoption



Source: Company Reports

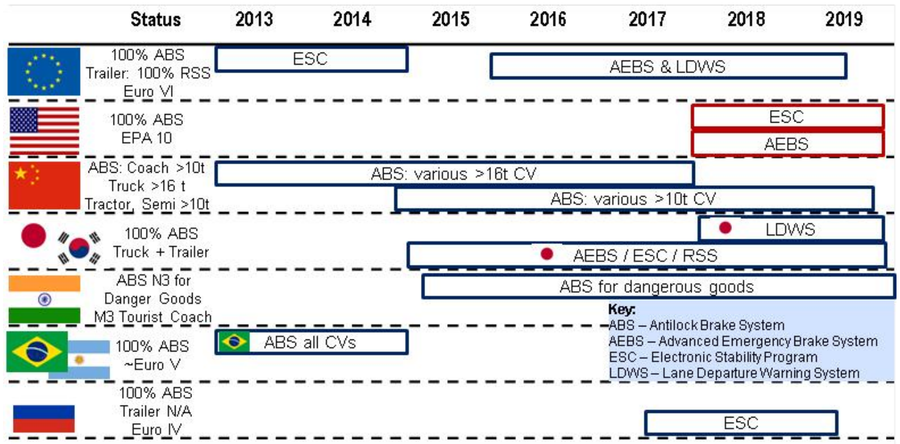
The Safety Component

Trucking companies, already facing modal competition from the rails and intermodal, are sensitive to a public perception that big trucks are accident-prone. This is somewhat deserved — crashes involving large trucks killed 3,921 people in the US in 2012, per NHTSA data. In response, there is a growing push across the industry, not just driven by regulators, but from suppliers, OEMs and trucking companies to increase the safety content on trucks. Wabco, for example, has outlined a "zero accidents" goal stating that by 2020 road fatalities involving trucks are reduced by 50% and the number of accidents is reduced by a like percentage.

The EU has been at the forefront of this initiative, passing mandates for anti-lock brakes (starting in 1997), Roll Stability Control (RSC) on trailers (2011) and Electronic Stability Control (ESC) for tractors (2014). Looking ahead, EU regulations requiring installation of Autonomous Emergency Brake and Lane Departure Warning systems across all vehicles will finalize in 2018. The US has passed similar legislation, with the NHTSA requiring anti-lock brakes on tractors manufactured after 1997 (and trailers in 1998). Proposals to enforce the installation of ESC and AEBS on large commercial trucks are anticipated to finalize later in 2015.

This trend is not however limited to developed markets. Governments in China, India and Brazil have been stepping-up the implementation of regulations that mandate additional safety technology, including ABS and ESC systems. For example, in Brazil, OEMs must now comply with the new legislation that mandates installation of anti-lock braking systems on 40% of new trucks, buses and trailers. As of 2014, this ABS rule applied to 100% of trucks built or imported in to Brazil.

Figure 40. Upcoming Commercial Vehicle Safety Legislation



Source: Company Reports

We highlight a few of the major safety technologies being utilized globally below:

- **Electronic Braking System (EBS):** Introduced in 1996, EBS systems are the natural progression of the Anti-lock Brake system. In an EBS system, air pressure for individual brakes is controlled by an Electronic Control Unit (ECU) which allows for more accurate and reliable braking by providing more air pressure for the brakes that require it. Alongside safer braking, EBS allows the vehicle OEM to control brake settings through the ECU to tweak brake 'feel' to match the company's specifications. EBS systems are particularly popular in Europe, where they are equipped on most new commercial vehicles.

- **Electronic Stability Control (ESC):** Developed for commercial vehicles in 2001, ESC systems utilize on-board computers to control brake torque and keep a vehicle moving in the intended direction. The extra stability is acquired through a combination of selective braking and automatic reduction in engine power. Unlike the precursor Roll Stability Control (RSC) systems, which are primarily concerned with rollover, ESC also helps correct over- and under-steer situations.

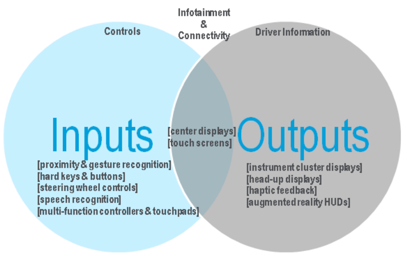
- **Advanced Emergency Brake System (AEBS):** AEBS assists drivers in maintaining safe following distances. Utilizing data from radar and video inputs, the AEBS provides the driver audio and visual warnings to help react to imminent danger. In addition, the system electronically applies the brakes to help minimize, or prevent, impacts in high-risk situations.

- **Lane Departure Warning System (LDWS):** Lane Departure Warning Systems utilize cameras to help prevent potential collisions due to unintentional lane movements. When erratic driving behavior is detected, the system provides warnings to the driver to help mitigate veering-related accidents.

Connecting the Car of the Future

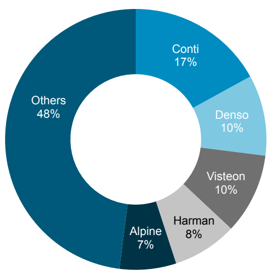
In our first Car of the Future report, we focused on infotainment, which was meant to familiarize investors with the different types of end systems an OEM could deploy. We also forayed briefly into the touch screen, a core component for the human machine interface (HMI). Infotainment systems, touch screens and other components are all products that fall under the cockpit electronics market, a market which can be classified into essentially two buckets: 1) inputs and 2) outputs. Here we focus on products that help create immersive, intuitive, fluid and simple HMI.

Figure 41. Cockpit Electronics Overlap



Source: Citi Research

Figure 42. Cockpit Electronics Global Share

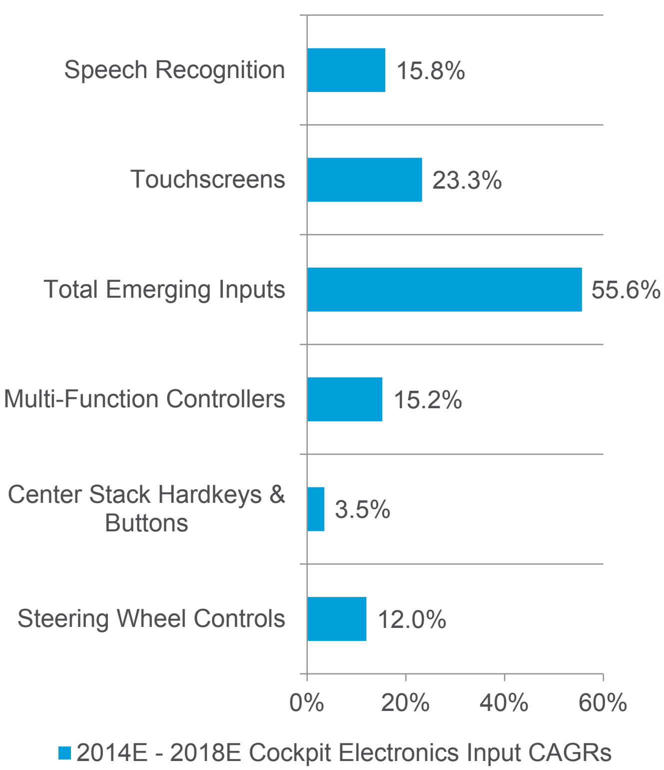


Source: Citi Research, Visteon

The Evolution of Cockpit Electronics

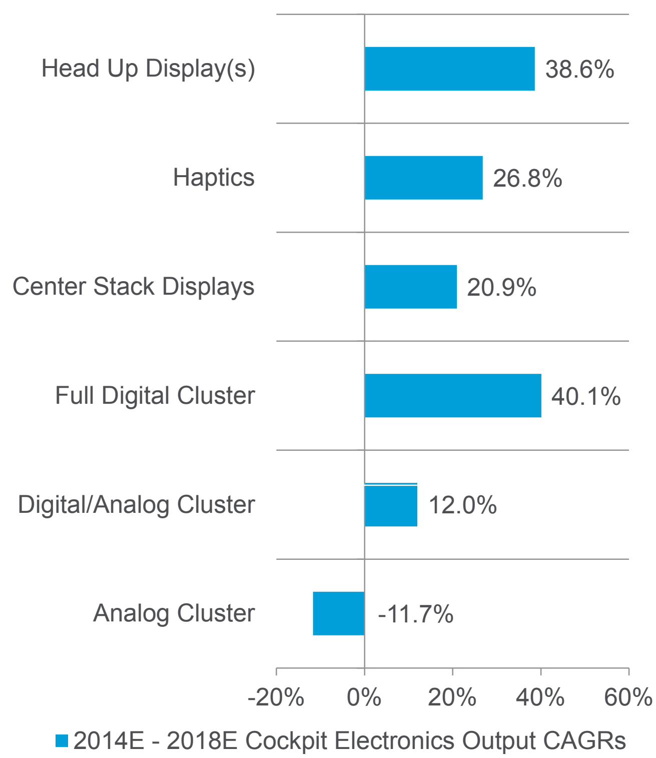
The cockpit electronics market is constantly evolving, similar to that of the consumer electronics market – not surprising considering consumer electronics technology is typically a leading indicator for what may end up in the automobile. The cockpit electronics market is expected to have a total addressable market of ~$50 billion by 2020. As mentioned above, the market can be bucketed into two categories: inputs and outputs. Typical inputs are electronic cockpit controls, such as: keys and buttons, steering wheel controls, multi-function controllers and touchpads, speech recognition and center stack touch screens. Typical outputs are products such as: center stack displays, instrument clusters, head-up displays and augmented reality head-up displays. 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 2014E-2018E unit CAGRs for varying technologies within these two buckets in the charts below.

Figure 43. Cockpit Electronics Input CAGRs (units, 2014E-2018E)



Source: IHS, Citi Research

Figure 44. Cockpit Electronics Output CAGRs (units, 2014E-2018E)



Source: IHS, Citi Research

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? Well, we answered part of that question in our last Car of the Future report - where we focused on the connected car from an infotainment perspective. However, that was only the tip of the automobile iceberg… In this report we focus on 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 report we will focus on HMI outputs, which include: the evolution of center stack displays, instrument display clusters, head-up displays and augmented reality. *We find these areas to be particularly interesting given their convergence with the active safety mega-trend.*

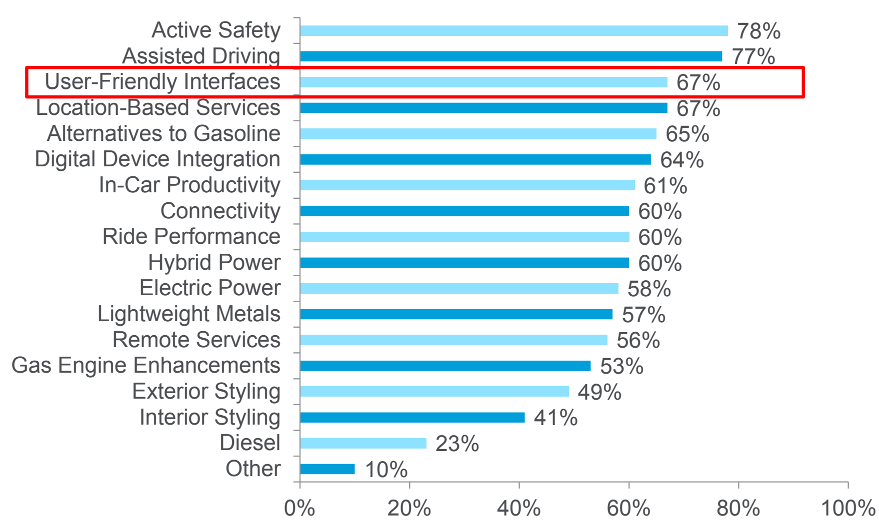
Why is the HMI so Important?

Analogous to William Shakespeare's "the eyes are the window to your soul", the human machine interface is the window to one's vehicle. 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 of 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.

67% view user-friendly interfaces are extremely-/somewhat-innovative products

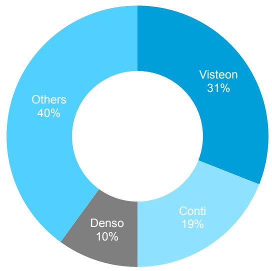
Figure 45. What Customers Find Innovative (% of sample who view the choice as either "extremely" or "somewhat" innovative)



Source: Boston Consulting Group, Citi Research

Starting with the Center Stack

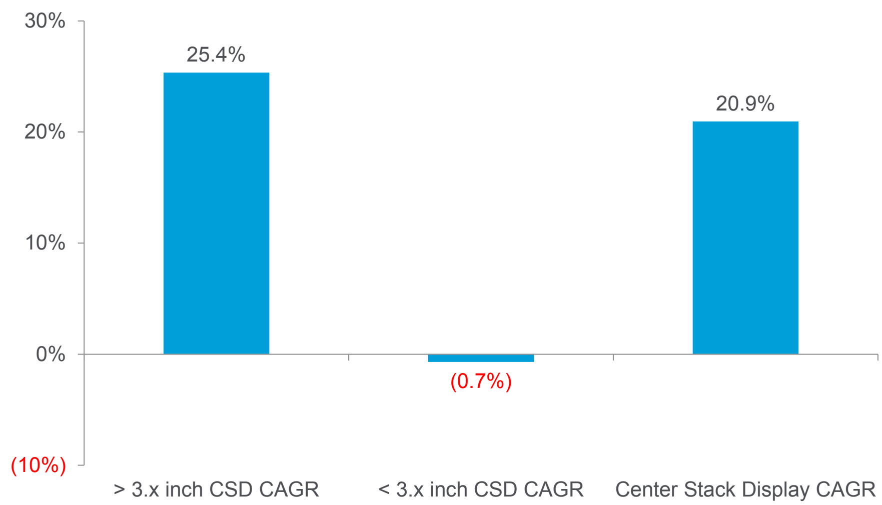
Figure 46. Displays Global Market Share



Source: Citi Research, Visteon

We start our analysis at the center…the center stack display (CSD). 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 LCD, but LEDs and OLEDs[4] 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 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 to OEM dynamic (where the supplier is to provide innovative solutions vs. generic commoditization).

Figure 47. 2014E to 2018E Center Stack Display Unit CAGRs



Source: IHS, Citi Research

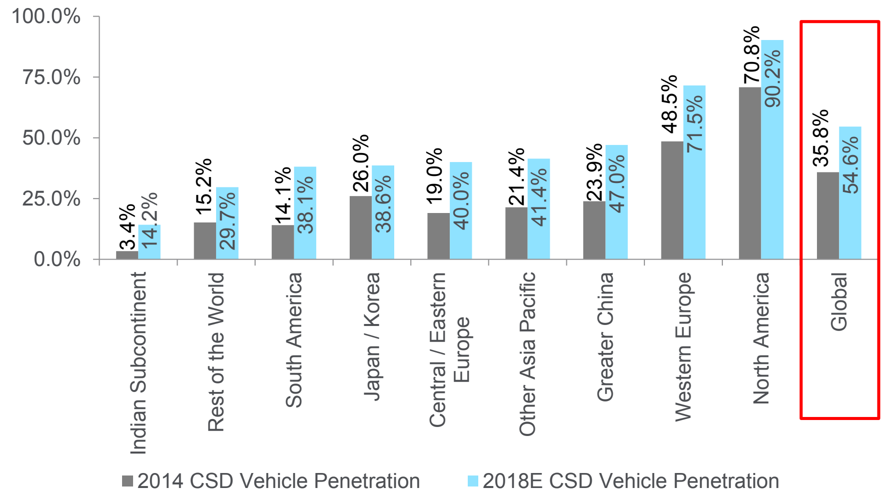
Dual Catalysts: Higher Penetration & Rising Density

We look at the center stack market on a catalyst by catalyst basis; as such we will first explore increasing vehicle penetration and then dive into the rising density. To understand penetration we must look at this market in such a way that we strip density out of the equation. We do this by looking at the forecasted number of vehicle sales per region and of those forecasted vehicles look at how many are being shipped with *at least* one CSD, regardless of screen size. In 2014E, at the global level, approximately 36% of all vehicles sold were estimated to have some sort of center stack display – by 2018E this penetration rate could be closer to ~55%.

[4] LCD = Liquid Crystal Display, LED = Light-Emitting Diode, OLED = Organic Light-Emitting Diode

Penetration varies by region with the three most important (on absolute volume) being N. America, W. Europe and China; these 3 regions account for ~70% of total global unit penetration.

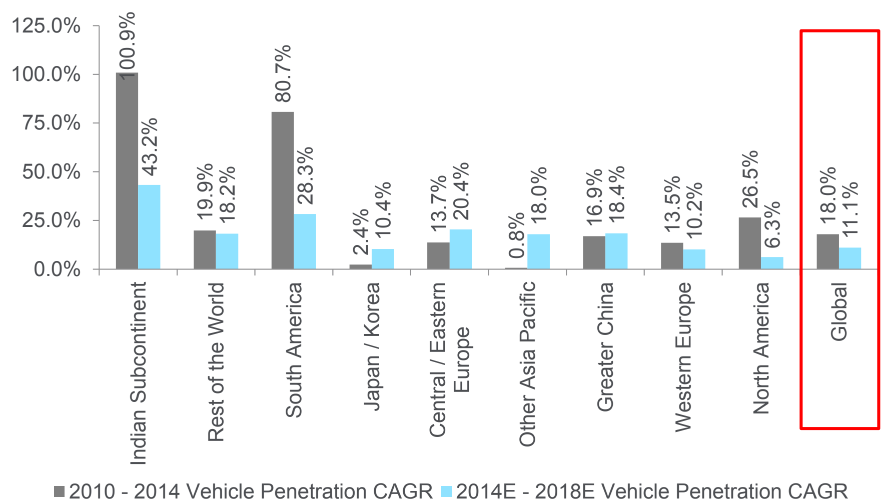
Figure 48. Center Stack Display Vehicle Sales Penetration



Source: IHS, Citi Research

At what penetration level will market saturation occur? Well, the answer is complicated, but importantly if we compare the 2010 to 2014 vehicle penetration CAGR to the 2014 to 2018 vehicle penetration CAGR, we can see that the overall market still has solid growth ahead of it. Furthermore, using the developed markets as a base highlights the future potential for the emerging market penetration story to gain incremental momentum.

Figure 49. 2014-2018E Penetration CAGRs Still Highlight Above Market Growth Potential



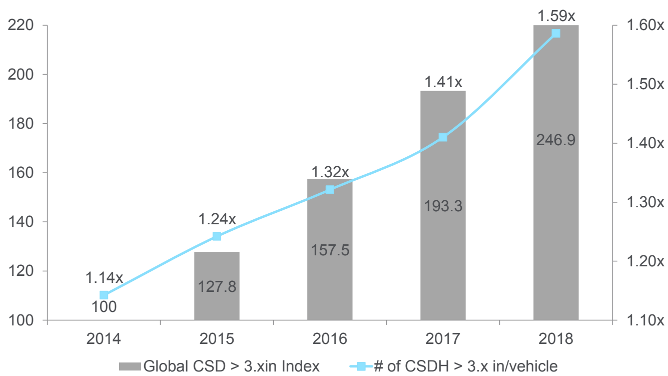
Source: IHS, Citi Research

Rising Density: Penetration Only Paints a Partial Picture

At the global level, OEMs are choosing to deploy more than one center stack display per vehicle. This trend can be occurring for many reasons, for example: 1) in the past the center stack display was integrated with an existing headset, so as OEMs adopt a more modular strategy this could create the need for a separate display in conjunction with the existing headset; 2) the desire to provide more real estate for different processes in order to help make the HMI more intuitive for the consumer; or 3) it could also be a function of one chipset being able to handle more displays. Either way, the CSD density is forecast to rise. It is important to note that

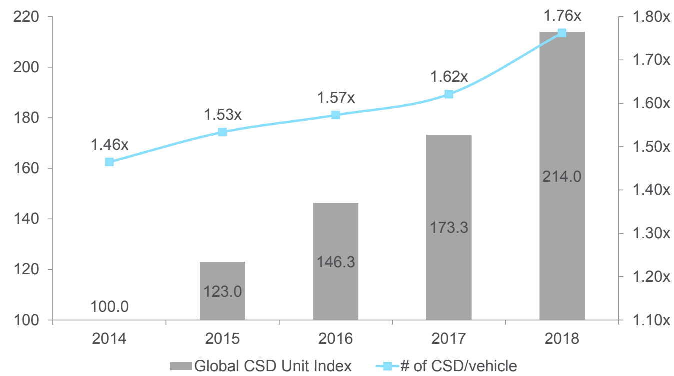
density can be viewed two different ways: 1) looking at density in conjunction with our Car of the Future "eligible" methodology, in which we look at density where the display sizes > 3.x inches; or 2) at face value for the whole market, encompassing all screen sizes. We favor the first methodology as it more aptly depicts the Car of the Future story.

Figure 50. Car of the Future Density Depiction & Unit Index



Source: IHS, Citi Research

Figure 51. Total CSD Market Density Depiction & Unit Index



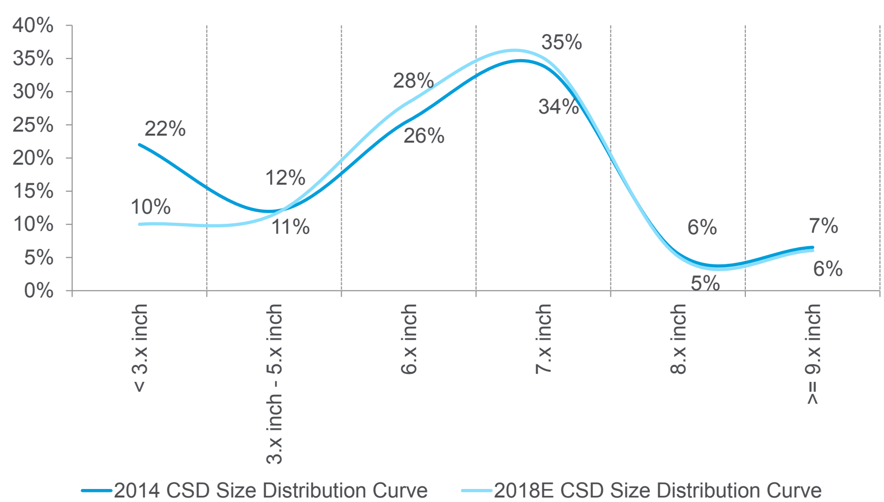
Source: IHS, Citi Research

The total number of center stack units sold in 2014, per the Car of the Future methodology, was estimated at 35.0 million units (indexed above) with a corresponding density of 1.14x displays per vehicle. By 2018, this is estimated to grow to 86.5 million units, with a corresponding density of 1.59x displays per vehicles.

Again, the best comparison to the Car of the Future theme, in our opinion, is derived from an analysis of potential units sold where the display size is > 3.x inches; anything < 3.x inches will be mostly discrete LCDs or at the very most, small passive matrix monochrome LCDs – not really a display system given the graphical capacity of these displays are limited. In the chart below, one can see the decline in the < 3.x inch screen display and the corresponding rise in 6.x- and 7.x- displays.

The shift in size highlights the consumer desire to be able to more easily view the GUI as well as provide the OEM with the platform to help build a simpler GUI, given the extra real estate. At a certain size an OEM 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 Tesla Model S and the Volvo XC90

Figure 52. 2014E vs. 2018E CSD Size Distribution Curve

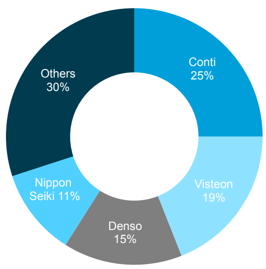


Source: IHS, Citi Research

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 proper decisions, whether while driving or required for vehicle maintenance. 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 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. 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; this is particularly important when considering that cluster grows in lockstep with production growth as the relationship between cluster and vehicle is 1:1.

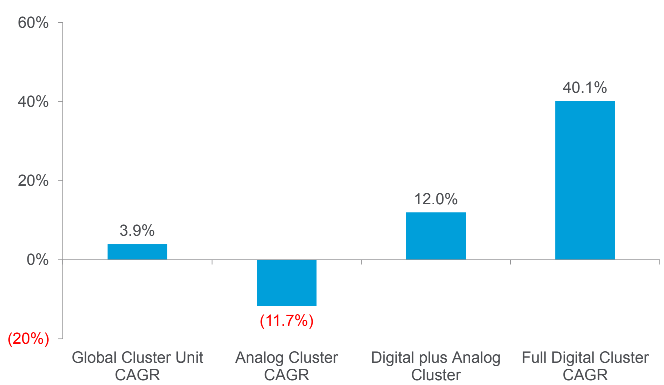
Figure 53. ICs Global Market Share



Source: Citi Research, Visteon

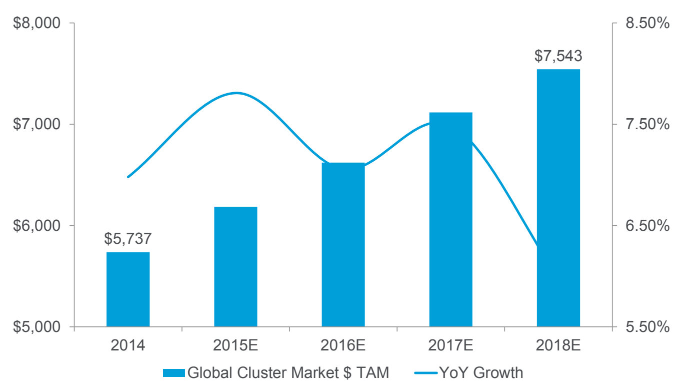
In our Car of the Future investing framework, we prefer suppliers who are more leveraged to the high growth cluster areas such as digital plus analog and full-digital display (see Figure 54). Of the major suppliers in Figure 53, we believe that Visteon is best positioned to capitalize on the emerging trend of instrument cluster digitization as we believe their current mix of products likely reflects ~25% analog and ~75% digital plus analog. Continental is next best positioned with a mix likely reflecting ~50% analog and ~50% digital plus analog; Denso's mix is likely ~60% analog and ~40% digital plus analog. Remember, the more digitized products are value-add supplier components that have a lot of specialized and customizable software solutions.

Figure 54. 2014E-2018E Global Cluster Unit CAGR by Technology



Source: IHS, Citi Research

Figure 55. 2014E-2018E Global Cluster $ TAM and $ YoY Growth

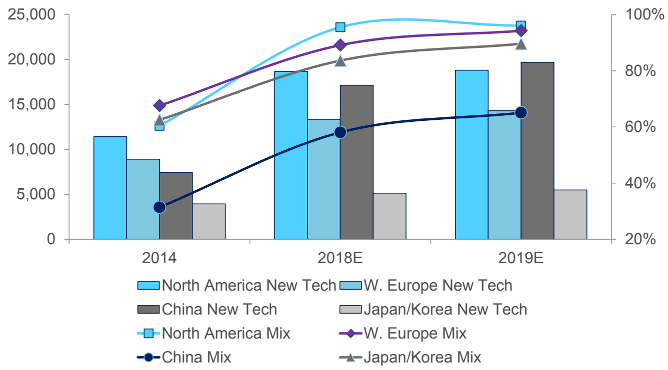


Source: IHS, Citi Research

Global and Regional Cluster Penetration by Technology

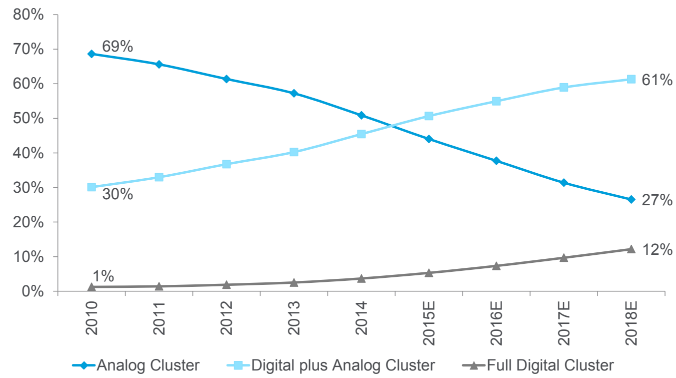
At the global level, there is a significant ramp up for digital plus analog AND full-digital display – as you shift to a more digitized display, suppliers can really provide a lot of value add at the software level. Take for example the full-digital cluster display in the new Lincoln Continental and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

Figure 56. New Tech Cluster Units and Penetration



Source: IHS, Citi Research

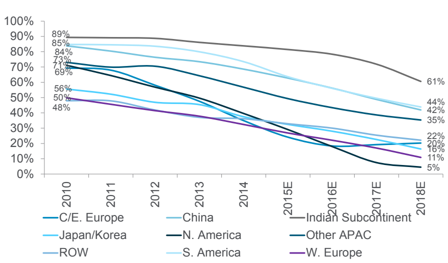
Figure 57. Global Technology Penetration – 1 Cluster per Vehicle



Source: IHS, Citi Research

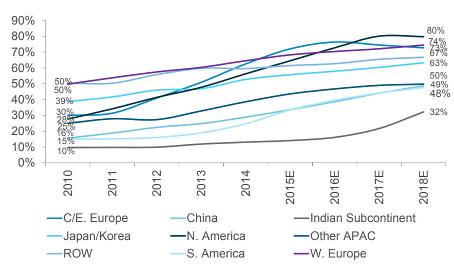
The decline of the typical analog cluster is consistent across both emerging and developed markets; however, the rate of adoption of the newer digital plus analog clusters and the full-digital clusters vary from region to region. North America, W. Europe, Japan/Korea and China remain important areas for adoption from a unit volume perspective. In North America, new cluster technology, as a percentage of the total mix will be ~95% by 2018 (digital plus analog or full-digital); W. Europe is close behind with 89% of the mix and Japan/Korea with 84% of the mix; and China with 58% of the mix. Despite China's low mix percentage, relative to the other regions, in has the second highest new cluster tech unit shipments in 2018E (17.1 million) and by 2019E China will be the leading region for new tech cluster shipments (19.7 million); for comparison, North America units in 2019E are expected to be 18.8 million units and for W. Europe 14.3 million units are expected.

Figure 58. Analog Penetration by Region



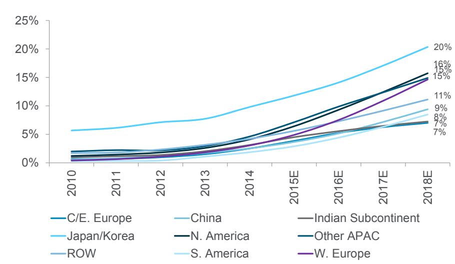
Source: IHS, Citi Research

Figure 59. Digital plus Analog Penetration



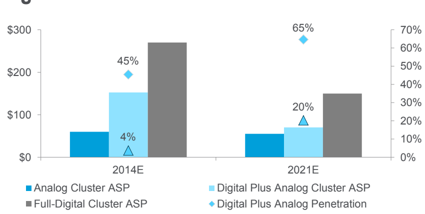
Source: IHS, Citi Research

Figure 60. Full-Digital Penetration by Region



Source: IHS, Citi Research

Figure 61. Global Cluster ASP & Penetration



Source: Citi Research Estimates, IHS

The Pricing Environment Amongst Different Clusters

The cluster market total addressable market (TAM) was estimated at $5.7 billion in 2014; by 2018 it is estimated this market will grow to $7.5 billion and by 2021 the market is expected to grow to ~$9 billion. While the CAGR may not look as promising as other technologies such as active safety, it is important to note that the total market CAGR 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 ASP decline in analog clusters, we can solve for technology specific average selling prices (ASPs), using IHS forecasted global aggregate ASP

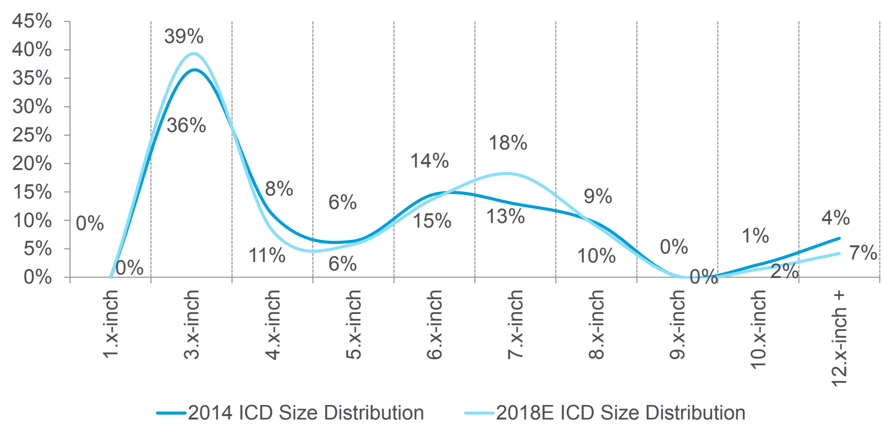
assumptions. Using this calculation we believe that mass market penetration ASPs (by 2018E-2021E) could be: ~$50-$55 for analog clusters; ~$75-$85 for digital plus analog clusters; and ~$150-$180 for full-digital clusters. In today's current environment, we believe that range could be the following: ~$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 discounts from suppliers.

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 2014E-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.

Figure 62. 2014E vs. 2018E ICD Size Distribution Curve



Source: HIS, Citi Research

Larger full-digital ICDs will likely be a more luxury/niche play, whereas more mass market adoption will occur for the digital plus analog technology. 3.x inch size is a good fit for digital plus analog; full-digital has to be larger to make sure all information is easily seeable.

Audi launched a virtual cockpit 12.3 inch full-digital ICD display in the '15 Audi TT which turned the ICD into the infotainment center, essentially removing the CSD. This won't likely be par for the course.

Enhancing HMI: HUDs and Augmented Reality

The head-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 system, 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 63. 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 64. Combiner HUD Display

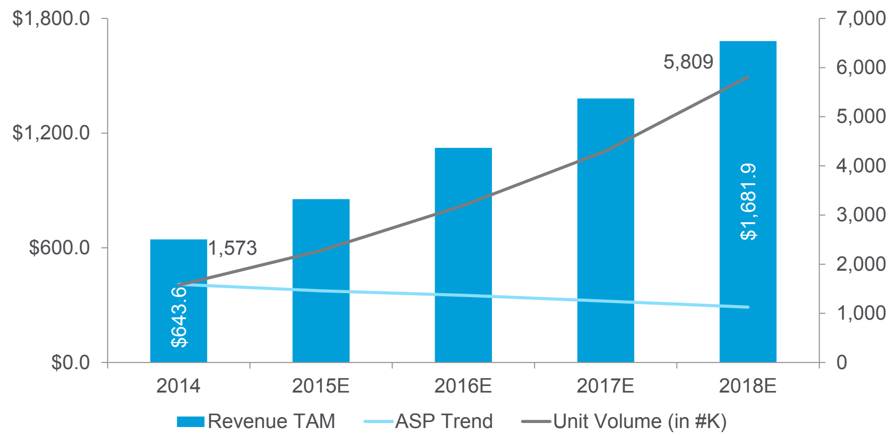
Source: MINI, Citi Research

Sizing Up the Markets - The Current and the Future

The overwhelming majority of HUDs currently produced are windscreen HUDs, which typically carry an ASP of ~2.3x more than combiner HUDs. In sizing up the market we believe that units (1 unit per vehicle) are expected to grow at a 2014-2018E CAGR of ~39% (1.6 million units to ~6 million units). At the same time, the revenue TAM is expected to grow at a CAGR of ~27% (from ~$650 million to nearly ~$1.7 billion). It is important to note that the growth trends vary by HUD technology – for example, the 2014-2018E revenue TAM of the windscreen HUD market is expected to grow by a CAGR of ~21% to $1.3 billion; the combiner HUD market CAGR is estimated at ~98%, growing to $375 million.

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 2018E.

Figure 65. HUD Market Overview – Revenue TAM, Unit Volume and ASP Trend

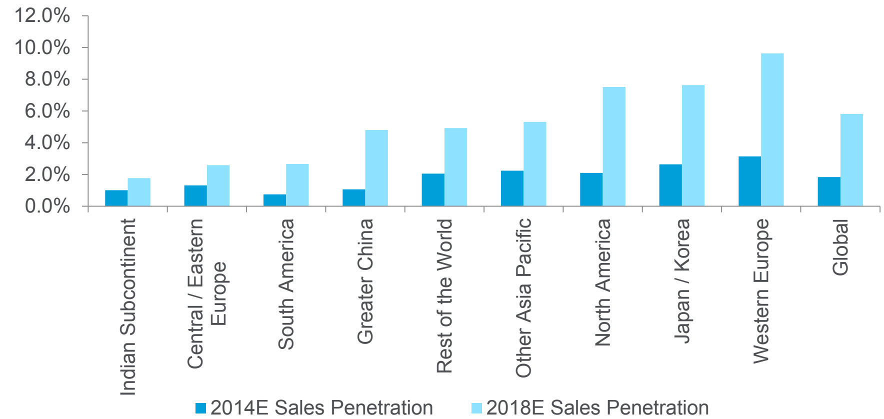


Source: IHS, Citi Research

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

By 2018 it is estimated that overall HUD penetration will be ~6%. 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; however, it remains imperative to consider adoption at the absolute unit level, as this is how suppliers generate incremental sales revenue and because without a unit volume base one would miss the explosive growth in China. So while the adoption rate is important to see which countries have a more favorable view on advanced automobile technology, one must just as equally focus on actual units shipped. As such, N. America, China and West Europe are estimated to have the highest unit volume sales by 2018, accounting for ~75% of total shipments (~1.4 to 1.5mln units per country).

Figure 66. Global Sales Penetration of HUDs (windscreen + combiner)

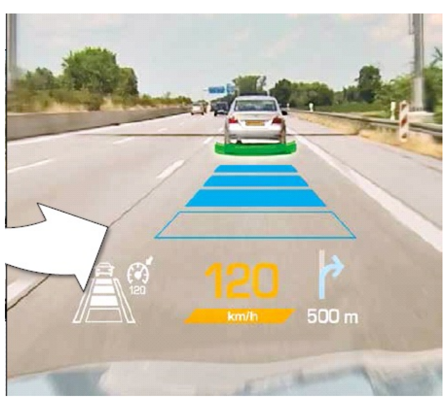


Source: IHS, Citi Research

A Further Step to the Future…Augmenting Reality

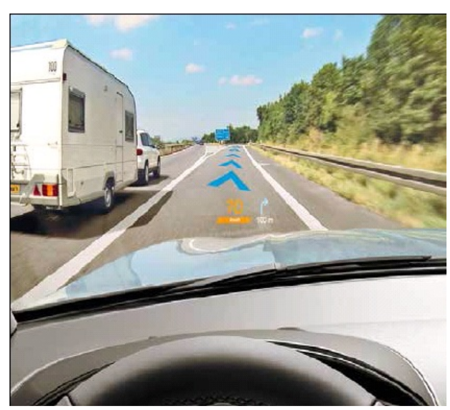
The beautiful thing about HUDs is that the very nature of the product allows for OEMs to leverage it as an ideal platform for multi-modal technological convergence. What we mean by this is that as the infotainment and active safety mega-trends continue to develop, they will eventually converge where 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 67. Augmented Reality HUD - ACC



Source: Continental, Citi Research

Figure 68. Augmented Reality HUD - NAV

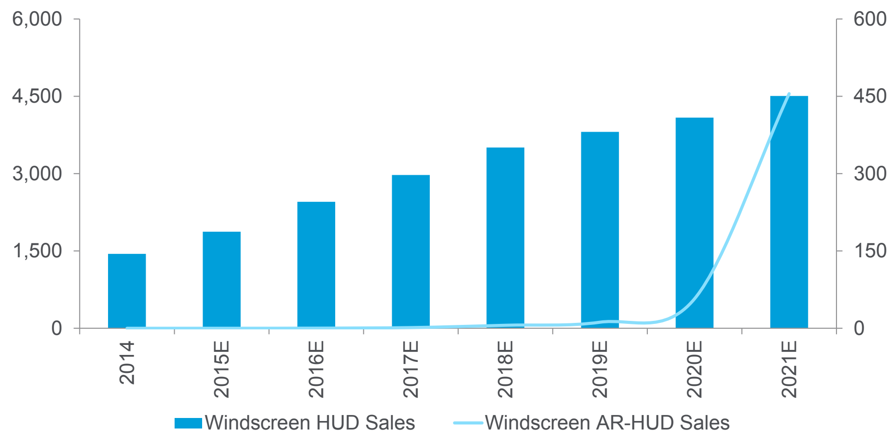


Source: Continental, Citi Research

A Small, but Hyper 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 2014E 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 69. Windscreen HUD Sales (LHS) and Windscreen AR-HUD Sales (RHS) / Windscreen AR-HUD sales are included in the total Windscreen HUD Sales



Source: 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) such as Nippon Seiki, Continental and Visteon. 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 TAM for total HUDs.

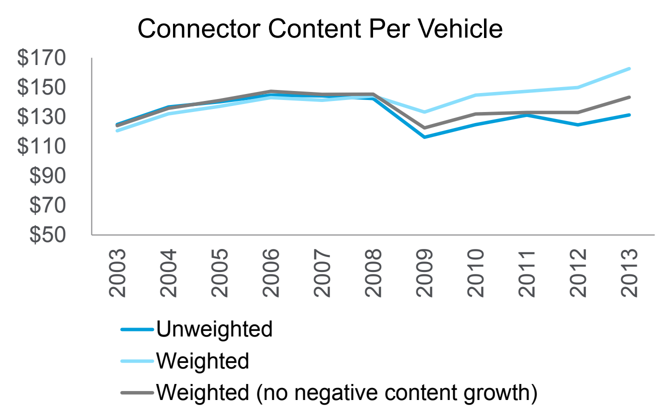
Connectors/Sensors a major beneficiary of vehicle electrification

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.

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. Because 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 ECUs. We forecast auto volume growth and an increase in the number of connectors per vehicle will result in the connector market expanding from $10.9 billion in 2013 to $11.9 billion in 2014, $13 billion in 2015, and $20.3 billion in 2020 (Figure 70 and Figure 71). We note our assumption of 2-3% global automotive production growth has been affirmed by major OEMs and third party estimates.

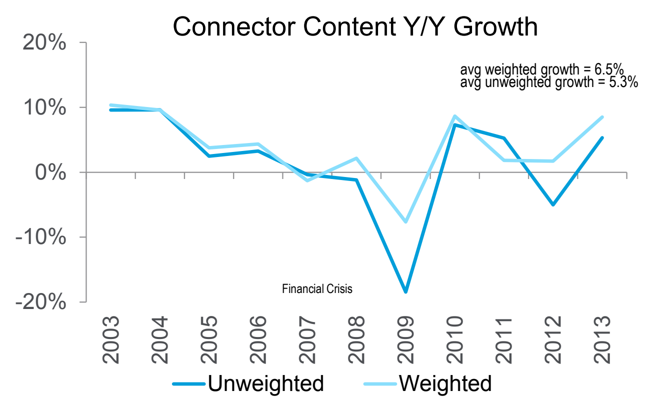
We estimate connector content has grown with weighted CAGR of +6.5% from 2002 to 2013 (assuming European cars have 2x content vs. North American cars; Asia has 0.5x content vs. N. America). We note content growth was negative during recession time (2008-2009), demonstrating a scale back of electronic content per vehicle when end market demand is highly uncertain. However, the recent trend of accelerating connector content growth rate has shown that technology development (particularly vehicle electrification) is fundamentally reshaping the automotive industry.

Figure 70. Connector Content Per Vehicle (2002-2013)



Source: Citi Research, Bishop

Figure 71. Connector Content Y/Y Growth

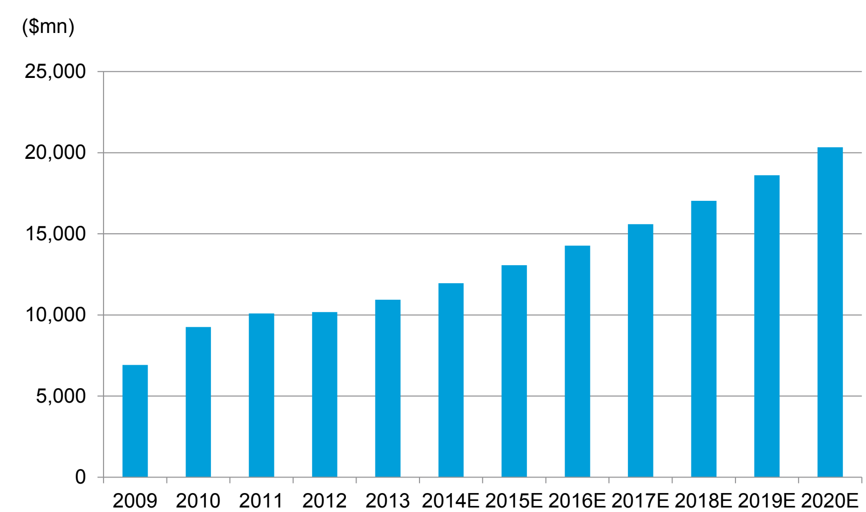


Source: Citi Research, Bishop

Major auto-use connector makers

Major auto-use connector makers include Yazaki, Sumitomo Wiring Systems, Japan Aviation Electronics, Hirose Electric, Iriso Electronics, and JST (Japan), TE Connectivity, Delphi, Molex, FCI (Europe) and Amphenol (US). 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 72. We forecast connectors will be one of the biggest beneficiaries of vehicle electrification



Source: Bishop, Citi Research estimate

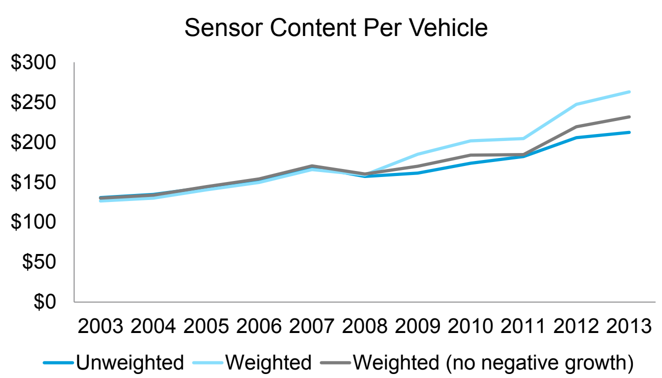
We forecast annual average sensor volume growth of 6%-8% per vehicle in addition to annual auto production growth of 2-3% less average price declines of 0-2% resulting in organic sensor growth of 7-10% without aggressive assumptions.

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 a weighted CAGR of +10.8% from 2008 to 2013 (assuming Europe cars have 2x content vs. N. America cars; Asia 0.5x content vs. N. America) and we forecast annual average sensor content growth of 7-10% versus just over 2% for ECUs. We note our estimates are in line with guidance from major sensor players (i.e. Sensata, TE Connectivity, etc).

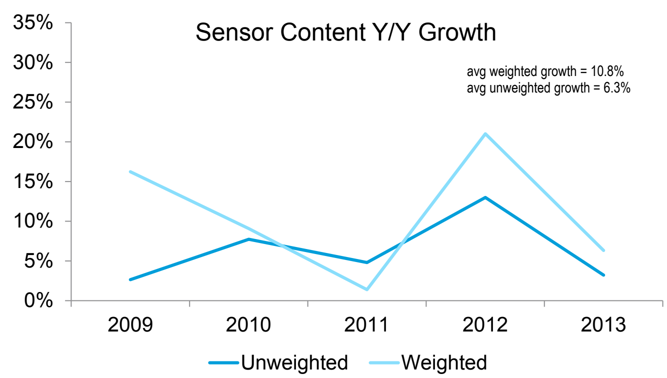
In addition, we expect continuous M&A activity within the automotive sensor industry given the low market concentration. This is evidenced by Sensata making a horizontal acquisition on Schrader and TE Connectivity and Amphenol acquiring downstream companies Measurement Specialty and GE Advanced Sensor/Casco. We believe big companies can create synergies from sensor industry consolidation by leveraging their global manufacturing footprint, design capabilities and existing relationship with Auto OEMs.

Figure 73. Sensor Content Per Vehicle (2008-2013)



Source: Citi Research

Figure 74. Sensor Content Y/Y Growth



Source: Citi Research

Figure 75. 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-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	Measures the quantity of air going into the engine
Pressure sensor	Engine	Monitors engine intake pressure, turbo pressure, 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 preventive 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

Figure 76. Supplier Matrix for Major Automotive Sensors

	Denso	Hitachi	MELCO	Panasonic	Nidec Elesys	TDK	Murata	Omron	Nicera	Infineon	Conti nental	Bosch	Sensata Technolo gy	Delphi
Oxygen sensor	○	○	○									○		
Air flow meter	○	○	○								○		○	
Pressure sensor	○	○	○			○				○		○	○	○
Temperature sensor	○	○	○	○		○						○	○	○
Current sensor	○		○	○		○					○	○	○	
Ultrasound sensor	○						○		○			○		○
Auto camera sensor	○	○	○	○	○				○		○	○		○
Radar sensor	○	○	○	○	○			○		○	○	○		○
Rudder angle sensor	○	○		○								○	○	
Yaw rate sensor	○	○		○							○	○		
Gyro sensor				○		○				○	○	○		
Acceleration sensor	○			○			○			○	○	○	○	○
Air pressure sensor							○			○	○		○	
Automotive antenna	○	○	○	○				○			○			○
GPS unit	○	○	○	○			○							

Note: This chart does not include all products by suppliers or suppliers for specific products

Source: Company data, Nikkei Automotive Technology, IRC, Citi Research

IT Services Enable the Car of the Future

Conceptually we think of technological advancements for the Car of the Future as being in the following categories – "Saving Lives", "Connecting", "Propelling" and "Building" the car of the future. Of these categories, the contribution of IT Services companies as enablers is most noticeable in the "Connecting" category, which includes Telematics.

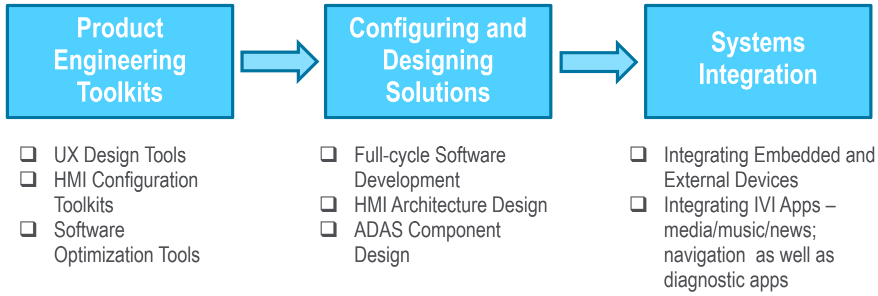
If one visualizes the "Car of the Future" as an integrated set of intelligent systems – say, for example, propulsion, navigation, safety, sensor data collection and analytics – it is then relatively straightforward to derive the role that an IT Services company can play in this trend. Typically, an IT Services company would design and build computing systems and integrate such systems into a cohesive end-product or service. There are at least four broad areas where these companies have a role to play in the "Car of the Future".

1. Product Engineering and Systems Integration
2. Enabling and Measuring Connectivity
3. Providing Human and Automated Support, where needed.
4. Processing Activities, e.g., Big Data Analysis

Product Engineering and Systems Integration

For Auto OEMs, the process of upgrading an existing ADAS or building a new one is complex. Using a software development framework that has pre-designed configurable functional components – for e.g., navigation, road recognition, vehicle detection and tracking and the integration of map and car sensor data – can result in a much more efficient process. Not every IT Services company has the relevant product engineering capabilities, but there is a good set of IT Services enablers that do have these capabilities. They can help the OEM in the User Interface (UI) and User Experience (UX) design process to enable safe, secure and seamless transactions.

Figure 77. IT Services Vendors Enable Product Engineering and Integration



Source: Citi Research

There are some good examples of Product Engineering currently.

1. Luxoft has a couple of different HMI-related product engineering and development platforms. Populus is a toolkit to develop HMI architecture and Teora is a platform to speed up HMI implementation.

2. Luxoft has a reference design platform called AllView, which links together the instrument cluster, head unit (if present) and mobile devices. The product works with other Luxoft platforms like Populus and Teora and also supports third-party app development.

3. IBM was selected in June 2014 by Toyota to create an onboard device and application development environment for Toyota Open Vehicle Architecture. This development platform will bring together an ecosystem of mobile app developers and content providers who provide content for T-Connect.

Once a component is designed, it must still be integrated with other components into a cohesive solution that appeals to the end-consumer. Rather than design every part of the solution from scratch, several industry participants including IT Services companies support GENIVI, which is a non-profit industry alliance committed to driving the broad adoption of an In-Vehicle Infotainment (IVI) open-source development platform. IVI applications include music, news, video feeds (for passengers), navigation and location services, telephony, internet services, etc. The GENIVI open-source platform consists of Linux-based core services, middleware, and open application layer interfaces (APIs) which IT Services companies can use to improve speed-to-market for IVI solutions they are developing. For an OEM that is committed to GENIVI, an IT Services vendor would typically combine relatively undifferentiated core components with highly differentiated and proprietary consumer-facing applications and interfaces.

Some examples of IT Services involvement in the integration process include

1. Accenture helped design and deploy the backend platform that helps enable the BMW Group's connected vehicle offering, ConnectedDrive. Specifically, Accenture helped integrate product management, customer management, ordering and contract management capabilities into the system so that BMW can roll out incremental services when available or when selected by the consumer.

2. Accenture supported Fiat Chrysler Automobiles in EMEA to design, build and run the Fiat 500X Uconnect™LIVE in-car, Internet-based services. Accenture is responsible for the technology services both on-board vehicles and for the back-end, as well as the integration with content providers and on-

board integration. Accenture also helped design the multi-channel user experience.

3. Luxoft works with Harman on several automotive projects, including embedded real-time operating systems, advanced navigation systems, in-vehicle Internet capabilities and the integration of social networks into the driving experience. The resulting IVI systems are used by several OEMs including Daimler.

Enabling and Measuring Connectivity

Connectivity opens up myriad opportunities for the OEM as well as the telecom operator providing the service. Several factors are shaping this opportunity.

1. The increasingly widespread availability of always-on devices.
2. The rising customer expectation that such services are standard.
3. The emergence of open standards like HTML5 which draws developers in.
4. The deployment of high-bandwidth cellular networks that drive app market growth as well as usage.
5. The shift from proprietary connected systems focused on safety/security to open as well as hybrid systems that offer broad-based infotainment.
6. The growth of big data capabilities that can provide incremental value based on the growth of connectivity-led transactions.

Due to the above factors and the implied opportunity, connectivity within cars is fast becoming a standard, rather than a luxury. Research firm Analysys Mason predicts that by 2019, 57% of new cars sold will have an embedded connectivity solution and by 2024 that percentage should rise to 89%.

This is not an easy opportunity to fulfill, however. First, there are significant costs and operational challenges that must be overcome. A full-fledged multi-user IVI system can consume a lot of bandwidth – consider a family of four traveling, with car diagnostics on; streaming music; navigation and one or more users consuming streaming video for entertainment. Such usage may also be unpredictable, depending on time of day, seasonal factors, weather, personal factors, etc. Second, there are several strategic choices the OEM and the telecom operator probably have to make. This starts with the type of telematics system choice – an embedded system with strict OEM-controlled choices will have different parameters compared to an open system that gives the consumer and systems integrator more leeway. Beyond such a choice, the underlying business and pricing model is also up for review – does the OEM want to charge a one-time payment, a recurring payment or a pay-as-you-go plan? Perhaps the right answer is to have a combination of these. Does the OEM want to broaden out the economics by working with an insurance company for usage-based insurance? How much does the OEM want to subsidize the offering? What is the telecom operator's plan to generate incremental revenues of their own? Privacy and security become concerns as well, especially if the OEM intends on selling location-based information for targeted advertising. These are some of the questions that must be answered.

In order to exploit the underlying opportunity or, at a minimum, offset the inherent cost, the starting point is the ability to measure different types of usage – the basic assumption is that not all connectivity is equal. For example, the consumer-directed download of media ought to be treated differently compared to the collection of driving behavior and patterns which in turn is treated differently from diagnostic information on the car itself. This is not a trivial task. Split-billing capability is very important. For example, the OEM should probably foot the bill for collecting diagnostic data but the consumer should probably pay for heavy bandwidth usage.

There are examples of such full-featured billing, charging and management systems today.

1. AT&T has announced Drive Studio with Amdocs as a key partner in charge of rating, billing and charging for "Connected Car" services. The AT&T Drive Studio connectivity solution choices include 4G/LTE, cloud solutions, virtual assistants, data services and entertainment offerings. This does include split-billing capability. The end goal is to treat the car as just one more connected device on the consumer's billing plan.

2. Ericsson has announced the Connected Vehicle Cloud, a fully API-based platform that provides integration points for easy connection to both external and internal systems. This is currently being used by Volvo for its Infotainment system and also by AT&T Drive Studio.

Providing Human and Automated Support

As the capabilities of what the computing systems onboard the car rise, so can the complexity. This directly leads to a demand for call center services, where either a human or automated agent can walk a consumer through the solution to their problem. The most obvious use cases are in the Safety and Security arena – for example, assistance when a vehicle is stolen or when a consumer locks themselves out of the car or when the car is in an accident. But a consumer can seek help in other areas as well, including navigation systems and setting up media choices.

Call center companies such as Convergys and Teletech as well as call centers run by telecom operators can benefit from the underlying demand.

Processing Activities like Big Data Analysis

Given the profusion of computing systems and sensors on an automobile, one can think of the modern car as a giant data collection engine. In fact, the automotive industry is expected to become the second largest generator of data by the end of 2015, according to IBM.

The most obvious "post-processing" activity is the use of this collected data, which can fall into various categories – location data; customer data (e.g., use of media); car diagnostic data; navigation data; and so on. Depending on the nature of the data, the OEM may have to make choices about whether to store it and for how long as well as about how to use, and possibly monetize, this data.

3. A company like Towers Watson, which has a leading practice in Usage-based Insurance, can clearly use data on driving patterns to benefit both the driver (possibly lower insurance) and the insurance company (promote safer driving habits).

4. IBM offers a Predictive Asset Optimization module that tracks both in-motion and at-rest data and can help the OEM benefit from such information.

Bridging Connectivity via Automotive Motors

In the Car of the Future, the volume per unit for electronic components like connectors, semiconductors, rechargeable batteries, and sensors is set to rise as cars come equipped with more and more electronics. In particular we anticipate growth in per-unit numbers for automotive motors, which comprise the "muscle" of the various components that make up the electrical system.

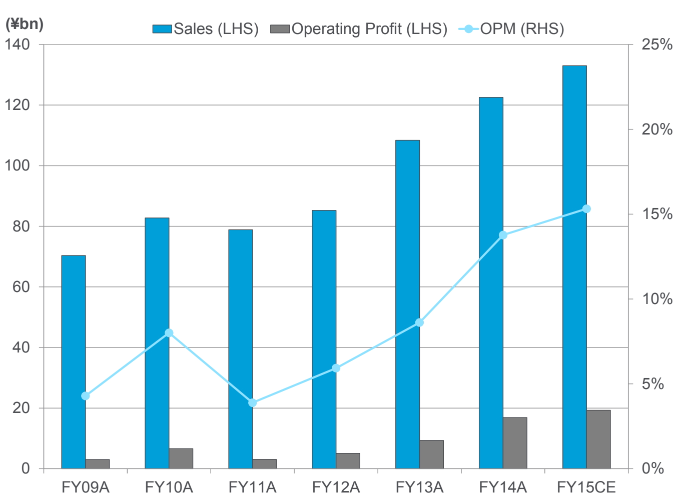
There are more than 20 applications for automotive motors, including drive motors for xEVs, motors used in electronic power steering systems, and motors used in power seats. Previously demand was comprised mostly of powertrain-related products like drive motors for xEVs and body-related motors used in mirrors and air conditioning systems. However, the scope of motor applications in cars is expanding, with motors being used in internal combustion engines and braking mechanisms as well.

Spotlight on Mabuchi Motor

We see Mabuchi Motor as a pure growth play among automotive makers. Prior to 2010 Mabuchi mainly shipped motors for consumer electronics, but since 2010 successful efforts to get into automotive motors have generated structural growth via expansion for the auto market, a rise in the volume of motors used per vehicle, and an increase in the customer base.

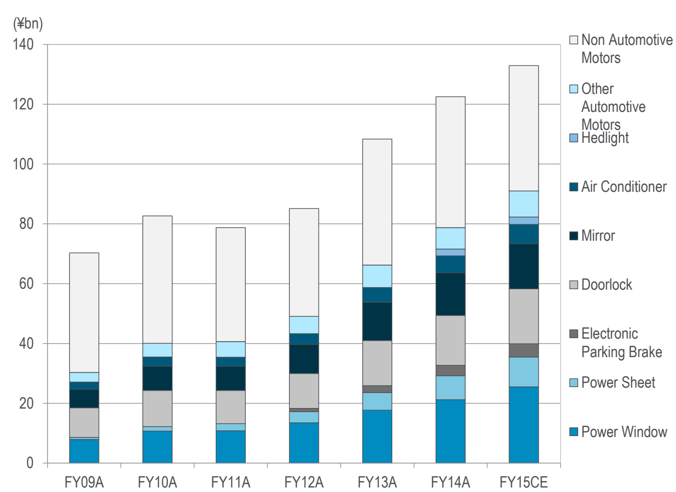
Perhaps the most common kind of automotive motor is a small motor used in the auto body. Mabuchi Motor has a particularly high share in motors used in side mirrors, air conditioners, and automatic door locking systems. In recent years the firm has beefed up its efforts in larger motors as well. In areas like motors used in power windows, power seats, and parking brakes, Mabuchi has seen high growth by taking market share and benefitting from increased usage of these motors in cars. We anticipate strong growth over the long term as well as Mabuchi is making progress in developing motors used in engine intake and exhaust systems (a key part of the powertrain) and key underbody systems like steering locks and idle speed controllers.

Figure 78. Mabuchi Motors Operating Metrics



Source: Company Guidance, Company Reports, Citi Research

Figure 79. Mabuchi Motors Revenue Build



Source: Company Guidance, Company Reports, Citi Research

A Quick Trip around the World: Infotainment

Trends in the Indian Market

Telematics and infotainment is an emerging trend in mid segment cars in India. Per some industry trackers, the average spend on electronics in a car in India is ~$400-$500 versus global trends of $2,000/unit. Cost is a concern even today.

Factory fitted equipment is not yet the norm – the typical aftermarket system retails for around $500, for which a consumer could get a 6 inch touch screen with DVD, tuner, Bluetooth and iPod/iPhone connectivity. Infotainment at present is more popular than navigation systems, as driving habits of Indians aren't yet complex – driving is typically restricted to commuter routes/neighborhood driving for which navigation is not really required. In 2012, it is estimated that of the 2.6 million vehicles sold, only 7.000 had an embedded navigation system.[5]

That being said, players like Harman are betting on secular trends in infotainment in the Indian OEM space. Harman's new Pune plant, inaugurated in November 2014, has a capacity for 400,000 units per year. Harman has worked extensively with Tata Motors to design the infotainment system for the new Tata Zest.

Figure 80. HARMAN's Touch Screen Multimedia System in the Tata Zest

Source: Tata Motors

Maruti Suzuki introduced a Smartplay Infotainment system in the top end Z+ trims of the Ciaz. The system has a 7 inch touch screen. With connectivity through UBS, Aux-in, CD and Bluetooth phone integration. The system also offers built in navigation with voice command functionality and doubles as a reverse parking camera.

Figure 81. Maruti Suzuki: Smartplay Infotainment system in the Ciaz

Source: Maruti Suzuki

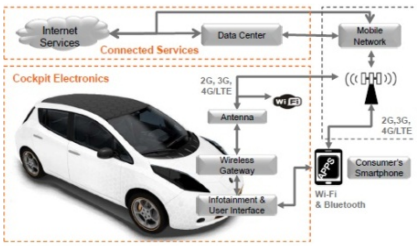
[5] Source: tu-auto.com

In addition, Ford might roll out its SYNC 3 technology in Indian markets by around 2016-17, as per Stefan Bankowski, Ford Product Development Engineer.[6]

Ways to Connect, Lots of Players

Bridging Car of the Future v2.0 with v1.0

Figure 82. Connected Car Architecture



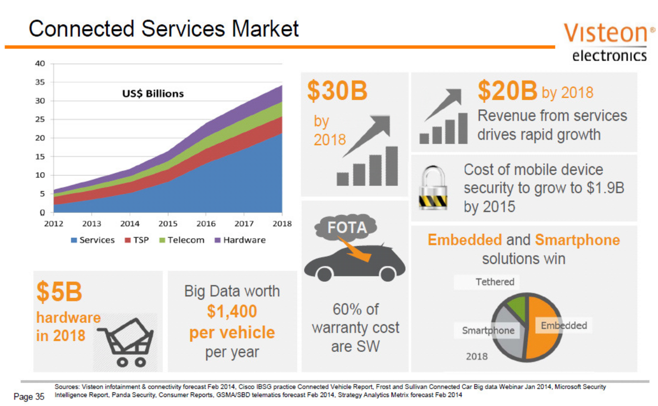
Source: Visteon from Citi Connected Car Symposium

There are essentially two ways to "connect" a car — embedded and brought-in. The embedded approach means that the car is the all-capable connected device from a hardware and software standpoint. GM's OnStar is a good example of this. Brought-in uses a driver's smartphone as the connectivity gateway to utilize software/applications that are either already built-in to the car (Ford Sync system) or already on the phone. There's a healthy debate towards who will "win", but more than likely both will simply co-exist with mix varying by price-points and regions. If we had to choose a winner, we'd choose embedded. While more expensive, embedded allows for more advanced applications of the Connected Car (safety, FOTA, big data, car sharing, etc.) will likely require added reliability.

One of the complicating factors for assessing this theme is that, unlike more traditional automotive applications, the supply chain for connectivity appears more complex on the surface with players ranging from OS vendors to HMI providers. This is further complicated by regional and customer exposure considerations.

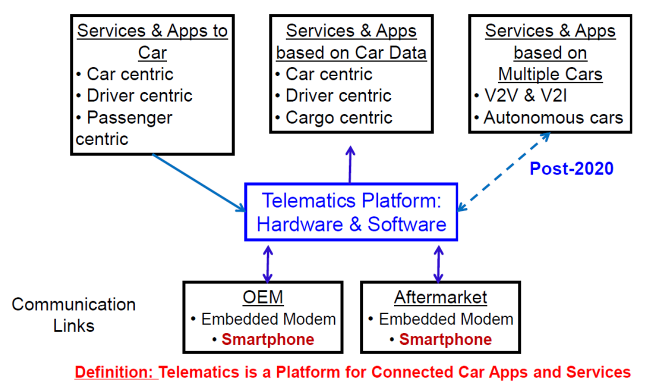
The following two charts provide a matrix for automakers and key suppliers to help investors better understand the supply chain dynamics for a Connected Car.

Figure 83. Connectivity Basics



Source: Visteon

Figure 84. Connectivity Basics



Source: IHS

[6] Source: PTI

Infotainment Environment and TAM

Infotainment sales are classified in two buckets: 1) OEM sales and 2) aftermarket sales. While some suppliers may choose to focus on one of the two, or both, we wanted to take the time to define the global market (OE and Aftermarket) in terms of units, revenue, and ASP potential. By 2020 the combined OE and Aftermarket total available market (TAM) is expected to be a $34 billion revenue opportunity with an average ASP of $291; this compares to the 2012 TAM of $23 billion and average ASP of $241.

In the Figure to the right, notice how Connected Telematics (tethering of smartphone) starts to teeter by 2020 while MFP (embedded TCU) and H-MFP (tethering and embedded TCU functionality) continue to grow at a 28% and 47% CAGR, respectively. Additionally, we highlight the increasing take rates of MFP and HMFP.

Figure 85. Global OE Front Unit Infotainment System Summary

(thousands)	2012	2013	2014	2015	2016	2017	2018	2019	2020
No Head Unit	8,139.9	8,357.2	8,690.7	8,998.0	9,191.6	9,229.4	9,149.2	9,080.4	8,126.1
Take Rate	10%	10%	10%	10%	10%	9%	9%	9%	8%
Conventional Audio	53,597.5	52,622.2	53,560.5	53,167.1	52,863.6	50,449.3	48,193.9	44,575.4	43,964.6
Take Rate	67%	64%	62%	58%	55%	51%	47%	42%	41%
Audio/Video	723.4	626.8	664.6	689.5	711.7	785.8	786.3	792.0	791.1
Take Rate	1%	1%	1%	1%	1%	1%	1%	1%	1%
Unconnected Navigation	9,450.0	9,842.3	10,565.6	11,763.8	12,128.1	13,300.9	14,646.9	16,077.7	15,576.4
Take Rate	12%	12%	12%	13%	13%	13%	14%	15%	14%
Connected Telematics	5,044.5	6,824.4	8,128.6	9,617.5	10,132.3	10,544.0	9,539.9	9,358.8	8,510.1
Take Rate	6%	8%	9%	10%	11%	11%	9%	9%	8%
Multi-Funcion Portals	1,893.0	2,224.2	3,204.2	4,618.1	6,355.4	8,305.6	9,622.8	11,007.4	12,526.0
Take Rate	2%	3%	4%	5%	7%	8%	9%	10%	12%
Hybrid MFP	807.8	1,191.9	1,827.2	2,836.6	4,622.5	7,102.7	10,672.8	14,202.0	17,964.4
Take Rate	1%	1%	2%	3%	5%	7%	10%	14%	17%
Total	**79,656.1**	**81,689.0**	**86,641.4**	**91,690.6**	**96,005.2**	**99,717.7**	**102,611.8**	**105,093.7**	**107,458.7**

Source: IHS, Citi Research Note: 2013-2020 are estimates

Figure 86. Global Aftermarket Front Unit Infotainment System Summary

(thousands)	2012	2013	2014	2015	2016	2017	2018	2019	2020
Conventional Audio	14,649.5	13,910.1	13,116.6	11,668.6	10,297.7	8,387.8	6,874.9	5,848.5	4,825.6
Audio/Video	2,406.4	2,412.1	2,399.7	2,344.3	2,114.0	1,854.6	1,513.7	1,271.2	1,171.5
Unconnected Navigation	5,674.9	5,163.1	4,567.5	3,997.3	3,382.9	2,871.0	2,496.5	2,355.2	2,228.8
Connected Telematics	286.8	533.3	878.2	1,333.8	2,009.7	2,792.9	3,480.0	4,040.9	4,462.1
Multi-Funcion Portals	277.2	340.3	477.0	734.9	773.4	717.1	632.6	526.0	427.6
Hybrid MFP	0.0	0.0	25.0	76.5	163.8	291.4	483.0	751.2	978.4
Total	**23,294.8**	**22,358.9**	**21,464.0**	**20,155.4**	**18,741.5**	**16,914.8**	**15,480.7**	**14,793.0**	**14,094.0**

Source: IHS, Citi Research Note: 2013-2020 are estimates

Conventional Audio

Conventional audio is defined as a head unit that produces audio, but cannot process video or provide navigation. Your standard AM/FM tuner, cassette player, CD player, Mini Disc, flash memory storage, HDD, or aux port technology are included in this segment.

As of 2013, roughly 68% of total front infotainment units sold (OE and aftermarket) were conventional audio; by 2020 it is forecast to be 42%. Conventional audio also carries the lowest ASP of all technology, thus as volume declines outsized profit potential for this segment faces headwinds.

Figure 87. Conventional Audio Head Units (OE Front)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America									
Vehicle Sales (K)	17,170.2	17,791.5	18,514.6	19,136.8	19,538.8	19,664.3	19,489.4	19,652.4	19,847.7
x Take Rate	64.9%	59.7%	54.7%	49.6%	47.9%	43.0%	37.5%	31.4%	24.9%
= Units Sold	11,149.5	10,620.7	10,122.7	9,495.7	9,358.2	8,450.3	7,307.0	6,167.7	4,947.5
x ASP ($)	90.0	88.2	85.6	83.0	80.5	78.1	75.7	72.0	68.4
= Revenue ($, mlns)	1,003.5	936.7	866.0	788.0	753.3	659.8	553.4	443.8	338.2
South America									
Vehicle Sales (K)	5,843.0	5,849.5	6,212.6	6,612.7	6,990.0	7,372.2	7,752.5	8,128.0	8,467.0
x Take Rate	75.0%	73.7%	73.1%	68.0%	64.8%	61.6%	56.6%	49.8%	47.3%
= Units Sold	4,384.8	4,309.2	4,541.1	4,495.7	4,529.0	4,541.4	4,387.1	4,048.4	4,009.0
x ASP ($)	60.0	63.0	69.3	76.2	76.2	72.4	68.8	65.4	62.1
= Revenue ($, mlns)	263.1	271.5	314.7	342.7	345.2	328.9	301.8	264.6	248.9
W. Europe									
Vehicle Sales (K)	13,153.0	12,820.4	13,301.3	14,052.1	14,484.0	14,958.2	15,335.4	15,579.7	15,614.9
x Take Rate	68.8%	63.4%	58.3%	51.0%	44.4%	35.0%	27.7%	23.2%	23.4%
= Units Sold	9,047.9	8,128.1	7,753.7	7,172.4	6,427.9	5,239.5	4,253.1	3,610.5	3,652.1
x ASP ($)	88.0	86.2	84.5	82.0	77.9	74.0	70.3	66.8	63.4
= Revenue ($, mlns)	796.2	701.0	655.3	588.0	500.6	387.7	298.9	241.1	231.7
Central Europe									
Vehicle Sales (K)	928.2	931.2	979.7	1,093.1	1,229.7	1,338.1	1,426.2	1,477.1	1,605.4
x Take Rate	73.3%	71.4%	69.9%	65.4%	61.9%	51.0%	45.9%	42.2%	41.1%
= Units Sold	680.7	665.0	684.6	715.2	760.7	682.5	654.2	623.8	660.1
x ASP ($)	75.0	78.8	79.5	78.7	77.2	73.3	69.6	66.2	62.9
= Revenue ($, mlns)	51.1	52.4	54.5	56.3	58.7	50.0	45.6	41.3	41.5
China									
Vehicle Sales (K)	19,193.3	20,872.6	23,112.0	25,171.1	26,943.4	28,457.6	29,541.3	30,284.1	31,007.0
x Take Rate	73.2%	72.5%	70.8%	68.3%	65.4%	60.9%	56.8%	52.0%	48.2%
= Units Sold	14,057.3	15,136.8	16,354.1	17,195.0	17,630.1	17,317.8	16,769.1	15,754.5	14,958.6
x ASP ($)	62.0	65.1	66.4	65.7	63.8	57.4	51.7	49.1	46.6
= Revenue ($, mlns)	871.6	985.4	1,085.9	1,130.4	1,124.2	993.9	866.1	773.0	697.3
Japan									
Vehicle Sales (K)	5,217.1	4,597.9	4,666.8	4,664.5	4,550.0	4,542.8	4,494.2	4,472.4	4,407.1
x Take Rate	38.7%	33.5%	33.6%	30.2%	24.8%	22.4%	20.3%	19.3%	16.5%
= Units Sold	2,018.1	1,542.0	1,567.1	1,410.2	1,126.6	1,016.3	913.3	861.6	725.6
x ASP ($)	92.0	90.2	88.4	86.6	82.3	78.1	74.2	70.5	67.0
= Revenue ($, mlns)	185.7	139.0	138.5	122.1	92.7	79.4	67.8	60.8	48.6
South Korea									
Vehicle Sales (K)	1,501.3	1,517.8	1,554.2	1,577.5	1,598.0	1,616.4	1,631.7	1,640.7	1,640.0
x Take Rate	69.2%	68.5%	64.0%	58.2%	52.4%	46.5%	42.4%	38.0%	37.6%
= Units Sold	1,038.9	1,039.4	994.8	917.6	836.8	751.8	692.3	624.2	617.4
x ASP ($)	89.0	87.2	85.5	83.8	81.3	77.2	73.3	69.7	66.2
= Revenue ($, mlns)	92.5	90.7	85.0	76.9	68.0	58.0	50.8	43.5	40.9
Rest of World									
Vehicle Sales (K)	16,649.6	17,308.1	18,300.7	19,382.6	20,671.4	21,768.4	22,941.1	23,859.3	24,869.8
x Take Rate	67.4%	64.6%	63.0%	60.7%	59.0%	57.1%	57.6%	54.0%	53.9%
= Units Sold	11,218.1	11,180.8	11,538.3	11,758.2	12,188.8	12,437.0	13,210.2	12,886.3	13,412.1
x ASP ($)	71.0	70.3	69.6	68.2	66.8	65.5	63.5	61.6	58.5
= Revenue ($, mlns)	796.5	785.9	802.9	801.9	814.6	814.6	839.2	794.1	785.2

Source: IHS, Citi Research Note: 2013-2020 are estimates

Audio/Video

Audio/Video is defined as a head unit that produces audio and video signals, but is not a navigation system or multi-function portal. These systems may serve as a vehicle's sound system, but they are not included (double counted) in conventional audio. Looking at the growth and opportunity for this segment (OE and Aftermarket), this product has the lowest 2020 units and revenue opportunity.

The take rates of this technology by region and highlight the limited adoption, which makes sense if you consider the alternatives of MFP and HMFP.

As of 2013, roughly 6% of total front infotainment units sold (OE and aftermarket) were Audio/Video; by 2020 it is forecast to be 4%. ASPs for Audio/Video are significantly better than conventional audio, but are still on the lower end of the infotainment system scale.

Figure 88. Audio/Video Head Units (OE)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America									
Front Seat Units Sold	37.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rear Seat Units Sold	1,028.0	1,002.3	933.7	850.6	766.6	702.6	633.5	571.5	514.3
x ASP ($)	410.0	405.9	401.8	397.8	393.8	386.0	378.2	370.7	363.3
= Revenue ($, mlns)	437.0	406.8	375.2	338.4	301.9	271.2	239.6	211.8	186.8
South America									
Front Seat Units Sold	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rear Seat Units Sold	60.6	61.9	60.6	57.6	54.7	50.3	46.3	44.0	43.5
x ASP ($)	445.0	440.6	436.1	431.8	427.5	418.9	410.5	402.3	394.3
= Revenue ($, mlns)	27.0	27.2	26.4	24.9	23.4	21.1	19.0	17.7	17.2
W. Europe									
Front Seat Units Sold	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rear Seat Units Sold	272.9	266.6	269.4	275.1	265.1	258.5	249.8	235.4	221.3
x ASP ($)	415.0	410.9	406.7	398.6	394.6	386.7	375.1	367.6	363.9
= Revenue ($, mlns)	113.3	109.5	109.6	109.7	104.6	100.0	93.7	86.5	80.5
Central Europe									
Front Seat Units Sold	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rear Seat Units Sold	14.3	15.0	15.1	14.8	14.1	13.2	12.4	11.4	10.4
x ASP ($)	450.0	445.5	441.0	432.2	427.9	419.3	406.8	398.6	394.6
= Revenue ($, mlns)	6.4	6.7	6.7	6.4	6.0	5.5	5.1	4.6	4.1
China									
Front Seat Units Sold	253.3	243.2	296.4	354.4	418.4	485.8	487.4	484.5	480.6
Rear Seat Units Sold	196.3	238.1	292.1	346.8	382.5	418.7	443.2	450.5	441.5
x ASP ($)	390.0	386.1	382.2	374.6	370.8	363.4	352.5	345.5	342.0
= Revenue ($, mlns)	175.3	185.8	225.0	262.6	297.0	328.7	328.1	323.0	315.4
Japan									
Front Seat Units Sold	104.3	92.0	65.3	56.0	54.6	50.0	44.9	44.3	43.2
Rear Seat Units Sold	54.5	49.5	49.4	48.6	45.6	45.1	45.2	44.4	43.0
x ASP ($)	484.0	474.3	469.6	467.2	462.6	448.7	430.7	417.8	409.5
= Revenue ($, mlns)	76.9	67.1	53.9	48.9	46.4	42.7	38.8	37.0	35.3
South Korea									
Front Seat Units Sold	61.6	49.3	46.6	46.5	32.0	32.3	24.5	24.6	23.8
Rear Seat Units Sold	29.7	29.1	28.5	27.9	27.4	26.8	26.3	25.8	25.3
x ASP ($)	465.0	460.4	455.7	451.2	446.7	442.2	428.9	424.7	416.2
= Revenue ($, mlns)	42.4	36.1	34.2	33.6	26.5	26.2	21.8	21.4	20.4
Rest of World									
Front Seat Units Sold	266.4	242.3	256.2	232.6	206.7	217.7	229.4	238.6	243.7
Rear Seat Units Sold	161.2	290.2	464.4	557.3	613.0	643.6	630.8	599.2	539.3
x ASP ($)	415.0	410.9	415.0	410.8	406.7	394.5	378.7	367.4	360.0
= Revenue ($, mlns)	177.5	218.8	299.0	324.5	333.4	339.8	325.8	307.8	281.9

Source: IHS, Citi Research. Note: 2013-2020 are estimates

Unconnected Navigation

Unconnected Navigation is defined as a head unit that utilizes GPS to provide route information and points of interest. Only systems with onboard maps are included here, meaning that there is no off-board data connection required; connected navigation head units are split across connected telematics, hybrid multi-function portals and multi-function portals, as these all require an off-board data connection.

As of 2013, roughly 15% of total front infotainment units sold (OE and aftermarket) were unconnected navigation; by 2020 it is forecast to also be 15%. ASPs for unconnected navigation are in the upper echelon of all infotainment systems.

Figure 89. Unconnected Navigation OE Head Units Take Rates by Region

Unconnected Navigation Take Rate (%)	2012	2013	2014	2015	2016	2017	2018	2019	2020
N. America	14.4%	15.4%	15.2%	16.8%	16.2%	19.4%	23.6%	29.1%	29.6%
S. America	1.4%	1.9%	2.2%	1.9%	2.2%	3.4%	5.4%	8.7%	9.8%
W. Europe	17.3%	17.5%	19.2%	20.0%	21.3%	25.9%	27.5%	26.7%	24.9%
C. Europe	6.5%	8.2%	8.7%	8.3%	9.6%	9.6%	10.4%	10.9%	10.4%
China	5.2%	4.8%	4.4%	4.0%	3.7%	3.5%	3.4%	3.3%	3.3%
Japan	14.3%	11.3%	9.3%	9.4%	10.4%	10.6%	9.3%	7.1%	5.5%
S. Korea	15.6%	13.9%	14.8%	16.3%	17.6%	17.8%	18.6%	19.1%	14.9%
RoW	15.4%	17.0%	18.1%	19.7%	18.6%	15.9%	15.4%	15.4%	13.4%

Source: IHS, Citi Research Note: 2013-2020 are estimates

Figure 90. Unconnected Navigation Head Units (OE)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America									
Units Sold	2,472.1	2,735.3	2,808.3	3,207.5	3,159.8	3,820.6	4,606.5	5,718.9	5,869.3
x ASP ($)	780.0	702.0	631.8	600.2	558.2	519.1	482.8	458.6	435.7
= Revenue ($, mlns)	1,928.2	1,920.2	1,774.3	1,925.2	1,763.8	1,983.3	2,223.9	2,623.0	2,557.3
South America									
Units Sold	82.9	113.2	139.1	128.5	155.9	247.2	415.6	709.7	825.6
x ASP ($)	850.0	765.0	711.5	640.3	589.1	542.0	498.6	458.7	422.0
= Revenue ($, mlns)	70.5	86.6	99.0	82.3	91.9	134.0	207.2	325.5	348.4
W. Europe									
Units Sold	2,279.5	2,238.6	2,554.2	2,807.8	3,088.8	3,871.0	4,219.6	4,166.0	3,881.0
x ASP ($)	680.0	714.0	678.3	644.4	612.2	581.6	535.0	492.2	452.9
= Revenue ($, mlns)	1,550.1	1,598.4	1,732.5	1,809.3	1,890.9	2,251.2	2,257.6	2,050.6	1,757.5
Central Europe									
Units Sold	60.7	76.7	85.6	91.0	117.6	128.6	148.8	160.3	166.7
x ASP ($)	794.6	754.8	717.1	681.2	647.2	595.4	547.8	503.9	478.8
= Revenue ($, mlns)	48.2	57.9	61.4	62.0	76.1	76.6	81.5	80.8	79.8
China									
Units Sold	1,004.5	1,005.5	1,006.5	1,007.5	1,008.5	1,009.5	1,010.5	1,011.5	1,012.5
x ASP ($)	660.0	627.0	595.7	536.1	493.2	453.7	431.1	409.5	389.0
= Revenue ($, mlns)	663.0	630.4	599.5	540.1	497.4	458.1	435.6	414.2	393.9
Japan									
Units Sold	745.4	518.3	432.1	438.2	475.0	480.6	416.3	316.3	242.6
x ASP ($)	870.0	852.6	835.5	793.8	754.1	716.4	680.6	646.5	614.2
= Revenue ($, mlns)	648.5	441.9	361.0	347.9	358.2	344.3	283.3	204.5	149.0
South Korea									
Units Sold	233.7	210.8	230.4	256.6	281.8	287.2	302.9	314.1	245.1
x ASP ($)	891.0	846.5	804.1	763.9	725.7	689.4	655.0	622.2	591.1
= Revenue ($, mlns)	208.2	178.4	185.3	196.0	204.5	198.0	198.4	195.5	144.9
Rest of World									
Units Sold	2,571.1	2,943.9	3,309.3	3,826.6	3,840.7	3,456.1	3,526.7	3,680.8	3,333.7
x ASP ($)	875.0	787.5	779.6	740.6	703.6	668.4	635.0	603.3	573.1
= Revenue ($, mlns)	2,249.7	2,318.3	2,580.1	2,834.2	2,702.4	2,310.2	2,239.5	2,220.5	1,910.5

Source: IHS, Citi Research Note: 2013-2020 are estimates

Connected Telematics

Connected Telematics is defined as a head unit that has a positioning module embedded within but does not feature a wireless communication module; rather, this head unit makes use of a driver's cellular device to establish wireless communication (Ford Sync).

Figure 91. Connected Telematics OE Head Units Take Rates by Region

Connected Telematics Take Rate (%)	2012	2013	2014	2015	2016	2017	2018	2019	2020
N. America	13.8%	17.0%	18.9%	17.0%	14.2%	9.9%	9.8%	9.2%	9.2%
S. America	2.5%	3.1%	4.6%	9.2%	9.2%	9.3%	9.3%	8.2%	7.5%
W. Europe	2.1%	6.8%	9.7%	10.2%	6.1%	3.0%	2.5%	1.5%	0.0%
C. Europe	2.0%	2.6%	4.2%	8.8%	6.3%	4.2%	3.2%	2.5%	1.5%
China	0.1%	0.1%	0.3%	0.9%	1.3%	2.3%	2.0%	1.6%	1.3%
Japan	40.7%	47.8%	49.1%	50.8%	53.3%	53.3%	53.7%	53.6%	53.5%
S. Korea	6.8%	9.4%	12.3%	15.3%	18.2%	20.0%	20.7%	21.4%	23.0%
RoW	2.0%	3.8%	4.7%	5.6%	7.5%	8.7%	4.2%	4.3%	2.7%

Source: IHS, Citi Research Note: 2013-2020 are estimates

As of 2013, roughly 7% of total front infotainment units sold (OE and aftermarket) were connected telematics; by 2020 it is forecast to be 11%. ASPs for connected telematics are currently at a modest premium to that of Audio/ Video, this premium is forecast to abate over time, reaching parity around 2017 at which the ASP will then be at a modest discount to Audio/Video.

Additionally, the % of connected telematics head units with navigation are increasing healthily for all regions; this just further reinforces the point made in the unconnected navigation section that connected navigation growth is growing at a faster clip than it's unconnected counterpart. Globally connected navigation unit growth is 23.6% CAGR ('12-'20) vs. unconnected at a 6.4% CAGR ('12-'20)

Figure 92. Connected Telematics Head Units (OE)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America									
Units Sold	2,369.0	3,024.8	3,493.1	3,253.5	2,765.4	1,947.9	1,912.8	1,817.7	1,821.5
% w/ navigation	15.0%	16.0%	20.0%	20.0%	30.0%	35.0%	40.0%	35.0%	35.0%
x ASP ($)	118.0	153.4	207.1	289.9	347.9	278.3	194.8	192.9	187.1
= Revenue ($, mlns)	279.5	464.0	723.4	943.3	962.1	542.2	372.7	350.6	340.8
South America									
Units Sold	145.5	182.2	284.2	605.6	646.2	684.1	724.4	669.1	636.5
% w/ navigation	5.0%	8.0%	15.0%	20.0%	25.0%	30.0%	35.0%	35.0%	30.0%
x ASP ($)	118.0	160.0	216.0	302.4	362.9	290.3	203.2	201.2	195.1
= Revenue ($, mlns)	17.2	29.1	61.4	183.1	234.5	198.6	147.2	134.6	124.2
W. Europe									
Units Sold	274.9	867.5	1,288.2	1,432.0	886.4	454.0	381.0	235.2	0.0
% w/ navigation	60.0%	35.0%	40.0%	45.0%	50.0%	52.0%	52.0%	48.0%	0.0%
x ASP ($)	320.0	230.0	225.4	220.9	216.5	212.1	207.9	166.3	0.0
= Revenue ($, mlns)	88.0	199.5	290.4	316.3	191.9	96.3	79.2	39.1	0.0
Central Europe									
Units Sold	18.7	23.8	41.2	96.1	77.7	55.9	46.2	37.2	23.8
% w/ navigation	60.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	60.0%	65.0%
x ASP ($)	320.0	240.0	235.2	230.5	225.9	221.4	216.9	212.6	208.4
= Revenue ($, mlns)	6.0	5.7	9.7	22.2	17.6	12.4	10.0	7.9	5.0
China									
Units Sold	13.0	22.9	80.7	233.2	344.2	644.4	599.2	489.7	393.8
% w/ navigation	100.0%	80.0%	60.0%	60.0%	40.0%	35.0%	35.0%	40.0%	40.0%
x ASP ($)	195.0	214.5	225.2	214.0	203.3	193.1	183.4	174.3	165.6
= Revenue ($, mlns)	2.5	4.9	18.2	49.9	70.0	124.4	109.9	85.3	65.2
Japan									
Units Sold	2,125.0	2,198.4	2,291.5	2,367.7	2,426.1	2,421.6	2,413.2	2,396.4	2,358.9
% w/ navigation	35.0%	38.5%	42.4%	44.5%	46.7%	49.0%	51.5%	54.1%	56.8%
x ASP ($)	600.0	540.0	550.8	539.8	523.6	507.9	487.6	463.2	440.0
= Revenue ($, mlns)	1,275.0	1,187.1	1,262.2	1,278.1	1,270.3	1,229.9	1,176.6	1,110.0	1,038.0
South Korea									
Units Sold	102.3	142.7	190.7	241.1	290.4	322.8	337.4	350.8	376.5
% w/ navigation	100.0%	95.0%	85.0%	80.0%	80.0%	85.0%	85.0%	85.0%	85.0%
x ASP ($)	380.0	361.0	343.0	325.8	309.5	294.0	279.3	265.4	252.1
= Revenue ($, mlns)	38.9	51.5	65.4	78.5	89.9	94.9	94.3	93.1	94.9
Rest of World									
Units Sold	327.4	663.3	862.6	1,083.4	1,553.8	1,892.6	963.4	1,026.0	665.7
% w/ navigation	15.0%	15.0%	18.0%	25.0%	40.0%	50.0%	55.0%	40.0%	45.0%
x ASP ($)	220.0	210.0	203.7	197.6	191.7	184.0	180.3	162.3	160.7
= Revenue ($, mlns)	72.0	139.3	175.7	214.1	297.8	348.2	173.7	166.5	107.0

Source: IHS, Citi Research Note: 2013-2020 are estimates

Multi-Function Portals

Multi-Function Portals are defined as head units that have an embedded telematics control unit with advanced connective features such as email, weather and live POI search. This head unit does not have to include navigation. The embedded transmission control unit (TCU) allows for data connectivity with the primary difference between the MFP and the hybrid MFP being that the HMFP can also be tethered or make use of your cellular phones connection.

As of 2013, roughly 3% of total front infotainment units sold (OE and aftermarket) were MFPs; by 2020 it is forecast to be 11%. ASPs for MFPs are currently at the peak of all infotainment systems; this coveted top ASP spot is forecast to swap throughout 2020 with similar technology, HMFPs.

Again, note the % of units for all regions with navigation. All in, connected navigation is expected to total 20.8mln units vs. 3.8mln units in 2012; connected navigation units are embedded within connected telematics, MFP, and HMFP forecasts in this section.

Figure 93. MFP OE Head Units Take Rates by Region

MFP Take Rate (%)	2012	2013	2014	2015	2016	2017	2018	2019	2020
N. America	2.9%	3.5%	5.4%	6.2%	7.0%	7.7%	8.4%	8.7%	12.2%
S. America	0.1%	0.3%	1.0%	2.4%	5.0%	6.7%	7.9%	9.0%	9.1%
W. Europe	5.1%	5.3%	5.2%	8.2%	11.1%	14.2%	16.4%	19.0%	20.4%
C. Europe	1.3%	1.4%	1.7%	2.6%	5.5%	11.5%	13.9%	16.3%	18.0%
China	2.4%	3.1%	4.8%	6.6%	8.7%	10.8%	11.5%	12.6%	13.3%
Japan	3.5%	3.9%	4.8%	5.6%	6.0%	5.4%	5.3%	5.0%	5.0%
S. Korea	3.2%	3.7%	4.3%	5.3%	6.7%	8.2%	7.3%	6.1%	5.6%
RoW	0.1%	0.1%	0.2%	0.5%	1.1%	2.6%	4.0%	5.1%	5.7%

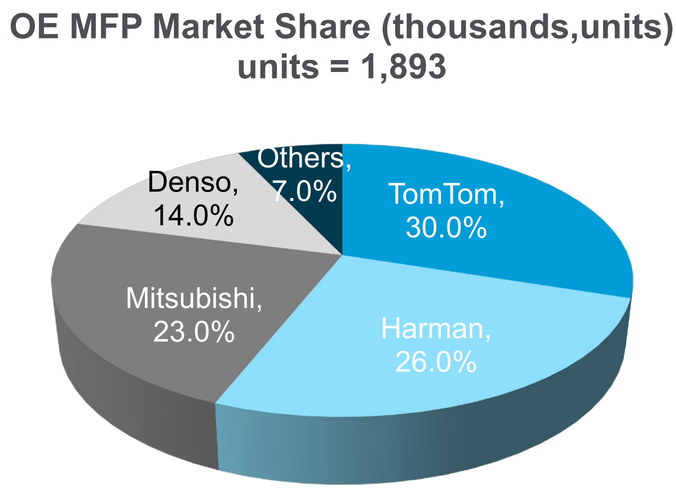
Source: IHS, Citi Research Note: 2013-2020 are estimates

Figure 94. Multi-Function Portal Head Units (OE)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America									
Units Sold	500.0	615.6	995.0	1,187.6	1,364.7	1,505.3	1,636.9	1,717.6	2,414.9
% w/ navigation	100.0%	100.0%	85.0%	70.0%	70.0%	70.0%	75.0%	80.0%	80.0%
x ASP ($)	1007.8	977.6	865.4	760.3	732.2	704.1	692.5	680.0	646.7
= Revenue ($, mlns)	503.9	601.8	861.1	903.0	999.3	1,059.9	1,133.6	1,168.0	1,561.8
South America									
Units Sold	8.4	14.9	59.5	161.7	351.4	497.3	609.9	732.7	771.3
% w/ navigation	100.0%	100.0%	85.0%	70.0%	70.0%	70.0%	70.0%	60.0%	60.0%
x ASP ($)	1045.7	1014.3	881.3	756.2	727.8	699.5	665.4	579.3	551.4
= Revenue ($, mlns)	8.8	15.1	52.4	122.3	255.8	347.9	405.8	424.4	425.3
W. Europe									
Units Sold	670.0	674.6	698.3	1,147.5	1,612.5	2,129.1	2,518.3	2,954.7	3,184.9
% w/ navigation	100.0%	100.0%	80.0%	65.0%	60.0%	50.0%	50.0%	60.0%	70.0%
x ASP ($)	610.0	720.0	634.5	569.5	532.8	480.1	457.8	471.5	483.4
= Revenue ($, mlns)	408.7	485.7	443.0	653.5	859.1	1,022.2	1,152.9	1,393.1	1,539.6
Central Europe									
Units Sold	12.5	12.8	17.1	28.5	67.8	153.3	198.5	241.1	288.2
% w/ navigation	100.0%	100.0%	80.0%	65.0%	40.0%	40.0%	40.0%	45.0%	45.0%
x ASP ($)	1011.0	1000.9	854.7	744.9	568.5	547.5	521.9	528.7	507.6
= Revenue ($, mlns)	12.7	12.8	14.6	21.2	38.5	83.9	103.6	127.5	146.3
China									
Units Sold	458.5	655.4	1,101.7	1,651.2	2,339.5	3,072.7	3,393.0	3,822.8	4,133.8
% w/ navigation	100.0%	100.0%	100.0%	80.0%	80.0%	80.0%	85.0%	85.0%	90.0%
x ASP ($)	748.0	725.6	703.8	596.2	578.8	561.9	564.9	564.3	584.3
= Revenue ($, mlns)	342.9	475.6	775.4	984.4	1,354.0	1,726.5	1,916.7	2,157.4	2,415.2
Japan									
Units Sold	182.5	177.6	222.1	262.8	274.4	247.5	236.0	224.3	220.8
% w/ navigation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
x ASP ($)	963.7	933.4	890.2	863.5	843.0	817.2	792.3	793.3	794.3
= Revenue ($, mlns)	175.9	165.8	197.8	226.9	231.4	202.2	187.0	178.0	175.4
South Korea									
Units Sold	47.6	55.8	67.4	83.0	107.7	132.3	119.3	100.4	91.7
% w/ navigation	100.0%	100.0%	95.0%	95.0%	90.0%	90.0%	95.0%	100.0%	100.0%
x ASP ($)	986.2	943.1	897.0	870.5	819.9	788.2	779.6	769.4	738.6
= Revenue ($, mlns)	46.9	52.6	60.5	72.2	88.3	104.3	93.0	77.3	67.8
Rest of World									
Units Sold	13.5	17.5	43.1	95.8	237.3	568.1	910.9	1,213.9	1,420.3
% w/ navigation	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
x ASP ($)	988.9	959.6	903.0	888.8	858.7	824.9	758.3	759.3	760.3
= Revenue ($, mlns)	13.4	16.8	38.9	85.2	203.8	468.6	690.7	921.7	1,079.8

Source: IHS, Citi Research Note: 2013-2020 are estimates

Figure 95. Supplier Market Share OE MFP Head Units (2012, thousands units)



Source: HIS, Citi Research

Hybrid Multi-Function Portals

Similar to MFPs, HFMPs are defined as head units that must have an embedded telematics control unit AND must also be able to make use of the consumer's smart phone or other device to offer additional services through a separate data plan (GM OnStar plus MyLink, BMW ConnectedDrive plus ConnectedApps).

As of 2013 roughly 1% of total front infotainment units sold (OE and aftermarket) were MFPs; by 2020 it is forecast to be 16%. ASPs for HMFPs are currently just below MFPs, which is the top ASP infotainment system; the coveted top ASP spot is forecast to swap throughout 2020 with similar technology, MFPs.

Figure 96. HMFP OE Head Units Take Rates by Region

HMFP Take Rate (%)	2012	2013	2014	2015	2016	2017	2018	2019	2020
N. America	1.0%	1.8%	3.2%	7.8%	12.9%	18.5%	19.5%	20.6%	23.4%
S. America	0.0%	0.1%	0.5%	1.8%	3.7%	6.2%	9.9%	14.8%	18.2%
W. Europe	2.2%	2.8%	3.5%	6.8%	13.4%	18.4%	22.7%	26.7%	29.6%
C. Europe	0.7%	0.7%	1.3%	2.8%	7.1%	15.8%	19.8%	22.9%	25.2%
China	0.0%	0.7%	1.0%	1.5%	2.1%	3.8%	8.0%	12.5%	17.3%
Japan	0.0%	0.7%	1.1%	2.0%	3.4%	6.4%	9.7%	13.3%	17.7%
S. Korea	0.4%	0.5%	0.8%	1.3%	2.3%	4.8%	8.7%	13.0%	16.6%
RoW	0.0%	0.1%	0.1%	0.3%	1.0%	3.3%	6.9%	9.2%	10.3%

Source: IHS, Citi Research Note: 2013-2020 are estimates

Figure 97. Hybrid Multi-Function Portal Head Units (OE)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
North America									
Units Sold	170.9	314.7	595.6	1,499.5	2,512.3	3,638.7	3,806.8	4,052.5	4,635.8
% w/ navigation	100.0%	95.0%	85.0%	70.0%	70.0%	60.0%	50.0%	40.0%	40.0%
x ASP ($)	1048.0	943.2	848.9	679.1	611.2	589.0	580.3	569.3	535.2
= Revenue ($, mlns)	179.1	296.8	505.6	1,018.3	1,535.5	2,143.3	2,209.1	2,307.3	2,481.0
South America									
Units Sold	0.0	8.7	28.5	118.8	260.1	459.6	767.2	1,204.8	1,537.5
% w/ navigation	0.0%	100.0%	85.0%	70.0%	70.0%	70.0%	70.0%	60.0%	60.0%
x ASP ($)	0.0	1150.0	1035.0	931.5	745.2	596.2	476.9	453.1	444.0
= Revenue ($, mlns)	0.0	10.0	29.5	110.7	193.9	274.0	365.9	545.9	682.7
W. Europe									
Units Sold	290.5	364.4	467.3	951.9	1,943.7	2,754.4	3,483.9	4,160.9	4,615.9
% w/ navigation	100.0%	95.0%	80.0%	50.0%	40.0%	30.0%	30.0%	30.0%	30.0%
x ASP ($)	1127.0	1014.3	912.9	730.3	584.2	549.2	538.2	527.4	495.8
= Revenue ($, mlns)	327.4	369.6	426.6	695.1	1,135.6	1,512.7	1,875.0	2,194.6	2,288.5
Central Europe									
Units Sold	6.6	6.9	12.4	30.6	87.2	211.0	282.4	337.8	405.2
% w/ navigation	100.0%	95.0%	70.0%	50.0%	40.0%	30.0%	25.0%	25.0%	25.0%
x ASP ($)	1140.0	1026.0	923.4	738.7	591.0	555.5	538.9	522.7	491.3
= Revenue ($, mlns)	7.5	7.1	11.4	22.6	51.5	117.2	152.1	176.6	199.1
China									
Units Sold	0.0	145.7	239.5	375.3	568.4	1,089.7	2,348.6	3,784.7	5,376.6
% w/ navigation	0.0%	100.0%	80.0%	70.0%	60.0%	50.0%	40.0%	40.0%	40.0%
x ASP ($)	0.0	998.0	898.2	718.6	574.8	517.4	507.0	496.9	467.1
= Revenue ($, mlns)	0.0	145.4	215.1	269.7	326.7	563.8	1,190.8	1,880.5	2,511.2
Japan									
Units Sold	0.0	32.9	51.3	92.2	156.9	290.5	434.5	593.6	780.7
% w/ navigation	0.0%	80.0%	80.0%	85.0%	85.0%	90.0%	90.0%	95.0%	95.0%
x ASP ($)	0.0	1450.0	1305.0	1174.5	939.6	845.6	820.3	795.7	779.7
= Revenue ($, mlns)	0.0	47.7	66.9	108.3	147.4	245.7	356.4	472.3	608.7
South Korea									
Units Sold	5.3	7.6	11.9	20.1	36.6	76.9	142.3	213.4	272.3
% w/ navigation	100.0%	100.0%	95.0%	95.0%	90.0%	90.0%	85.0%	85.0%	90.0%
x ASP ($)	1145.0	1087.8	979.0	783.2	626.5	563.9	552.6	541.6	530.7
= Revenue ($, mlns)	6.1	8.3	11.6	15.7	22.9	43.4	78.6	115.6	144.5
Rest of World									
Units Sold	5.4	10.2	21.9	60.0	204.8	715.3	1,576.9	2,189.2	2,561.3
% w/ navigation	100.0%	100.0%	100.0%	80.0%	70.0%	40.0%	35.0%	35.0%	35.0%
x ASP ($)	1145.0	1030.5	927.5	742.0	593.6	534.2	518.2	502.6	492.6
= Revenue ($, mlns)	6.2	10.5	20.3	44.6	121.6	382.1	817.1	1,100.4	1,261.6

Source: IHS, Citi Research Note: 2013-2020 are estimates

The Rise of the Touch Screen

As technology, electrification and infotainment continue to advance in the automobile, new human machine interfaces (HMI) become more prevalent. If we look at the cell phone (consumer electronics) for example, it has evolved from physical keys with a screen to now an entire touch screen display. The trends in consumer electronics are starting to migrate to that of the automobile. We are evolving from the day of knob and tuners to a more sophisticated, technologically advanced piece of equipment. As mentioned in the above section, the more advanced technological infotainment options make use of touch screen HMIs, including but not limited to: Audio/Video, Unconnected Navigation, Connected Telematics, MFPs and HMFPs. With the continued evolution of infotainment systems, we believe that touch screens will remain a mission critical piece of the puzzle as more and more information is required by the end user.

Auto Specific Touch Screens

The market for auto specific touch screens is growing rapidly. The combined global unit volume (capacitive and resistive) is expected to grow at a 23% CAGR ('13-'19). The addressable revenue for this market is also expected to grow significantly, from roughly $428 million in 2013 to $1.3 billion in 2019 (21% CAGR).

From a volume perspective both NA & APAC appear to be the best two regions for OEMs/suppliers to position themselves.

NA is forecast to grow at an 11% unit CAGR ('13-'19); APAC is forecast to grow at a 49% unit CAGR over the same time period, quite impressive given the volume. Western Europe should also help adoption of touch screens in the near-term, but their volume is not forecast to reach levels commensurate with NA or APAC.

Figure 98. Total Auto Specific Touch Screens and ASP

Unit Sales in 1000's	2011	2012	2013	2014	2015	2016	2017	2018	2019
North America									
ASP ($)	46.0	44.6	43.7	41.7	41.0	40.3	39.0	37.8	36.8
Units (1000's)	3,356	4,465	5,559	6,829	7,810	8,891	9,592	10,049	10,348
Revenue (mln)	**154**	**199**	**243**	**285**	**320**	**358**	**374**	**379**	**381**
South America									
ASP ($)	44.9	44.0	43.3	43.5	43.3	43.2	42.6	41.3	40.5
Units (1000's)	171	214	282	421	544	689	836	1,007	1,189
Revenue (mln)	**8**	**9**	**12**	**18**	**24**	**30**	**36**	**42**	**48**
West Europe									
ASP ($)	42.7	41.7	41.7	41.5	41.1	40.5	39.6	38.4	37.4
Units (1000's)	1,417	1,833	2,360	2,776	3,221	3,689	4,116	4,624	4,939
Revenue (mln)	**60**	**77**	**98**	**115**	**132**	**149**	**163**	**177**	**185**
East Europe									
ASP ($)	36.1	35.5	36.8	35.8	35.0	35.0	34.7	34.8	34.2
Units (1000's)	105	188	218	384	593	671	792	933	1,193
Revenue (mln)	**4**	**7**	**8**	**14**	**21**	**23**	**28**	**32**	**41**
Asia Pacific									
ASP ($)	37.1	38.3	40.0	42.3	41.1	39.9	38.1	37.6	36.6
Units (1000's)	795	1,347	1,653	2,196	3,017	5,112	7,988	12,409	17,858
Revenue (mln)	**29**	**52**	**66**	**93**	**124**	**204**	**305**	**467**	**654**
Rest of World									
ASP ($)	35.0	34.4	33.2	35.1	36.9	36.2	34.8	33.8	33.0
Units (1000's)	4	5	9	19	33	59	90	123	153
Revenue (mln)	**0.1**	**0.2**	**0.3**	**0.7**	**1.2**	**2.1**	**3.1**	**4.2**	**5.1**
ASP	0.00	42.67	42.42	41.61	40.87	40.12	38.80	37.80	36.81
Units	5,848	8,052	10,081	12,625	15,218	19,111	23,414	29,145	35,680
Revenue	**256**	**344**	**428**	**525**	**622**	**767**	**908**	**1,102**	**1,314**

Source: IHS, Citi Research Note: 2013-2019 are estimates

Capacitive vs. Resistive: The Battle of Tech has Begun

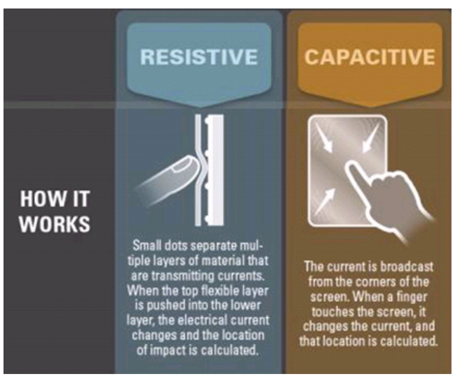
Resistive Screens

A resistive touch screen is a flexible material layered on top of other layers of material. The lower layers of materials have currents running through them, so when a user presses on the top layer, the material presses against the lower layers and changes the flow of the current; this change in current allows for the calculation of the location of impact. A resistive touch screen generally costs less than its capacitive counterpart (polyester film) and allows for more external activation options (finger, gloved finger, and stylus). Globally, resistive touch screens units are expected to grow at a ~7% CAGR from 2013-2019; revenue for the same period is expected to grow at a ~1.5% according to IHG.

Capacitive Screens

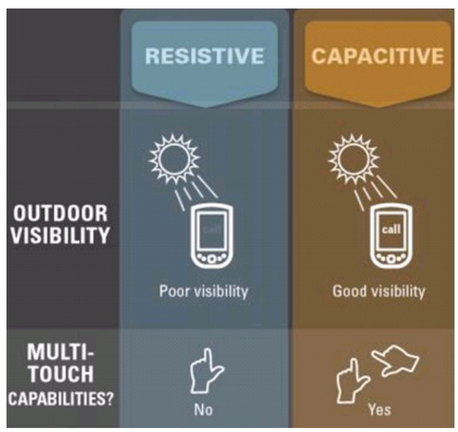
A capacitive touch screen has currents running from the four corners of the screen and when a finger touches it the current is changed and a location is then calculated. Additionally, a capacitive touch screen is more expense than a resistive touch screen, but offers benefits that its counterpart does not, including: (1) increased sharpness; (2) increased brightness and more easily viewable in outdoor lighting; (3) better sensitivity to finger activation; and (4) offers multi-touch capability. Globally, capacitive touch screen units are expected to grow at a ~51% CAGR from 2013-2019; revenue for the same period is expected to grow at a ~45% CAGR.

Figure 99. How a Touch Screen Works (Cell Phone) – Cricket Wireless Infographic



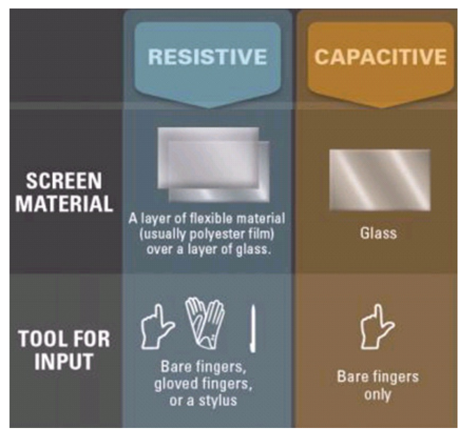
Source: Cricket Wireless website

Figure 100. How a Touch Screen Works (Cell Phone) – Cricket Wireless Infographic



Source: Cricket Wireless website

Figure 101. How a Touch Screen Works (Cell Phone) – Cricket Wireless Infographic



Source: Cricket Wireless website

Figure 102. Capacitive Touch Screen by Geo (units, ASP, revenue)

Unit Sales in 1000's	2011	2012	2013	2014	2015	2016	2017	2018	2019
North America									
ASP ($)	0.0	60.6	53.4	45.5	43.2	45.0	43.3	41.5	39.8
Units (1000's)	0	223	834	1,502	2,733	4,001	5,276	6,130	7,244
Revenue (mln)	**0**	**14**	**45**	**68**	**118**	**180**	**229**	**254**	**289**
South America									
ASP ($)	0.0	50.0	48.0	50.6	50.4	49.2	47.3	45.1	43.5
Units (1000's)	0	11	37	84	174	310	460	615	833
Revenue (mln)	**0**	**1**	**2**	**4**	**9**	**15**	**22**	**28**	**36**
West Europe									
ASP ($)	0.0	55.5	52.1	49.3	46.6	44.0	42.9	41.2	39.5
Units (1000's)	0	92	354	611	1,128	1,660	2,264	2,821	3,458
Revenue (mln)	**0**	**5**	**18**	**30**	**53**	**73**	**97**	**116**	**137**
East Europe									
ASP ($)	0.0	42.0	47.2	46.9	41.5	39.4	37.5	38.0	36.5
Units (1000's)	0	9	26	69	166	242	333	476	716
Revenue (mln)	**0**	**0**	**1**	**3**	**7**	**10**	**12**	**18**	**26**
Asia Pacific									
ASP ($)	0.0	42.0	48.4	54.8	50.7	47.4	44.9	43.3	41.6
Units (1000's)	0	391	744	1,273	2,172	3,425	4,873	7,569	11,250
Revenue (mln)	**0**	**16**	**36**	**70**	**110**	**162**	**219**	**327**	**468**
Rest of World									
ASP ($)	0.0	42.1	40.7	44.5	43.6	43.6	39.7	39.2	37.4
Units (1000's)	0	0	1	4	11	26	50	75	107
Revenue (mln)	**0.0**	**0.0**	**0.0**	**0.2**	**0.5**	**1.2**	**2.0**	**2.9**	**4.0**
ASP	0.00	49.55	51.13	49.60	46.52	45.65	43.79	42.21	40.64
Units	0	726	1,996	3,544	6,384	9,664	13,254	17,686	23,608
Revenue	**0**	**36**	**102**	**176**	**297**	**441**	**580**	**747**	**959**

Source: IHS, Citi Research

Figure 103. Resistive Touch Screen by Geo (units, ASP, revenue)

Unit Sales in 1000's	2011	2012	2013	2014	2015	2016	2017	2018	2019
North America									
ASP ($)	46.0	43.8	41.9	40.6	39.8	36.4	33.8	32.0	29.9
Units (1000's)	3,356	4,242	4,725	5,327	5,076	4,890	4,317	3,919	3,105
Revenue (mln)	**154**	**186**	**198**	**216**	**202**	**178**	**146**	**125**	**93**
South America									
ASP ($)	45	44	43	42	40	38	37	35	34
Units (1000's)	171	204	245	337	370	379	376	393	357
Revenue (mln)	**8**	**9**	**10**	**14**	**15**	**14**	**14**	**14**	**12**
West Europe									
ASP ($)	43	41	40	39	38	38	36	34	32
Units (1000's)	1,417	1,741	2,006	2,165	2,094	2,029	1,852	1,804	1,482
Revenue (mln)	**60**	**71**	**80**	**85**	**80**	**76**	**66**	**61**	**48**
East Europe									
ASP ($)	36	35	35	33	33	33	33	32	31
Units (1000's)	105	179	192	315	427	430	459	457	477
Revenue (mln)	**4**	**6**	**7**	**11**	**14**	**14**	**15**	**14**	**15**
Asia Pacific									
ASP ($)	37	37	33	25	16	25	28	29	28
Units (1000's)	795	956	909	922	845	1,687	3,115	4,839	6,607
Revenue (mln)	**29**	**35**	**30**	**23**	**14**	**42**	**86**	**139**	**186**
Rest of World									
ASP ($)	35	34	32	33	34	30	29	25	23
Units (1000's)	4	5	8	15	22	32	41	48	46
Revenue (mln)	**0.1**	**0.2**	**0.3**	**0.5**	**0.7**	**1.0**	**1.2**	**1.2**	**1.0**
ASP	43.77	41.99	40.27	38.48	36.78	34.47	32.28	30.99	29.34
Units	5,848	7,327	8,085	9,081	8,834	9,447	10,160	11,460	12,074
Revenue	**256**	**308**	**326**	**349**	**325**	**326**	**328**	**355**	**354**

Source: IHS, Citi Research

Does Size Matter?

Touch screens come in various different sizes, with the larger sizes typically carrying a heftier price tag. The larger screen sizes do come with advantages though, including accuracy of screen touch and less need to squint to read the screen. From a unit perspective, the large volume touch screens remain range bound between 6” and 8”, a statistic that isn’t forecast to change by 2019. Within this range band, the most rapid growing screen size is the 8” screen, growing at a 27% CAGR (’13-’19). This particular screen size represented just 39% of the market in 2013 and is expected to increase to 46% of the market by 2019. While other screen sizes have impressive CAGRs (4”, 5”, 10”, 12”), their 2019 volume is forecast to represent a combined 10% of the market by 2019, up from 6% in 2013.

As you can see from the table to the right, that highlights global screen size forecasts, the largest volumes are 6” and 8” screens. Relatively speaking, the 12” and higher screen sizes appear to be more of a niche play, but we believe that as technology continues to advance and consumers get used to the larger screens it should gain popularity.

Figure 104. Global Touch Screen Unit Sales & Forecast by Screen Size (units, thousands)

	2011	2012	2013	2014	2015	2016	2017	2018	2019
4"	0	0	2	45	189	302	371	481	634
5"	216	368	550	902	1,191	1,522	1,969	2,347	2,831
6"	1,203	2,264	2,778	3,630	4,523	5,547	6,834	8,134	9,656
7"	1,838	2,170	2,776	3,105	3,734	4,294	4,799	5,355	5,837
8"	2,574	3,215	3,933	4,866	5,474	7,316	9,294	12,654	16,532
10"	1	2	2	10	23	24	23	22	23
12"	17	31	38	58	76	99	118	147	161
17"	0	2	3	7	6	6	6	7	8
Total	**5,849**	**8,052**	**10,082**	**12,623**	**15,216**	**19,110**	**23,414**	**29,147**	**35,682**

Source: IHS, Citi Research

Telematics

The word "Telematics" is the combination of "Telecommunications" and "Informatics" and was originally coined to reflect the blending of computers and phone networks. The Oxford Dictionary defines Telematics as "the branch of information technology that deals with the long-distance transmission of computerized information".

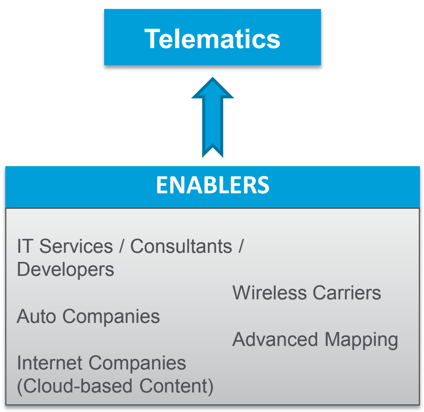
This generic definition embraces a wide range of applications, although the term has become more narrowly aligned with automotive or vehicle telematics because so many recent developments revolve around the "Connected Car" concept. This section devotes a lot of attention to the Connected Car concept but we also highlight other Telematics applications in Fleet Management, Rail Transportation, Insurance and Aerospace.

How Does Telematics Work?

The three components of a basic Telematics solution are Platform, Connectivity and Content/Support. This is illustrated in the Figure below and the providers of these components are the enablers shown in the Figure 105 on the left.

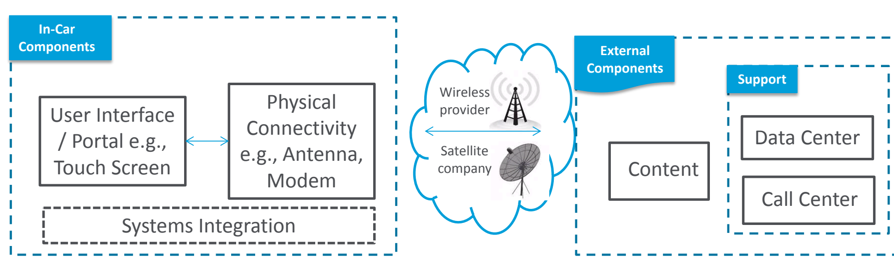
- **Platform:** The user interface or portal – typically a touch screen nowadays – helps the user (driver or passenger) communicate with the system, accepting inputs as well as displaying outputs / responses to requests.
- **Connectivity:** The connection to the external components.
  - The physical connection device, e.g., antenna, modem, etc.
  - The wireless provider or the satellite company.
- **Content / Support:** The external components – this can include OEM-specific and other content, the back-office support and call center support functions.

Figure 105. Telematics Enablers



Source: Citi Research

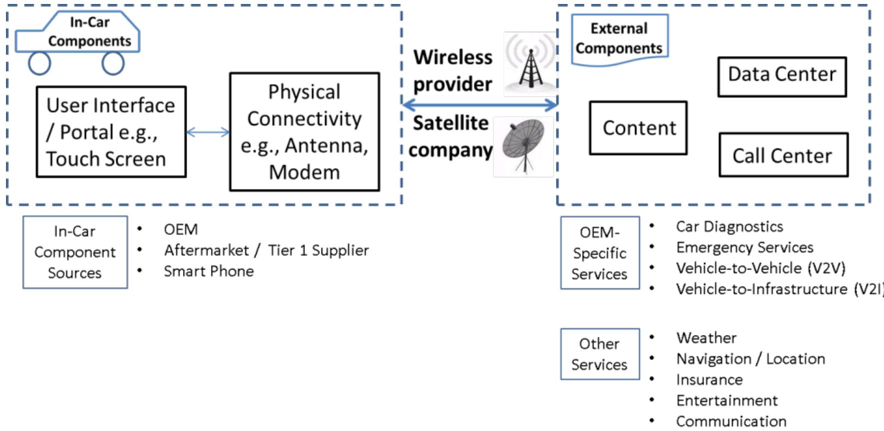
Figure 106. Telematics Components – Platform, Connectivity and Content/Support



Source: Citi Research

Vehicle Telematics brings Mobility and its benefits to the automotive environment. Given Auto companies fashion that environment and the users' experience; they are obviously key enablers of the trend. Figure 107 below shows the various Telematics building blocks and services.

Figure 107. Automotive Telematics Building Blocks and Services

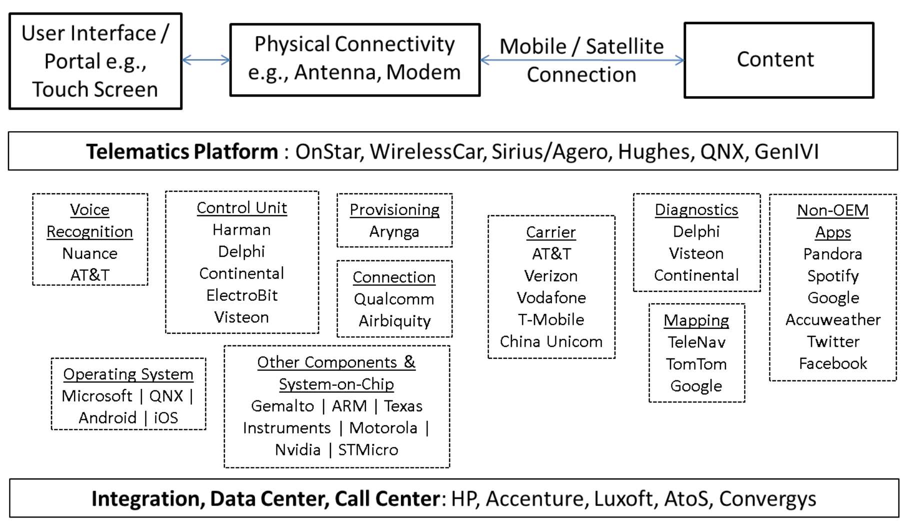


Source: Citi Research

The lower left of the Figure 107 above illustrates that the in-car components can be installed directly by the OEM or the user can have them installed using an aftermarket product or in some cases, the user's smartphone could serve as the portal. The lower right makes the point that certain services like car diagnostics, seem to be best provided by the OEM. At the same time, we believe that the OEM has no particular advantage providing services like weather, entertainment or navigation since commonly-available mobile apps can serve the purpose quite well in those cases.

Figure 108 below shows the Connected Car Value Chain, including some representative players. The list of companies is not comprehensive.

Figure 108. Automotive Telematics Value Chain and Representative Players



Source: Citi Research

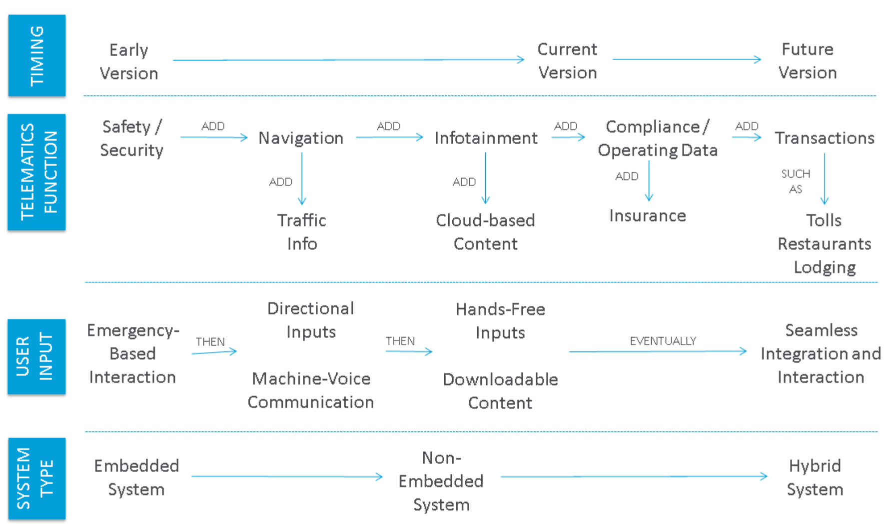
Evolution of Connected Car / Vehicle Telematics

Early Telematics had limited appeal but technology and market advances have moved it from a niche market to mainstream

Vehicle Telematics has been around for a while, but the early versions had limited functionality and consequently, also had limited appeal among consumers. General Motors' initial 1996 implementation of OnStar provided accident notification and emergency use. BMW was the next market entrant, in 2001. Over the last decade several technological and market advances have taken this from a niche offering to the verge of becoming mainstream. The primary change was the proliferation of mobile phones, which led to an increased desire among consumers to be always connected. The rise of smart phones further fueled this trend – the Telematics system no longer had to be embedded, i.e., built into the car and non-embedded systems with access to Internet-based applications became a possibility. The growth of non-embedded systems also opened up the market to aftermarket players in addition to Auto companies. The increasing functionality and consumer demand led to a larger number of Auto companies launching their own Telematics offering.

- *BMW and GM modified their existing offerings in 2007 to include embedded Infotainment. Mercedes and Lexus followed suit. Also, that same year, Honda / Acura introduced non-embedded (mobile) Infotainment.*
- *In 2008-09, Ford introduced their non-embedded "Sync" system. GM standardized its OnStar offering on a wider range of cars in 2009.*
- *In 2010, BMW started offering a non-embedded option for Infotainment. The same year, Infiniti started offering an embedded Telematics option. Toyota brought the Lexus telematics functionality down-market.*
- *2011-13 saw widespread Telematics adoption as well as increased use of the non-embedded option as Hyundai, Subaru, Kia, Chrysler, Volvo all jumped in. So, the last few years have seen near-universal adoption by global auto companies, partly driven by several governments – the EU with its eCall directive and Russia with its Automated Crash Notification (ACN) push – raising the possibility of mandated Telematics in the future, at least for the safety / security function.*

Figure 109. Evolution of Connected Car Feature / Functionality



Source: Citi Research

Telematics Use Cases

The basics of Automotive Telematics are discussed above. Here we discuss some of the pros and cons before we dive into non-automotive Use Cases. Automotive Telematics has shown a steady growth trajectory which should continue. We attribute this to the following reasons.

1. Improves the customer relationship by engaging more frequently with the customer, based on usage data;
2. Tracks customer usage of car features to determine use frequency, which can eliminate wasted features or highlight less-used features that should be modified;
3. Potential for new revenue streams – premium features like streaming audio, video (to back seat) and usage-based insurance;
4. Lowers maintenance cost as some updates and changes can become software-based rather than hardware-based, which would imply they can be done over-the-air (OTA);
5. Legal requirements; and
6. In the case of electric vehicles, promotes peace of mind by providing a current map of charging locations.

Risks - Could Telematics Momentum Stall?

The skepticism around Telematics largely stems from the fact that users have so far been resistant to subscriber-based payment models – in other words, it is not clear how the investment could be effectively recouped.

Competition from non-embedded systems (smartphones) is also a concern but we do not buy this because fully functional Telematics systems should have access to car operations data and that can arguably be better accessed via embedded systems. We do believe, however, that a lot can be done to improve the current user experience associated with a Telematics system by making the look and feel similar to popular smartphone interfaces.

Lastly, privacy concerns are also a potential mitigating factor to the trend.

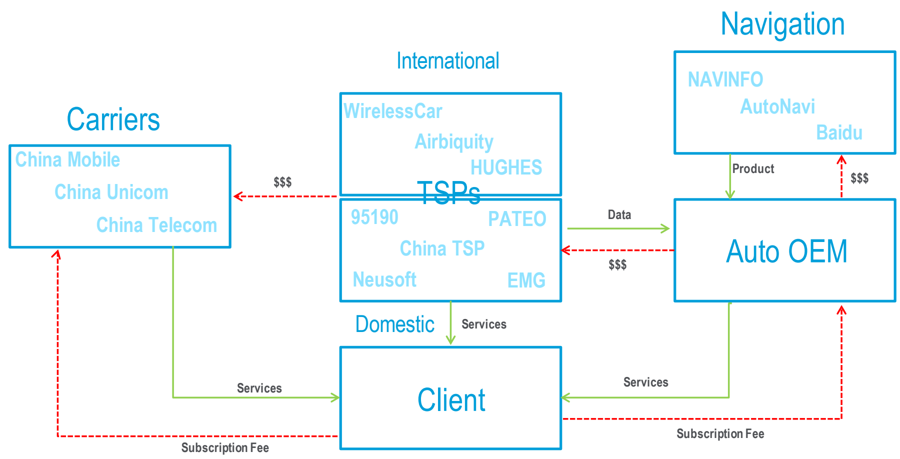
China Telematics Focus

The market in China is truly unique with ~60% of the passenger vehicle market dominated by foreign and JV brands. Each of these foreign and JV brands have unique positioning and offerings in telematics and connectivity, which includes but is not limited to: (1) BMW ConnectedDrive; (2) Hyundai blueLink; (3) Nissan Carwings; (4) Toyota G-Book; (5) HondaLink; (6) Audi Connect; (7) Ford Sync; and (8) GM's OnStar.

Now, aside from the fact that China market share is dominated by foreign and JV brands, that is not stopping the domestic OEs from rolling out telematics and connectivity products on their own. Below we list key China telematics players and the echo system that currently exists.

The telematics ecosystem for China is very unique. Multiple players exist with each offering value added services ultimately for the end consumer

Figure 110. China Telematics Ecosystem



Source: Trajectory Group, Citi Research

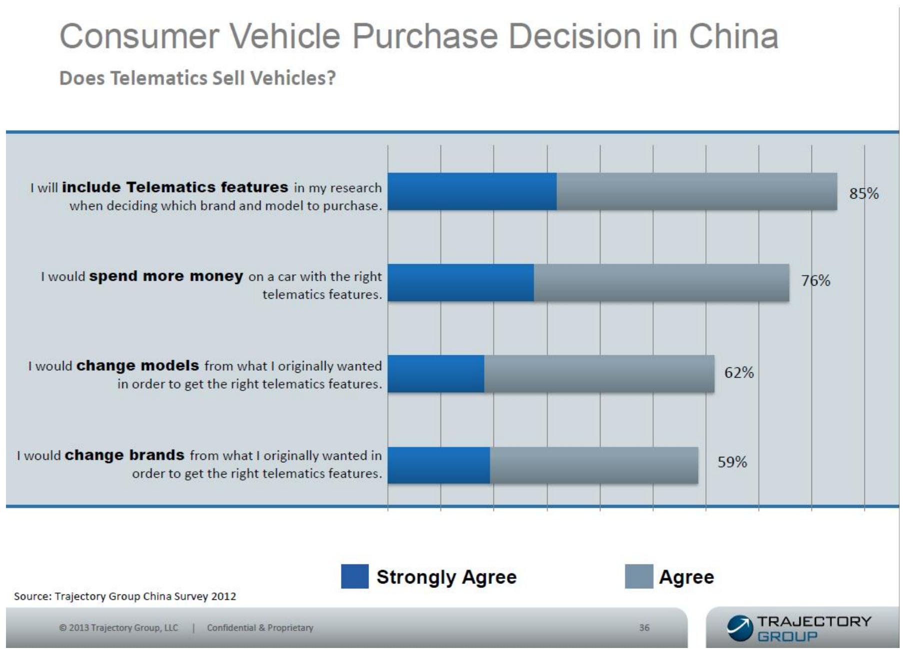
Telematics is truly becoming an integral part of the consumers purchasing decision

85% of those surveyed agreed in some fashion that they will include telematics features in their purchase decision

76% say they would spend more money on the car with the right telematics features

The Sale: The Trajectory Group's unique survey helps to isolate certain key points regarding the stickiness, revenue opportunity, and consumer elasticity of telematics services.

Figure 111. Purchase Decision

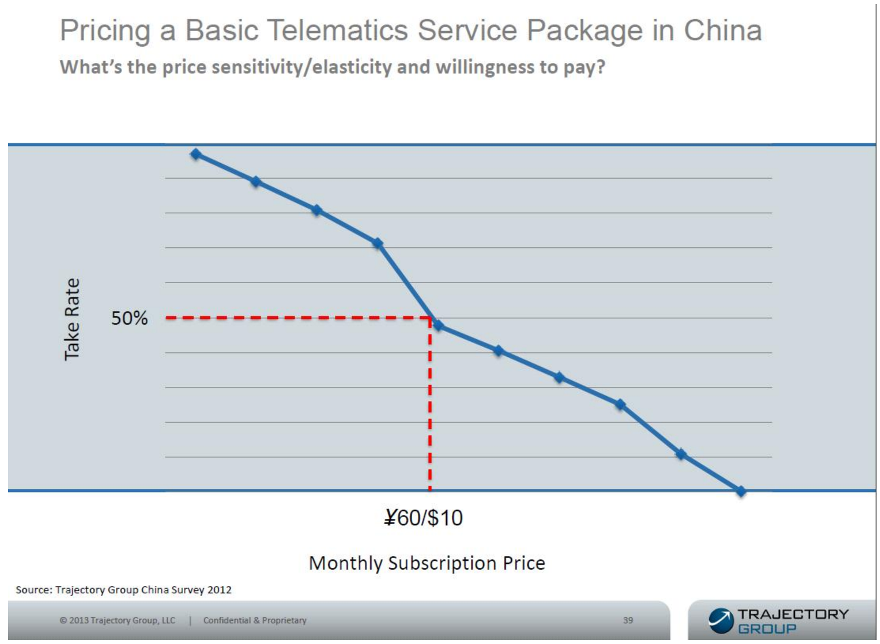


Source: Trajectory Group, Citi Research

The Subscription Pricing: The 76% willing to spend more money on the right telematics features brings up quite the interesting point…how can one monetize the telematics trend? Again, we turn to the Trajectory Group's survey for answers.

Figure 112 highlights customers' elasticity for telematics pricing packages. In order to achieve a 50% take rate, the monthly subscription price would need to be ~$10/month.

Figure 112. Telematics Product Pricing



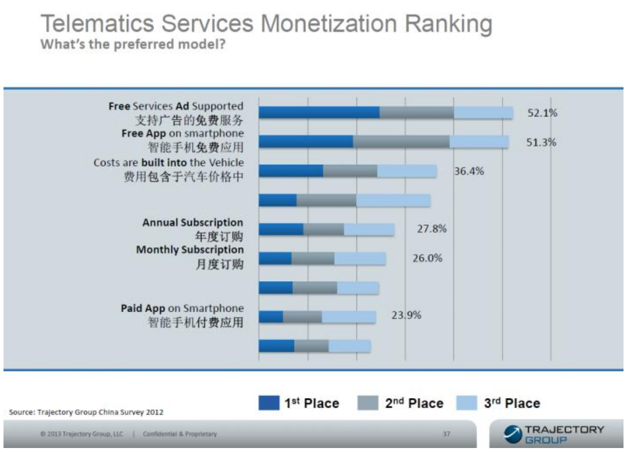
Source: Trajectory Group

Other Service Uptake Alternatives: Now that we've had a look at a hypothetical subscription model price per month, we need to evaluate how consumers view this option relative to other potential options.

According to the Trajectory Group, the most preferred method of telematics uptake would be via free services with ads supported; 52.1% of those surveyed ranked this as a top 3 choice. Other options include: (1) Free Smartphone App – 51.3% had as a top 3 choice; (2) costs built into the vehicle – 36.4% had as a top 3 choice; and (3) annual/monthly subscriptions – 28% and 26% had as a top 3 choice, respectively.

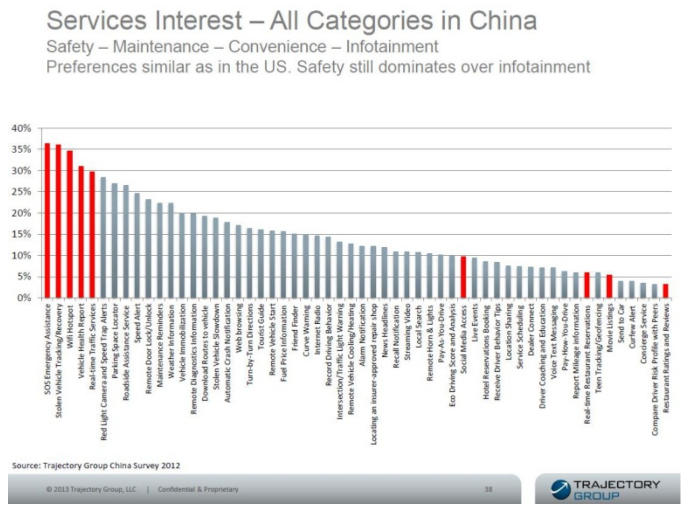
The Conclusion: The wants and use cases for telematics in China is not that different from what we are seeing in the US. Both regions have a strong preference to use telematics to increase vehicle safety, ease of maintenance, convenience, and for infotainment; of those top preferences, safety takes the pole position. The figure below highlights telematics use cases from the Trajectory Group's China survey.

Figure 113. Services Monetization Preferences



Source: Trajectory Group

Figure 114. Telematics Use Cases



Source: Trajectory Group

Propelling the Car of the Future

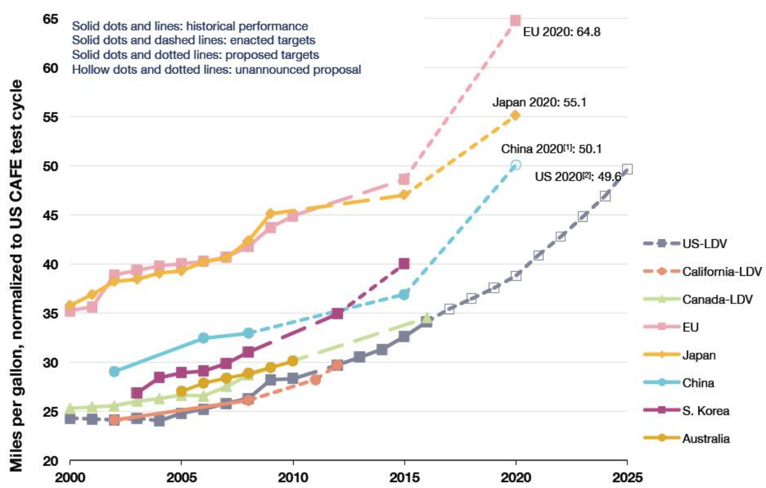
Over the past few years, the convergence of regulatory and consumer demands across geographies have compelled automakers to pursue development strategies that focus on improved fuel economy, reduced emissions, and the pursuit of energy independence at the state level. These sweeping global regulatory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

That said, even considering the significant strides already taken in developing emerging technologies, for investment considerations, 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, with oil prices roughly ~40% lower than they were at this time last year. Lower energy costs have spurred vehicle mix shifts, particularly in the US, and raised debate around the need for such stringent fuel economy standards (as we spotlight in greater detail below). Another topic to add to this discussion concerns the implications to propulsion from autonomous vehicles. 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 (NO_x) and particulates (PM10).

Figure 115. Emissions Regulations: Gram CO2 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

- **More power** – With increased regulation, consumers are still looking for at least the same amount of or, indeed, more power from their powertrains.

US Focus: Discussing CAFE "Mid-term Review' in 2017

With oil prices down significantly from year-ago levels, average gas at the pump sliding 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 US CAFE requirements that will be 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 early 2018, will be to evaluate the feasibility of current fuel economy/emissions plans out to 2025, updating rules put in place in 2012 by 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 or a shift in government priorities dulls the sense of urgency to reform.

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. It appears to us that the substance of the debate would focus on the out-years 2022-2025 of the program. What the mid-term review can accomplish is to allow automakers to argue for loosening this second phase of US CAFE standards, which we would expect to see at least to some degree. Proposals for amendments could range from scaling back mid-decade fuel economy targets while introducing stricter, farther out mandates (say, to 2030), creating additional opportunities for automakers to acquire CAFE credits (which may tone down expectations for EVs), and even introducing a higher gasoline tax that could help align the economic interests of all parties involved.

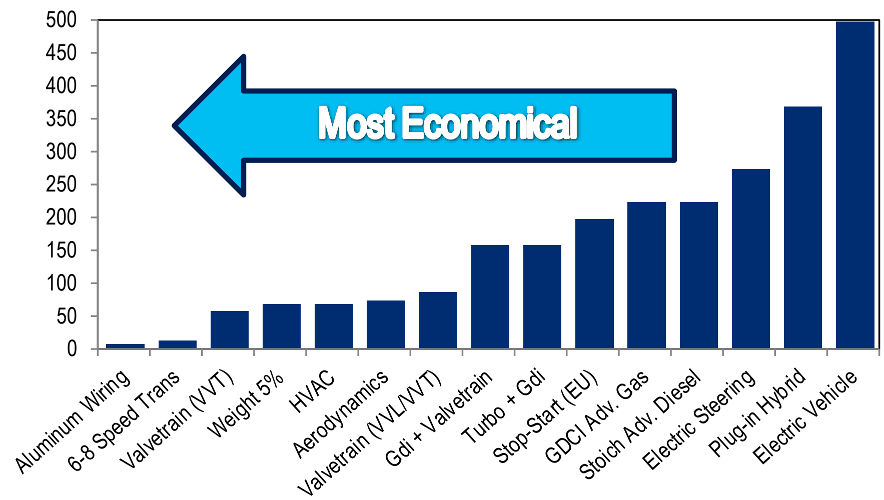
Of course, a new US presidential administration will be in place by the time of the mid-term review, and that administration's receptiveness (or lack thereof) to current plans could represent one of the largest variables in expected outcomes. Another roadblock could be automakers themselves, whose production strategies increasingly rely on standardized global platforms to achieve synergies and economies of scale. With other geographies also ratcheting up fuel economy/emissions standards, it may be less tenable for automakers to draw up alternate plans for the US, though we concede that more lenient standards would probably be welcomed by the industry. At this point, the situation remains fluid and is sure to gain wider attention as we move closer to time of review, with the most likely changes, if any, coming in the form of slower pace of alternate fuel system penetration, rather than any ratcheting back of technology innovation itself.

How to Meet the Requirements

In order to fulfill the stricter of these proposals, it's clear that automakers will likely need to rely on a larger mix of non-conventional technologies such as alternative fuels, electrification and perhaps even hydrogen fuel-cells to hit benchmarks out to 2025 and beyond.

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

Figure 116. 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 (Europeans with diesel, Japanese with hybrids) 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 US 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

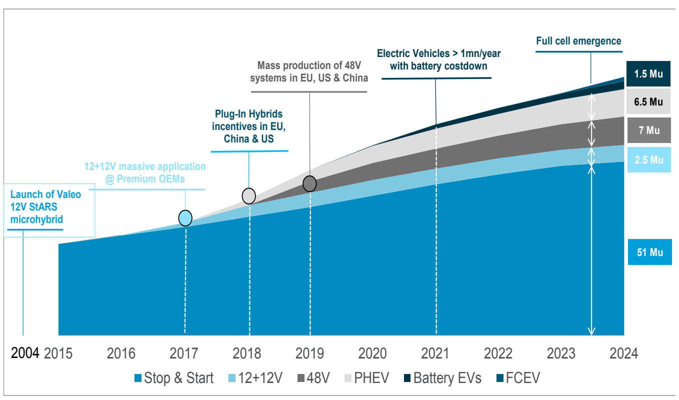
popular solutions thus far. Advances in these technologies should allow for continued market penetration for the foreseeable future, though at some point automakers will likely need more advanced combinations to satisfy 2025+ standards.

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 US. Traditional cost-benefit analysis often points to diesels as ranking among the more compelling technologies for the US market — mainly because of appealing payback, compelling performance and the greater mix of US highway driving (hybrids, for instance, tend to return best in city driving). However, diesel technology simply doesn't have a strong reputation in the US (at least not yet) and often does not score well in outside opinion surveys. Although we do expect diesel penetration to increase in the coming years, automakers will need to educate consumers who may have a negative bias towards the technology.

A Look at the Different Technologies Propelling Change

Figure 117. Growth in Engine Technologies



Source: Valeo

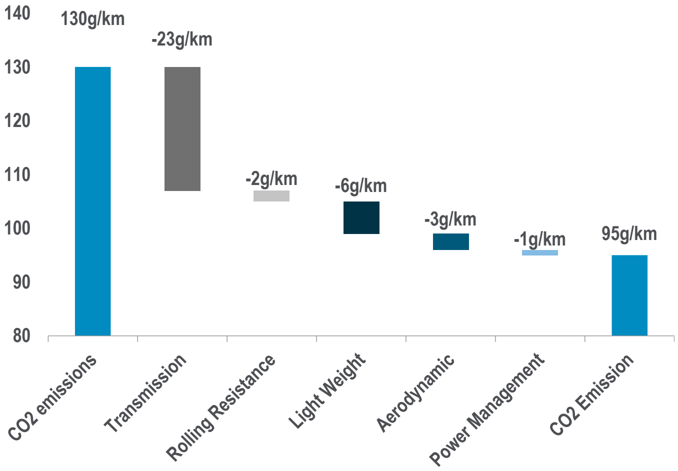
Figure 118. Overview technologies, CO_2 Saving and Market growth potential

	Technology	CO2 Saving	Market Growth (2014-2024)
Efficient Engines	Turbochargers	10%	6%
	Direct Injection	10% - 20%	9%
	Variable Valve Timing	1% - 5%	8%
	Thermal Management	Significant	27%
	New Combustion Techniques	Slight	21%
Efficient Transmissions	Automatic Manual Transmissions	7%	8%
	Electric Clutch	7%	10%
	Dual Clutch Transmissions	10%	12%
	Continuous Variable Transmissions	7%	4%
Efficient Engines	Stop Start	7%	11%
	Mild Hybrid	25%	36%
	Full Hybrid	40%	17%
	Plug In Hybrid	70%	33%
	Electric Vehicle	100%	18%

Source: Company Data, Citi Research

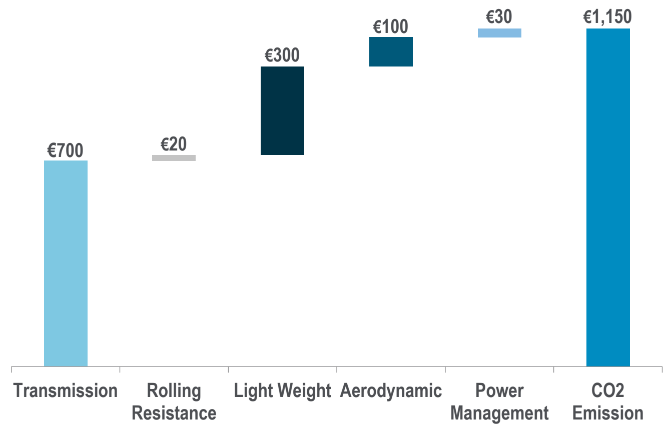
Continental provides numerous solutions below that will help OEMs reach their 2020-21 targets, which we highlight in the chart below. What is evident is that improvements will come from various areas, particularly more efficient engines/transmissions and higher electrification.

Figure 119. Meeting Emissions Reductions



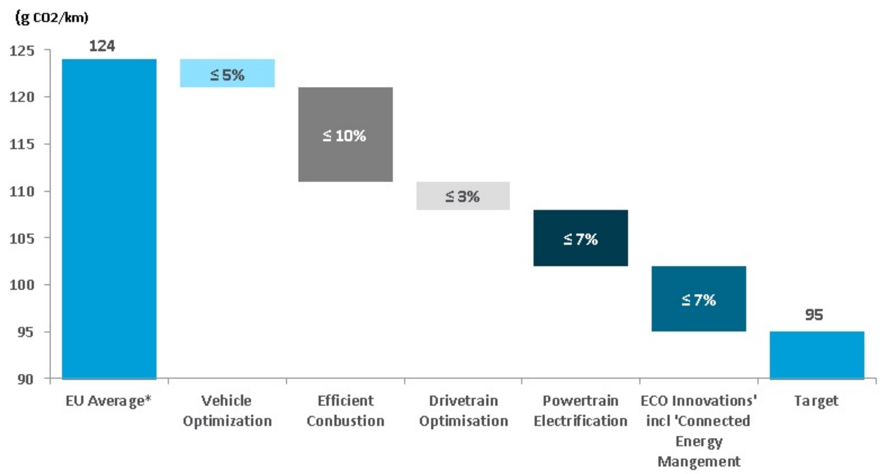
Source: Plastic Omnium Alphatech, Citi Research

Figure 120. Cost of Meeting Emission Reductions



Source: Plastic Omnium Alphatech, Citi Research

Figure 121. How to Reach CO_2 Targets



Source: Continental; *EU Market Average in 2013

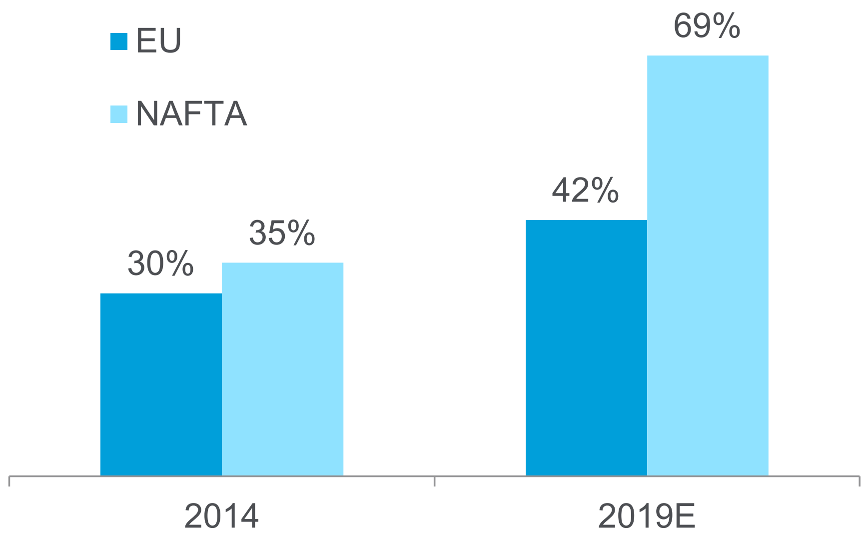
Valeo categorizes these into two distinct areas: 1) efficient engines and 2) efficient transmissions, which we detail below.

1) Efficient Engines

Continental believes that gasoline direct injection should grow by c.130% to 2019 and be installed in 48% of gasoline engines in 2019 (vs 3% in 2007).

- **Direct Injection:** Direct injection systems allow fuel 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 CO_2 emissions by an extra 10-20%. Valeo believes Gasoline Direct Injection having a CAGR of about 9% to 2024. Penetration rates are currently around 30-35% in Europe and 31% in North America.

Figure 122. Gasoline Direct Injection Systems Installation Rate



Source: Continental

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.

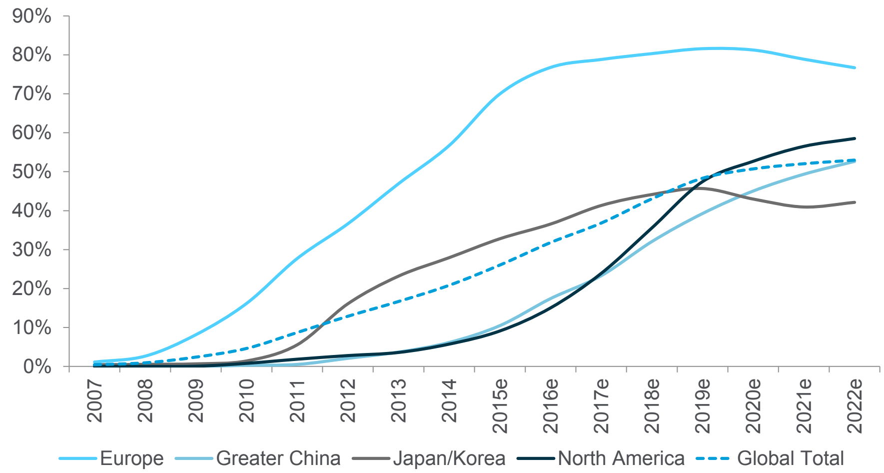
- **Thermal management:** Monitoring and influencing the heat of the engine can contribute significantly to the efficiency of the dynamics and, as a result, this has the potential to be one of the fastest growing areas for powertrains, according to Valeo, growing at a CAGR of 27% over the next ten years. 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 c.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 (c. 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 haven high penetration in Europe at >50% in new cars, are not credited by the US EPA's fuel economy testing system given the limited idle time in the test and therefore this technology could see slower uptake in the US, 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.

Figure 123. Stop-Start Penetration by Region



Source: IHS, JD Power, Ward's, Citi Research

- **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%.

Figure 124. 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

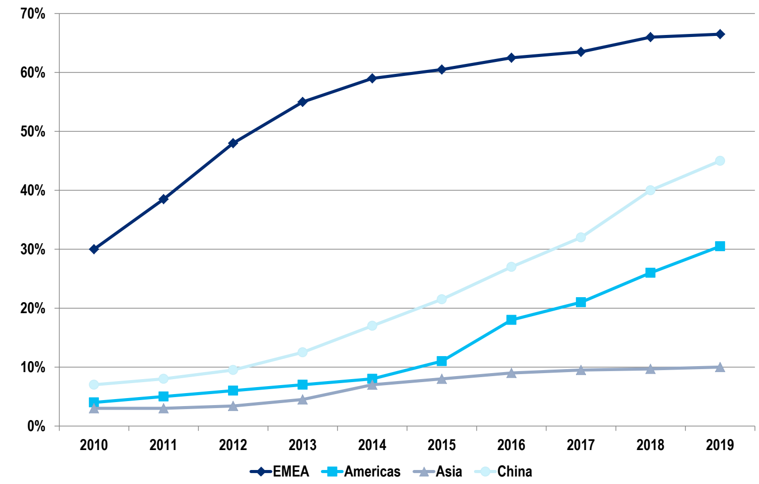
Figure 125. Global Turbocharger Penetration rates (Diesel and Gasoline)

	2014	2019
China	23%	41%
NAFTA	21%	38%
Europe	67%	69%
India	46%	48%
Japan	18%	23%
Korea	42%	45%
LatAm	17%	24%

Source: Honeywell

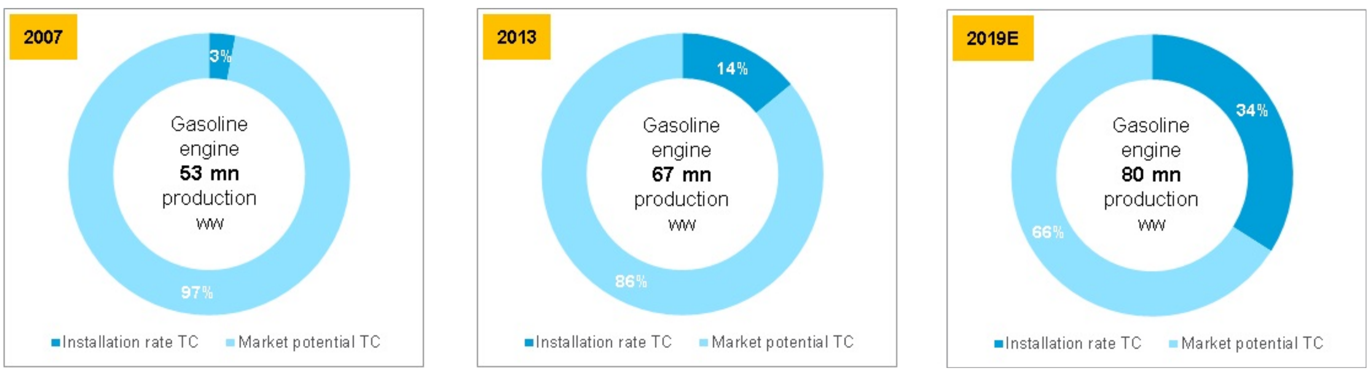
Although the overall market is forecast by Valeo to grow by 6% annually over the next ten years, global penetration rates of turbochargers significantly differ, according to Honeywell. Indeed, penetration in Europe is about 67% of new vehicles and is the highest penetrated market in the world, which, we believe, is due to the prevalence of diesel, which is more popular in Europe and has higher penetration rates of turbochargers. North America, where diesel is less popular, by contrast, has penetration rates of less than 20%, but could rise by 90% by 2020 according to the EPA. In China, 23% of new cars had a turbocharger in 2014, but this rate and should rise to 41% by 2019. In total, according to Honeywell forecasts, 49mn turbocharged vehicles will be sold worldwide by the end of the decade.

Figure 126. Installation Rates of Turbochargers in Gasoline Engines



Source: Conti

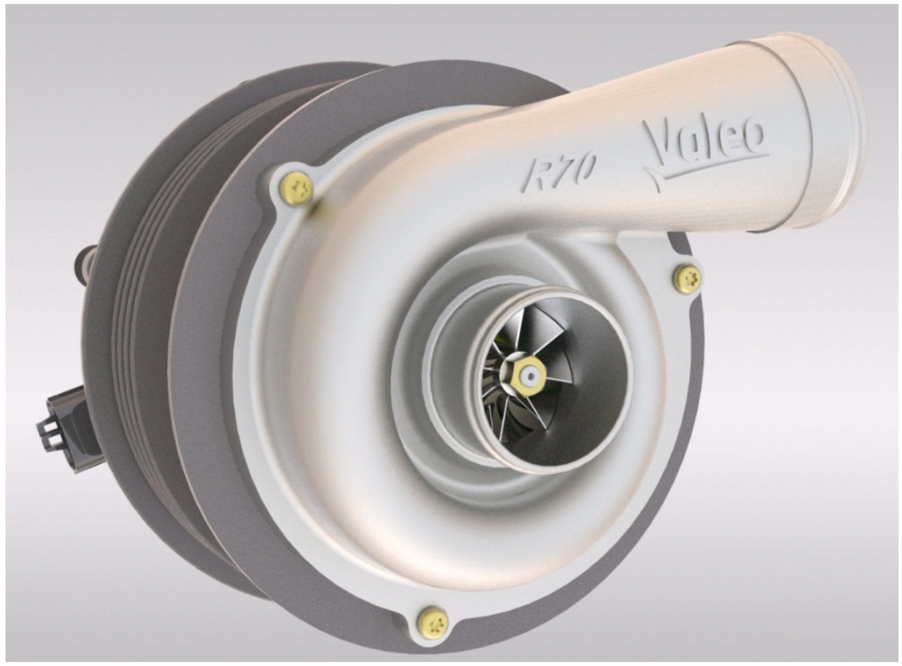
Figure 127. Installation Rates of Gasoline Turbo Chargers and Market Potential



Source: Continental

- **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 128. 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:** 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. 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.

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

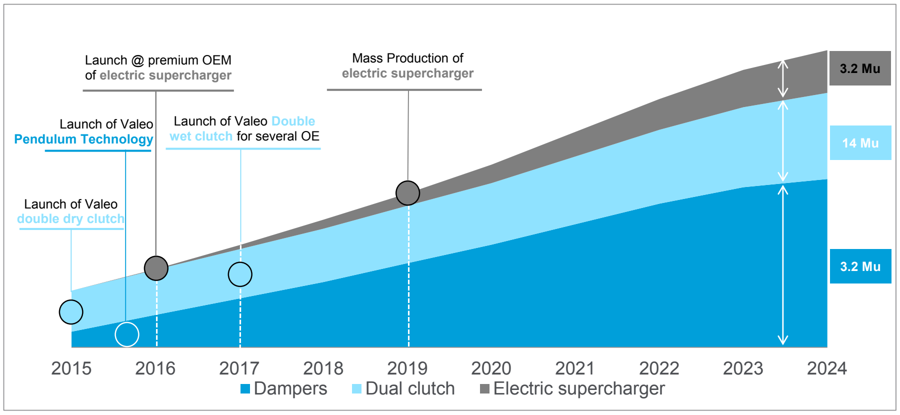
- **Automated Manual Transmission:** Growing at a slower pace than DCT (8% per year to 2024, according to Valeo) are automated manual transmissions, which have been in use since the mid-1980s. AMT use the same gear system as manual, but are changed automatically through a hydraulic system. These reduce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

- **Continuous Variable Transmissions:** CVT 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 129. Growth in Dampers, Dual Clutch, and Electric Superchargers

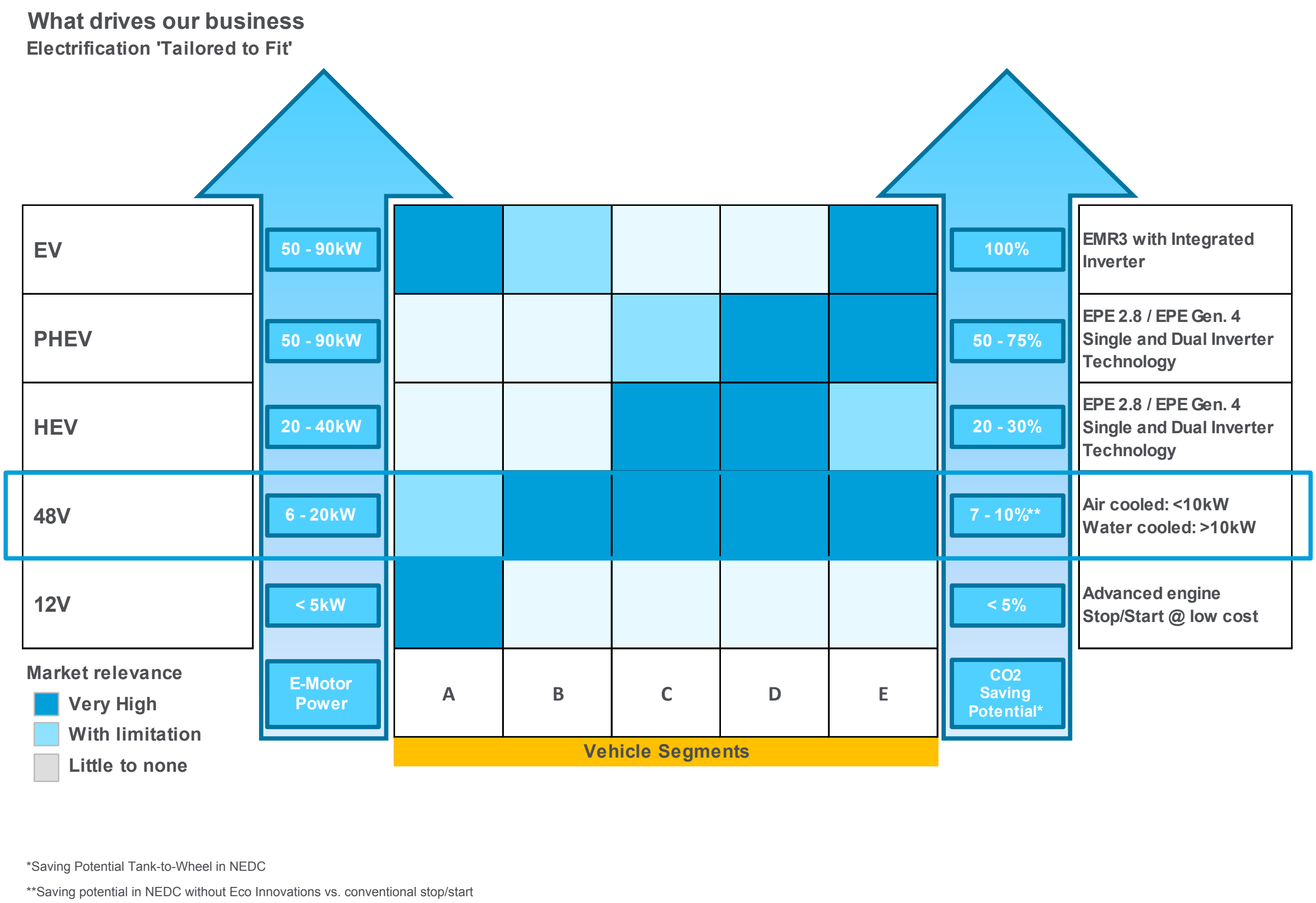


Source: Valeo

Electrification of the Powertrain

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% and Citi believes that the market could grow to about12 million units by 2020. In Figure 130, 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.

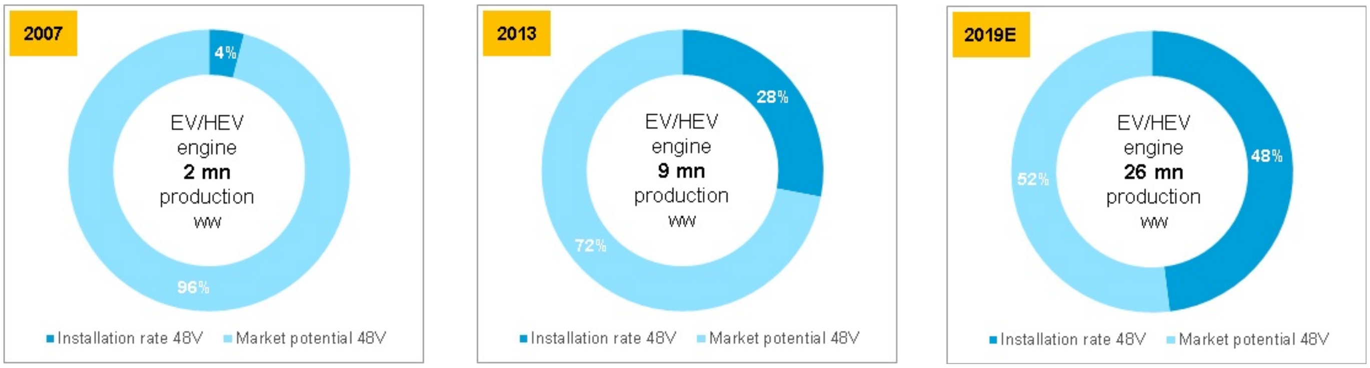
Figure 130. Electrification of the Vehicle



Source: Continental

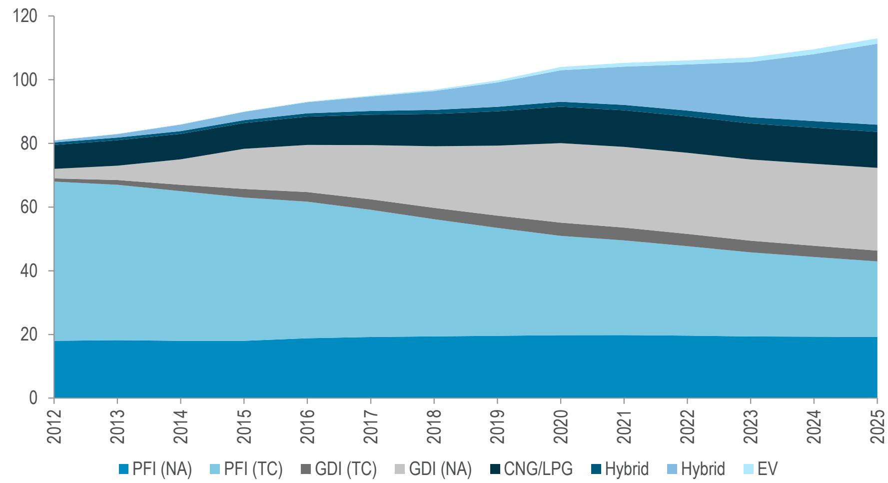
Below we also highlight the market potential for 48V batteries in xEVs, which, according to Continental, could reach almost 50% by 2019.

Figure 131. Installation Rates of 48V Systems and Market Potential



Source: Continental

Figure 132. Global PV/LV Engine Production



Source: Continental. *NA – Natural Aspirated; TC – Turbo Charged; PFI – Port Fuel Injection

The Keys to the Car: Powertrain Systems

When we look to our mid-term outlook for the auto industry (the next 5-10 years), we're considering a timeframe that encompasses 1-2 product cycles. According to our estimates, internal combustion and related technologies are still forecasted to be the dominant force through this period. These include popular features such as downsized GDI/turbo engines with higher efficiency, stop/start systems, advanced transmissions, weight reduction, high-efficiency axles/drivelines, and select hybrids. Other systems are at the early stages of adoption such as EV, and still others are in early concept phases but are years away from even small volumes on the road, like compressed natural gas (CNG).

Figure 133. Powertrain Systems Overview

	Traditional ICE Downsizing & Boosting	Diesels	Full Hybrids	Plug-in Hybrids (PHEV)	Electric Vehicle (EV)	CNG
Fuel efficient gains	15-20% better mileage. Turbocharging preserves performance. Future advancements promise another 20% improvement. Stop/Start can add 5-12% too	35-40% better mileage. Superior to many full hybrids in highway driving, which is more prevalent in the U.S.	25-50% improvement in today's NiMH hybrid systems. Advantage over diesels in city driving. Less so in highway driving.	40-100+% improvement with all electric drive (10-40 mile range)	100+% improvement with zero tailpipe emissions (Renewable sources can drive WTW gains over time)	Significant emissions reductions, but somewhat lower energy density vs. conventional ICE
Appeal to performance & adoption hurdles	High – 20% superior torque typically. No real adoption hurdles.	High – 50% higher torque and "fun to drive". Consumer acceptance an issue in U.S.	Medium – Performance compromised somewhat but low adoptability hurdles. Consumers perceive it as "Next Gen" technology.	Medium - Dual motor/battery lessens battery anxiety risk for consumers.	Medium– "Fun to drive' factor of EVs partially offset by potential battery range anxiety, with the latter likely to be addressed by infrastructure and improving battery range (or switching)	Medium – No major performance give but need for refueling infrastructure (unless able to refuel at home)
Appeal to environmental & national goals	Low - Not an environmental "game changer". Stricter proposed regulations beyond MY20 might make these technologies less impactful.	Developing – Recent marketing in U.S. and old stigma of diesels starting to diminish, but environmental appeal remains a challenge	High – Emission reduction and lower dependency on foreign oil. Great environmental appeal particularly in larger cities.	High – Pure electric range offers breakthrough from conventional hybrids. Less infrastructure anxieties	Very High – Reduces emissions and dependency on foreign oil. Lithium availability and battery recycling are debatable issues but don't present an issue. Some promise in solid-state batteries and lithium air	High – Lower foreign oil dependency. WTW GHG improves over gasoline
Cost	Reasonable. Technologies exist and logistics manageable. Ideal choice for capital constrained auto industry and strained consumer.	High – Similar to slightly below typical hybrids, better durability adds to value proposition. A more expensive option than traditional GDI-turbo	Higher than diesel but payback improves with higher gas prices and greater city driving. In the U.S. where highway driving exceeds city, diesel makes more sense at present gasoline prices.	High – But more affordable with government credits/incentives. Battery cost reductions key over time.	High – But more affordable with government credits/incentives. Key is reduction in battery cost over time and creative ways to unlock the consumer value proposition (i.e. Better Place model)	High – CNG vehicles carry $7-8k price premium, more than diesels for less "fun to drive" factor.
Challenges	Squeezing more MPG savings to meet increasingly stricter global standards	Emissions costs and consumer perception	Costs, safety, and potential changes in consumer demand.	Costs, safety and infrastructure	Costs, safety and infrastructure	Infrastructure and less zero tailpipe emission appeal as EVs

Source: Company data, METI, and Citi Research estimates

Electric Vehicles & the Potential for Disruption

After plenty of false starts, the electric vehicle's path to eventual disruption may be upon us. The appeal of Electric Vehicles (EVs) lies both in their long-term cost proposition and unique benefits, which are discussed below. But before proceeding any further, it's worth injecting a dose of reality when discussing the automotive industry. Disruptive change, even that which is compelling, cannot occur overnight in an industry characterized by long product cycles, capacity requirements and high costs. There are also other compelling stories in traditional gasoline/diesel technologies, NGVs and hybrids. That all said, the race for the early mover EV crown may be decided in the next 4-6 years thanks to the success and future product plans of Tesla Motors. In this section, we discus both the disruptive appeal that EVs offer and how the broader industry might react to this megatrend.

From an operating cost perspective, electric vehicles (EVs) remain superior with a fuel cost-per-mile of only $0.04, beating CNG at $0.07 and conventional gasoline, even at current levels. Besides energy costs, EVs offer maintenance savings from the absence of required oil changes and other functions. Performance also tends to be superior thanks to unique torque characteristics. And despite debates over well-to-wheel emissions, the zero tailpipe emission selling points are nonetheless a powerful consideration both to consumers and regulatory bodies.

Costs, long charging times and infrastructure are the greatest barriers to mass adoption, even when contemplating federal tax credits. Lower-priced US electric vehicles offering limited range have not sold particularly well, though a major litmus test will be conducted with the mid-year 2017 debuts of GM's Chevy Bolt and Tesla's third generation Model III, both targeted at the mass market. Skeptics will point to the slow pace of battery technology advancements as proof that EVs may only be suitable for luxury buyers, though we firmly disagree. While we acknowledge the ramp in EVs will remain slow (still < 2% in most markets by 2020, per IHS), we think the outlook for these vehicles remains bright. First, despite slow advancements in traditional lithium-ion chemistries, the pipeline of promising technologies is far from dry (solid state, lithium-air). Second, innovative battery switching method offer a way around range and depreciation anxieties. Of course, all eyes are on the next generation of 200-mile, mid-market EVs coming out around 2017.

Figure 134. 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 Research estimates

Why Now? Tesla's Significance to the Industry

Although still a low-volume luxury carmaker, we view Tesla's early success with the Model S as having confirmed the following about electric vehicles:

1. It's possible to combine all the unique benefits of EVs (superior performance, sufficient range, greater usable trunk capacity, lower maintenance costs, green) with an attractive design and appealing marketing message. We don't believe any other EV in the market has yet to deliver all of these factors in a single car.

2. They can generate substantial consumer/media interest particularly when, in our view, they're sold at outlets that don't face a possible conflict of interest tied to selling both gasoline and EV vehicles.

Although the Model S in itself is unlikely to pose a disruptive threat to global automakers, Tesla does plan to deliver a more affordable $30-35k "Gen-3" vehicle available roughly in the 2017 time frame. This vehicle too may not necessarily prove disruptive, but it may be significant in two ways: 1) A $35k price point is historically what's required to begin the path towards achieving sizeable volume of over 100k units (typically 2-3 years after launch), in theory enough to crown Tesla as the 1st mover in the affordable pure EV market. One doesn't need to look far to appreciate the value of this crown — just look at Toyota's remarkable hybrid leadership with the Prius vs. today's strong but late hybrid competition; 2) For any automaker, achieving an early mover advantage could be strategically critical ahead of the potential for more mass EV adoption early/mid next decade — once battery costs come down further and capacity is added.

Let's face it. Despite launching a number of innovative electric vehicles in recent years, the traditional OEM-dealer business model works best if EV penetration rises slowly over time. A substantial industry investment in gasoline/diesel powertrain capacity/IP is one reason for this, but another comes from some possible resistance from concerned auto dealers facing prospects of lower service levels on EVs (no oil changes, filters, etc.). This potential dealer conflict might partially explain why traditional automakers' EV sales have underwhelmed (Chevy Volt, Nissan Leaf). To reiterate, it's not that traditional automakers aren't recognizing the EV trend or innovating within it (Volt is a great example of impressive innovation), it's just that the industry's interests are better aligned to a gradual ramp vs. anything remotely disruptive. And for the past few years, the industry has been right. Fuel economy regulations (particularly here in the US) haven't forced an excessive amount of EVs onto the market, consumer/media interest has been limited, if not outright skeptical (remember the media reaction to the minor Chevy Volt fire incident?), and a handful of EV-related companies failed to deliver on promises and were ultimately forced to restructure/liquidate. There are plenty of examples of why slow is the truly preferred pace in the auto industry.

Trend Spotlight: Is the 200 Mile EV Enough?

We have been heavily contemplating Tesla's recent announcement to discontinue its $71,070 60kWh Model S (208 mile range) and replace it with the 70kWh Model S "70D" (240 mile range). Given that the Model S is a high-end luxury car the $5,000 increase in base price would likely not provide an incremental dampener of demand (given press reports citing low volume sales on the Model S 60kWh), so our first instinct was that this was a potential setup to make room for the Model 3. Our focus then shifted to the range anxiety debate; a topic heavily publicized since Elon's tweet *"Tesla press conf at 9am on Thurs. About to end range anxiety…via OTA software update. Affects entire Model S fleet."* The over-the-air software provided

smart-routing and map planning for charging stops, but it did not unlock potential in the current battery pack to generate more range. With falling gas prices we believe that in order to generate more incremental EV segment demand, the current range would need to be extended. What Tesla did by removing the 60kWh Model S Tesla was just that – now, the lowest available Model S is a 240 mile range vehicle, a 15% improvement vs. the prior base model. As Tesla looked to distance themselves from the base ~200 mile 60kWh Model S, in favor of the extended 240 mile 70kWh Model S, we began to wonder at what range would consumers not feel the dreaded range anxiety.

Leveraging Recent Survey Work

The concept of range anxiety and the recent Tesla announcement lead us to do a deeper dive on the concept – specifically what is the range required by a consumer to feel comfortable going with a full EV solution. For this analysis we leveraged some very interesting presentations and survey work from the recent *SAE 2015 Hybrid & Electric Vehicles Technologies Symposium*; in particular we leaned heavily on survey work done by *Frost & Sullivan*.

The Survey Results

Of the *Frost and Sullivan survey's* 1,824 participants, only 6.6% said that they would consider a full EV for their next car purchase. This ranks above both CNG and Fuel Cell consideration but, it does fall short of PHEV. What is interesting here is the EV consideration by segment - the highest absolute consideration came from CUVs/SUVs, compact cars and mid-size cars, which combined accounted for ~71% of the potential EV consideration. Luxury cars/SUVs had a strong showing, accounting for ~13% of the potential EV consideration.

Figure 135. Intended Next Vehicle Purchase Segment by Power Type

	Total	Gas	Diesel	Gas-Electric Hybrid	Diesel-Electric Hybrid	CNG	Plug-in Hybrid EV	Full EV	Fuel Cell
Subcompact Car	6%	32%	8%	25%	4%	5%	8%	10%	9%
Compact car	16%	36%	4%	27%	6%	5%	9%	9%	4%
Mid-Car	22%	47%	3%	24%	3%	2%	9%	7%	4%
Large Car	4%	42%	8%	20%	7%	1%	11%	10%	0%
memo:Luxury Car	*16%*	*33%*	*8%*	*22%*	*7%*	*6%*	*10%*	*8%*	*6%*
CUV/SUV	34%	45%	6%	24%	4%	5%	7%	5%	3%
Pickup	12%	55%	8%	11%	7%	2%	5%	5%	6%
Small Van	5%	49%	4%	21%	4%	5%	6%	5%	5%
Large Van	1%	21%	26%	5%	16%	5%	16%	5%	5%
memo: Luxury SU	*8%*	*31%*	*9%*	*16%*	*4%*	*13%*	*12%*	*9%*	*6%*

Source: Frost & Sullivan

Figure 136. Intended Next Vehicle Purchase Segment by Power Type

	Total	Gas	Diesel	Gas-Electric Hybrid	Diesel-Electric Hybrid	CNG	Plug-in Hybrid EV	Full EV	Fuel Cell
Subcompact Car	109	35	9	27	4	5	9	11	10
Compact car	292	105	12	79	18	15	26	26	12
Mid-Car	401	189	12	96	12	8	36	28	16
Large Car	73	31	6	15	5	1	8	7	0
memo:Luxury Car	*140*	*46*	*11*	*31*	*10*	*8*	*14*	*11*	*8*
CUV/SUV	620	279	37	149	25	31	43	31	19
Pickup	219	120	18	24	15	4	11	11	13
Small Van	91	45	4	19	4	5	5	5	5
Large Van	18	4	5	1	3	1	3	1	1
memo: Luxury SU	*50*	*15*	*4*	*8*	*2*	*6*	*6*	*4*	*3*
	1824	**807**	**101**	**410**	**84**	**70**	**142**	**120**	**75**
		44.3%	5.6%	22.5%	4.7%	3.8%	7.8%	6.6%	4.1%

Source: Frost & Sullivan

While EVs are still considered a niche market, and will likely remain a lower demand category for the foreseeable future we wanted to focus on items that may in fact increase the adoption rate of this technology. As such, we looked to another area from the *Frost and Sullivan* survey, this one focusing on EV range requirement. They posed a unique question to consumers, "If you were to purchase an all-electric battery vehicle in the near future, what would be the ideal driving range before having to recharge the battery?" the aggregate weighted average total was 218 miles; however, it is worth noting that this desired range would only meet the requirements of ~40% of the entire sample size.

Figure 137. Ideal EV Driving Range by Segment

	Total	Sub compact Car	Compact Car	Mid-Car & Large	Luxury Car	Small & Mid SUV	Large SUV	Luxury SUV	Minivan	Pickup
330+ miles	36%	36%	34%	34%	28%	36%	39%	34%	42%	43%
251-300 miles	9%	12%	9%	7%	12%	12%	7%	8%	4%	10%
201-250 miles	14%	12%	16%	13%	15%	13%	11%	21%	10%	12%
151-200 miles	15%	14%	16%	17%	18%	12%	18%	17%	15%	13%
101-150 miles	13%	10%	13%	20%	15%	11%	12%	11%	13%	13%
75-100 miles	8%	12%	6%	5%	4%	10%	10%	8%	13%	5%
<= 75 miles	5%	4%	6%	4%	8%	6%	3%	1%	3%	4%

Source: Frost and Sullivan

Figure 138. Ideal EV Driving Range by Segment

	Total	Sub compact Car	Compact Car	Mid-Car & Large	Luxury Car	Small & Mid SUV	Large SUV	Luxury SUV	Minivan	Pickup
330+ miles	657	39	99	161	39	192	34	17	38	102
251-300 miles	164	13	26	33	17	64	6	4	4	24
201-250 miles	255	13	47	62	21	69	10	10	9	28
151-200 miles	274	15	47	81	25	64	16	8	14	31
101-150 miles	237	11	38	95	21	59	10	5	12	31
75-100 miles	146	13	18	24	6	53	9	4	12	12
<= 75 miles	91	4	18	19	11	32	3	0	3	9
	1824	109	292	474	140	533	87	50	91	237
W.Average	218	218	216	212	211	218	218	222	216	229

Citi estimates for small/mid/large SUV breakout & Pickups include Large Vans

Source: Citi Research

A similar story could be told for this analysis by vehicle segment since the simple weighted averages only highlight a value that would meet only ~40% of the populations criteria. The results are even worse for some of the larger vehicles such as: pickups, minivans and SUVs/CUVs.

The Citi Factor: Moving the Needle to Majority Acceptance

There is little change in our opinion, from the last Car of the Future report, that the race to EV adoption is very much still on. In fact, if we look at the competitive environment of participants, it has actually expended given the recent news of the Chevy Bolt – some other competitors include Tesla, Nissan and BMW. The question we have, which is largely answered by the *Frost and Sullivan* survey, is when does EV reach a more mass adoption? Does it remain a GEN 3 car event? Or is it now a GEN 4 story due to the consumers desires to have more range? We already know that the targeted GEN 3 car EV push is centered on ~200 miles of range, but with the recent analysis and survey work from *Frost and Sullivan,* it would appear that the 200 mile range may not be enough for majority adoption, as it would only fill ~40%-45% of total consumer demanded EV range.

So we thought it would be more telling to size up the market using the *Frost and Sullivan* survey work and the GEN 3 targeted range of 200 miles. In our analysis the targeted GEN 3 segment would comprise of vehicles within the following segments: 1) high end mid-size cars; 2) mid-size specialty cars and 3) lower luxury vehicles. This market accounts for ~1,300,000 vehicles sold in the US per year. If we assume that the 200 mile range only meets the criteria for ~40-45% of potential consumers, this implies a total addressable market of ~553,000 vehicles.

Is Lincoln Ripe For This? Exploring "Lincoln 2.0" (EV)

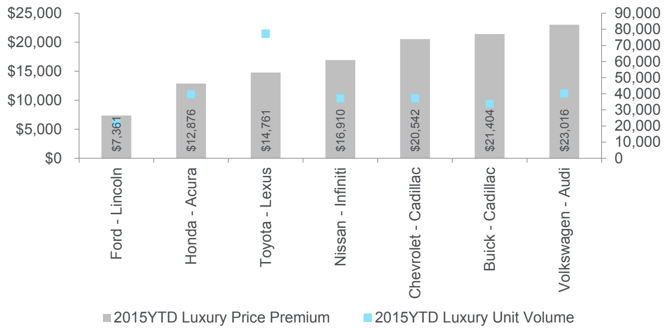
Ford is clearly committed to Lincoln's success having outlined a bold plan for product launches and expansion into China. We like Ford's near-term strategy of reestablishing the brand with a broader and fresher product lineup. As we think one step further, however, we can't help but pinpoint Ford's Lincoln brand as being eventually (i.e. beyond mid-decade) ripe for this type of strategic maneuver—that is an exclusive xEV brand (EV and perhaps PHEVs/HEVs).

Here's why:

1. Lincoln has struggled as a luxury brand with domestic market share falling, resulting in low dealer throughput versus peers and the narrowest price gap between its non-luxury sister brand, Ford. As stated above, we like Ford's near-term strategy for the Lincoln brand, but wonder whether it can establish long-

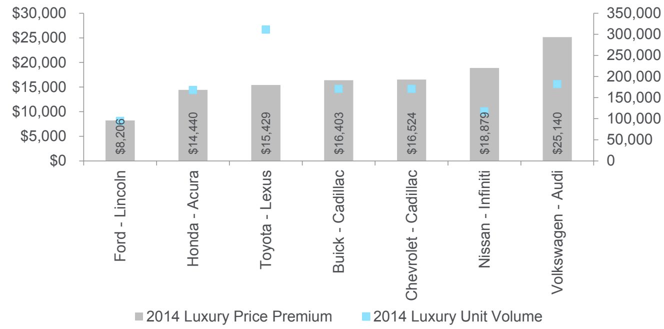
term (i.e. beyond mid-decade) leadership considering that the Ford brand is likely to continue receiving cutting-edge technology (higher-pricing), non-domestic luxury competition will likely stay intense and now Tesla may be encroaching on the lower-end luxury market.

Figure 139. Ford-Lincoln Price Gap vs. Competition (2015 YTD)



Source: JD Power, Ward's, Citi Research

Figure 140. Ford-Lincoln Price Gap vs. Competition (2014)



Source: JD Power, Ward's, Citi Research

2. The Lincoln MKZ hybrid is generating good momentum in states like California. So electrification is in some already attaching itself closer to the brand in places that are critical to win in order to reestablish Lincoln.

3. With a name like Lincoln, in our view the brand carries meaningful potential to resonate more broadly with consumers. In the spirit of the brand, why not consider something big?

4. Using Lincoln as Ford's xEV brand dips into the EV pool just enough to avoid arriving late but also enough to avoid overlooking other promising technologies across Ford's product lineup (EcoBoost, NGVs, diesels, hybrids, etc.). Financially, we don't see a ton of risk—we estimate that Lincoln only generates ~5% of Ford's North America EBIT.

5. It would be fully in-line with Ford's "Power of Choice" strategy, only with a different go-to market strategy (dedicated brand and sales force) that's clearly more suited for EVs. As EVs presumably get cheaper over time, the option to expand the lineup to the Ford brand would still be there with Lincoln more easily being slotted as a luxury brand.

6. Ford expects 42% of the 2015 North America premium market to be in the C/CD segment—likely the next battle ground for electric vehicles.

7. Although Lincoln does have ~900 dealerships that also sell Ford brand vehicles, there are also ~200 that only sell Lincoln vehicles—a workable distribution channel, in our view.

Compressed Natural Gas (CNG)

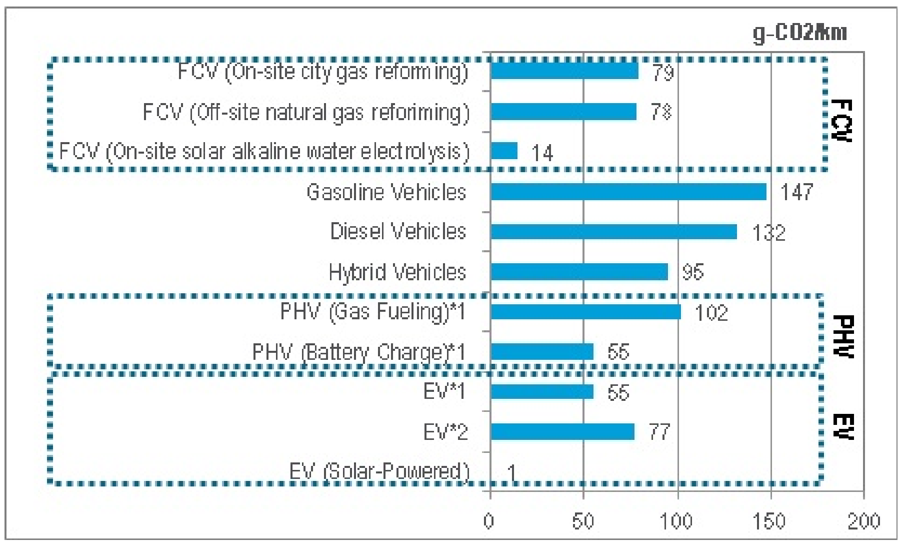
Compressed natural gas (CNG) technology is at present confined mainly to commercial fleets, though a small volume of light duty vehicles utilize a bi-fuel approach (gasoline or natural gas can be used to fuel the vehicle). GM currently has bi-fuel Impala and Silverado HD offerings, as well as a dedicated CNG Express van, and Ford offers the bi-fuel F-150 and C-MAX CNG and Focus CNG in Europe. CNG has an advantage in its long range capability, though a trade-off comes with the larger fuel tank displacing trunk space. According to consulting firm BCG, CNG

light vehicle volumes in the US could grow to over 300,000 vehicles by 2020, up from around 100,000 in 2014 (~20% growth CAGR). Of course, this impressive growth comes off a very small base. If CNG can become a competitive alternative to hybrid, diesel and advanced gasoline options, there could be a place for it as a viable powertrain option, though current low gas prices and lack of infrastructure don't help its value proposition. On a more promising note, CNG has been touted as a potential solution to greater US energy independence, and larger economic investment could help provide CNG with a powerful branding message.

Fuel Cell: Spotlight on Toyota Mirai

Toyota announced its Mirai fuel cell vehicle on December 15, 2014, priced at ¥7,236,000 including tax. Toyota defines the Mirai as a vehicle that runs generating its own power via the chemical reaction of hydrogen, a leading energy of the future, with the oxygen in the air, and as a car that draws open the curtain on a new era of mobility, offering not only superb environmental performance but also convenience and a pleasurable drive. Hybrid vehicles, which blend electric power and gasoline, as symbolized by the Prius, have long driven Toyota's progressive environmental image but we expect the Mirai to inherit this role moving forward.

Figure 141. CO2 Emission (Well to Wheel JC08 Mode) Comparison



Note: *1 Energy mix as of FY2009.
*2 Energy mix as of FY2012.
Source: "Energy efficiency and GHG emission analysis report", JARI

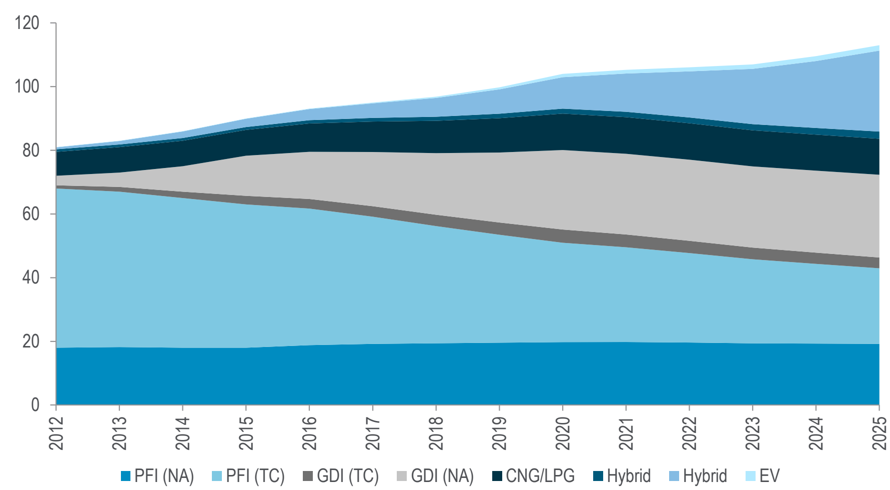
The Mirai is characterized by its adoption of the Toyota Fuel Cell System (TCFS), which blends fuel cell and hybrid technologies, and by the key components of the fuel-cell stack, the fuel-cell boost converter, and the high-pressure hydrogen tank, which are being developed in-house. The Mirai takes the electricity created from the chemical reaction in the fuel cell stack between hydrogen and the oxygen in the air, raises its voltage in the fuel-cell boost converter, and drives a motor with it. It is possible to adopt the 650V-spec power units used in existing hybrid cars thanks to the fuel-cell boost convertor. The strength here is that the Mirai's costs are lowered, as it can use the motors and batteries shared with hybrid cars, annual sales of which exceed 1 million units.

Infrastructure build-out holds the key to the spread of fuel cell vehicles and the involvement of the government is crucial. Japan's Ministry of Economy, Trade and Industry drew up a hydrogen and fuel cell strategy roadmap in June 2014. In phase 1, through to the mid-2020s, the aim is to have fuel cell vehicles launched on the market, build out hydrogen station infrastructure, revise regulations, and deliver hydrogen and vehicle prices that encourage the spread of fuel cell vehicles. The plan is to broadcast to the world the possibilities of hydrogen and fuel cell vehicles at the Tokyo Olympics to be held in 2020. In phase 2, from the late 2020s to around 2030, a large-scale hydrogen supply system will be set up. In phase 3, around 2040, a hydrogen supply system that will be CO_2 free as a whole will be set up. Currently, hydrogen is generally extracted from fossil fuels such as natural gas and petroleum and CO_2 is produced in the manufacturing process, so fuel cell vehicles are only "eco-cars" while they are being driven. The build-out of an energy infrastructure between phase 2 and phase 3 will thus be a key point if fuel cell vehicles are to spread in earnest as ultimate eco-cars.

We often hear people debate which will take off, fuel cell vehicles or EVs. The advantages of fuel cell vehicles over EVs are that they have long ranges and that they do not require long periods of time to be replenished with energy. To overcome this, since 2010 Toyota has been bolstering research into solid-state batteries, lithium-air batteries, and other next-generation batteries, with battery technology innovation holding the key to success or failure. We see Toyota's strategy as to make R&D more efficient by bringing in the Toyota New Global Architecture and revising the way the development burden is split between it and affiliated suppliers, while accommodating next-generation technologies on all fronts.

A Quick Trip around the World: Propulsion

Figure 142. Global Engine Penetration Roadmap to 2025

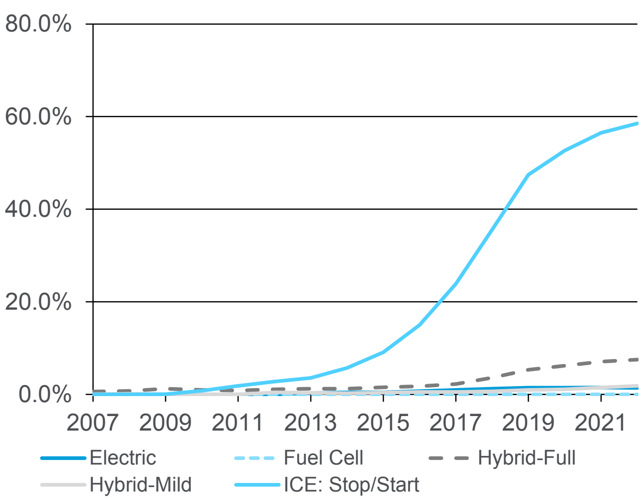


Source: IHS, Continental and Citi Research estimates

North America

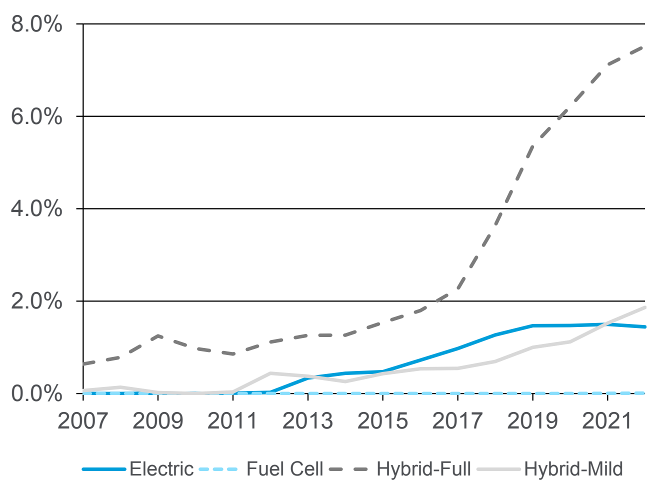
The North America propulsion landscape through 2020 will continue to be dominated by the internal combustion engine and its variants that were discussed above. We expect gasoline turbocharging penetration to rise from a mid-single rate today closer to 20% by the end of the decade, with diesel turbo's staying mostly constant. As shown in the charts below, this will be supplemented by stop-start systems and more advanced transmissions and driveline systems. GDI is also expected to grow at a mid-double digit CAGR. Electric vehicle penetration should also start to gain a bit of momentum and we look forward to the launch of GM's Chevy Bolt full-electric and the Tesla Model III, both scheduled to debut for model year 2017 with ~200 mile range capability and a low-to-mid $30,000 price range (after incentives). Both launches will be critical for determining the willingness and speed of mass market consumer to adopt EV technologies. Additionally, Nissan is expected to unveil the next-generation Leaf in 2017 with a new battery pack and chemistry rumored to deliver upward of 120 mile range (up from the ~80 mile version now and ~70 miles when it first debuted in mid-year 2011).

Figure 143. North America Emerging Propulsion Penetration Outlook



Source: IHS, JD Power, Ward's & Citi Research

Figure 144. North America Emerging Propulsion Penetration Outlook (ex. Stop/Start)

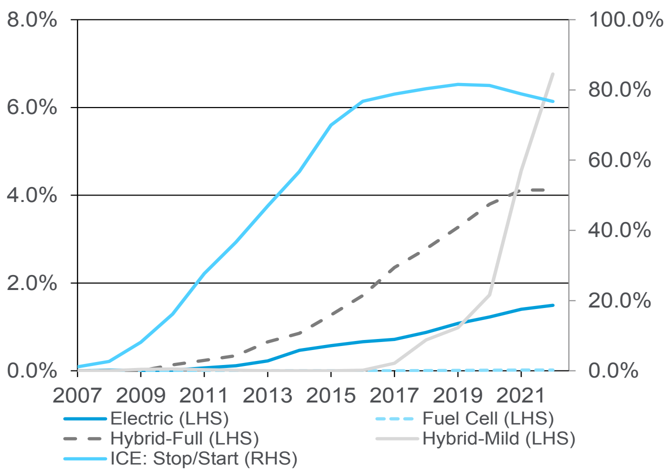


Source: IHS, JD Power, Ward's & Citi Research

Europe

From a powertrain efficiency perspective, Europe is clearly ahead of North America with diesels accounting for over 50% of sales and stop/start systems being far more penetrated (~60% currently vs. North America < 10%), thanks in part to better compatibility with manual transmissions. The outlook for full-hybrids is positive but not quite as robust as in North America in part due to the smaller presence of the Japan-based automakers. Gasoline turbo penetration is forecasted to rise from 35% to 40% by the end of the decade in a similar trend as what we are seeing in North America. The outlook for electric vehicles is also somewhat more robust thought still forecast to be less than 2% of volume by 2020. The challenge for automakers managing fuel economy needs in North America Europe is to design around different regulation standards, product mix and city versus highway driving patterns (US is more weighted towards highway driving).

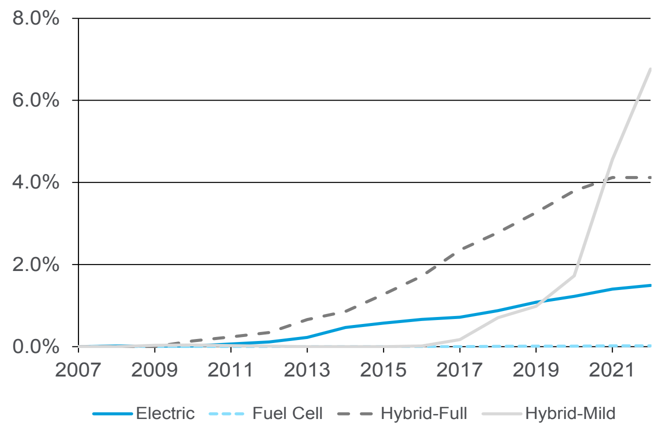
Figure 145. Europe Emerging Propulsion Penetration Outlook



Note: LHS = left axis; RHS = right axis

Source: IHS, JD Power, Ward's & Citi Research

Figure 146. Europe Emerging Propulsion Penetration Outlook (ex. Stop/Start)



Source: IHS, JD Power, Ward's & Citi Research

China

Since 2009, China has bypassed US and become world's largest car market and currently China accounts roughly a quarter of global auto sales.

However, despite being the largest market, China hasn't built global-standard technologies in the auto industry yet. Roughly two-thirds of the cars sold in China are foreign brands, with most of the R&D conducted in their European, American, Japanese, or Korean headquarters. Chinese brands are still mostly concentrated in the low-end, selling at cheap prices with barely acceptable quality. However, if we say there is nothing China could contribute to the Car of the Future, it may be too pessimistic. China, compared to other major industrial countries, still enjoys some relative comparative advantages, which for propulsion we believe stems largely from strong government support on electric vehicles, especially on pure electric vehicle and plug-in hybrid electric vehicles.

Chinese Government as a Comparative Advantage

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

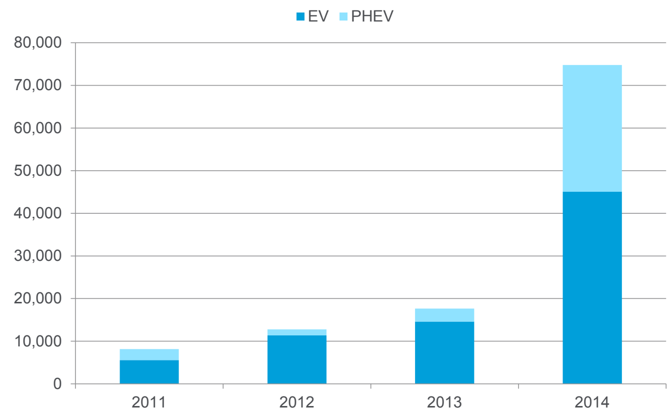
- 60% of China's oil consumption relies on import, and this ratio will rise to 75% by 2030 by IEA. Though oil price experience a plunge recently, Chinese government still hopes to build an energy independence for strategic safety reason.
- Despite of strong government support, China's traditional car 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 for manufacturing industry, with success in high-speed rail, telecom equipment and power equipment. The embarrassing situation in the auto industry is simply too hard to accept.
- Therefore, after losing on internal combustion engine cars, Chinese government hopes to catch up in the curve and build a leadership in electric cars.

Figure 147. China – Central Government Subsidy on EVs

Rmb	2013	2014	2015
Pure electric vehicle			
80km <= R < 150km	35,000	33,250	31,500
150km <= R < 250km	50,000	47,500	45,000
R >= 250km	60,000	57,000	54,000
Plug-in hybrid electric			
R >= 50km	35,000	33,250	31,500
Fuel cell vehicle	200,000	190,000	180,000

Source: Chinese Government, Citi Research

Figure 148. China – Pure EV & PHEV Sales (Passenger Vehicles)



Source: CAAM, Citi Research

As a result of such eager to support EV industry, China is subsidizing more on a BYD E6 than US government on a Tesla Model S. Some other favorable policies, such as license plate exception of lottery in Beijing and exception on bidding in Shanghai, also helps penetration of electric vehicles. Though we also holds the view that too much subsidies could distort the resource allocation by market, the reality is electric vehicles indeed encountered strong growth in recent a few years, especially in 2014.

Figure 149. BYD – e6 Pure EV

Source: Sina, Citi Research

Figure 150. BYD – Qin PHEV

Source: Sina, Citi Research

Figure 151. BYD – K9 Pure EV Bus

Source: cnAutoNews, Citi Research

Figure 152. Kandi – Low-speed EV

Source: EVTimes, Citi Research

Among the major categories, we have seen different degrees of success:

- **Pure electric vehicles:** noted 45k sales volume in 2014, with key models including BYD E6, JAC iEV4, BAIC E150EV, SAIC Roewe E50, etc. This accounts ~0.2% of passenger vehicles sold in China.
- **Plug-in hybrid electric vehicles:** noted 30lk sales volume in 2014, with key models including BYD Qin, SAIC Roewe 550PHEV, etc. This also accounts ~0.2% of passenger vehicles sold in China.
- **Electric buses:** noted 8.2k sales volume on pure electric ones and 10.4k sales volume on hybrid ones in 2014, with key OEMs including Yutong Bus, BYD, CSR Times Electric Group, Ankai, etc. This accounts ~10% of buses sold in China.
- **Low-speed electric vehicles:** lacks reliable industry statistics due to chaotic market participants and low requirement, but it's believed to be around ~180k annual sales volume and 1 million total ownership.

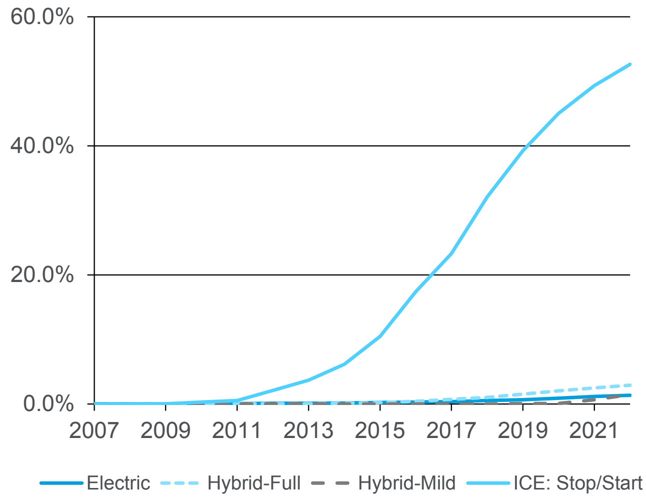
Looking forward, we made an SWOT analysis on EV development in China:

- **Strength:** Strong government support, less legacy obstacles, complete supply chain on motors, etc.
- **Weakness:** Tight R&D resources, primitive battery management, weak branding.
- **Opportunities:** World's largest car market and continuously growing.
- **Challenges:** Battery technology (LFP vs. NCA/NCM), customers' environmental awareness.

Propulsion Outlook

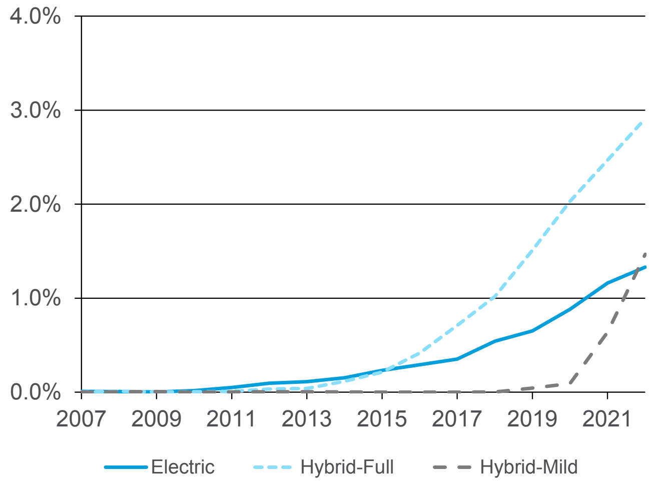
Advanced powertrain technologies are expected to rapidly increase penetration in the coming years. Gasoline turbocharger penetration, currently around 12%, should exceed 20% by the end of the decade. This will be supplemented by stop/start penetration growing to over 50% penetration past 2020. Dual-clutch and continuously variable transmissions are expected to see the highest penetration gains amongst transmission systems.

Figure 153. China Emerging Propulsion Penetration Outlook



Source: IHS, JD Power, Ward's & Citi Research

Figure 154. China Emerging Propulsion Penetration Outlook (ex. Stop/Start)

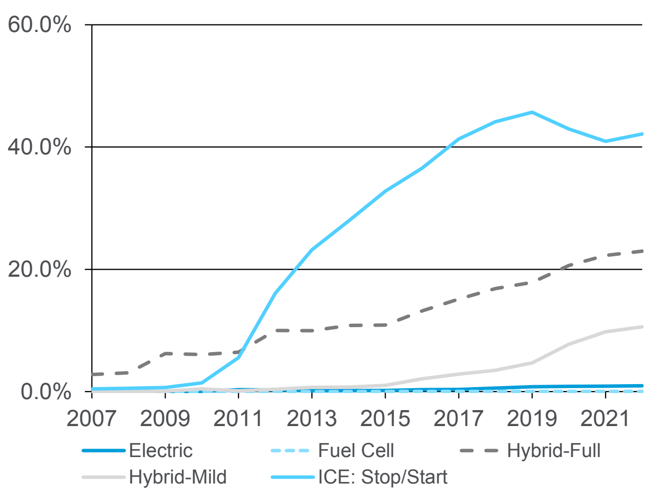


Source: IHS, JD Power, Ward's & Citi Research

Japan

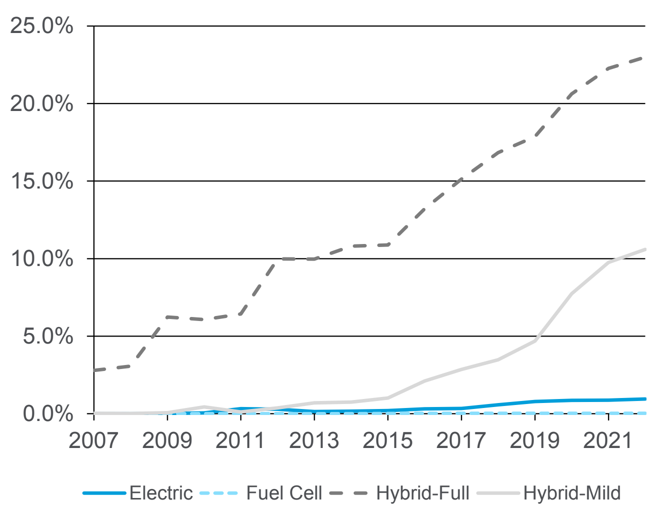
The Japanese market is unique in its strength around hybrid adoption rates, helped in large part by the popularity of Toyota's Prius. While the all-new Prius' 2015 debut was delayed due to design issues, it is finally set to arrive in dealer showrooms for the 2016 model year. Reports suggest that the base model will achieve 55mpg, with "eco" plug-in models delivering upward of 60mpg. As with other geographies, ICE engines will continue to comprise the bulk of new vehicle sales, with performance enhancers like stop/start systems showing the highest growth.

Figure 155. Japan Emerging Propulsion Penetration Outlook



Source: IHS, JD Power, Ward's & Citi Research

Figure 156. Japan Emerging Propulsion Penetration Outlook (ex. Stop/Start)



Source: IHS, JD Power, Ward's & Citi Research

India

Propulsion by Alternative Fuels: CNG / LPG

India's leading PV maker Maruti Suzuki sold ~63,000 units of factory-fitted CNG (compressed natural gas) in FY15 – a 23% uptick vs. FY14. The contribution of CNG vehicles to total sales increased to 5.4% from 4.9% in FY 2013-14. Per press reports (Souce: Auto.ndtv.com) around 50% of Wagon R, Eeco and Ertiga sales in cities like Delhi and Mumbai are accounted for by CNG variants. At present, Maruti has 6 CNG + Petrol models in its line-up – spanning entry level models like the Alto / Alto K-10 and also the van / UV segment with the Eeco and Ertiga.

Figure 157. Maruti Suzuki Range Extender Hybrid

Source: auto.ndtv.com

Figure 158. Tata Nano CNG Variant

Source: Citi Research

The key constraint to quicker adoption of CNG is the slow ramp up of outlets supplying CNG fuel. As of Sept 2014, there were less than 1000 CNG outlets in the country – and mostly restricted to cities and metros. This compares against > 50,000 petrol / diesel fuelling stations.

Electric Vehicles

The National Electric Mobility Mission Plan (NEMMP) 2020 was approved by the government in 2012. The document provides a mission and a roadmap for the faster adoption of xEVs (hybrid and electric vehicles) and their manufacturing in India. The government believes that by 2020 it is possible to achieve 6-7 million units of new vehicle sales of xEVs – which would annually save around 2.2-2.5m tons of fuel. Thus far, conversion has been slow as consumers are somewhat unsure of the attendant infrastructure for electric vehicles – namely the availability of charging points.

To spur conversion toward xEVs, the government has introduced incentives under the FAME India Scheme (Faster Adoption and Manufacturing of Hybrid and Electric vehicles in India). Under the scheme, the government will give incentives for xEVs up to Rs29,000 / 2 wheeler and up to Rs138,000 / car. The government plans to spend up to Rs7.95 billion ($125m) in the first 2 fiscal years under this scheme. The scheme will commence in all metropolitan cities and then branch out to other major cities and smart cities. The range of incentives for various vehicle classes is as below:

Figure 159. Incentives for xEVs under the FAME Scheme

Vehicle Type	Range of incentives / vehicle
Motorcycles / scooters	Rs1,800-Rs29,000
Electric / hybrid car	Rs13,000-Rs138,000
3W	Rs3,000-Rs61,000
LCVs	Rs17,000-Rs187,000
Buses	Rs3,400,000-Rs66,000,000

Source: Company reports

OEMs are also keen to participate in this initiative – many of them showcased their concepts at the Auto Expo 2014 (Figure 160). Commercial roll out of EV technology though remains restricted for now, until more clarity emerges on aspects like technology development fund, charging infrastructure and demand incentives.

Figure 160. Concepts Showcased at Auto Expo 2014

OEM	Vehicle car	Vehicle concept	Description
Maruti Suzuki	Passenger car	Swift - Range Extender	658cc petrol engine + 55kw motor powered by lithium ion battery
M&M	LCV	eMaxximo	LCV with EV drivetrain from Mahindra Reva
Tata Motors	LCV	e-Magic	3 phase AC induction motor
Toyota	Passenger car	Camry hybrid	Petrol engine + electric motor and Nickel hydride battery
TVS Motor	Scooter	Hybrid Qube scooter	110cc engine + 800 watt electric motor with lithium ion battery

Source: Industry, Press reports

Figure 161. Auto Expo 2014: Mahindra Halo Electric Concept

Source: Citi Research

Figure 162. Auto Expo 2014: Mahindra XUV5OO Hybrid

Source: Citi Research

Figure 163. Mahindra Reva

Source: Citi Research

Figure 164. Hero Leap – Hybrid Scooter

Source: Citi Research

A survey undertaken under the aegis of the Department of Heavy Industries highlights key issues and consumer concerns in Figure 165 and Figure 166. Across segments, range and charging time are not considered significant issues – rather, pick up, top speed and battery replacement are considered important barriers to adoption of xEVs. From a customer perspective, maintenance cost is the most important criteria, followed by battery costs.

To incentivize usage across various segments, customers have indicated different preferences. For instance, across segments, cash / tax subsidies is the primary preference, which is why the government has begun providing incentives. This follows with a subsidy on batteries – and then aspects like free parking, toll discounts, etc.

Figure 165. Customer Purchasing Criteria (1 represents most important)

	4W	2W	LCV	3W	Bus
Spares					4
Range				2	
Running cost			3	3	3
Charging time	5	5			
Top speed	4	4	5	4	
Pick up	3	3	1	5	2
Battery Cost	2	2	4		
Maintenance cost	1	1	2	1	1

Source: Department of Heavy Industries; Note: 1 is highest ranking

Figure 166. Customer Preference for Incentives

	4W	2W	3W	LCV	Bus
Toll Discount					2
Others	xEV Kits	Electricity cost	xEV Kits	xEV Kits	
Free Parking	3	3	4	4	5
Subsidy on Batteries	2 (56%)	2	5	2	3
Cash/Tax Subsidies	1 (58%)	1	1	1	1

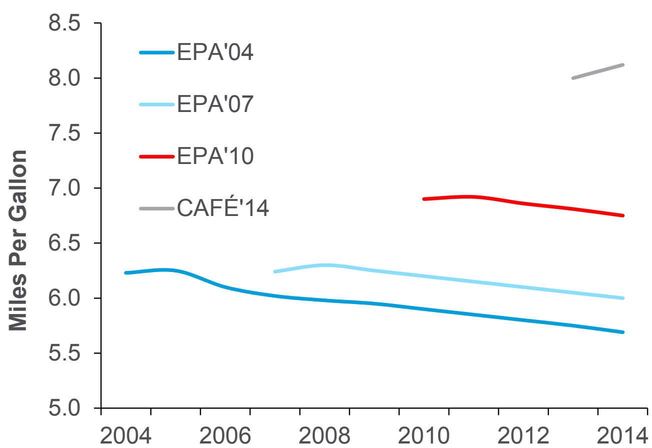
Source: Department of Heavy Industries; Note: 1 is highest ranking

Spotlight on Commercial Vehicles

In developed regions like North America, Western Europe and Japan, a nearly two-decade push from clean air regulators like the EPA has resulted in particulate matter (PM) and NOx being virtually eliminated. More recently, though, the regulatory focus shifted to reduction of greenhouse gases. In the US starting in 2014, heavy duty trucks had to meet fuel economy / carbon emission standards. Through various means, like improved aerodynamics and some improvement in engine efficiency, fuel efficiency gains in excess of the mandates' 10% requirement have been met.

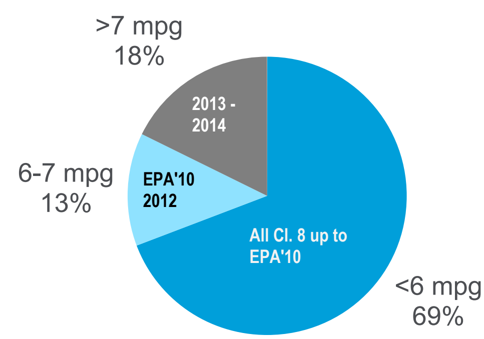
The greenhouse gas (GHG) regulations are the latest in a series of steps that have led to significant improvement in fuel economy. In fact, we estimate a new truck today can realize well north of 8 MPG. At the same time, we estimate that ~70% of the market is getting less than 6 MPG. While diesel costs are no longer $4/gallon-plus, even at the current national price (~$2.80), the potential savings for long-haul fleets are significant. Using that $2.80/gallon diesel price, and assuming 100K miles driven, a carrier currently operating a truck with an EPA'04 engine could realize close to $13K in annual fuel savings by upgrading to a new CAFE'14 compliant truck.

Figure 167. Miles per Gallon by Engine Technology Type



Source: Citi Research; ACT Research

Figure 168. US Class 8 Fleet Fuel Economy



Source: Citi Research; ACT Research

Keep in mind, the push for environmental regulations is not just a US and European phenomenon. A number of emerging market countries have rolled out and enforced their own emissions guidelines. We highlight a few of these guidelines below:

Figure 169. Upcoming Environmental Regulations by Region

	Market	2013	2014	2015	2016	2017
On-Highway Markets	US	EPA 2013	EPA 2014 (GHG)		EPA 2016	EPA 2017 (GHG)
	Europe		Euro VI			GHG
	Brazil					
	China	NS IV			NS V	
	India				BS IV	

Source: Company Reports

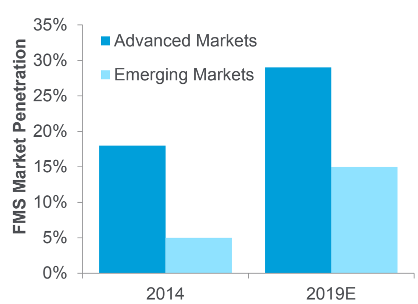
Second, OEs have developed a slew of new technologies to optimize both driver and vehicle performance. We highlight a few of these products below:

- **Adaptive Cruise Control (ACC):** Utilizing radar systems to detect nearby traffic, ACC systems are an active version of cruise control. The system monitors, and reacts to, surrounding traffic, keeping the truck moving at a set distance behind vehicles in the same lane. Alongside the implied safety benefits, ACC helps the driver optimize braking and acceleration while on the road, which is estimated to lower fuel consumption 5-10%.

- **Trailer Aerodynamics:** OEs have introduced a variety of trailer add-ons and design changes to minimize aerodynamic drag on the tractor-trailer. Based on industry estimates, vehicle aerodynamics generate as much as 70% of fuel burn for a commercial vehicle at high speeds, with nearly 75% of the drag coming from the trailer. As a result, trailer aerodynamics modifications are estimated to reduce fuel consumption anywhere from 3-15%.

- **Automated Manual Transmissions:** Alongside the aforementioned driver retention benefits, AMT's provide considerable fuel efficiency gains for operators. Due to the optimized shifting compared to traditional manual systems, AMTs provide an estimated 7% fuel efficiency improvement over the life of a vehicle.

Figure 170. FMS Market Penetration



Source: Company Reports

Finally, with drivers the largest contributor to fuel efficiency (there can be up to a 35% difference in fuel use between good and bad drivers), more operators are opting in to Fleet Management Solutions (FMS) or telematics systems to better monitor fleet performance. Based on a 2014 DoT study, drivers monitored by a telematics system improved fuel economy by 5% and 9% for sleeper and day cabs, respectively. In addition, unsafe driving (i.e. hard braking, sudden lane changes) was cut in half, while incidences of speeding were cut 30-40%.

Building the Car of the Future

Lighting

Overview: We update our analysis of the state of lighting markets with the last twelve months seeing significant increases in the market capitalization of lighting players and the listing of European LED leader, Hella. Automotive lighting is relatively unusual in that it is something that end-customers can easily observe. Halogen dominates the lighting market with almost.80% of front headlights using Halogen bulbs currently, with Xenon comprising most of the remainder of the market. LED could, we believe, cannibalize this market, increasing its market share to 20% by 2020 from 2-3% today. We believe that the LED market could grow from about €2.4 billion ($2.7bn) today to €13 billion ($14.6bn) by 2020.

Figure 171. Differentiation of Light Products

	Halogen	Xenon	LED	Future technologies (such as Laser)
Attractions	● Cost advantage (e.g. from standardised production)	● Triple lifetime compared to Halogen	● Lifetime surpasses vehicle lifetime	● Highest illumination level close to legal limits
			● Design flexibility	● Minimised space requirements
	● Basic, conventional Technology with uncomplicated handling	● Brighter, wider reach	● Highest flexibility for dynamic systems	● Design flexibility
		● Highest standardisation	● Daylight colour impression	● OEM marketing trend
Issues	● Lowest illuminance	● High system complexity	● Used in premium segment so far only	● No volume-series production readiness
	● Highest fuel consumption	● Legislation requires cleaning and levelling system	● High system complexity	● Eye-safety concerns
	● Less lifetime		● Currently still relatively high cost due to non-standardised production	● Very high system complexity
	● Low colour appearance			● High cost level

Source: Hella

LED stands for Light Emitting Diode and these work by connecting a 1mm-wide diode (an electrical component allowing electricity to flow in only one direction) to an electrical current that releases 'photons', which appear as light. The color of the light differs depending on the energy gap in the diode, which means that LEDs can come in a variety of colors, using little electricity to become bright. LEDs have a lifetime of up to 20,000 hours, an average of 20x longer than halogen. In an LED headlight, the diode is covered by a reflective body and lens, which is in turn encased in the plastic that forms the basis of the headlight design. LED headlights, unlike LEDs for use in household appliances, are also built with a heat sink to dissipate heat away from the diode. We estimate that the average price of a Front LED light is c. €120-€130 ($135-$145), about 3x that of a standard Halogen light partly reflecting higher electronic content and the higher cost of LED bulb of €10 vs. €0.50 ($11 vs. $0.56) or a Halogen bulb.

Figure 172. Comparison of Headlights

	Halogen	Xenon	LED
Light Source	Coiled filament	Discharge lamp	Semiconductor
Light Colour (Kelvin)	3,200	4,000	6,000
Lifetime (hours)	300-1,500	2,500	10,000-20,000
Wattage	55	35	<20
Luminous Flux	3,200	3,200	5-500
Efficiency (lm/W)	25	90	100
Fuel Consumption		25% saving vs halogen	40% saving vs halogen

Source: Citi Research

Current market share and growth

In general, lighting has a shorter product life than other components, partly as changes often feature in mid-cycle facelifts, which are around the 3-4 year stage of a typical 6-7 year car product cycle. Lighting's prominence in mid-cycle facelifts we believe reflects the capacity for lighting to provide OEMs with distinctive styling and branding. It should be noted that Lighting product is typically designed for specific models with Lighting also visible to consumers, influencing their purchase decision for vehicles.

Currently, penetration rates of Front Lighting LED are currently only 2-3% globally and 4% in Europe though penetration rates are higher for LEDs in Rear Lighting at 22-23% globally and 30% in Europe. Below, we highlight current values for the various segments of auto lighting.

Figure 173. Market Value by Segment in OE Passenger Car Lighting

2013-2014(1)	Global Market Value	European Market Value
Halogen	€4.3bn	€0.9bn
Xenon	€3.2bn	€1.1bn
LED	€0.8bn	€0.4bn
Rear Lamps	€2.2bn	€0.6bn
Interior Lighting Systems	€1.1bn	€0.4bn
Small Lamps	€1.1bn	€0.3bn
Total	**€12.7bn**	**€3.7bn**

Source: L.E.K. Consulting, Hella; (1) June 2013-May 2014

By 2018/19, LEDs headlamps will likely represent c.20% of the world market.

It seems possible that LED lighting could eventually replace halogen in headlamps. Take-up may be lower in the US partly as a result of legal hurdles, such as regulation that every car must allow the driver to switch between high and low beam, which nevertheless could be altered as early as 2015 and partly as a result of the car mix (12% of cars are premium, compared to 30% in Germany and 25% in the UK).

Halogen penetration should fall as LED use increases.

LED is set to take market share predominantly from halogen lighting but also Xenon. Hella sees Xenon penetration in headlamps falling to 15% in 2018 from 22% currently in Europe and globally sees Xenon penetration falling from 13% to around 10% by 2018.

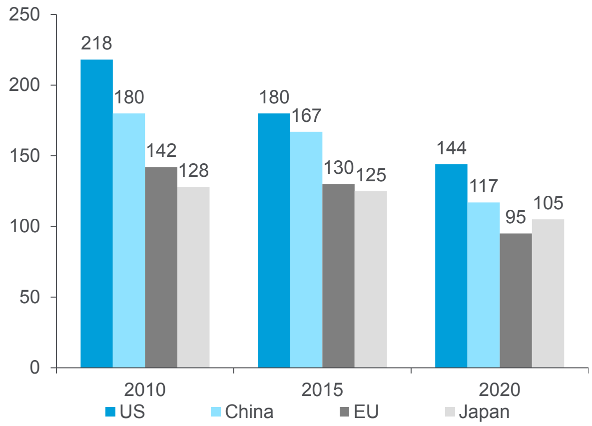
We see the potential for growth of LED to be even higher, with penetration rates of front LED headlamps in Europe at 30% by 2018 and penetration rates of rear headlamps of nearly 45% in 2018 compared with 20% currently. Such rates of penetration would not be dissimilar to those achieved historically by other innovative technologies such as electronic stability control and gasoline direct injection in Europe and North America.

Why is LED lighting growing so fast

1. Fuel efficiency

LED lights offer greater energy reduction than other lights in the region of 1-2g of CO_2 per km for the average car, which is relatively significant in light of the EU's 2020/21 emissions rules targets of 95g of CO_2. As a further example the average amount of wattage used in halogen lights is 135W, for the same amount of emitted light, Xenon lights uses 90W, while LEDs use only 50W. Improving technology could reduce this wattage of LEDs over time to almost 30W.

Figure 174. World CO_2 Regulation (Emission Limits in g/km of CO_2), 2010-2020



Source: Continental

Figure 175. Change in CO_2 Emissions by Car Company, 2009-12

	Average CO_2 emissions (grams per km)				
	2009	2010	2011	2012	2013
BMW	150	148	145	138	133
Daimler	160	158	150	140	134
Peugeot	135.8	131.8	127.5	122.5	115.9
Renault		137	131.7	125.5	115.9
VW	151	144	137	134	128

Source: Company Data

OEMs must lower CO_2 emissions to as low as 95g/km by car.

2. Design flexibility

LEDs give OEMs far greater control over the design and unique branding of their nameplates and increase the value proposition also for LED automotive suppliers. Essentially, the flexibility reflects the small size of the diode vs halogen and xenon bulbs. Auto consumers can easily observe innovation in new model launches with Lighting able to provide a much more modern and sleek image for cars and contribute to brand development. Furthermore, LEDs offer less deep casing suggesting more manufacturing flexibility for car makers.

3. Automation

LED flexibility means that headlamps can be automated: adaptive cut off lines, lighting up corners...

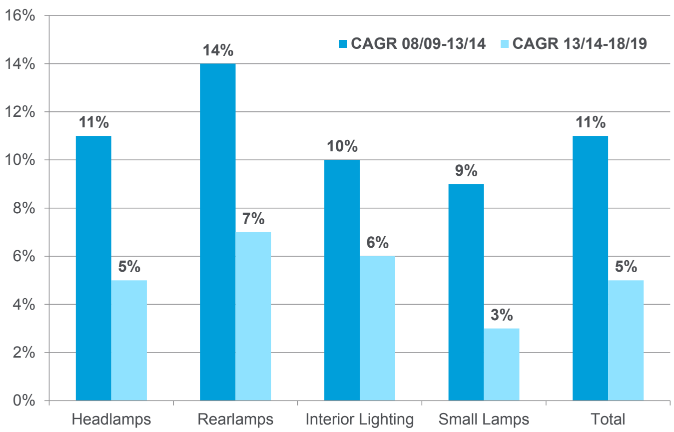
The relatively small size of LEDs (1mm^2) in particular facilitates the automation of headlamps, with each light able to be individually controlled. As a result, new systems with LEDs can automatically dim or turn off; they can adjust to road conditions and move in order to illuminate bends in the road or at corners. This element is particularly useful in avoiding dazzling oncoming cars.

4. Safety benefits could lower road accidents

LEDs produce the same light color as daylight and Valeo believes that this improved visibility could reduce braking distance by 6 meters at 120km/h.

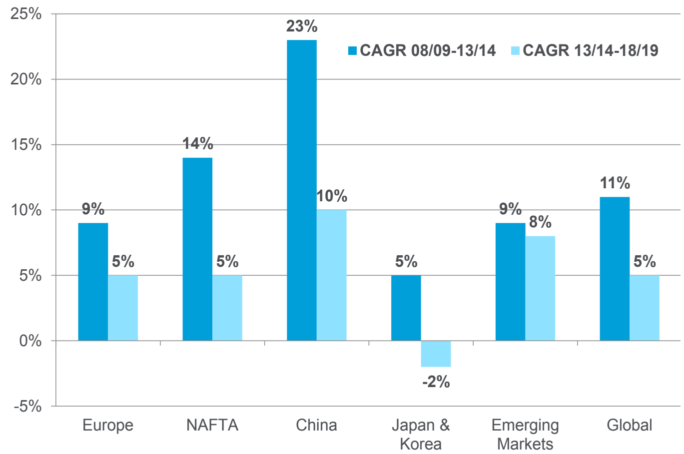
The light colour of LED, which is similar to daylight (5,500K), provides additional safety benefits compared to halogen and Xenon. Indeed, Valeo indicates that the additional visibility of LEDs shortens braking distance by 6 meters at 120km/h.

Figure 176. Global Demand Growth for Car Lighting, by Product



Source: L.E.K. Consulting

Figure 177. Global Demand Growth for Car Lighting, by Region



Source: L.E.K. Consulting

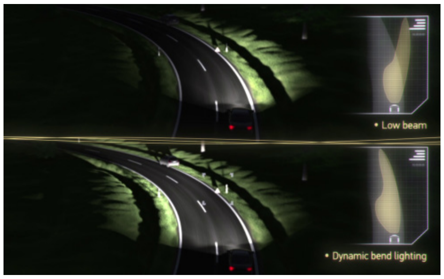
LED Headlamp Products

- **The Adaptive Front Lighting System** uses road and weather conditions, as well as location (in the city or in the countryside) and car speed to determine optimal light distribution. It uses a rotating cylinder between the light and the lens. The cylinder is contoured to allow different light distributions. These distributions include town light, at speeds below 55 km/h, which deploys a horizontal cut-off line to minimize glare; a country road light activated at speeds between 55 km/h and 100km/h, similar to conventional low beam; motorway light, activated above 100km/h, has a wide curve. These lights adapt to oncoming vehicles, meaning the driver does not need to take any action.

- **Vertical cut-off lines** use a camera to detect other road users (preceding and oncoming traffic). If there is no traffic, the lights are automatically at high beam. As oncoming vehicles get closer, the headlights can be moved so as not to dazzle other drivers. When preceding vehicles are identified by the cameras, the headlights are moved so that a ‘tunnel’ is created, whereby the preceding car is not lit by headlamps, but the road either side is. As with Adaptive Front lighting, a cylinder is used to support these functions.

- **Matrix LED headlamps** uses a camera to detect oncoming traffic and vehicles in front. These headlamps have a high beam with 25 LED chips, which can each be individually operated so as not to dazzle other drivers. As a car passes, the Matrix LED headlamps will turn off lights in procession so that only the passing car is not illuminated, while the high beam illuminates all other areas on either side of the vehicle. This essentially produces glare-free high beam.

Figure 178. Adaptive Fronting Systems

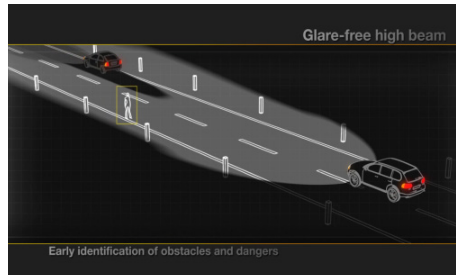


Source: Hella

Figure 179. Matrix LED

Source: Hella

Figure 180. Vertical Cut-Off Line

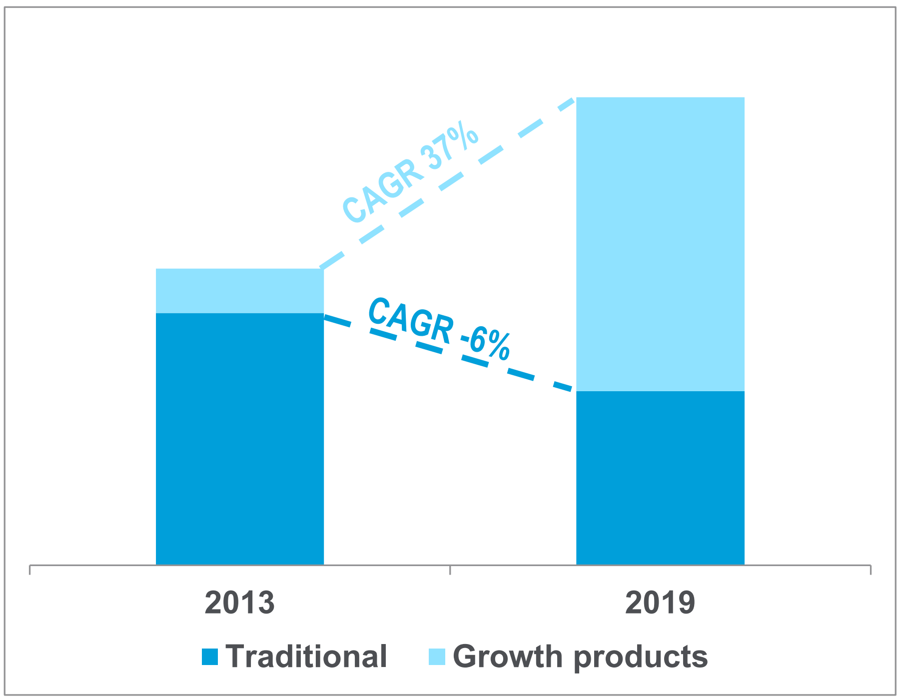


Source: Hella

Concerns

A key source of concern is the potential decline of traditional lighting products, such as Halogen and Xenon, as LED could potentially cannibalize traditional lighting sales and prices. In the chart below, we show Valeo's forecasts for growth differences between traditional products and new products in its Visibility division from 2013-2019, which highlights the potential decline in revenue from older products.

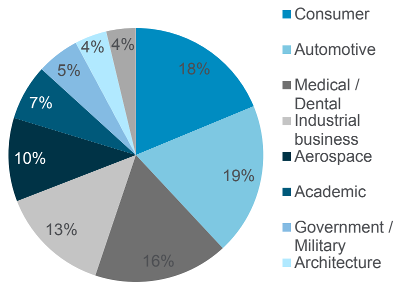
Figure 181. Product Revenue Growth: Traditional vs Innovative Products



Source: Valeo

Additive Manufacturing

Figure 182. Additive Mfg – End Markets



Source: Wohler Report

Additive manufacturing (more commonly known as 3D printing) is the process of repeatedly applying thin layers of materials to build objects generated from 3D computer animated design (CAD) files. The technique is most commonly used by engineers during the prototyping stage of the design process and interest around manufacturing end use parts has started to pick up momentum as the build quality and speed of the technology improves. The automotive sector along with aerospace and healthcare have led the way in terms of incorporating 3D printing into the design and production process.

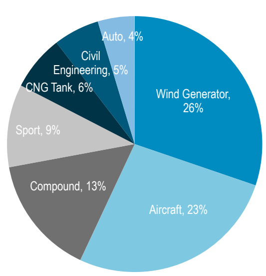
Car manufacturers and parts suppliers account for nearly 20% of the 3D printing market and we believe it will continue to represent a disproportionate share of the market in future years. Today, auto manufacturers are mainly using 3D printers to speed up the iterative design process. We have long seen companies such as Ford apply the technology to create unique jigs and fixtures that are used during the manufacturing and assembly process. More recently, we are beginning to see the likes of Mercedes, Porsche, Ford and other utilize 3D printers from Voxeljet in an indirect fashion to create sand casts and molds of key components such as engine blocks and transmission cases during the forging process. We are already seeing specialty vehicles (limited quantities) such as race cars and high-end sports cars build end-use components from the scoop hood to spoilers printed on 3D printers. Companies such as US-based Local motors and China's Sanya Sihai have begun production of entire car bodies utilizing additive manufacturing technologies.

We also see several niche automotive markets where 3D printing can foster new business models. For example, the collectible cars market has a strong hobbyist following where spare parts can be both expensive and difficult to find. We see the potential for car makers with deep catalogs of parts to market or license designs to be 3D printed.

While we believe the technology is still years away from a world of mass customization, we think the ability to design without constraint provides customers with significant competitive advantages. Nearly every auto manufacturer that we have spoken to has some elements of 3D printing in their production workflow and we expect this trend to continue as materials and processes improve.

Carbon Fiber: Automotive Uses Expanding

Figure 183. Carbon Fiber by Share Application (2013)



Source: Citi Research Estimates

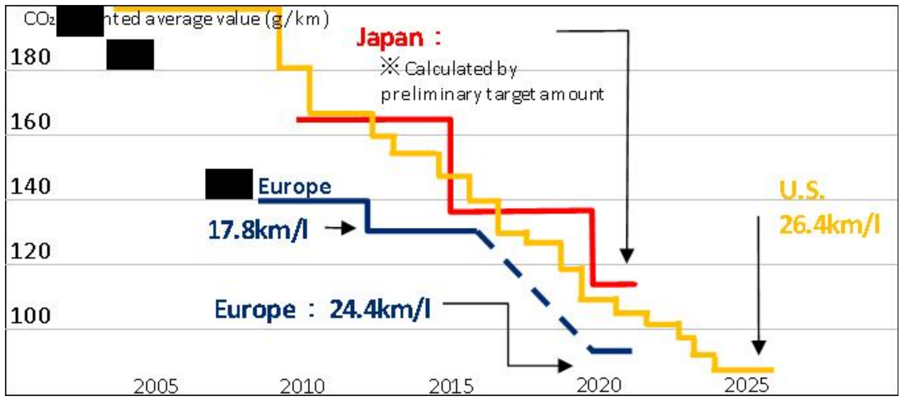
We expect the carbon fiber market to grow 18% YoY in 2014, to 48,000MT/year, with the aeronautics segment up 17% YoY, to 14,000MT and the general industrial-use segment up 22% YoY, to 31,000MT, fueled by demand for automotive and pressure vessel applications. Although automotive applications are still a small part of the overall carbon fiber market, auto-related demand grew about 80% in 2013, to 2,700MT. Projections made by Toray and others suggest carbon fiber demand will total 140,000MT/year by 2020—a roughly threefold increase from the expected 2014 level. The auto industry is forecast to be key to that growth.

The Outlook for the Automotive Carbon Fiber Market

We expect stricter gas mileage regulations to have a major impact on materials industries, including the carbon fiber industry. European regulations will limit CO_2 emissions to 95g/kg in 2020 (down about 26% from the current limit of 127g/kg). There are limits to the mileage improvements still possible using current gasoline engine and diesel technologies. Attention is likely to continue to shift toward other technologies, including hybrid electric vehicles (HEVs), plug-in hybrid

electric vehicles (PHEVs), and fuel cell vehicles (FCVs). Making vehicles lighter will remain an important theme of research. We expect demand to grow for materials allowing lighter battery packs in EVs and PHEVs and lighter hydrogen tanks in FCVs. In the case of EVs, lighter autos will allow expensive battery packs to be made smaller, allowing an overall cost reduction. We believe one major trend in automotive materials aimed at achieving weight reductions will be toward composite solutions that combine steel, the main material used today, with more aluminum and carbon fiber. Many automakers are already talking about composite material solutions as the key to progress.

Figure 184. Comparing automotive CO2 exhaust regulations in Japan, the US, and Europe



Source: Company Data, Citi Research

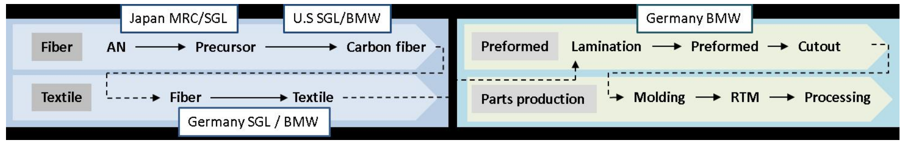
Spotlight on the BMW i3

In the following section we look at how carbon fiber is being used in the auto industry today and at the outlook for further development. BMW's i3 is the first mass-produced automobile to use carbon fiber composites. The i3 is an electric vehicle. We believe the battery pack alone weights about 300kg, although the overall vehicle weight is only about 200kg heavier than a comparable gasoline-powered vehicle because the i3 does not have a conventional engine. Because of the battery weight, however, it was necessary to achieve substantial reductions elsewhere. The chassis section BMW refers to as the "drive module" is made from aluminum. The cabin section riding on the chassis, called the "life module," is made from carbon fiber-reinforced plastic. These choices reduced the vehicle's weight by about 400kg. In the end, BMW succeeded in reducing the weight of the vehicle form a 1.4MT basis to under 1.2MT. BMW has not disclosed exactly how much CFRP is used in the i3, but we believe each vehicle consumes nearly 100kg of CFRPs. We believe the plug-in hybrid i8 uses a similar body framework.

Making the i3

The manufacturing process begins with production of precursor at Otake by MRC-SGL Precursor Co., a joint venture owned 66.66% Mitsubishi Rayon and 33.34% by SGL. The precursor is shipped to SGL Automotive Carbon Fibers (or SGL ACF, owned 51% by SGL and 49% by BMW), in Washington, where it undergoes thermal processing and becomes large tow carbon fiber. The Washington thermal processing stage relies entirely on hydroelectric power, which greatly reduces electricity costs. The finished product is then shipped to SGL ACF's base in Wackersdorf, Germany, where it is woven into carbon fiber fabric with all the fibers oriented in a single direction and bound with a special white thread. Traditional CFRP molding uses pre-pregs—carbon fiber fabrics pre-impregnated with resin—but SGL and BMW use un-impregnated carbon fiber fabric.

Figure 185. Current CFRP Body Production Process for the BMW i3



Source: Citi Research; company reports

Other Auto OEMs Possibly Joining the CFRP Movement

Tesla

According to late-November 2014 reports from Reuters and other media sources, Tesla's CEO has said that the company is talking with BMW to explore the possibility of cooperating in areas such as batteries and carbon fiber components. We believe Tesla vehicles already use CFRPs for some body parts, but a full-scale adoption of CFRPs at Tesla would have a major impact on the overall market.

Audi

Audi has already used CFRPs in some of its car models, including the R8. According to Audi's website and other sources, a future space frame it calls the Multimaterial Space Frame may use CFRPs to strengthen steel and aluminum frame components or CFRPs may be used alone as frame components. Audi explains that it favors CFRPs because they are 60% lighter than steel, because they have design advantages, and because they have superior impact absorption properties in a unidirectional impact. At the first of the annual press conferences Audi began calling in March 2014, management suggested the company will begin to use CFRPs in addition to aluminum on all future models in the interest of reducing vehicle weights. Audi has also said that using the most appropriate materials in the most appropriate ways is at the core of its composite materials design philosophy.

General Motors

At the FY3/15 H1 results meeting, Teijin management said its development project with GM is in the final stages, with materials certification complete, and that Teijin was considering construction of a carbon fiber plant in the US. At peak, (expected to be around 2020), Teijin could be supplying thermoplastic CFRP components for anywhere from several hundred thousand to a million autos annually, mainly GM models. Teijin aims to boost CFRP composite sales to ¥150bn–¥200 billion per year ($1.25-$1.7bn) by around 2020. Supplying automakers will be very important in achieving that goal.

Other Benefits of CFRPs

CFRPs promise to help make automobiles much lighter, but they offer other benefits. In the case of the i3, CFRPs reduced the number of parts required substantially. BMW replaced more than 400 steel parts with about 150 carbon fiber parts, a reduction of about a third, allowing a substantial reduction in the factory space required to make the vehicle. Painting processes were simplified as well. Steel body parts require rust-preventative undercoats. Because the i3 body is mostly made of plastic, these undercoats are not necessary. Their absence saved about 10kg, according to BMW. Painting CFRPs produces less effluent waste than painting steel and reduces capital investment in painting to about 20% of the level conventional processes require. CFRPs also allow more complex body designs, suggesting they may play an important role in automobile branding.

Issues with Carbon Fiber for Autos

First, the biggest issue is probably how to get the cost down for CFRP as a whole. We estimate that carbon fiber itself costs around ¥3,000/kg ($25/kg)for regular tow and ¥1,500/kg ($12.5/kg) for large tow, which is close to 20x-40x the cost of high-tensile steel. As we noted earlier, throughout Japan efforts are being made to develop technologies and cut costs for precursor production and fire-resistance processes. Currently, we estimate that in the case of CFRP molded parts, which use resins with thermosetting properties, the cost rises to ¥5,000/kg $42/kg) or more, which is caused by the high cost of the resin itself and the long forming time required. We estimate this is 50x or more the cost of high-tensile steel.

However, it is possible to significantly vary the cost of materials for CFRP, according to the ratio of carbon fiber and resin and the resin chosen. The molded product price of aluminum, which competes with CFRP as a light weighting material, is approximately ¥800/kg ($6.7/kg). Given the properties of carbon fiber, such as its strength and specific gravity, we think that if the cost of CFRP can be brought to the ¥1,000/kg level ($8/kg), its cost competitiveness would improve by leaps and bounds. We also think it would be theoretically possible to cut the cost to the ¥800/kg level at the material cost only stage through the combination of large tow carbon fiber and thermoplastic resin, if the strength issue can be overcome. Currently the forming process-related costs (forming time is naturally also an important issue) are a bottleneck, but we think that there is plenty of room left to cut costs, by shortening forming times through the proactive use of thermoplastic resin and by maximizing economies of scale through expansion in the scale of mass production.

Carbon Fiber Recycling

We feel that recycling will become an unavoidable issue as automotive carbon fiber spreads in earnest. Even now, a few thousand tonnes of CFRP is recycled every year but we suspect that much of it is disposed of by incineration or in landfill. We think that many of the several firms that recycle CFRP in Japan and overseas separate out the resin and the carbon fiber via thermal cracking and process the results into chipped thread, middle fiber, etc., and then sell it. Currently when a normal vehicle is scrapped, after CFCs and other chemicals have been recovered, the vehicle is placed in shredder after being compressed, steel, non-ferrous metals, and shredder dust are sorted out and reused or sent for landfill. In the case of thermoplastic CFRP, it is relatively easy to separate out carbon fiber and plastic through the application of heat, so we feel that recycling should be simple to a degree; however, the issue is with thermosetting CFRP. In this case, we think it is compressed, pulverized, and then incinerated or sent for landfill and we feel there are a lot of issues with CFRP, which is stronger than metals, such as to what extent existing presses can cope with it.

China: Building and Distributing

Manufacturing the Car of the Future in China

Despite continuous labor cost inflation, China still enjoys lower manufacturing cost than most of the industrial countries in general. Even in China domestic market, for similar sizes and functionalities, Chinese brands cars are on average ~30% cheaper than foreign brands. Such cost leadership is more phenomenal on SUVs and MPVs, with a typical example Wuling Hongguang by SAIC-GM-Wuling.

Wuling Hongguang and Hongguang S are 7-seater MPVs with 2.7-meter wheelbase and 1.2-1.5L gasoline engine. Selling at Rmb40-60K ($7-10k), it noted enormous sales volume in China: 750,000 in 2014 and 190,000 in the first quarter of 2015. Wuling as a whole sold 1.8 million vehicles in 2014 and 525K in 1Q15, being an invisible giant in China auto market.

Keys for cost control include: keep it simple, deliver the basics; use low-cost materials such as plastics; focus on value with MP3 player only; smart design with easy-fit parts; avoid over-engineering and stick to low-grade steel; reuse old components such as engine and chassis; offer basic safety standard at basic model; achieve high volume and operating leverage; stay with old plant and low overhead cost; locate in western China with cheap labors; use local suppliers; as well as use low-cost distribution with humble stores.

Figure 186. SGMW – Wuling Hongguang

Source: ChinaAuto Web, Citi Research

Figure 187. SGMW – Wuling Hongguang S

Source: ChinaAuto Web, Citi Research

Figure 188. SGMW – Wuling Hongguang and Hongguang S Specifications

Model	OEM	Low MSRP	Top MSRP	Warranty (Yr/km)	Engine size (L)	Transmission	Seats	Power (Ps)	Max Torque (Nm)	Max speed (km/h)	L (mm)	W (mm)	H (mm)	WB (mm)
Wuling Hongguang	SGM Wuling	43800	49300	3y/60,000	1.2L	5MT	5-8	86	108	140	4305	1680	1750	2720
Wuling Hongguang	SGM Wuling	46800	52800	3y/60,000	1.5L	5MT	5-8	112	146	160	4305	1680	1750	2720
Wuling Hongguang S	SGM Wuling	52800	61800	3y/60,000	1.2L	5MT	5-8	86	108	140	4400	1680	1770	2720
Wuling Hongguang S	SGM Wuling	51800	79300	3y/60,000	1.5L	5MT/4AT	5-8	112	147	160	4400	1680	1770	2720
Alto	Changan Suzuki	41800	59900	3y/100,000	1.0L	5MT/4AT	5	71	92	160	3570	1600	1470	2360
Sail	SGM Chevrolet	56800	66800	3y/100,000	1.2L	5MT/5AMT	5	87	115	165	3947	1690	1503	2465
Sail	SGM Chevrolet	59900	71900	3y/100,000	1.3L	5MT/5AMT	5	103	127	175	4300	1735	1504	2500
Sail	SGM Chevrolet	64800	75800	3y/100,000	1.4L	5MT/5AMT	5	103	131	170	3947	1690	1503	2465
Sail	SGM Chevrolet	67900	79900	3y/100,000	1.5L	5MT/5AMT	5	113	141	180	4300	1735	1504	2500
Verna	Beijing Hyundai	73900	102900	3y/100,000	1.4L	5MT/4AT	5	107	135	175	4375	1700	1460	2570
Verna	Beijing Hyundai	99900	106900	3y/100,000	1.6L	4AT	5	123	155	180	4375	1700	1460	2570

Source: Autohome, Citi Research

With such competitive cost, GM introduced this model to India market, renamed as Chevrolet Enjoy and competing with Japanese low-cost MPV there. An earlier minivan model by Wuling, called Rongguang, was also introduced to Egyptian market by GM, renamed as Chevrolet N300.

Figure 189. Chevrolet – Enjoy in India (Wuling Hongguang in China)

Source: XGO.com, Citi Research

Figure 190. Chevrolet – N300 in Egypt (Wuling Rongguang in China)

Source: XGO.com, Citi Research

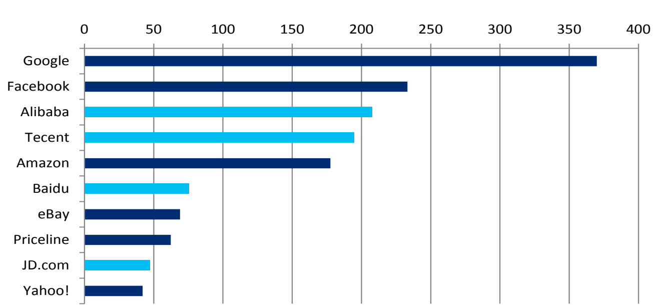
Distributing the Car of the Future in China

China has some of the world's largest internet companies, thanks to the large population and broadband and smart phone penetration. Among top-10 internet companies in the world by market cap, China has four positions in the board: Alibaba, Tencent, Baidu and JD.com. There are also auto portals listed in NASDAQ, Autohome and BitAuto, which are also larger than their US peers such as TrueCar of Autobytel.

Being newly emerged auto market with ~70% customers as first-time buyers, there is strong demand for car database, comments and dealer information, and such auto portals provide these data well, together with user feedbacks on online forums. Also, relative to mature market, there is less obstacles from old interest groups, thus auto portals got bigger opportunities to grow in China.

The portals monetize mainly in two ways: display ads for auto OEMs, and directing sales leads to dealers after dealers paying a subscription fee. Some other functions also include dealers' advertising and used car bidding, and the shift from PC to handsets also calls led to development of mobile phone-friendly pages and mobile apps.

Figure 191. World – Top 10 Internet Co. by Market Cap (US$bn)



Source: Bloomberg, Citi Research

Figure 192. World – Auto Portals Comparison

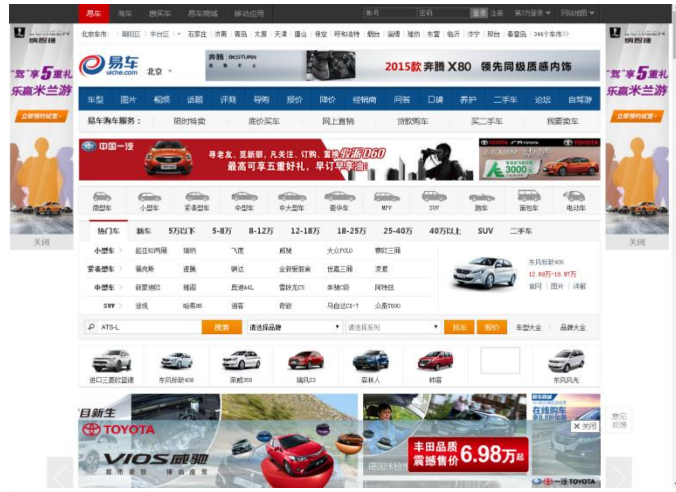
	Ticker	Market cap (US$mn)	2014 Revenue (US$mn)	2014 Net profit (US$mn)	2015E BBG Revenue (US$mn)	2015E BBG Net profit (US$mn)
Autohome	ATHM	5,368	346	122	528	176
BitAuto	BITA	2,411	399	79	597	72
TrueCar	TRUE	1,340	207	-48	284	13
Autobytel	ABTL	126	106	3	117	12

Source: Bloomberg Consensus for 2015 Forecast, Citi Research

Figure 193. Autohome – Autohome.com.cn

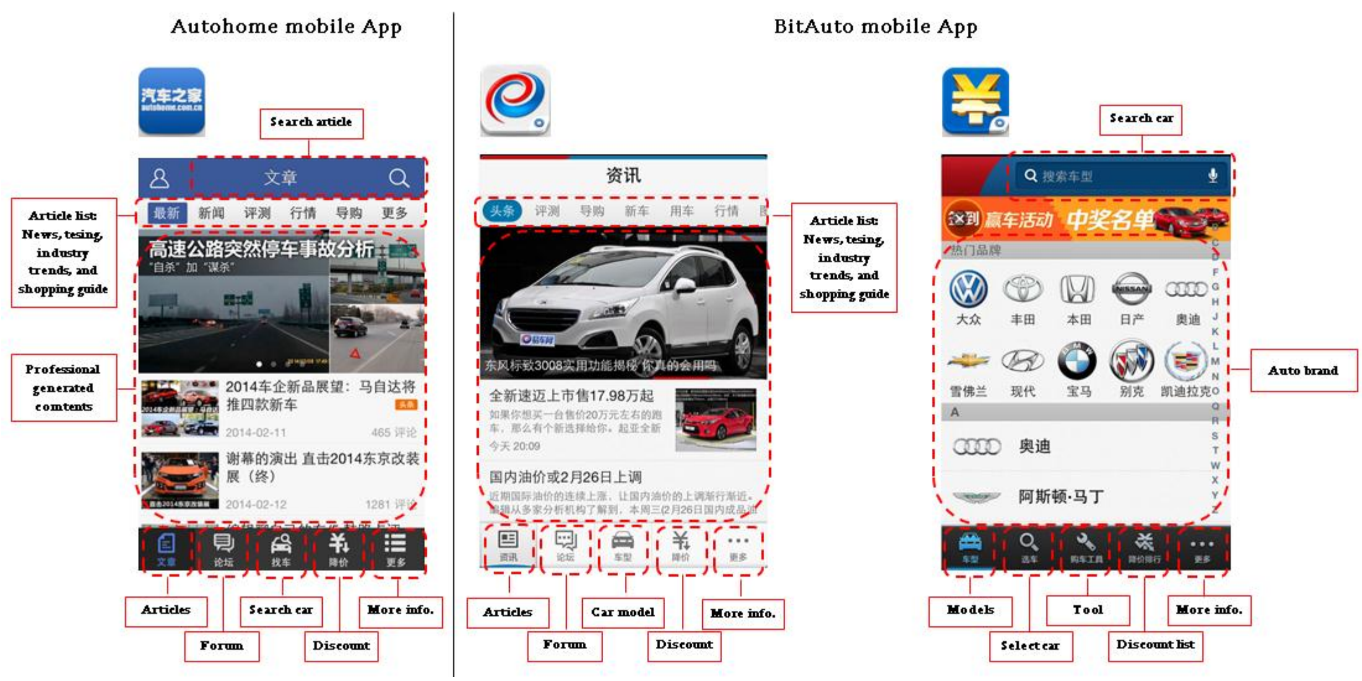
Source: Autohome, Citi Research

Figure 194. Bitauto – bitauto.com



Source: Bitauto, Citi Research

Figure 195. Comparison Between Autohome's and Bitauto's Flagship Mobile Apps



Source: Company data, and Citi Research

India: Light Weighting Initiatives

Light weighting or the use of lighter materials to lower vehicle weight has been around for over 10 years now, but we expect that the pace of change will become more rapid for 2 reasons: a) Fuel emission / efficiency standards are becoming more stringent with the standards expected to go up a notch in 2017 and then again in 2022. B) On the other hand, the consumer preference is slowly tilting toward slightly larger vehicles – the 'center of gravity' of the industry which was an 800cc engine around 5 years ago is now between 1.1l-1.3l – and larger engines = heavier cars. We think light weighting technologies will gather momentum over the next decade. We detail a few initiatives that India based OEMS / ancillaries have been engaged in over the past decade – this list is merely indicative and not exhaustive.

Figure 196. Light Weighting Technologies / Processes

Company	Technologies / processes applied for light weighting of vehicles
Mahindra and Mahindra	Hollow shafts, low thickness castings / forgings, plastic fenders (replacing steel), hydro formed chassis, Al castings (replacing cast iron), alloy wheels (replace steel wheel rims)
Tata Motors	Parts optimization through simulation techniques, use of high strength materials in structural applications, compression molded and injection molded plastics and composites to replace steel, Al housings instead of steel castings, Al cab frames, Al wheel rims, lighter batteries
Maruti Suzuki	Usage of tailor welded blanks in door frames and tailgate, K series engine substantially uses Al, fuel tanks made of plastic instead of metal
GM India	Engine blocks, valves and rockers made of aluminum and lightweight materials
Fiat India	Reduced thickness of plastic and sheet metal components, converted steel components to Al and engineering thermoplastics, alloy wheels instead of steel wheels
Honda Siel Cars India	Use of high tensile steels to cut weight, also usage of lighter materials like magnesium
Delphi India	Safety sensors molded in plastic - 30% lighter than conventional sensors; infotainment products molded in plastic replacing steel - 50% weight reduction; more usage of plastics in fuel modules, throttle bodies and ECU housings.

Source: Company reports

According to data from ARAI (Automotive Research Association of India), light weighting initially focused on the use of advanced steels, fiber reinforced composites and used of lighter metals like aluminum and magnesium. From thereon, newer technological innovations have come through in aspects like multi material recycling, multi material simulation, multi material joining, new modular architectures.

At the 2014 Auto Ancillary show in Pune, industry experts discussed light weighting through the increased usage of composites and polymers. The main benefits of using composites are reduction in weight by 20%-40% compared to steel, a 40%-60% reduction in tooling costs and less assembly time. LFTs (long fibre thermoplastics) have many applications in light weighting in cars, with the principal ones being acoustic shielding and underbody panels. IAC (International Automotive Components) expects that by 2018, plastics will average around 18% of a vehicle's weight, vs. 14% in 2000. Metals on the other hand will shrink from 63% to 55%.

ACMA (Automotive Components Manufacturers Association) has signed a MoU with Fraunhofer Institutes (FI) in Germany to focus on light weighting technologies and initiatives. The joint consortium of FI and ACMA will work to reduce weight in 3 ways:

1. Use the same material but reduce its weight through technological applications – e.g., sheet metal thickness can be reduced by using tailor welded blanks.

2. Weight reduction by combining multiple materials.

3. Weight reduction using alternate materials – composites, ceramics and engineering plastics.

But there are issues that inhibit quicker adoption of technologies too – a) final price of the vehicle is <$10,000 or >70% of the total industry (2.5m units PV annual sales) – this restricts the use of higher cost materials like Al and Mg. Tensile strength of Al is less compared to mild steel – so it cannot be used in applications like bus bodies. The vendor base (at the tier 2 / 3 level) is still fairly nascent in terms of competencies – so there are issues in material supply (quality / quantity), design and development of components. There are challenges with respect to repair of vehicles for minor aspects like scratches, dents, etc. – e.g., if a plastic bumper cracks it has to be fully replaced – which is more expensive than hammering out a dent in a steel bumper.

Company Spotlight: Jaguar Land Rover

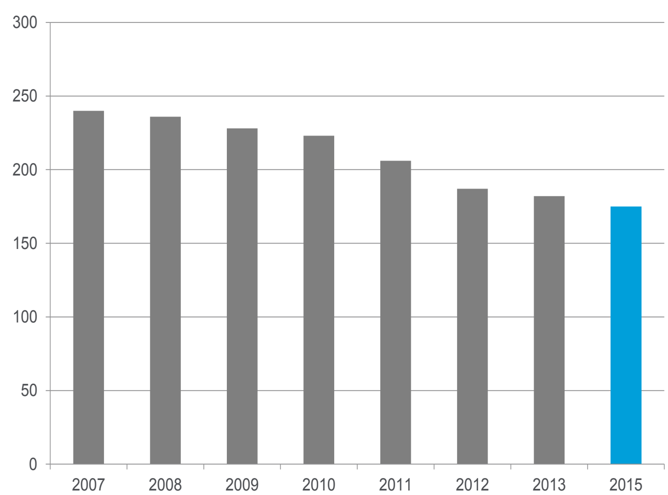
Aluminum in vehicle structures imparts several benefits: (a) weight saving + more fuel efficiency + lower emissions, (b) Lower mass results in better driving dynamics. Aluminum body structures were initially introduced to the Jaguar line. The weight of the cars was reduced by around 40%, using aluminum stamped panels, castings and extrusions. JLR's new Range Rover and Range Rover Sport directly benefit from this aluminum structure. Each is over 400kg lighter than its predecessor. A 169g/km CO2 Range Rover is significant progress as per management – and this is possible given the 420kg reduction in weight for the new Range Rover compared to the previous generation. With the new Jaguar F-TYPE Coupé, JLR's engineering team has created the most rigid Jaguar body structure ever. JLR introduced its advanced aluminum architecture in September 2013 – which forms the basis for future Jaguar Land Rover products, starting with XE and which will be scaled up to the XJ over a period of time. These lightweight vehicles are to be complemented by a new family of premium, lightweight, low-emission, four-cylinder petrol and diesel engines which will augment the aluminum intensive construction of the cars / SUVs.

In addition to lowering emissions, there are other major environmental benefits in the lifecycle of the cars. For example, the aluminum sheets used to form the body panels in JLR cars are made of recycled material. JLR aims aim to increase this to 75% of the entire vehicle when it becomes feasible. The reduction in weight also impacts the environmental footprint of the cars as less fuel is needed to transport lighter cars.

Figure 197. Aluminum Side Panels

Source: JLR

Figure 198. JLR EU Fleet Average Tailpipe CO_2 Emissions



Source: JLR

Trend Spotlight: It's All About Smaller & Lighter in India

There are 3 overarching trends in India on the PV side – vehicles are gradually becoming larger and the center of gravity is increasing from 800 cc to 1.1-1.3 L; b) there's been an increased trend towards diesel vehicles over the past few years, given the disparity in petrol / diesel prices in 2012/13. And even though this disparity has reduced, it's expected that the petrol diesel mix should stabilize at a 50-50 ratio, vs. 65-35 in the past. Given that diesel cars are generally heavier due to larger engines, a lot of developmental activity is focused on smaller turbo charged engines. C) There is also a greater focus on turbo charging and smaller engines to meet environmental norms that come into effect in CY17 and CY22.

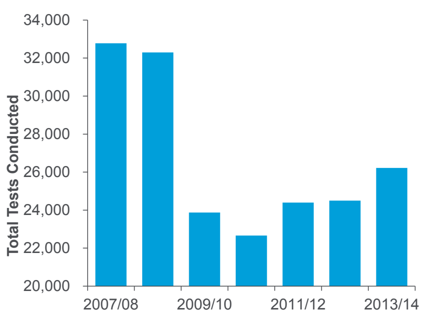
Honeywell Turbo Technologies (HTT) has made some progress in this sphere – it has developed a turbocharged petrol engine – the Revotron 1.2T – for Tata's Zest sedan. This engine was developed by HTT's Pune and Bangalore teams, along with global inputs from Honeywell and also in conjunction with Tata Motors. HTT has a team of almost 200 engineers working in Bangalore on turbocharging technology. The Pune plant has a production capacity of 1mn turbochargers. Per HTT mgmt, Indian is moving toward European trends, which has seen a 40% adoption of turbochargers within petrol engines. On the diesel engine side, the adoption rate of turbochargers is already above 50% in India

Spotlight on Commercial Vehicles

Driver Recruitment and Retention

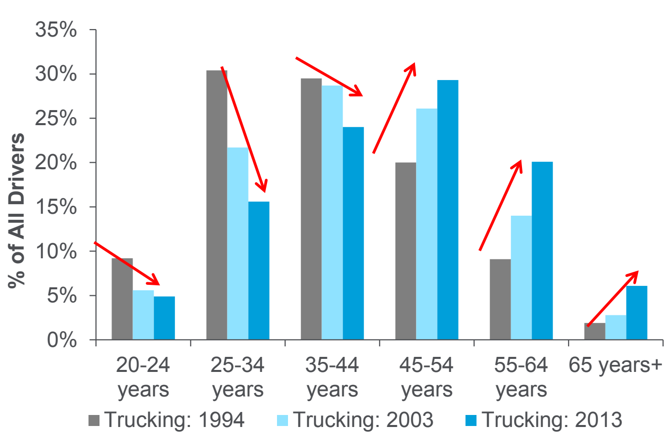
It is not just governmental regulations that are driving increased commercial vehicle technology advancement. In certain developed regions, especially the US, increasing pressure to find – and retain – drivers has created challenges for operators. According to the ATA, the US is currently "short" about 30-35 thousand drivers. Exacerbating the issue, operators have been increasingly reliant on 45 year old-plus drivers as fewer 'young' (age 20-30) entrants are seeking employment in the space. This trend is not limited to the US: several European countries have reported a shortage of available drivers in recent years. In the U.K, the aggregate number of people taking the practical large goods vehicle (LGV) licensing test (a read-through for potential new drivers) has dropped by over 30% since 2007.

Figure 199. UK LGV Tests Passed



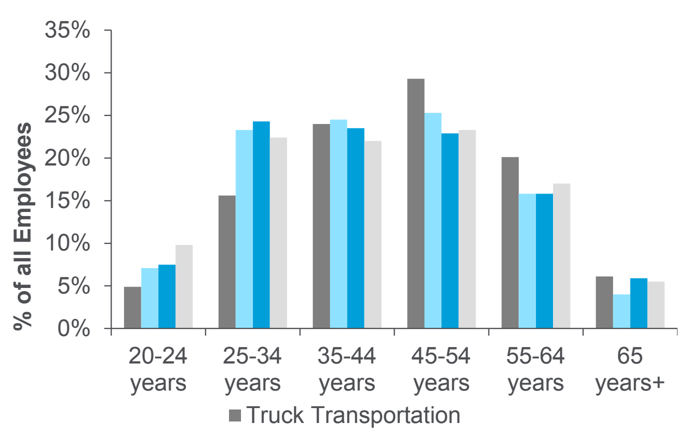
Source: Department for Transport Statistics

Figure 200. Drivers are Getting Older as Largest Cohort Ages



Source: Citi Research and American Transportation Research Institute

Figure 201. With Construction Attracting More Younger Workers



Source: Citi Research and American Transportation Research Institute

In response to these challenges in recruiting (and retaining) drivers, operators have been forced to get more creative (beyond just raising driver wages). One of the levers that operators are pulling is to shift towards more premium spec'd trucks. As drivers are no longer satisfied with the Spartan design of long-haul trucks, new technology aimed at modernizing and improving the “experience” has made its way onto commercial vehicles to entice prospective drivers. OEs and suppliers are approaching this issue from two angles: improved driver comfort and ease of use. For driver comfort, a variety of cabin design changes, from improved ergonomics to smartphone and tablet integration, to more intuitive interfaces have been implemented. For ease of use, simplified components, such as Automated Manual Transmissions, and more reliable parts, including air disc brakes, are being used, with Europe again leading the pack in terms of utilization.

We discuss some of these technologies below:

- **Automated Manual Transmissions (AMT):** AMT's are a modern variant on the traditional manual transmission, providing assisted gear-shifting for the driver. Unlike manual transmissions, which require the driver to control the clutch, the AMT automatically disengages the clutch to allow gear shifting when needed. A dominant technology in Europe, AMT’s are quickly gaining ground in N. America.

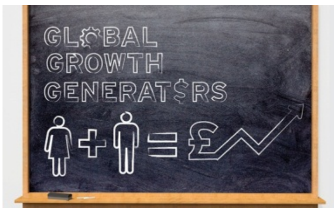
  AMT-equipped trucks are becoming increasingly-popular in North America. This is especially the case for new drivers, as they are easier to operate, as an AMT eliminates the need for the driver to operate a clutch and manually shift the truck through its gear sequence. In effect, this helps to lower the barriers to entry for new and less experienced drivers, greatly expanding the pool of potential employees. In addition, we are hearing more instances of AMTs helping to retain experienced drivers, some of which have put-off retirement due to the less burdensome driving style. This growth is being felt by the European OEMs, like Daimler and Volvo, which have been “importing” this European technology in to the US Detroit Diesel, for example, owned by Daimler, more than doubled it projected AMT sales in 2014, and stated that its plant capacity is already sold out for 2015.

- **Air Disc Brakes –** Disc brakes are a more efficient alternative to the traditional drum brake, offering shorter stopping distances, a more passenger-like feel, and shorter maintenance (~15 minutes vs. over an hour for drums). The major downside, however, is the considerable cost differential vs. drums, with disc brakes carrying a premium of $800-1,000 per axle.

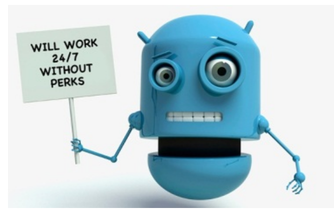
  Compared to traditional drum brakes found on most US trucks, air disc brakes provide a much more reliable and comfortable braking experience for the driver. Paired with the less experienced driver pool, these brakes both improve the overall safety of the vehicle, while making driving a more comfortable experience. In addition, air disc brakes carry a unique benefit in the US, when it comes to CVSA inspections. While CVSA roadside checks are designed to check for wear and performance of drum brakes, a standard set of regulations for disc brakes have yet to be finalized. As a result, fleets utilizing air disc brakes have much higher CVSA pass rates compared to drum users, helping to keep trucks on the road longer.

Citi Global Perspectives & Solutions (Citi GPS) is designed to help our clients navigate the global economy's most demanding challenges, identify future themes and trends, and help our clients profit in a fast-changing and interconnected world. Citi GPS accesses the best elements of our global conversation and harvests the thought leadership of a wide range of senior professionals across the firm.

All Citi GPS reports are available on our website www.citi.com/citigps



Women in the Economy
Global Growth Generators
May 2015
Click here...



Technology at Work
The Future of Innovation and Employment
February 2015
Click here...

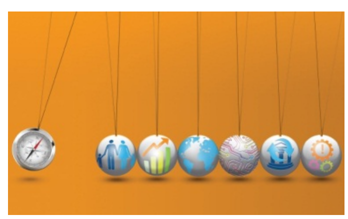
Investment Highlights in 2015
Dealing with Divergence
January 2015
Click here...

Corporate Finance Priorities 2015
Driving Corporate Growth in Divergent Markets
January 2015
Click here...

The Re-Birth of Telecom Monopoly
Is the Industry Broken and Heading Back to its Monopolistic Roots
November 2014
Click here...

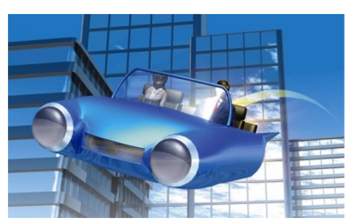
Energy 2020: Out of America
The Rapid Rise of the US as a Global Energy Superpower
November 2014
Click here...

Asset Allocation for a New Era
Diversification, Not Rotation, is the New Watchword
October 2014
Click here...



Future Opportunities, Future Shocks
Key Trends Shaping the Global Economy and Society
October 2014
Click here...

Taking It To The Streets
The New Vox Populi Risk
May 2014
Click here...



The Car of the Future
Transforming Mobility As We Know It
May 2014
Click here...

Disruptive Innovations II
Ten More Things to Stop and Think About
May 2014
Click here...

Upwardly Mobile III
Mobility Unchained: From Mobile Commerce to IoT
January 2014
Click here...

2014 Year Ahead
Investment Themes
January 2014
Click here...

Abenomics
Four Arrows to Target Four Challenges
October 2013
Click here...

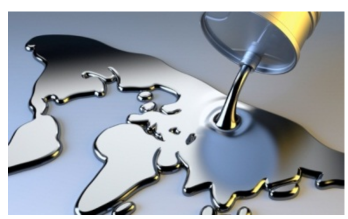
Energy Darwinism
The Evolution of the Energy Industry
October 2013
Click here...

Call of the Frontier II
On the Right Track to be Tomorrow's EMs
September 2013
Click here...

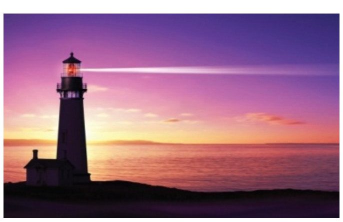
Energy 2020
Trucks Trains & Automobiles: Start your Natural Gas Engines
June 2013
Click here...

The Global Search for Yield
How Today's Markets Shape Tomorrow's Companies
May 2013
Click here...

Disruptive Innovation
Ten Things to Stop and Think About
April 2013
Click here...



Energy 2020
Independence Day: Global Ripple Effects of the N American Energy Revolution
February 2013
Click here...

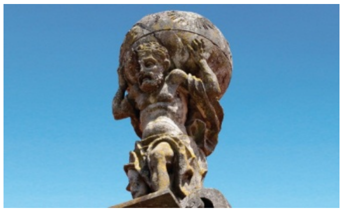


2013 Year Ahead
Investment Themes
January 2013
Click here...

2013 Year Ahead
Corporate Finance Priorities
January 2013
Click here...

Upwardly Mobile
Mobile Payments: A Long Winding Road
November 2012
Click here...

China in Transition
What We Know, What We Don't Know
November 2012
Click here...



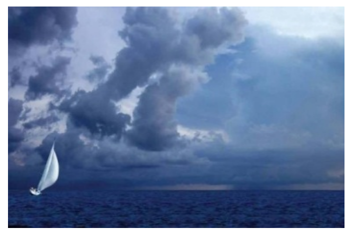
Global Debt
Mr. Macawber's Vindication
November 2012
Click here...

Sub-Saharan Africa
The Route to Transformative Growth
September 2012
Click here...

China & Emerging Markets
China is About to Rebalance. How Will EM be Affected?
July 2012
Click here...

Energy 2020
North America, the New Middle East?
March 2012
Click here...

Upwardly Mobile
An Analysis of the Global Mobile Payments Opportunity
March 2012
Click here...



2012 Year Ahead
Corporate Finance Priorities
January 2012
Click here...

2012 Year Ahead
Investment Themes
January 2012
Click here...

Call of the Frontier
The Search for a New Generation of Emerging Markets
November 2011
Click here...

c

Trade Transformed
The Emerging New Corridors of Trade Power
October 2011
Click here...

Notes

Notes

IMPORTANT DISCLOSURES

This communication has been prepared by Citigroup Global Markets Inc. and is distributed by or through its locally authorised affiliates (collectively, the "Firm") [E6GYB6412478]. This communication is not intended to constitute "research" as that term is defined by applicable regulations. Unless otherwise indicated, any reference to a research report or research recommendation is not intended to represent the whole report and is not in itself considered a recommendation or research report. The views expressed herein may change without notice and may differ from those views expressed by other Firm personnel.

You should assume the following: The Firm may be the issuer of, or may trade as principal in, the financial instruments referred to in this communication or other related financial instruments. The author of this communication may have discussed the information contained herein with others within the Firm and the author and such other Firm personnel may have already acted on the basis of this information (including by trading for the Firm's proprietary accounts or communicating the information contained herein to other customers of the Firm). The Firm performs or seeks to perform investment banking and other services for the issuer of any such financial instruments. The Firm, the Firm's personnel (including those with whom the author may have consulted in the preparation of this communication), and other customers of the Firm may be long or short the financial instruments referred to herein, may have acquired such positions at prices and market conditions that are no longer available, and may have interests different or adverse to your interests.

This communication is provided for information and discussion purposes only. It does not constitute an offer or solicitation to purchase or sell any financial instruments. The information contained in this communication is based on generally available information and, although obtained from sources believed by the Firm to be reliable, its accuracy and completeness is not guaranteed. Certain personnel or business areas of the Firm may have access to or have acquired material non-public information that may have an impact (positive or negative) on the information contained herein, but that is not available to or known by the author of this communication.

The Firm shall have no liability to the user or to third parties, for the quality, accuracy, timeliness, continued availability or completeness of the data nor for any special, direct, indirect, incidental or consequential loss or damage which may be sustained because of the use of the information in this communication or otherwise arising in connection with this communication, provided that this exclusion of liability shall not exclude or limit any liability under any law or regulation applicable to the Firm that may not be excluded or restricted.

The provision of information is not based on your individual circumstances and should not be relied upon as an assessment of suitability for you of a particular product or transaction. Even if we possess information as to your objectives in relation to any transaction, series of transactions or trading strategy, this will not be deemed sufficient for any assessment of suitability for you of any transaction, series of transactions or trading strategy.

The Firm is not acting as your advisor, fiduciary or agent and is not managing your account. The information herein does not constitute investment advice and the Firm makes no recommendation as to the suitability of any of the products or transactions mentioned. Any trading or investment decisions you take are in reliance on your own analysis and judgment and/or that of your advisors and not in reliance on us. Therefore, prior to entering into any transaction, you should determine, without reliance on the Firm, the economic risks or merits, as well as the legal, tax and accounting characteristics and consequences of the transaction and that you are able to assume these risks.

Financial instruments denominated in a foreign currency are subject to exchange rate fluctuations, which may have an adverse effect on the price or value of an investment in such products. Investments in financial instruments carry significant risk, including the possible loss of the principal amount invested. Investors should obtain advice from their own tax, financial, legal and other advisors, and only make investment decisions on the basis of the investor's own objectives, experience and resources.

This communication is not intended to forecast or predict future events. Past performance is not a guarantee or indication of future results. Any prices provided herein (other than those that are identified as being historical) are indicative only and do not represent firm quotes as to either price or size. You should contact your local representative directly if you are interested in buying or selling any financial instrument, or pursuing any trading strategy, mentioned herein. No liability is accepted by the Firm for any loss (whether direct, indirect or consequential) that may arise from any use of the information contained herein or derived herefrom.

Although the Firm is affiliated with Citibank, N.A. (together with its subsidiaries and branches worldwide, "Citibank"), you should be aware that none of the other financial instruments mentioned in this communication (unless expressly stated otherwise) are (i) insured by the Federal Deposit Insurance Corporation or any other governmental authority, or (ii) deposits or other obligations of, or guaranteed by, Citibank or any other insured depository institution. This communication contains data compilations, writings and information that are proprietary to the Firm and protected under copyright and other intellectual property laws, and may not be redistributed or otherwise transmitted by you to any other person for any purpose.

IRS Circular 230 Disclosure: Citi and its employees are not in the business of providing, and do not provide, tax or legal advice to any taxpayer outside of Citi. Any statements in this Communication to tax matters were not intended or written to be used, and cannot be used or relied upon, by any taxpayer for the purpose of avoiding tax penalties. Any such taxpayer should seek advice based on the taxpayer's particular circumstances from an independent tax advisor.

NOW / NEXT

Key Insights regarding the future of Automobile

INNOVATION

Today, automakers are forced to guesstimate what features consumers want to buy in their new car and consumers don't always know at the point of sale what they want to buy, risking both sides leave something on the table. / **A new subscription model could see automakers offering autonomous packages essentially at cost while deriving profit from subscriptions to driving services that are turned on later through an over-the-air update.**

REGULATION

Advanced auto technology, either through Advanced Driver Assistance Systems or next generation engine propulsion has generally been driven by consumer demand. / **Regulation in Europe and the US on safety, improved fuel economy and reduced emissions will push adoption and influence OEM decision making on what options become standard equipment.**

TECHNOLOGY

The move from analyst to digital to touch screens on the dashboard is just the beginning. / **The human machine interface in future cars (center stack displays, instrument display clusters, head-up displays and augmented reality will help the consumer control the advanced aspects of their new vehicles as intuitively as possible.**