September 17, 2015

Cars 2025: Vol. 3

Monetizing the rise of Autonomous Vehicles

Equity Research

It's the Technology, not the Cars: Buy the Suppliers

Rise of a $100bn parts market by 2025

Autonomous vehicles are on a fast ramp to commercial availability over the next 10 years. In our view, the potential societal benefits – from fewer accidents and traffic jams to wider access to mobility – are great enough to overcome the substantial obstacles to adoption. We estimate the shift will expand today's $3bn ADAS market to a $96bn ADAS/AV market by 2025. With this report, we examine how best to invest in this rapidly expanding market.

Bigger growth boost than market thinks

We scoured the globe for companies with upside to ADAS/AVs, coming up with the top 35 names with exposure and quantifying revenue tailwinds. We estimate new content could add 110bp/300bp of incremental top-line growth annually over the next 5/10 years. Pure-play **Mobileye** is the most leveraged, with **Valeo, Autoliv,** and **Delphi** benefiting the most among auto suppliers, **Nippon Ceramic**, **IRISO,** and **Nvidia** see the most impact among the Tech component and semi names. **Negatively exposed:** auto insurers.

Agnostic to the OEMs

While no auto technology report would be complete without some mention of the Apple car and Google, the conclusions highlighted here are agnostic to whether or not these new entrants succeed, as the incremental content will be required regardless of who makes the vehicle.

Consumers hesitant; validation is key

Our survey of 2,000 consumers suggests there is quite a bit of skepticism with 49% of respondents not interested in AVs – rejection is much higher among 45+ year olds. This reinforces our view that social acceptance and regulation are the largest barriers to adoption and likely only fall into place after extensive validation and testing.

Beyond the car: $3.5tn benefit to society

We estimate that reduced congestion, accident reduction, increased productivity, and lengthened tails of mobility could drive a staggering $3.5tn of gross social and economic benefits, though this will be realized over a long period of time.

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Introduction: Why we should care about autonomous cars

The social and economic implications are dramatic

With over 1.55bn vehicles on the road, 375bn hours spent driving, and 1.2 million global traffic deaths annually (according to the WHO), the implications of safer, more convenient, and greener mobility are far reaching. We think ADAS (Advanced Driver Assistance Systems) and ultimately Autonomous Vehicles (AVs) have the ability to drive improvements in these areas through multiple channels: 1) accident reduction with 90% of crashes caused by human error, 2) reduced congestion from safer driving and features like Connected Adaptive Cruise Control, 3) additional productivity from multitasking, and 4) adding additional vehicle users by lengthening the tails of mobility. As shown in **Exhibit 1** and addressed in more detail below (pages 55-64), we quantify these gross benefits at $3.5tn globally. While this may overstate the benefit, as we do not net costs from things like fewer jobs for professional drivers, less auto production, or lower municipal income from tickets, fines, and so forth, the benefits appear enormous.

Exhibit 1: We expect a global $3.5tn benefit from ADAS and AVs
Global economic benefits from autonomous driving, $ in bn

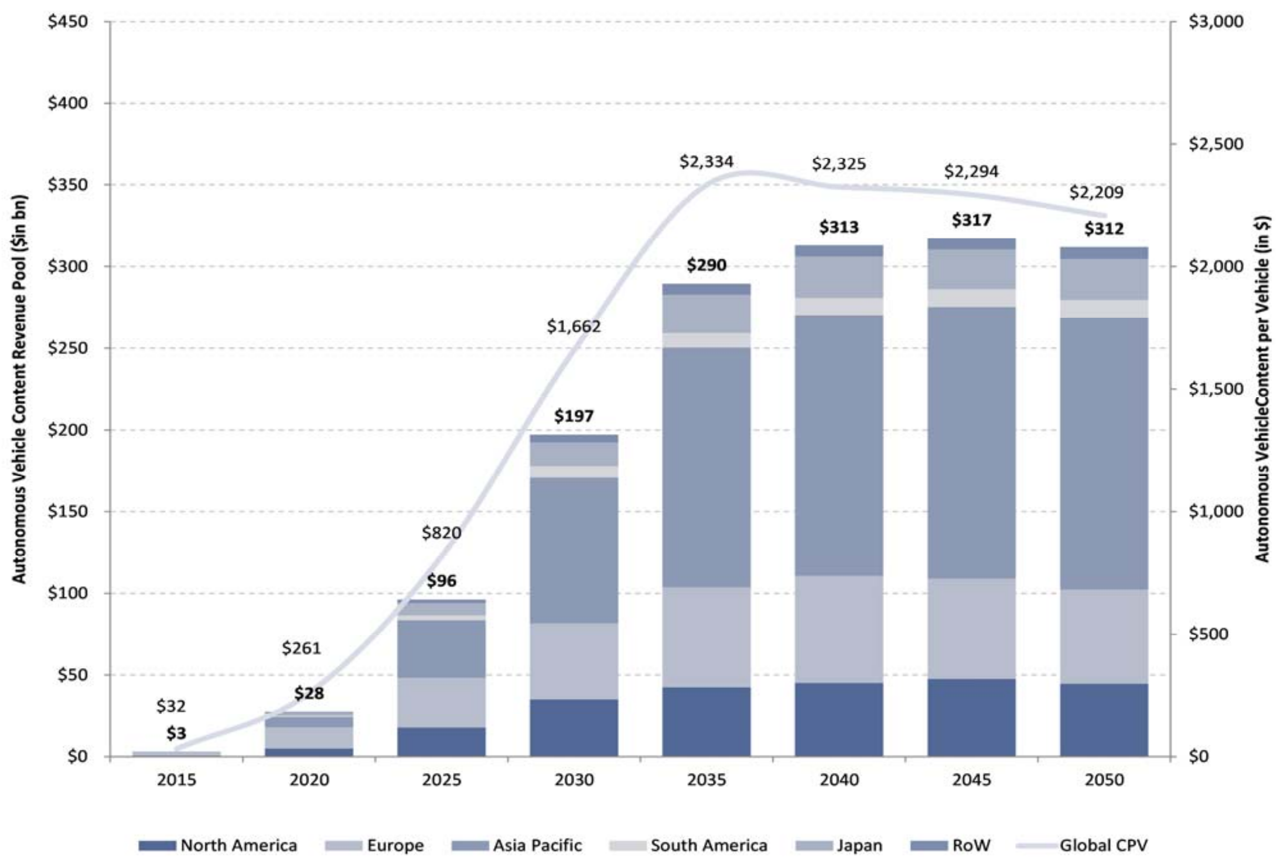
Global Economic Benefits from Autonomous Driving					
	Accident Reduction	Congestion Reduction	Increased Productivity	Additional Drivers	Total Benefits
United States	$249	$7	$195	$331	**$782**
North America	$261	$10	$199	$352	**$821**
South America	$81	$4	$67	$90	**$242**
Europe	$348	$13	$262	$282	**$904**
Asia Pacific	$439	$15	$321	$499	**$1,275**
Middle East/Africa	$74	$4	$72	$114	**$264**
Global	**$1,202**	**$47**	**$921**	**$1,337**	**$3,506**

Source: Goldman Sachs Global Investment Research.

The component opportunity is substantial

Many reports have been written about the potential impact of AVs on overall longer term industry demand and on the business models of the OEMs. While we think these questions are interesting, the answers likely fall out of many people's investment time horizons. But as **Exhibit 2** shows below, ADAS and AV growth is happening now and we believe there are plenty of companies that are well positioned to take advantage of it. As we move from drive assist (Level 1 and Level 2) to semi-autonomous and fully autonomous driving (Level 3 and Level 4, respectively) we have the convergence of not only increased penetration but also increased content. As we show in more detail later in this report, we estimate content per vehicle moving from $300-$400 per unit for ADAS to about $2,800 for automation. Putting these two factors together we project a 42% CAGR in global ADAS/AV revenue over the next 10 years. This would bring the industry from a revenue base of about $3bn at present to nearly $28bn in 5 years, almost $96bn in 10 years, and $197bn if we are willing to look out to 15 years.

Exhibit 2: See a 42% CAGR in ADAS/AV related revenue over the next 10 years
Autonomous vehicle content revenue pool by region and content per vehicle



Source: Goldman Sachs Global Investment Research

As illustrated in **Exhibit 3** below, in some cases we are talking about the creation of very large markets for components/software services that barely have sales in the automotive space today, in componentry like LIDAR, V2X modules, and auto cybersecurity, that could be $10.6bn, $4.6bn and $3.3bn markets in 10 years. Other components like cameras, radars and ECUs that are already part of the ADAS package will see significant capability upgrades along with much higher fitment rates driving similarly rapid growth. Another important point is that an increasing proportion of this content cost will be from software. We estimate that only about 25% of the cost of an L1 system is software, this rises to the mid- to high-30% range in L2 and L3, and rises further to the low 40s for L4, meaning that the margins on the these next generation systems should also be higher.

Exhibit 3: There is a substantial market opportunity for suppliers…
Market Opportunity in $mn

Market Opportunity ($ US mn)	2015E	2020E	2025E	2030E	2035E	2040E	2045E	2050E
Cameras	$725	$5,659	$16,260	$26,019	$30,638	$30,693	$29,659	$28,389
Radar	$527	$5,396	$21,013	$40,579	$41,037	$38,914	$36,098	$33,791
LIDAR	$0	$1,811	$10,556	$35,792	$81,583	$93,404	$98,160	$98,036
Embedded Controls	$730	$5,175	$12,774	$17,398	$21,346	$22,557	$22,489	$21,971
Actuation	$90	$759	$2,276	$4,513	$8,001	$9,038	$9,400	$9,364
Electrical & Electronic Architecture	$429	$3,122	$8,168	$11,596	$12,640	$13,434	$13,373	$13,116
V2X	$0	$792	$4,579	$14,773	$32,435	$34,107	$34,410	$33,374
HMI	$102	$1,425	$6,501	$15,093	$20,983	$22,355	$22,444	$21,971
Mapping	$179	$2,155	$9,416	$20,115	$22,943	$24,762	$24,855	$24,509
Embedded Modem	$10	$120	$519	$1,074	$1,122	$1,158	$1,131	$1,099
Security Software	$51	$713	$3,302	$8,727	$14,835	$20,187	$22,602	$23,674
Passive Hardware	$52	$377	$987	$1,506	$2,006	$2,427	$2,585	$2,635
Total	**$2,894**	**$27,506**	**$96,352**	**$197,185**	**$289,569**	**$313,038**	**$317,205**	**$311,930**

Source: Goldman Sachs Global Investment Research.

Looking beyond the automotive suppliers of ADAS, there is also substantial opportunity for some of the Japanese, European, and US semiconductor and component companies. As we show in **Exhibit 4** we estimate about $1.4bn in ADAS content from comm semis, processors, logic, and connectors, today which we see ballooning to $12bn in 5 years and $35bn in 10 years' time.

We believe that some of the key enabling technologies from a component perspective, such as processing and logic (provided by companies including Mobileye and Nvidia), are generally understood by the market (if only directionally). However, many of the "sensing" functionalities that enable autonomous driving are not necessarily provided by companies that are always thought of as so called "sensor companies." For example, cameras use image sensors (provided by companies like Sony, ON/Aptina, and Melexis). Similarly, radar relies on traditional analog/mixed signal semi capabilities (from companies including TI, NXP, Freescale, and ADI, many with a historical background in both analog and communications semi chips). Finally, there will be continued growth in many of the building block components like analog semis, MCUs, and connectors.

Exhibit 4: …as well as for semiconductor providers.
Market Opportunity in $mn

Market Opportunity ($ US mn)	2015E	2020E	2025E	2030E	2035E	2040E	2045E	2050E
Comm Semis	$10	$201	$990	$2,604	$4,498	$4,749	$4,775	$4,647
Processor	$491	$3,591	$9,316	$13,714	$17,493	$18,544	$18,539	$18,126
Logic	$249	$2,439	$8,457	$18,626	$32,637	$35,413	$36,117	$35,500
Analog/Other	$380	$3,107	$9,494	$16,438	$20,462	$21,668	$21,620	$21,142
Sensors/MEMS	$181	$1,386	$3,873	$6,118	$7,476	$7,949	$7,946	$7,783
Connectors	$70	$586	$1,841	$3,393	$4,651	$5,252	$5,425	$5,418
Passive/RF components	$52	$377	$987	$1,506	$2,006	$2,427	$2,585	$2,635
Total	**$1,432**	**$11,688**	**$34,958**	**$62,400**	**$89,222**	**$96,003**	**$97,006**	**$95,251**

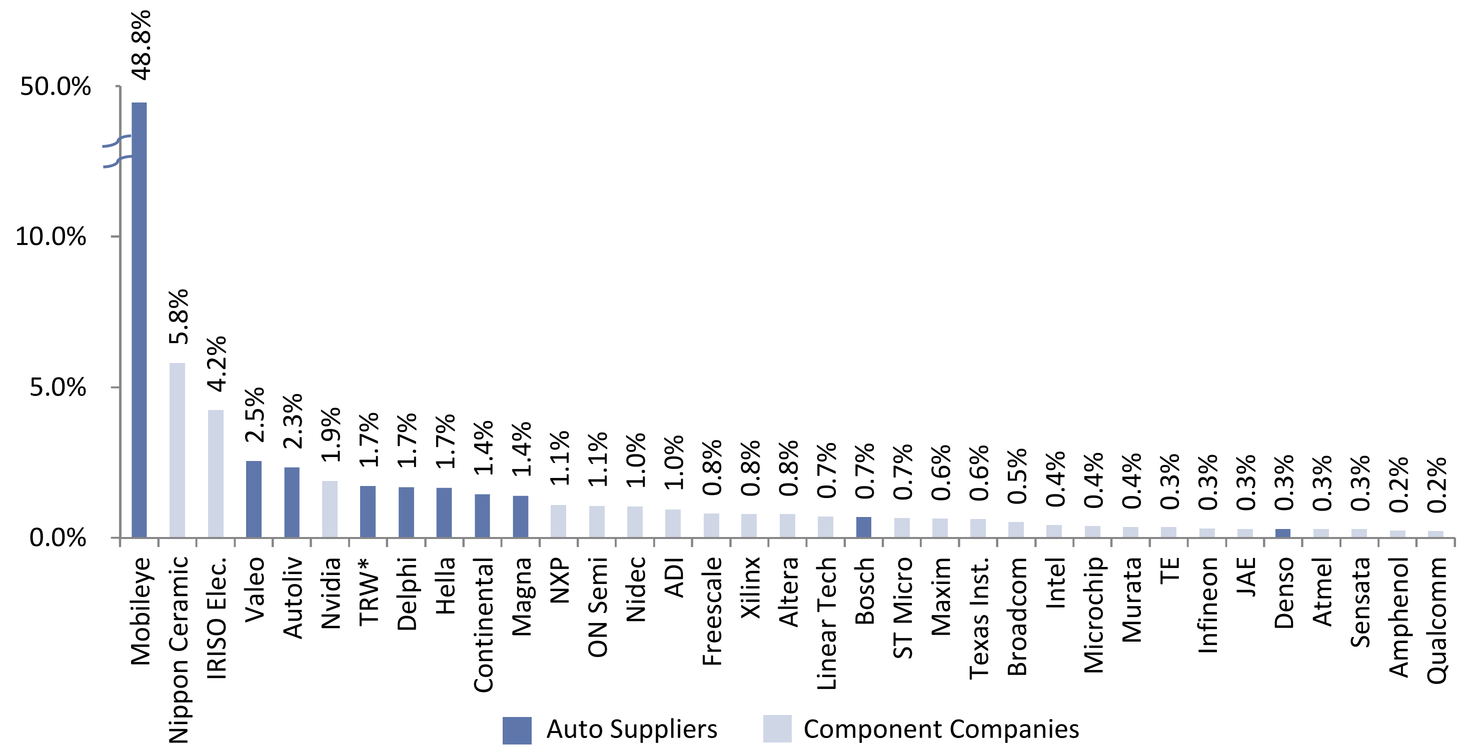
Source: Goldman Sachs Global Investment Research.

Mobileye, select auto suppliers and semi/component makers are the best way to play this trend

So how much could this add to top the growth prospects of our covered companies? The answer as it turns out is quite a lot. Once we have come up with the industry revenue pools highlighted above, we apply existing/projected market share to 35 relevant companies which are exposed to this theme to see what the growth contribution could be on a company by company basis. As we show below in **Exhibit 5**, over a five-year period this would suggest that ADAS could add 110bp to top line growth each year for these selected names. Looking out over 10 years the number rises to a staggeringly high 300bp driven by a threefold increase in revenue we project from 2020 to 2025. Finally looking at a 15-year CAGR out to 2030 would suggest 190bp of contribution to top line growth.

Focusing on the five-year outlook as we do in **Exhibit 5** which is the most relevant from an investor perspective, we see **Mobileye** as having the strongest contribution from ADAS which is set to drive a 49% CAGR –not surprising given its pure-play status in vision algorithms. This is followed by **Nippon Ceramic**, **IRISO Electronics, Valeo, Autoliv, Nvidia**, and **Delphi,** which are either diversified auto suppliers, or smaller Japan-based electronic component makers. It is interesting that the larger Semi component suppliers are below 200bp, owing in many cases to their large size and diverse end market exposure, though for a few like **NXP** and **ON Semi** the annual revenue contribution of roughly 100bp would seem far from trivial.

Exhibit 5: See an average of 110bp of annual incremental revenue contribution from ADAS/AV over the next five years
Annual revenue contribution from ADAS – five-year CAGR



Note: TRW recently acquired by ZF Friedrichshafen.

Source: GS research estimates.

The answer to autonomous investing is not Apple

With significant speculation on Apple's potential foray into the auto business, no report on autonomous vehicles would be complete without some mention of potential new entrants like Apple and Google. It appears quite likely that Apple is pursuing an expanded role in autonomous cars, likely intrigued by the rapidly changing role of technology within the world of mobility and a potentially huge TAM. But the business of physically building cars is a difficult one which is extremely capital intensive and requires the manufacturers to take on extensive contingent liabilities for products that last more than 20 years. While Apple has typically pursued an "asset light" approach to device manufacturing leveraging others to do the assembly, in the case of the autos these sub-contractors (possibly the OEMs of today) will require a return on these substantial capital investments and need to be compensated for warranty and other liabilities which could make it difficult for Apple to participate without diluting margins. In the case of Google, we believe the focus is more about increasing its presence on the software side of the vehicle by producing industry-leading AV capability, and that the company would leave the device design and production to capable partners, like it does with Samsung for handsets. Whether these strategies are carried through successfully or not, the conclusions of this report do not change: the content increase from $370 per unit to $2,800 per unit will take place regardless who's badge is on the vehicle, and so we see a much more bankable commercial opportunity with the aforementioned suppliers.

Favorite stocks to prosecute this theme

Mobileye (Buy, $48.96): $70, 12-month price target – pure play on ADAS, with an autonomous driving kicker
Mobileye is a pure play on vision-based autonomous driving software, and in our view it is the leader in technology for ADAS and semi-autonomous/autonomous driving. MBLY's technology is used on over 240 car platforms, including early stage programs for semi-autonomous cars with 13 OEMs (of which 4 are in production). Mobileye's competitive advantage in semi-autonomous technology is underpinned by its large database from over 20 OEMs which allows it to develop its deep-learning networks for free space analysis (which powers Mobileye's holistic path finding technology). While we expect semi-autonomous driving to contribute 36% of incremental sales to 2020, we also continue to expect Mobileye to benefit from strong growth in front-facing cameras for ADAS applications driven by regulatory requirements for automatic emergency braking, where we see Mobileye's monocular camera solution as superior to other technological approaches (in particular for functions such as automatic pedestrian emergency braking, which is harder to deliver with technologies such as radar). As such, we expect Mobileye to be a significant beneficiary of the ramp of ADAS (L1and L2) to 68%/81% penetration in Europe/North America by 2020; while the ramp of L3 semi-autonomous models beginning in 2016 (reaching 8%/2% of European/North American shipments by 2020) should lead to a significant increase in Mobileye's ASPs (semi-autonomous chips command an ASP of $150 vs. $50 for L1 and L2 ADAS).

Magna International (Neutral, $50.73): $59, 6-month price target – an underappreciated ADAS play
Magna is one of the most diversified suppliers in our coverage with product groups ranging from metal forming, to seating, to powertrain and drivetrain, to complete vehicle assembly. While the company had made the decision to exit parts of ADAS selling its camera system business to Conti in 2010, it has reversed course and has been rebuilding its portfolio for the last 5 years. At present the company has a number of "near field" technologies like rear cameras and ultrasonic sensors, but also has "far field" forward cameras and domain controllers (ECUs). The company is expecting to see just over $400mn in ADAS revenue this year making it the fourth largest ADAS auto supplier in the world on our estimates. Testament to its capability, it was awarded the camera sensor program for the GM "Super Cruise" working with Mobileye. This system is expected to be rolled out onto select Cadillac models in 2017 offering hands and foot free driving in certain conditions. While valuation had been one of the things holding us back in the past, with the recent pullback in the shares there is now 16% upside to our price target, and with our analysis suggesting ADAS could add 140bp to growth to the top line, the risk reward for MGA has certainly improved in our view.

TE Connectivity – leader in automotive connectors
TE Connectivity is a leading supplier of connectors and sensors for the automotive end market. We believe that TE is positioned to benefit from autonomous driving given its broad portfolio (including both connectors and sensors) and strong market share in connectors (over 35% based on data from Bishop & Associates). While we do not expect a step function increase in TE's growth rate in auto from autonomous driving, we believe that more connectors will be needed to link the hardware systems that enable this

(e.g., cameras, radar, LIDAR, etc.). In addition, we believe that TE's relatively small but fast-growing sensor business could see some benefits from autonomous driving.

Nidec (CL-Buy, ¥9,248): ¥11,400, 12-month price target – unrivalled small precision motor giant moves to ADAS/autonomous driving

Nidec is the top global maker of brushless motors. It began focusing its energies on this field well before interest in automotive technology began rising. Thanks to successful M&A up to this time, the company is on the verge of a growth expansion and investment recoupment period. Nidec has carved out a top global position in motors for electric power steering (EPS) systems. Recently, it has bolstered its growth potential by stepping up ADAS development through the acquisition of Honda Elesys (acquiring core autonomous driving technology including millimeter wave radar, automobile cameras, and ECU) and by taking steps to capture oil hydraulic pump replacement demand through the acquisition of GPM (in line with the shift in oil hydraulic pumps to motors). Nidec's FY3/16 automotive-related sales guidance is ¥300bn, while its FY3/21 target, including M&A, is ¥700 bn-¥1tn (vs. total company sales of ¥2tn). It is targeting total sales of ¥10tn in 2030, which includes several trillion yen in automotive-related sales, suggesting to us that it may transition into being an integrated car electronics maker. In this report, we estimate long-term sales growth potential, focusing on ADAS/autonomous driving systems (we calculate only additional value per vehicle). We estimate that ADAS/autonomous driving systems will contribute sales of US$4,614mn (around ¥553.6bn) in 2030 as a result of increased installation rates for EPS motors and automobile cameras/millimeter wave radar equipment together with market share gains.

Murata Mfg. (Neutral, ¥17,385): ¥19,500, 12-month price target – global leader in passive components, value of components used in autos rising on growth in wireless communications

Murata Mfg. is a top global maker of passive and high-frequency components. Its multi-layer ceramic capacitors, high-frequency components, and wireless communications modules are used in smartphones and a wide array of other digital equipment. Automotive use offers good prospects as a future growth driver. Passive component usage in autos is set to increase over the longer term as autos are transformed into digital equipment via the move to autonomous driving systems. Of particular interest here are high-frequency components and wireless communications systems. Autonomous driving requires vehicle-to-vehicle (V2V) technology (communication between vehicles and from roads to vehicles). We envisage rapid growth in the frequency bands used in automobiles and in demand for communications equipment inside and outside vehicles (e.g., dedicated short-range communications equipment). Component usage in cell phones sharply increased on the shift from feature phones to smartphones, and Murata should benefit from a similar rise in the automotive field in value per vehicle of high-frequency components such as SAW/BAW filters and wireless communications components such as Wi-Fi and Bluetooth components. Murata's automotive component sales were ¥144.3bn in FY3/15, and we estimate a sales contribution from ADAS/autonomous driving systems alone of US$950mn (roughly ¥115bn) in 2030.

Conti (Buy, €196.65): €231, 12-month price target – market leader in ADAS, moving up the technology curve

Conti is a major beneficiary of the growth potential of the ADAS market. With about €700mn of revenues from ADAS, Conti is the largest ADAS auto supplier in the world, by our estimate. Our analysis on the ADAS market suggests that this division alone can add roughly 140bps to top-line growth over the next five years. Conti has one of the most comprehensive ADAS products offering amongst the auto suppliers and should continue to benefit from its strong relationship with the German OEMs, the likely early adopters of advanced autonomous driving features, in our view. We remain positive on Conti's fundamentals for several reasons. (1) Strong organic growth: Driven by the Automotive division, we forecast Conti should continue to have above-sector-average organic growth of 6.2% over 2016-2019. In addition to ADAS, the strong growth for the Automotive division is driven by growing content for its powertrain business. (2) Improving margins: We forecast group margins improving from peak level in 2014 by 100bp to 12.4% by

2019 driven by the margin improvement at the powertrain business and despite the forecasted decline in the tire margins (3) Strong FCF yield: While a part of this will likely be used for further bolt-on acquisitions and dividends, in our view, we expect Conti to de-lever at an increased pace over the coming years. On our estimates, Conti has a 2015 FCF yield (before dividends and acquisitions) of 5.2%. While valuation has been in the recent past the main reason on our Neutral view on Conti, we view the 15% pullback since August 11 an attractive entry point into a period that is likely to see accelerating growth for the Auto division.

Valeo (Buy, €120.50): €138, 12-month price target – ADAS to help deliver best-in-class growth

Valeo has been one of the fastest growing auto suppliers in our coverage over the recent years driven by an impressive reorganization of its portfolio towards products geared to the mega trends in the industry and a transition to more technology/innovation based solutions. In ADAS, Valeo is currently one of the largest suppliers of cameras and radars, with the target of launching Lidar in 2016. Valeo's partnership with Mobileye on the vision solution and their joint project on laser scanner will be an advantage on the time to market versus their European peers. We continue to forecast best-in-class top-line growth for Valeo among our coverage, driven by the strong growth of its innovation products; electric superchargers, stop-start systems, LEDs, parking assistance, ultrasonic sensors etc. While we acknowledge that high-single-digit organic growth over 2015-2020 is already factored into current consensus estimates, continued delivery of this is likely to drive further sector-relative re rating in our view.

Exhibit 6: Snapshot of the various levels of Autonomy according to NHTSA

Autonomy level		Driver attentiveness/road monitoring	Comment	Example	
Level 0	**No-Automation**	Driver in **complete and sole control**	Could contain driver support systems, but only warnings; driver never cedes control	Blind Spot Warning	
Level 1	**Function-specific Automation**	Driver maintains overall control, but **can cede limited authority**	One or more specific control functions that operate independent from each other	Adaptive Cruise Control	**ADAS**
Level 2	**Combined Function Automation**	Driver responsible for monitoring the roadway and **available for control at all times on short notice**	At least two primary control functions designed to **work in unison** to relieve driver control	Adaptive Cruise Control with Lane Centering	**ADAS**
Level 3	**Limited Self-Driving Automation**	Driver enabled to cede full control under certain traffic conditions, but is **available for occasional control with a comfortable transition time**	Vehicle designed to ensure safe operation during automated driving mode, **but can determine when the system is no longer able to support automation,** i.e., an oncoming construction area	Autonomous Driving Supporting Multitasking with Transition Time Back to Driver When Necessary	**Autonomous Driving**
Level 4	**Full Self-Driving Automation**	Driver to provide navigation input, but is **not expected to be available for control at any time during the trip**	**Vehicle designed to perform all safety-critical driving functions** and monitor roadway conditions for an entire trip.	Full Autonomous Driving in Any Situation	**Autonomous Driving**

Source: NHTSA, Goldman Sachs Global Investment Research

The volume outlook: “Keep your scanners peeled, KITT”

There are three main factors guiding our volume forecasts. The **first** is the pace at which L1 and L2 ADAS systems which exist in vehicles today continue their brisk ramp (definitions of L1 to L4 in **Exhibit 6**). The **second** is the starting point at which semi-autonomous and fully autonomous L3 and L4 vehicles become commercially viable (think Michael Knight and his autonomous Pontiac Trans Am). The **third** is the likely pace of adoption once the AV technology is officially introduced. Taking the US, for example, as we show in **Exhibit 7** and discuss in greater detail later in the report, there are a number of enablers involved.

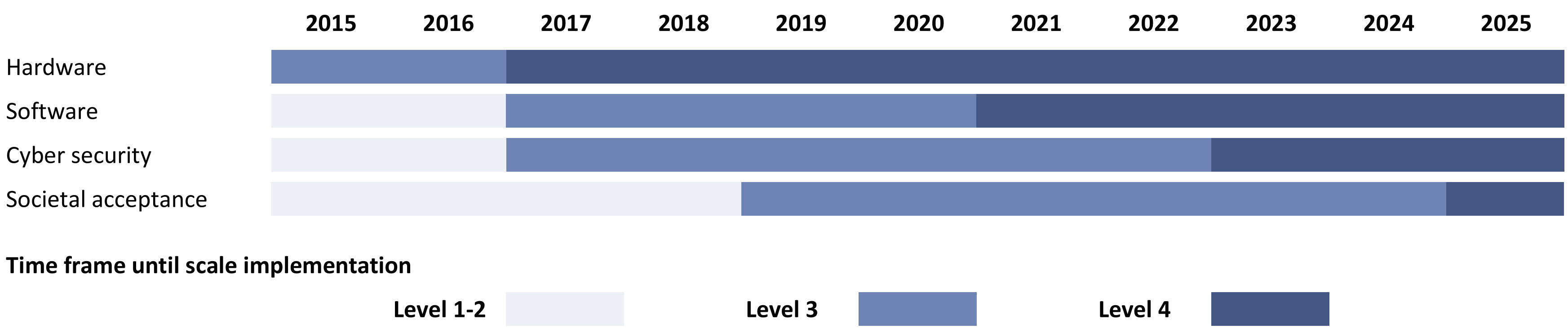
1) **The hardware solution** is the least daunting constraint, in our view, given that many ADAS solutions are already in use and there has been a significant amount of new investment in sensing, connectivity, and processing developed over the past few years. We think hardware feasibility for commercial L3 exists today and should be available for L4 in roughly two years.

2) **The software solution** is more of a constraint. We believe vision software will need to achieve a quantum leap in capabilities vs. current ADAS software to get to the “superhuman” sensing capability that will be needed for fully autonomous vehicles to be validated. We see L3 as feasible in 1-2 years but L4 likely not until 2020.

3) **Cyber security** capabilities currently deployed by OEMs are largely inadequate on many existing models – never mind L3 and L4 – according to several industry experts we spoke with. That said, there are a number of companies like TowerSec, Argus, and Security Innovation that have developed firewalls and communication authentication systems that should be effective in protecting against hackers, especially in vehicles designed with security in mind. Our discussions with experts in the field lead us to believe that cyber security should be able to keep pace with the demands of the OEMs.

4) **Societal acceptance** is the biggest barrier, in our view. Not only is there a significant amount of skepticism among the driving population – for instance our survey results indicate that approximately 50% of respondents would not be interested in purchasing an autonomous vehicle, but acceptance from a legal and regulatory perspective is also likely to be a steep curve. In the US, there is no specific federal regulation on AVs, though the NHTSA has issued some guidelines for testing as have at least four states (California, Florida, Michigan, and Nevada) and the District of Columbia which have passed legislation allowing the testing of AVs. Even so, entities such as the NHTSA, state legislatures and DMVs, police agencies, and the courts could intervene if AVs are deemed to be unsafe. Therefore, we believe an extensive and inclusive validation process will need to be conducted, and as we describe in the following pages, we do not see this being completed until approximately 2018 for L3 and around 2025 for L4. Ultimately, we think the benefit to society will be so large that implementation will happen.

Exhibit 7: We see regulatory and social barriers as the largest hurdle facing the adoption of AVs
Timeline of enablers for the implementation of autonomous driving (US market only)

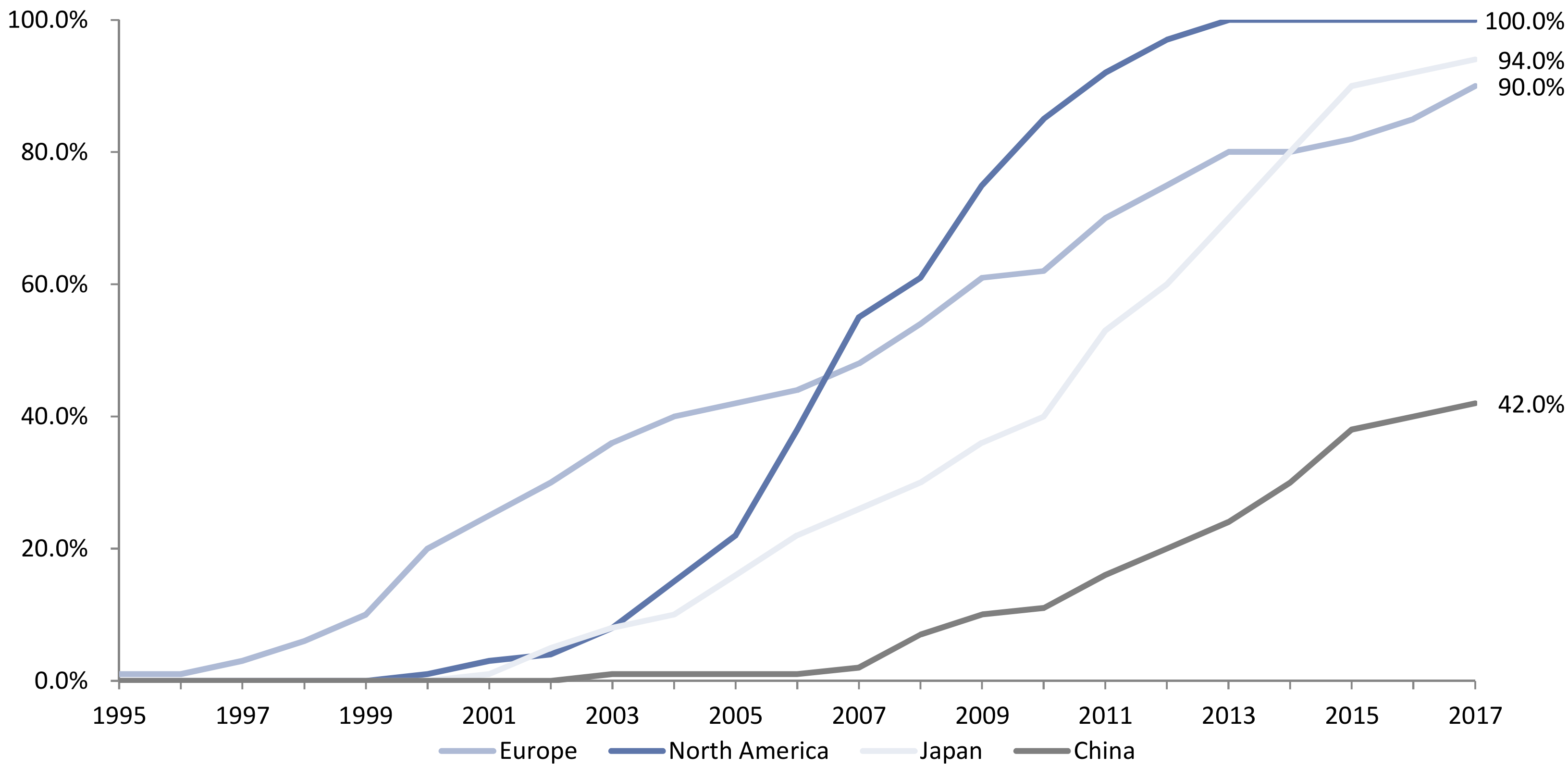


Source: Goldman Sachs Global Investment Research

Our forecast that Level 3 AVs will be available in the US around 2018 is equivalent to about half a product cycle (meaning cars are already being developed with this capability in mind), and our forecast for Level 4 AVs in 2025 is about two product cycles away. Once these AVs launch, we look at indications of what the adoption curve might actually look like. The most salient data we think comes from the implementation of past automotive technologies, with a very good recent example being Electronic Stability Control (ESC) which had different paces of adoption in the various regions (**Exhibit 8**). In the US, it took just 14 years to get to 100% fitment –supported by federal legislation making it mandatory by September 2011. In contrast, Europe has taken 20 years to get to 80%, with Japan being somewhere in the middle, requiring 15 years to get to 90%. While front air bags are a more difficult comp because they have been at 100% fitment in the US (and nearly 100% in Europe) for two decades, Brazil has seen a surge to 97% penetration in about 14 years, also driven by legislative requirements.

While there is already a regulatory push for ADAS in Europe, and one soon coming in China (expected for 2018) and even likely one in the US, we do not see a regulatory push for fully autonomous vehicles which are more of a blend of convenience and safety at Levels 3 and 4. So while not perfect, we chose to use the longer implementation period of ESC (i.e., 20 years) as a proxy in developing our forecasts.

Exhibit 8: We look to the longer end of the ESC adoption curve as a basis for our forecasts
Adoption of Electronic Stability Control for new vehicles by geography



Source: Continental, Goldman Sachs Global Investment Research.

There are likely to be different implementation paths, depending on the region, driven by differing approaches to regulation, income levels, and OEM sponsorship. Our L1-L4 sales penetration forecasts by region are summarized in Exhibits 9-12.

North America

We estimate that the US ADAS penetration is currently at about 8% (Levels 1 and 2) and reaches 100% around 2025 through a blend of Levels 1-3. This represents a relatively fast ramp for ADAS (14 years), driven by our expectation for increasing regulatory support of Levels 1 and 2 driver assist. A recent example of this support was the US Department of Transportation announcement that 10 automakers are committing to including automatic electronic braking systems (AEBs) as a standard feature on all new models.

However, for semi- and fully autonomous vehicles we forecast a longer time frame. We model Level 3 starting in 2018 and Level 4 in 2025 and assume it takes 21 years to reach full penetration for either semi-autonomous/autonomous vehicles. This is still one of the faster ramps, geographically, supported by the large investments being made by US OEMs and by many of the technological contributors being from the US. While there is no firm legal framework for AVs, large and important federal entities like the NHTSA are supportive of AV development.

Europe

We estimate that current European Level 1-2 ADAS penetration is roughly 12% and reaches 100% penetration at a pace similar to the US. We believe this is supported by the European NCAP (New Car Assessment Program) which already incorporates relatively advanced features such as pedestrian automatic emergency braking, and will count towards star ratings from 2016 onwards. For autonomous vehicles we model in a slightly accelerated time frame relative to the US, with Level 3 coming at the end of 2016, though we assume Level 4 launches at a commercial level in 2025 like in the US. We model in a 21 year adoption period for full/semi automation. We expect European OEMs to be big adopters given their premium product offering and given support from sophisticated suppliers like Bosch and Conti. While the Vienna Convention will likely need to be updated to include AVs in its definition of motor vehicles, we do not see this as a major obstacle if the technology is validated.

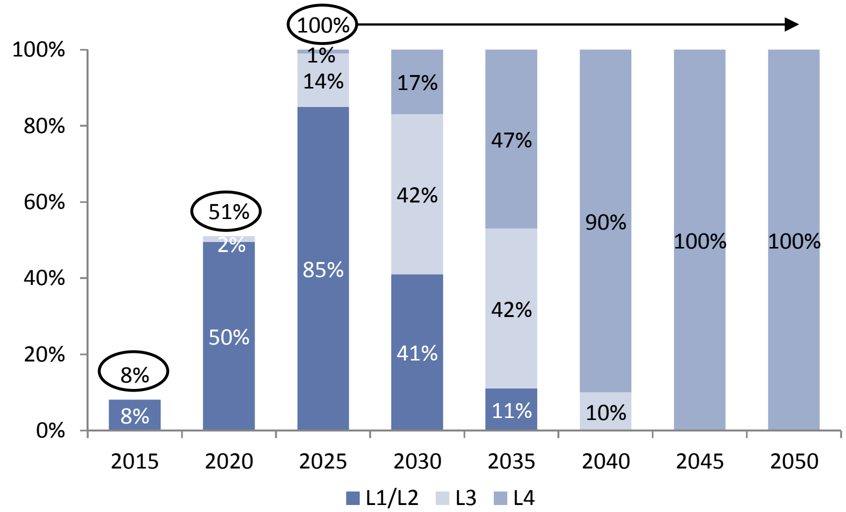
Asia Pacific ex-Japan

By comparison, ADAS penetration is still quite low in Asia ex-Japan at around 2%, and we think it will likely take until 2028 to hit 100%, a four-year lag compared to the US and Europe mostly driven by the existence of low-cost vehicles with lower safety specs. However, we do think the region should get a boost by the CNCAP (China NCAP), which we expect to incorporate ADAS into crash ratings by 2018. We also model in a lag for the adoption of Level 3 and Level 4 (in 2022 and 2030, respectively) with100% full/semi penetration not coming until 2047, a 26-year adoption period. On the positive side, congestion and other factors do incentivize adoption and there are large internet players like Baidu and Tencent that are investing in AV technology. On the negative side, with a large swath of demand made up by low-cost vehicles, it may take time for the technology to trickle down.

Japan

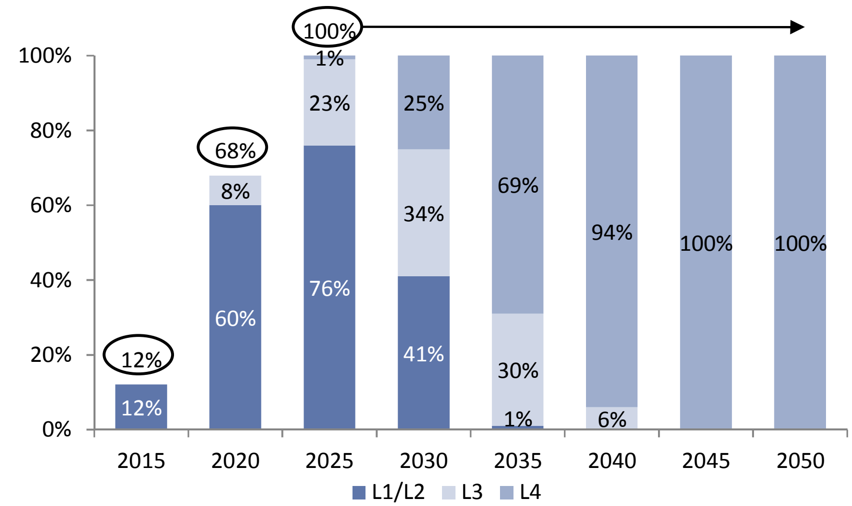
We estimate that Japan ADAS penetration is currently relatively high at about 8%, and we model 100% penetration by 2027, which represents a 15-year implementation cycle. For autonomous driving, we model Japan launching Level 3 in 2019 and Level 4 in 2028, which is a more conservative starting point relative to North America and Europe, though the 20-year adoption cycle is similar. While Japan has dominant OEMs and suppliers critical to ADAS like Denso, we believe the regulatory approach is likely to be more cautious in a country where autonomous vehicle testing is not yet permitted.

Exhibit 9: Model Level 3 and 4 launching in 2018 and 2025 in N America
North America light vehicle sales penetration forecast



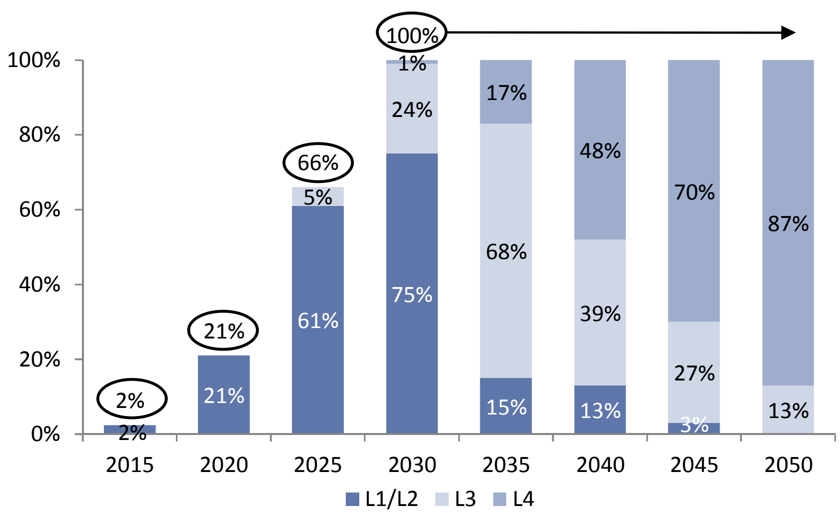
Source: Goldman Sachs Global Investment Research.

Exhibit 10: We see a slightly accelerated Level 3 implementation in Europe
Europe light vehicle sales penetration forecast



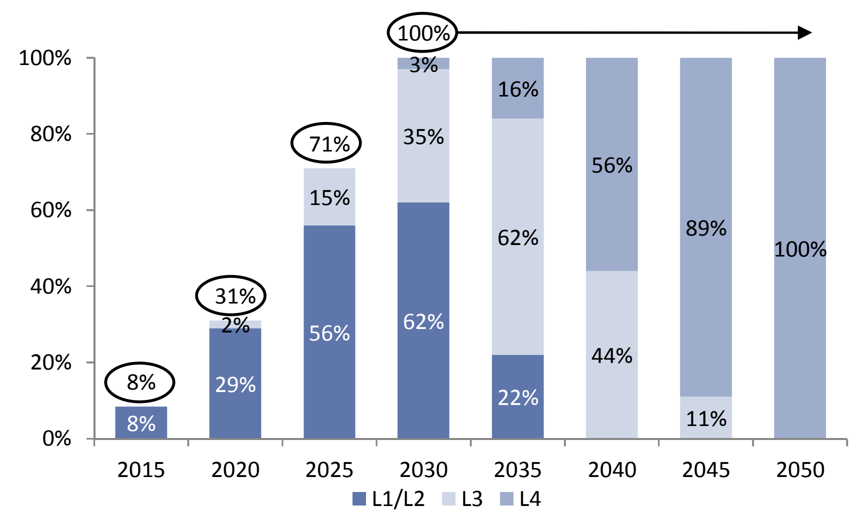
Source: Goldman Sachs Global Investment Research.

Exhibit 11: ADAS and AV adoption will take longer in Non-Japan Asia
Asia Pacific ex-Japan light vehicle sales penetration forecast



Source: Goldman Sachs Global Investment Research.

Exhibit 12: Expect a more conservative implementation for Level 3-4 in Japan
Japan light vehicle sales penetration forecast

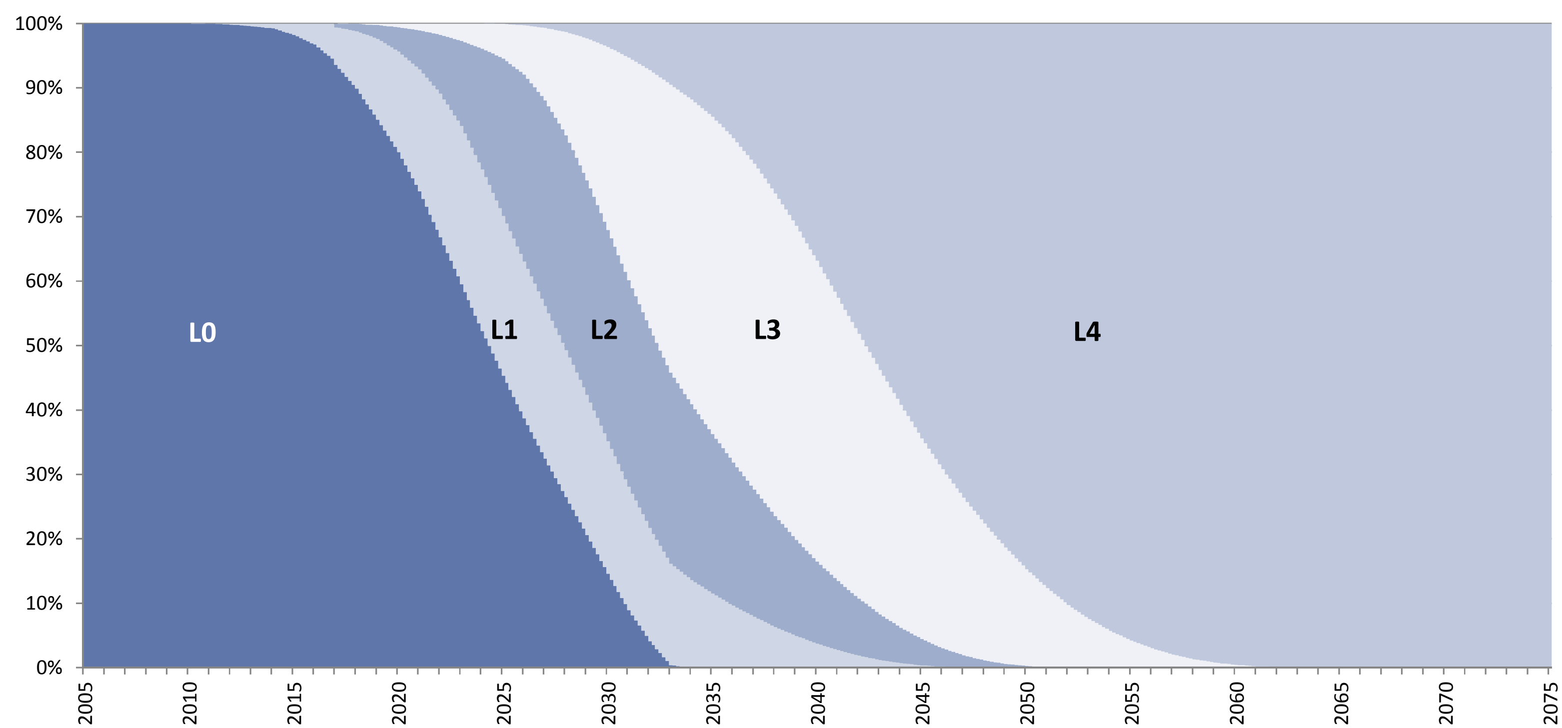


Source: Goldman Sachs Global Investment Research.

While sales could potentially adapt quickly if the technology is proven, it takes a long time to turn over the vehicle stock. Unlike handsets or personal computers, vehicles have a very long duty cycle – typically about 20 years. In **Exhibit 13,** we run this analysis for North America. ADAS at present is only 1% of vehicles in operation (VIO), and based on a normalized scrap rate and the sales projections outlined above we estimate 40% of vehicles in operation on the road will have Level 1 or Level 2 by 2025. For autonomous vehicles (Levels 3 and 4) to reach the same percentage of the VIO would take until 2034, and we would not likely see a full conversion of the fleet until 2060.

This has important implications for certain facets of the business. Vehicle-to-vehicle technology (V2V), for instance, requires other vehicles to be fitted with the same DSRC (dedicated short-range communications) radio to be effective. Most sources have suggested that safety benefits start to accrue at penetration rates of 25%-30%. Either way, there is likely to be a meaningful aftermarket opportunity to fit these modules in existing vehicles. This also has important implications for **insurance**, where premiums are collected on cars in service not just on cars sold, as discussed in depth at some length starting on page 48.

Exhibit 13: The vehicle stock would take much longer to change over, with a full conversion of the US fleet to AV not likely until 2060
North America vehicles in operation forecast by vehicle autonomy level



Source: Goldman Sachs Global Investment Research

Enabler 1 – The Hardware side: Solutions in hand driving a big content opportunity

Given that some of the more basic ADAS technologies have existed for the better part of a decade and given the R&D investment that has been poured into semi-autonomous and autonomous driving, the hardware capability that exists today is reasonably advanced. By most accounts the sensor and V2X technologies that have been developed to date do not require huge additional technological leaps for autonomous driving and existing computing platforms should be able to deliver the necessary processing power. In our view, component costs and software challenges will ultimately dictate the pace of the industry's state of "technical readiness" for AV.

What is clear is that the content increase per vehicle is likely to be very meaningful, as are the commercial opportunities for suppliers/semi and component manufacturers and software providers. In **Exhibit 14**, we show a bottom-up analysis of the individual component systems and per-unit costs that will be required for each level of automation. These estimates come from over two dozen meetings we have hosted with industry experts and are meant to represent the system costs at scale.

For **Level 1**, we estimate a price tag of $300-$400 per unit, which in general is a one sensor system. For **Level 2**, we estimate a cost of approximately $1,200 per unit for sensor fusion and additional software capability. The big step up happens with semi-autonomous driving at **Level 3** which we estimate at approximately $2,760 per vehicle for a full suite of sensors including LIDAR, a V2X module, stepped-up HMI, and additional actuation and ECU content. As we move to **Level 4**, the aggregate price moves up only about $90, to $2,850, as there is not much additional physical equipment required, and the hardware costs come down, but this is essentially offset by increased software capability which comes at a higher price. This is analogous to the smartphone, which has seen limited cost increases to the consumer in the past five year despite having increased capabilities.

Exhibit 14: Content increases set to accelerate significantly from Level 2 to Level 3, which requires a full sensor suite, V2X, and increased software capability
Bottom-up content map for the various levels of autonomous vehicles

System	Description	$ Content per Vehicle				Select Aggregators	Select Software/Value add hardware Providers	Select Semiconductors/Other Providers
		L1	L2	L3	L4			
Cameras	Core vision system for object recognition, traffic sign and signal recognition, and path detection. Available in mono, stereo and trifocal configurations	$150	$200	$300	$255	-Conti -Denso -Delphi -Magna -TRW -Magna -Valeo -Autoliv	-Mobileye -Bosch -Toshiba -Conti	-Sony -Melexis -ON (Aptina) -STMicro -Freescale -Renesas -Infineon -ADI -Linear Tech -Maxim -NXP -Rohm -TE -TI -Fujitsu -Microchip -Atmel -JAE -Molex -Hirose -Amphenol
Radar	Long range forward radar systems typically used to provide range, angle, and doppler velocity. Works well at night and in poor weather	$125	$375	$400	$300	-Conti -Delphi -Denso -Valeo -Bosch -TRW -Autoliv	-In-house by aggregators	-TI -NXP -ADI -Infineon -Linear Tech -Maxim -ON -Renesas -Freescale -Maxim -STM -Rohm
LIDAR	Laser based scanning device that creates 3D images of surrounding objects with a 360 degree field of view	$0	$0	$800	$900	-Bosch -Delphi -Conti -Denso -Valeo	-Quanergy -Velodyne -ibeo -Leddartech -TriLumina	-Xilinx -Altera -STMicro -Freescale -Renesas -Bosch -Fujitsu -Microchip -Atmel -InvenSense -Infineon -TI -ADI -Freescale
Embedded controls	Domain controllers / ECUs used to tie together multiple electronic sub-systems, enhancing communication of these "domains"	$130	$125	$200	$200	-Delphi -Magna -Conti -TRW	-Nvidia -Intel -Infineon -Elecktrobit	
Actuation	Largely more robust EPS, Electronic braking, and throttle and shifter as well as redundancies	$16	$16	$76	$86	-TRW -Bosch -ADVICS -Conti		
Electrical & Electronic Architecture	Increased electrical connection and distribution content between systems with more redundancies and fault tolerances built in	$71	$98	$112	$120	-Delphi -Leoni -Lear -Yazaki -Sumitomo	-TE -Molex -Nippon	-Broadcom -Linear Tech -Freescale -TI -Amphenol -Sensata -NXP -Infineon
V2X	Provides vehicle to vehicle and vehicle to infrastructure communication using a dedicated DSRC module	$0	$0	$350	$300	-Delphi -Denso -Bosch -Conti	-Cohda -Qualcomm -Autotalks	-Broadcom -NXP -Qualcomm -Sharp -Sony -STMicro
HMI	The "Human Machine Interface" monitors driver status, signals mode changes, and provides biometric identification. Includes eye tracking cameras, illumination, advanced algorithms and hardware	$0	$100	$200	$200	-Conti -Delphi -Valeo -Bosch -Denso	-Lemoptix -Luxoft -Tobii -Seeing Machines	-Nvidia -Intel
Mapping	High definition mapping services (includes sparse vs dense recording approaches)	$0	$175	$200	$225		-TomTom -HERE (formerly Nokia Maps) -Google	
Embedded modem	Offers on-board connectivity functions through the 3G/4G LTE network	$0	$10	$10	$10	Most Tier 1 ADAS suppliers	-Qualcomm -Intel	
Security software	Ensuring the integrity of on-board communications and software through firewall, and anomaly detection, signal identification among other approaches	$0	$50	$100	$225		-TowerSec -Argus -Security Innovation -Arilou -Escript	
Passive Components	Other components used in autonomous vehicles such as those used in wireless, radio, and capacitor systems	$9	$11	$16	$25	Most Tier 1 ADAS suppliers	-Murata -Nippon ceramic	
Total System Cost		**$370**	**$1,160**	**$2,764**	**$2,846**			

Note: We assume that 75% of level 1 systems use cameras and 25% use radar, not both.

Source: Conti, Delphi, TRW, Magna, Autoliv, Mobileye, Quanergy, Ibeo, Cohda, Cisco, TomTom, Argus, Security Innovation, Broadcom, Nvidia, GM.

Cameras

Product description: The capability for detailed object detection and path recognition makes cameras an indispensable part of the ADAS and ultimately AV package. The fact that it performs less well in poor weather conditions and at night means it likely needs to be complemented by other systems. Common approaches are **monocular** (single camera suitable for Level 1 and 2), **trifocal**, (typically one traffic sign detection camera and 2 vision cameras which can calibrate distances), and **stereo** (a dual set of cameras meant to enhance depth measurement used by Daimler and others).

Who makes it: Currently Delphi, Denso, Bosch, Continental, TRW, Magna and Valeo are the largest manufacturers of the physical cameras, which represents about half the system cost on our estimates. They partner with a large swath of semi and component suppliers, including image sensors (including Sony, Melexis and ON/Aptina) and logic/custom chips (from companies including ST Micro). As we discuss in more detail in the software section, Mobileye's EyeQ3 chip is the most widely used algorithm for vision, though some Tier 1 suppliers like Bosch and Conti and companies like Toshiba are starting to produce their own vision algorithms.

Radar

Product description: For almost all of the system aggregators we have spoken with, radar will play an important complementary role in ADAS sensing, mainly because of its ability to detect objects at long distances and high functionality in bad weather. Even with most radar systems being upgraded to 77 or 76 GHz from 24 GHz, the system is very cost effective running at about $75-$125 per unit coming to $125-400 per vehicle, by our estimate.

Who makes it: Right now radars are quite vertically integrated with the largest manufacturers being Conti, Delphi, Denso, TRW, and Bosch. While they have partners in areas like semiconductors and components, a sizable part of the value chain – including software – is done in house for these suppliers. Many of the key components in radar are traditional analog/mixed signal semi capabilities, and they are provided by companies including TI, NXP, Freescale, and ADI (many with a historical background in both analog and communications semi chips).

LIDAR

Product description: LIDAR (Light Detection and Ranging) is a laser-based scanning device derived from the same technology used in supermarket scanners but which instead emits multiple beams at high frequency, concurrently receiving signals as they illuminate objects (anywhere from 200,000 to 1,000,000 illuminated points per second). Automakers use the resulting data to create 3D images of objects 360 degrees around the vehicle. The advantage of LIDAR sensors aside from the detail of the images they create is they work very well at night time and tend to have better performance in bad weather. While previous-generation LIDAR technology involved fairly expensive devices that would effectively spin to create a 360 field of view (a very recognizable feature of the Google car for instance), a number of companies have moved towards much more compact components that are solid state and much less expensive, which we believe has significantly increased the relevance of these sensors.

Who makes it: Velodyne developed the system which is currently being used by Google's autonomous vehicles, but it has become a more competitive field with Quanergy and Ibeo offering more compact next-generation solutions at a lower cost. Velodyne has also developed a much more compact "puck LIDAR" with no visible rotating parts, and Quanergy and Ibeo have partnered with Tier 1 suppliers Delphi and Valeo to do the physical manufacturing of the component. From a chip/component perspective, some current implementations of LIDAR use programmable chips (companies like Xilinx and Altera) and processors (e.g., an ARM core) to interpret the signals, and a laser diode to send the light. Our industry discussions also suggest there is some interest in using MEMS and actuator technology in future versions of LIDAR (companies with this type of capability include ST Micro, Bosch, Freescale, and ADI).

Embedded controls/ECUs

Product description: Electronic Control Units already are a key part of a vehicle's architecture supporting the integration of critical software functions in a vehicle in areas such as powertrain, transmission, braking, HMI, and telematics – to name a few. As more autonomous capability is added, the level of communication between these "domains" is set to increase significantly, requiring additional processing capability. As a result, we model increases in domain controller/ ECU content to help manage these very large data flows.

Who makes it: Currently the content increase required for autonomous driving appears to be $100-$200 dollars, and based on our research we assume the top end of that range for L3 and L4. The largest beneficiaries would be Delphi, TRW, and Magna on the component side. Nvidia appears very well positioned on the processor side with Infineon and Intel also actively involved in building out this business.

Actuation

Product description: Actuation refers to the additional physical mechanisms for lateral control, acceleration, and braking that will be required to operate the vehicle autonomously. In some cases the vehicle can leverage systems that exist today – for instance, electric power steering and ABS brake systems with ESC have the essential functionality for autonomous braking and steering, though additional redundancies would need to be added for full automation. And there are other functions such as electronic throttle and, ultimately, the move to an electronic shifter that would eliminate the need for a steering column and represent brand new content for many vehicles.

Who makes it: We estimate actuation content at about $86 per vehicle for L4. There are a wide variety of companies which are impacted by this market such as TRW, Bosch, and Continental, to name a few of the larger players in chassis/braking systems. We also highlight Nidec a top global player in motors for electric power steering (EPS), among other actuation applications.

V2V module

Product description: By all accounts, V2V will be an important complement to AV, adding robustness to autonomous driving by supplementing the visual sensor suite and supporting some of the knock-on benefits of autonomous driving, such as reducing traffic congestion through features like connected adaptive cruise control.

Who makes it: The most basic component is the DSRC (dedicated short-range communications), which is set to cost $300-$350 at scale, according to DOE estimates, though this could go above this cost with additional functionality. Currently the hardware is made by Delphi, Denso, Bosch, and Conti, with the core chip/software content providers such as Cohda Wireless, NXP, Qualcomm, Broadcom, and Autotalks.

Human machine interface

Product description: While HMI technology is being worked on independently from automation, there are a number of ways in which we think AVs will require a more robust content in this area. First, as we transition to semi-autonomous we need to understand the driver in a more profound way and assess if he/she is in a condition to take control of the vehicle. The driver will also require acoustic, haptic, or visual impulses to be informed of what mode of driving he is in and when he needs to take over. Second, AVs will require biometric identification, for security purposes but also for convenience purposes, recognizing which driver is in the vehicle and downloading personal settings. Based on conversations with industry experts, to accomplish this you will need a driver facing camera and advanced eye tracking software as well as an illumination system (undetectable to the driver), and additional processing hardware.

Who makes it: At present by in large all the major aggregators like Denso, Conti, Bosch, and Valeo are working on these solutions. The market leader in eye tracking systems is a Swedish company called Tobii, (TOBII.ST) which also serves a number of different markets outside of automotive. Other important HMI/eye tracking technology companies are Lemoptix and Luxoft based in Switzerland, and Seeing Machines out of Australia.

Mapping

Product description: Mapping has garnered more attention, as it seems to have become widely accepted that some form of mapping will be required for autonomous driving. While sensors can accomplish a lot, there is a need to geographically locate the vehicle and enhance the GPS signal for things like path planning and long distance navigation. Live V2V mapping is now considered an important complement to other sensing technology. The amount of attention paid to mapping has increased with the recent sale of HERE, which was frequently discussed in the press.

There is still some debate over sparse vs. dense mapping, the latter being the route taken by Google, which puts less emphasis on the sensor suite and more emphasis on detailed 3D mapping. Others have opted for a more incremental approach, rolling out less detailed maps over greater areas that can be improved over time by the drivers themselves.

Who makes it: Currently the principal mapping companies are HERE, TomTom, and Google, though Chinese online players Baidu and Tencent have expressed plans to develop these products for the Chinese market. Our research indicates that the per-unit cost of mapping could be brought to below $100 at scale, though it is well above this today given the production is subscale.

Security software

Product description: As we outline in much more detail below, as vehicles become more digitally connected and automated the issue of hacking becomes a key issue. This has increased in profile recently with the remote hacking of a Jeep Cherokee as reported in Wired, as well as many other Youtube demonstrations of vehicle hacks. In order to address this, a number of companies have introduced firewalls, intrusion prevention/detection, identity verification, and cryptography among other systems all designed for the automotive market.

Who makes it: Given that automotive cybersecurity is a relatively new phenomenon the field is still fast evolving. Some of the more important players in the space now are TowerSec, Argus and Redbend from Israel, and Boston-based Security Innovation, to name a few.

Enabler 2 – Software: Towards superhuman perception and environmental modelling

We see software as representing one of the key building blocks in delivering semi-autonomous and fully autonomous driving. While software used to interpret radar signals and camera images is already in vehicles today, to deliver ADAS, more sophisticated algorithms for semi-autonomous driving are already in the process of being developed within the current model cycle for a couple of OEMs. Over time we expect further strides in software capabilities for interpreting visual and other sensor-driven inputs to enable fully autonomous driving, which will likely work in tandem with mapping software/data, among other things. While this section focuses on vision software and the improvements needed to support autonomous driving, software in general touches almost all facets of ADAS, from the algorithms downloaded onto ASIC chips for cameras, V2V, Lidar , HMI, etc. to the operating systems and embedded security, to the extensive coding and testing required by Tier 1 suppliers and OEMs for the safe integration of the capability into a vehicle. All of these things will continue to significantly drive up the software content of ADAS/AV systems driving higher value add.

In order to deliver semi-autonomous and fully autonomous driving, the software used to determine a car's position and trajectory on the road must deliver a new level of capabilities compared to the current ADAS software that is on the road today. Indeed, such software must facilitate sensing ability which is superhuman.

In **ADAS systems** on the road today, the human driver has his hands on the steering wheel at all times and remains in control of the car. Whereas such systems do not tolerate **false positives** (i.e., the car must not randomly do emergency braking), legally and from the point of view of consumer acceptance, the industry does tolerate a low degree of **false negatives** (i.e., where the car should have applied the brakes but did not). Official tests for false negatives must be passed, but this does not guarantee that there will never be a failure and is accepted as long as the failure rate is very low (an analogous approach is taken by car makers and regulators for other safety features such as airbags).

By contrast, in **semi-autonomous driving**, the driver will legally be allowed to have his hands off the steering wheel for a certain amount of time such that he can do other tasks but will be required to take control again if prompted by the system. Most research points to 10-15 seconds as a reasonable time to give back control of the vehicle to the human driver safely. Under these conditions we characterize the required capabilities of the sensing/image interpretation software as superhuman with essentially **zero false negatives**. The system needs to know everything about the car's surroundings at the point when the human driver is transitioning back to full control – e.g., where pedestrians are positioned, the structure of the road, and the positions of other cars. This is well beyond the ADAS sensing capabilities found in cars today.

When the move to **fully autonomous** driving happens (that is, when the human driver gives up full control to the vehicle for the entire trip and no one will need to be present in the driver's seat), it is our view that the threshold for acceptance will be much higher and systems will need to be shown to make far fewer mistakes than a human driver. While in our view fully autonomous is at least a decade away, we note Mobileye is readying software for some basic semi-autonomous driving (such as hands-free driving in highway scenarios without multi-tasking) on four separate car models, including Tesla and General Motors. Altogether there are a total of 13 OEMs currently working under contract with Mobileye with launches expected in 2016-2018, so progress towards Level 3 and eventually Level 4 is ongoing.

We see several key attributes that software for facilitating autonomous driving will need to have in order to deliver sensing capabilities which are appropriate.

- **Holistic path finding** to determine where to drive (and where not to drive). Were all the roads in the world to have perfect lane markings under all conditions, then it would be possible simply for image interpretation software to follow these to determine what trajectory the car should follow. However, in many situations there are no lane markings, the weather conditions may be poor, or there may be lane splits. It will be necessary for the software to prompt the car to drive on the right path in an error-free manner in all conditions.

  Given that humans are able to take the right path by interpreting visual stimuli other than lane markings, a sensor-based system must also be able to do so. Thus, holistic path planning software is able to leverage cues such as the road edge, barriers, and track of other vehicles, et cetera. This is done by utilizing **deep learning** to analyze multiple images in order to correctly interpret such visual cues. This means every pixel in the field of view is identified, creating an **environmental model** which allows the car to determine the “free space” – so the car knows exactly where to drive (but also where not to drive, for example, by identifying barriers).

- **Sensor fusion** to form a broad field of view and analyze images and data from multiple kinds of devices. Today, ADAS systems may use one forward-facing camera with a 50-degree field of view, which is sufficient to avoid forward collisions with other vehicles. However, for semi-autonomous and autonomous driving, a field of view of 360 degrees will ultimately be required as a primary field of view. The vehicle will therefore likely use multiple cameras, LIDAR which sees well at night, radars which perform well in poor weather, and V2V which detects vehicles before they are in visual range. All of these data inputs will need to be processed by the software.

- **Specialized software modules** will also be required for semi-autonomous and fully autonomous driving that are not necessarily required for ADAS. One example is **Debris detection** (from 10cm to up to 50m away) which is under development at Mobileye. Another key function is **Traffic sign recognition**. While ADAS systems will increasingly incorporate these as a convenience feature (e.g., there will be over 250 traffic signs in certain 2015 platform launches), there could be a need for around 1,000 signs for autonomous driving. Such signs will give prompts about lanes and exits, for example, and it will also necessary to be able to read pavement markings.

We believe the automotive industry, in order to achieve autonomous driving capabilities, is likely to utilize software that interprets cues from the visual world collected by camera (and other) sensors allied to moderately detailed maps. This is a variant of the “**sense and understand**” approach to autonomous driving, which may be contrasted with a second approach, known as “**store and align**.” In our view, these two may be seen as the two central cases at the extreme ends of a spectrum of approaches to autonomous driving, and we believe an in-between solution leveraging elements of both is likely to be the most practical from both a financial and a logistical perspective.

Sense and understand leverages sensors to gather visual information from around the car, and software then processes it to provide an interpretation such that the car can react or orient itself on the road accordingly. Such an approach is currently exemplified by ADAS solutions that are already on the road in vehicles today – for example, automatic emergency braking (AEB), whereby a vehicle recognizes when it is about to collide with another vehicle and automatically brakes. It effectively mimics the approach taken by humans, who do not strictly need any stored (i.e., memorized) data about a particular location in order to be able to respond appropriately to visual clues.

Store and align is an approach involving building up a dense 3D recording/map of the road and surrounding environment, and then in real time using sensors to match environmental cues to the database in order to work out the accurate position of the vehicle relative to the road. This is achieved by completing two "pre-drives" whereby a detailed HD recording is made of the road in each. Following this, a comparison of the two allows for non-fixed objects to be excluded from the database, with only the permanent parts of the road remaining.

Exhibit 15: Store/Align (Google) vs Sense/Understand (Mobileye)
Spectrum of approaches to autonomous driving

	Store/Align	Sense/Understand	
Maps	**360 degree, 3D maps** from pre-drive recordings	**Sparse Recording** (map complements sensors)	**No recording**
Sensors	Sensors **match environment to database** to determine position of car	Sensors collect information and **build real-time environmental model**	
Software	**Compares known fixed objects (from database) with sensor inputs** to detect obstacles	Interprets and reacts to sensor outputs in real time to control car (i.e., **free-space analysis and holistic path finding**)	
Requirements	Up-to-date HD maps, (cloud) storage, network connection	**Deep learning** to allow the car to determine the "free space" – where the car can travel	
	e.g. Google	**e.g. Mobileye**	

Source: Goldman Sachs Global Investment Research

We believe that using one or the other approach in its purest form may be a less than optimal solution.

While **store and align** has the advantage of potentially reducing the level of sophistication required from sensors and associated processing, it has certain drawbacks. The principal one we see is a need to continuously update the data composing the detailed HD map, which in our view may lead to logistical and cost issues and potentially limit its sphere of application to the most well-capitalized players. Petabytes of data would likely be required to cover the US alone, and maintaining a real time update of such data would likely require a significant ongoing commitment.

That said, while a pure **sense and understand** approach is theoretically possible, and avoids the need for maintenance of a detailed HD map, in practice introducing some element of mapping improves redundancy and gives additional reliability to the robotic system. An analogy from human experience is the driver who rents a car while on a holiday abroad. He can of course preform the task of driving in his new environment, but in practice he will know the roads better in his home country and drive better on them, and thus when in a foreign location will need to tread more carefully. Further advantages of maps include the obvious requirement of high-level route planning as well as the potential to prepare the car for unusual road features like unorthodox turns, traffic, et cetera, thereby avoiding extreme maneuvers.

Enabler 3 – The introduction of V2V and V2I: Vehicles in continuous communication

Introduction to V2V/V2I

V2V/V2I stands for vehicle-to-vehicle/vehicle-to-infrastructure communication technology, which allows vehicles and stationary roadside units equipped with the function to communicate with each other by sending out a wireless signal with a range of roughly 300m. The technology utilizes DSRC radios which are a similar technology to conventional Wi-Fi but which work on a separate section of the wireless spectrum. V2V/V2I is currently being developed and implemented globally for a variety of uses, including applications in safety, mobility, and overall efficiency. We believe that the main focus of implementing V2V technology in the US is safety. Given the NHTSA's involvement and the variety of benefits it brings at a limited cost, we believe that V2V/V2I technology will be a major technology utilized in vehicles for autonomous driving.

Key benefits from V2V/V2I technology

While we see several key benefits from broad implementation of V2V/V2I systems, we believe that the majority lie within three key areas.

1) **Safety:** For fully implemented vehicles without autonomous driving functions, V2V/V2I would provide drivers with early warnings of incoming hazards, before they are perceived by the human drivers, giving them increased reaction time. For example, we see the potential for warnings to provide drivers with increased time to adapt to upcoming traffic conditions due to icy roads, traffic jams, emergency braking, recent crashes, red lights, and so forth. In vehicles fitted with an NHTSA-defined vehicle awareness device, a driver would see increased safety benefits, as other nearby vehicles would be made aware of any emergency situation the driver was experiencing, thereby reducing the potential for rear-end collisions, for example.

2) **Redundancy:** In vehicles with autonomous driving and advanced ADAS features, V2V would provide another layer of redundancy into the system. The V2V/V2I would be able to pick up emergency messages from vehicles much further ahead in the road than what the sensor array could physically pick up. As a result, the vehicle would have increased time to interpret the data and adjust its driving or send messages to the driver to take over control with adequate warning time. **We do not believe that fully autonomous vehicles would reach the needed threshold of safety for full adoption without the use of V2V/V2I to complement the suite of sensor technology.**

3) **Fuel efficiency:** We also see V2V/V2I technology contributing to overall fuel economy through the use of cooperative active cruise control. Currently, active cruise control utilizes sensors to determine if the vehicle ahead is slowing and applies the brakes to maintain a set distance. With cooperative active cruise control, the vehicles could utilize a platooning method of travel which allows them to communicate their respective braking and acceleration patterns to vehicles behind it, smoothing the flow of traffic and reducing the frequency of slowing down and accelerating, which provides fuel economy gains.

Other uses: We see additional uses for V2V/V2I technology, particularly with V2I. In particular, we cite traffic management and toll road collection as potential uses. For traffic management, one example would be stoplights that utilize data on the exact number of vehicles traveling towards it and at what speed, which could allow for better traffic flow management decisions made at busy intersections. Toll road collection is another area where implementation of V2I technology could be useful. For example, the government in Japan has initiatives supporting the use of V2I at toll booths for electronic toll collection.

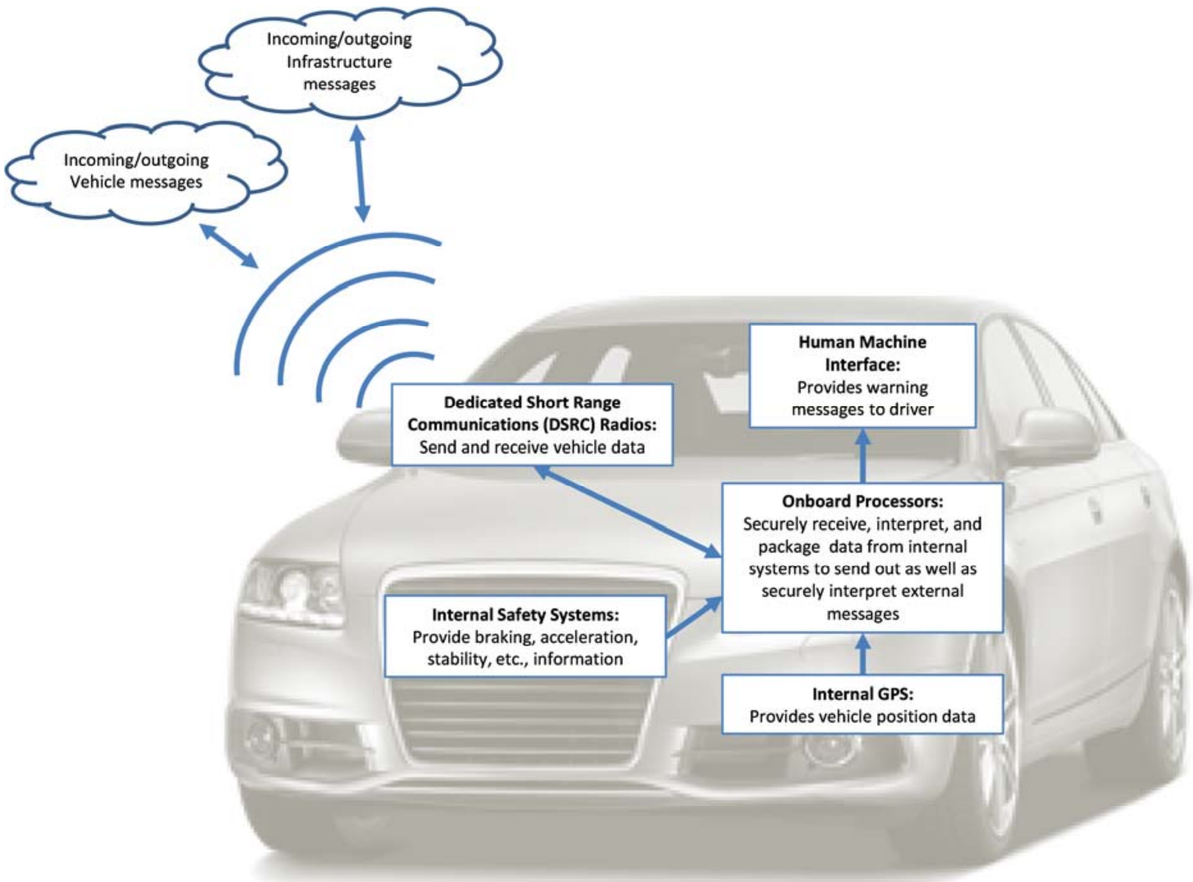
NHTSA providing a push in the US

From our discussions with the NHTSA and from reviewing the literature it has published, it is clear to us that the agency has been very focused on V2V and has been working to accelerate legislation mandating fitment of V2V modules in new vehicles. Currently, the NHTSA has accelerated the review period for a proposed rulemaking on V2V which it expects to submit to the Office of Management and Budget by the end of 2015. Following the review, the rulemaking would go through a public comment period – which typically lasts six to nine months, and then the final rules could be published in mid-2017 if there were no major revisions. After this, we expect there to be a phase-in period of roughly 3-4 years, based on previous rulings, before widespread integration by the automakers occurs. However, because V2V technology is significantly different compared to past technologies, we see the risk of a longer phase-in period. In addition, the NHTSA has expressed interest in researching aftermarket implementation, as the agency highlighted the importance of having an easily-implementable solution for existing vehicles in the fleet to maximize usage and the potential benefit of the technology.

Vehicle Wireless Technology

V2V/V2I: As mentioned above, DSRC currently resides on the wireless spectrum, bordering conventional 802.11 Wi-Fi wireless LAN, with a dedicated 75 MHz bandwidth segment on the 5.8-5.9 GHz frequency band. This requires that any V2V/V2I communication signals are sent on the dedicated frequency to avoid any kind of interference. To enable this, V2V-enabled vehicles require, at a minimum, DSRC radios and a GPS receiver with a processor to take speed and location information and broadcast out the appropriate message through the frequency to be received and interpreted by any surrounding vehicles (**Exhibit 16**). The system can be scaled up by incorporating additional vehicle sensors such as those for ABS, ESC, windshield wipers, and radar sensors. In addition, because the messages are secured with public/private key technology, the transmission can be instant and applications can be applied to fast moving vehicles. V2I technology, meanwhile, allows roadside units to relay important road messages to vehicles such as weather or traffic incident warnings.

Exhibit 16: V2V systems require several components working together to send and receive critical messages



Source: Goldman Sachs Global Investment Research.

Barriers to implementation

We believe that the true value of V2V/V2I technology can only be recognized once there is critical mass (defined by some sources as 25%-30% penetration of the vehicle stock) and a significant amount of vehicles/roadside units are communicating with each other. According to a recent NHTSA study, the cost per vehicle to the consumer is expected to be relatively agreeable at $340 when purchased as an option on a brand new unit. The agency also expects to see aftermarket solutions with limited capabilities costing between $160 and $390 – including installation cost estimates. These aftermarket offerings range from a vehicle awareness device which offers no warnings or displays to a full retrofit into the existing system.

With cost as an unlikely deterrent we believe the primary barriers to entry are the following.

Data security: We see potential for consumers to question the security of the system. Given recent high-profile vehicle hackings, we believe that automakers and component manufacturers need to ensure that the messages being sent and received by drivers are secure. The accuracy and timeliness of the messages being sent need to be validated in order to prevent either fraudulent or dated messages from being sent and received by surrounding drivers.

Spectrum sharing: As it stands today, DSRC is allocated a 75MHz bandwidth for all V2V and V2I communication. While this is currently sufficient, there are ongoing concerns about the idea of sharing bandwidth with the expanding Wi-Fi signals. In addition, with the 260mn vehicles on the road today in the US, there exists potential for the spectrum to become crowded and slow down the sending and receipt of messages – creating a concern. Outside of conventional DSRC, the 4G/LTE spectrum could also become crowded as the information being transmitted by large numbers of vehicles is added to the existing data usage from existing mobile devices.

Privacy: In addition to data security, we see data privacy as an additional concern. We believe that consumers, particularly Millennials with additional exposure to the web and social media, see data privacy as a significant concern. For V2V/V2I specifically, these relate to vehicle tracking and information gathering. For example, with the use of roadside units, we would expect motorists who exceed the speed limit and drive past red lights and stop signs to be easily caught, without the use of cameras or police.

Key industry players

Automakers: Despite the fact that various aspects of the DCRC have not been fully standardized/formalized a few OEMs have moved forward with plans to offer them on vehicles. Currently, GM and Mercedes-Benz both expect to release their versions of V2V communications in 2017. GM expects to begin offering its V2V technology on the 2017 Cadillac CTS. Mercedes, on the other hand, will be introducing its version of V2V communications on the redesigned 2017 Mercedes E-Class. Based on details released by Mercedes, it appears that the system will be limited to similarly-equipped Mercedes vehicles only and consists of a warning icon on a map and an audible warning as other vehicles approach the area. The Mercedes system is also set up to automatically receive alerts triggered via airbag deployment or vehicles with their hazard lights on. The company expects the system to receive alerts from emergency vehicles or other manufacturers' vehicles, as the NHTSA will introduce a common standard and security protocol.

V2V component suppliers: Component suppliers like Delphi, Denso, Bosch, and Conti will in all likelihood take a central role in the manufacturing of the physical V2V/V2I models. But as we discussed above much of the software capability has been developed by chip makers such as Cohda Wireless, Qualcomm, and Autotalks which will play an integral part by working with both government regulators as well as automakers to develop solutions which share a common standardized system or language so that messages can be transmitted regardless of make and model.

Security providers: Given the recent headlines regarding vehicle hacking and potential privacy concerns, we believe that security providers would play a big role in the implementation of V2V systems. We believe that security must be ensured in order to allow for widespread adoption, as we expect some consumers to be reluctant to accept V2V without their fears of hacking and privacy assuaged. From our discussions with industry participants, we believe that the existing safety protocol for V2V seems up to the job of protecting V2V messages; however, we think additional testing is needed. Currently, the industry utilizes the IEEE 1609.2 communication standards, which address issues of securing the V2V/V2I messages by using public key cryptography. These standards have been established for DSRC use and offer protection from spoofing attacks. We believe that, for widespread adoption of V2V/V2I, industry acceptance and collaboration using the security standards can support the growth and security of V2V/V2I networks.

Local/national governments: Lastly, we feel that local/national governments will play a role in the implementation of V2V/V2I technologies. While the NHTSA is already outlining legislation for V2V/V2I technology, we believe that government funding will also be a consideration in addition to rulemaking. We see several potential benefits from V2I technology affecting both safety and efficiency. In terms of safety, V2I could provide drivers with early warnings of upcoming bad weather, congestion, or road work. For efficiency, we see potential uses in regulating the flow of traffic not only by providing drivers with more accurate traffic light data but also by providing driver usage data for traffic analysis. Assuming that roadside units will be used to achieve these V2I benefits, we expect that new units will need to be built both inside cities as well as on highways, incurring a cost for either local/state municipalities or the national government. While it is still a bit early to speculate on which regions will be first to implement roadside units, it is important to point out that some sort of government funding is likely needed to achieve full potential of the technology. Therefore, we see a risk in a delayed full implementation given the added complexities of government spending and the associated infrastructure upgrades.

Enabler 4 – The global regulatory framework: Still being established with validation as the largest barrier

While no formal legislation exists for the commercial sale of autonomous vehicles, the significant amount of capital being invested by auto and tech companies to develop advanced driver assist systems has forced governments to be more accommodative of autonomous feature testing on public roads. And though we do not expect there to be a uniform approach brought at the federal level, we believe industry regulators like NHTSA may help foster increased penetration of active safety features through their inclusion in the New Car Assessment Program (NCAP). Outside the US, there is already some inclusion of advanced safety technologies into NCAP ratings – which should help drive demand for these products in the coming years. However, further validation of ADAS and a demonstrated level of socially acceptable risk are most likely needed prior to commercially viable autonomous vehicles.

Around the world, the current regulatory framework is not set up to contemplate the legalities and liabilities associated with vehicles that drive themselves (i.e., vehicles with little-to-no human interaction/direction). This results from the lack of a clear regime for liability of an autonomous vehicle: if it crashes, is the OEM, software provider, or operator at fault? What if the vehicle had no occupant, is the owner liable? While these remain difficult questions to answer with no clear precedent, we do not believe the lack of legal precedent will be the barrier to autonomous vehicles. As it stands, there are several regions (US, Europe, Japan, and Singapore) where the current legislative environment is becoming more conducive to autonomous vehicle research and development. This is mostly the result of auto OEMs, suppliers, and technology companies continuing to invest a significant amount of capital in this field.

However, at present there is no region-wide (i.e., at the federal level in the US, or across the Euro-area) legislation that exists. Instead, there exists only a patchwork of states and countries that have passed some autonomous vehicle regulations with the intention of clarifying testing procedures but which have in many cases resulted in somewhat more prohibitive rules that will likely need to be amended or repealed in the future to allow operation of AVs.

One thing that appears consistent in multiple regions is a large difference that exists between views on ADAS, which is purely safety driven, the benefits of which are understood, and which governments generally support, and autonomous driving, which is primarily about convenience and for which government agencies will need to see much more validation testing in order to support.

L1 and L2 are likely to be championed by governments: We believe state governments and regulatory bodies like the NHTSA will become even more proactive in mandating active safety technology on newly manufactured vehicles given the well understood benefits (lower crashes, lower fatalities). The NHTSA is currently in the process of a proposed rulemaking for V2V technology implementation. Additionally, from our discussions with industry participants, NHTSA appears to be open to the inclusion of advanced safety features in the US NCAP as the agency is motivated to pursue how it can save lives both now and in the long term.

L3 and L4 – semi-autonomous and autonomous driving likely to see a higher hurdle: We see challenges in the adoption of the additional stages of autonomous driving where vehicle operators no longer need to give their undivided attention to the road. While these stages are a matter of convenience for drivers – relaxing and letting the vehicle do all the work – we believe that government support will require further validation of systems, which also includes determining the correct metrics to measure and determining a socially acceptable level of risk. As noted during our discussion with Bryant Walker Smith (Assistant Professor of Law at the University of South Carolina), there is unlikely to be a specific federal law establishing the legality of AVs. Rather, a regulatory body such as the NHTSA could use fines and investigations to influence automakers. Ultimately, the regulator could use its investigative and recall authority to shepherd the process of autonomous features in the right direction. At the state level, DMVs could also affect adoption positively or negatively by choosing to certify or not certify autonomous vehicles. And local legislatures, courts, and police agencies could weigh in as well. As a result, we see the testing and validation of L3 and L4 as the largest hurdle to be overcome, as many believe the legal framework, while it may lag testing and validation, will nonetheless occur at a fairly similar pace.

Autonomous vehicle adoption outside the US: We believe that legislation in **Europe** will follow the US closely –and most likely see a quicker penetration rate longer-term. We think this because several governments (UK, Netherlands, Sweden) have taken a fairly assertive stance in accommodating and supporting the development of autonomous vehicles. From an ADAS perspective there is the near-term support by Euro NCAP's inclusion of advanced safety features into its star ratings. Furthermore, industry experts we spoke with noted that, while the Vienna Convention clearly states that a vehicle must have a driver who is able to control it at all times, the expectation is that this can be fairly easily amended –though it typically takes several years. In **China**, while the government has been relatively quiet on the topic so far, the widely expected inclusion of active safety features into C-NCAP in 2018 bodes well for ADAS demand – and the introduction of full AVs will certainly be heavily directed by government policy. Lastly, in **Japan**, while the government has expressed a positive attitude toward autonomous driving, the targeted dates for implementation of different levels of autonomy appear conservative compared to the dates most experts see as in line with expected technological innovations, so there will most likely be a slower adoption rate within the region.

Exhibit 17: Current legislative environment friendly to vehicle testing, but not yet commercialization… NCAP programs helping push for advanced technologies
Global summary of regulatory regimes by region

	North America (US)	Europe	China	Japan
Current Legislative Environment	No uniform approach at the federal level; patchwork of states with autonomous laws that serve to foster R&D but are prohibitive. Electronic Stability Control mandated on all vehicles produced after 2011.	Similar to US, no formal European Union oversight; however, individual countries have created varying degrees of autonomous testing regulatory frameworks.	Government has been quiet on the topic, but most believe supportive to innovation for autonomous vehicles.	Current law does not allow L4 autonomous driving. However, OEMs can perform R&D on public roads with permission each time from Ministry of Land and National Police Agency.
New Car Assessment Program (NCAP)	US NCAP does not currently take active safety features into account for vehicle ratings star, but does recommend crash avoidance technologies like forward collision warning, lane departure warning, and rearview video systems. However, we believe inclusion into NCAP star ratings being considered.	Euro NCAP Advanced rewards vehicles for safety technologies (e.g., blind spot monitoring, lane support systems, vision enhancement systems, and autonomous emergency braking).	C-NCAP includes potential for 1 safety bonus point for electronic stability control. Absent this, there is no formal inclusion or recommendation for advanced safety technologies. However, active safety features are expected to be included in 2018.	JNCAP includes and advanced safety assessment for new technologies to avoid accidents: autonomous emergency braking systems and lane departure warnings systems.
Barriers to Autonomous Vehicles	Prohibitive patchwork of state regulations, no formal federal target. Requirements vary: trained expert, special license, minimum number of autonomous miles prior to public road testing.	More lenient patchwork of individual country regulatory frameworks than the US. However, must amend Vienna convention.	Appear low given lack of formal regulation and willingness to include in future NCAP.	Government has positive attitude to autonomous driving, but progress of the discussion is slow compared to the US and Europe.
Upcoming Milestones	DOT/NHTSA have issued notice of proposed rulemaking that may lead to mandate for V2V technology; update expected by end of 2015. However, no formal target for autonomous vehicles.	"Drive Me" test by Volvo in Gothenburg, Sweden of 100 driverless cars from 2017 to 2019. Though some regulatory clarity in Sweden is required. NCAP inclusion of pedestrian automatic braking in 2016.	2018 C-NCAP draft rule expected to circulate at end of 2015, expected to include active safety and collision prevention into its five-star requirements.	Cabinet Office is targeting L2 autonomous driving by 2017, L3 autonomous driving in early 2020s, and L4 autonomous driving in late 2020s.
GS target date for first autonomous vehicles	2025	2025	2030	2028

Source: DOT, NHTSA, OECD, JNCAP, Company data, Goldman Sachs Global Investment Research

Enabler 5 – Consumer acceptance: A generational divide, but concerns can be addressed

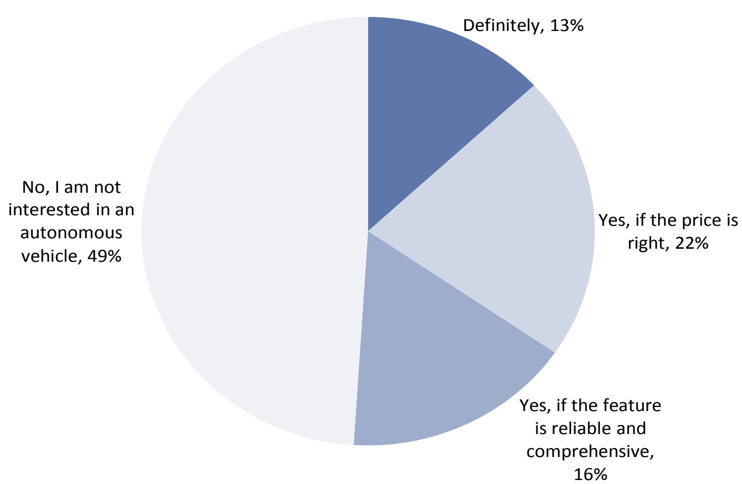
The introduction of autonomous vehicles will have major implications for industry players and consumers alike. And as consumer acceptance/adoption is the primary requirement for its success, we looked to gauge how consumers perceive the technology at present. To do so, in July 2015, we undertook a survey of 2,000 consumers in the US, conducted by a third party hired by GS, with demographics that closely emulate the consumer expenditure survey by the BLS. We asked participants a series of questions on certain aspects of autonomous driving and draw the following conclusions.

Skepticism with respect to adoption prevails

Even with the benefits of ADAS already visible to many, auto OEMs face a considerable hurdle in convincing the public to accept autonomous vehicle technologies. According to the survey, 49% of respondents (**Exhibit 18**) said they would not be interested in buying/leasing an autonomous vehicle. Acknowledging this, we note that penetration rates for new technologies like Electronic Stability Control, which is now commonplace, take time to ramp up. However, given the complexity of autonomous vehicle technology, we believe that extensive validation will be needed before attitudes change.

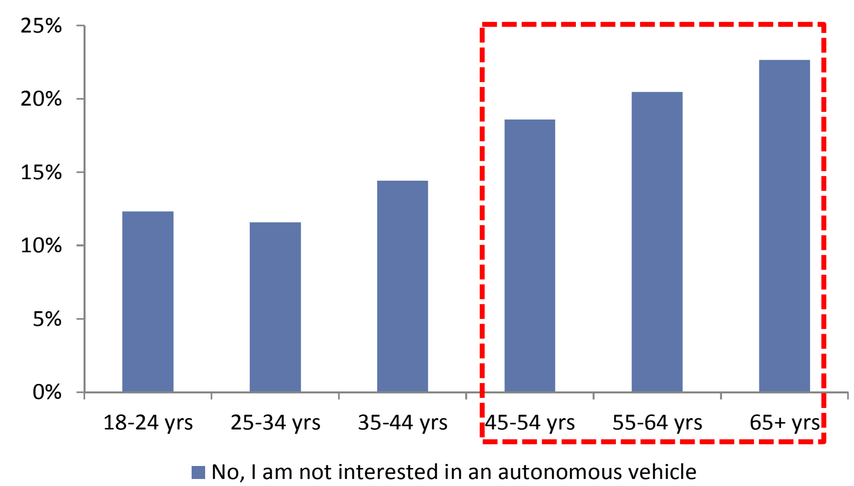
Within the "no, will not consider an autonomous vehicle" segment, we note that more than half of the respondents (**Exhibit 19**) fall in the age group of 45+ years. So, in terms of technology adoption it appears that the older segment of the population is harder to change and more hesitant to put their trust and safety in the "hands" of an autonomous vehicle.

Exhibit 18: Consumers remain skeptical of adopting autonomous vehicles
Would you consider purchasing/leasing a vehicle with autonomous driving capabilities?



Source: Goldman Sachs Global Investment Research

Exhibit 19: ...with the skeptics more skewed towards the older population
Age composition of the group not interested in autonomous driving



Source: Goldman Sachs Global Investment Research

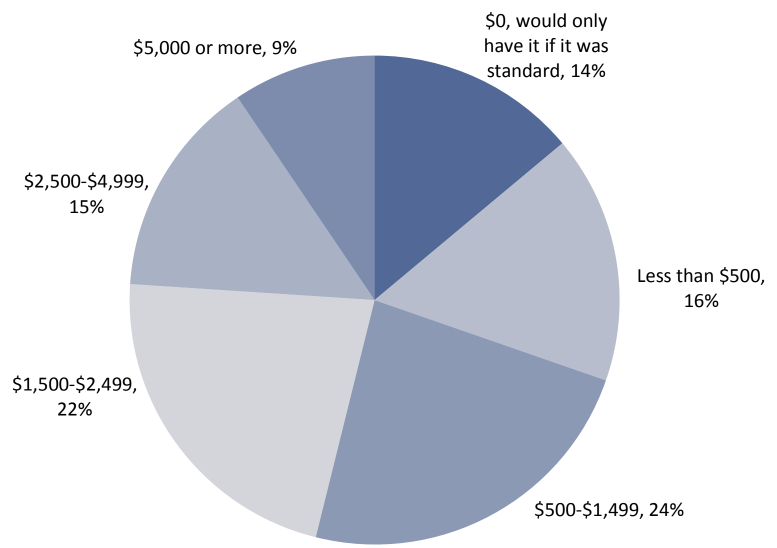
Value for money may need substantiation; reliability a concern, more so than data privacy

When asked about the incremental price they would be willing to pay for the additional features, only 24% of the respondents were willing to pay $2,500 or more for the technology (**Exhibit 20**). With fully autonomous vehicle capability expected to cost approximately $3,000 per our cost build-up, additional efforts will be required by auto OEMs to convince consumers of the value proposition and why autonomous driving features are worth the additional expenditure.

In terms what causes concern for buyers, equipment/system reliability is paramount for approximately 32% of respondents (**Exhibit 21**). Price was also a significant barrier, accounting for 18% of respondents' greatest concern – supported by the aforementioned willingness to pay. This further reinforces our view that it is imperative to get the validation step of autonomous driving technology right, a process during which consumers can also be educated about the benefits.

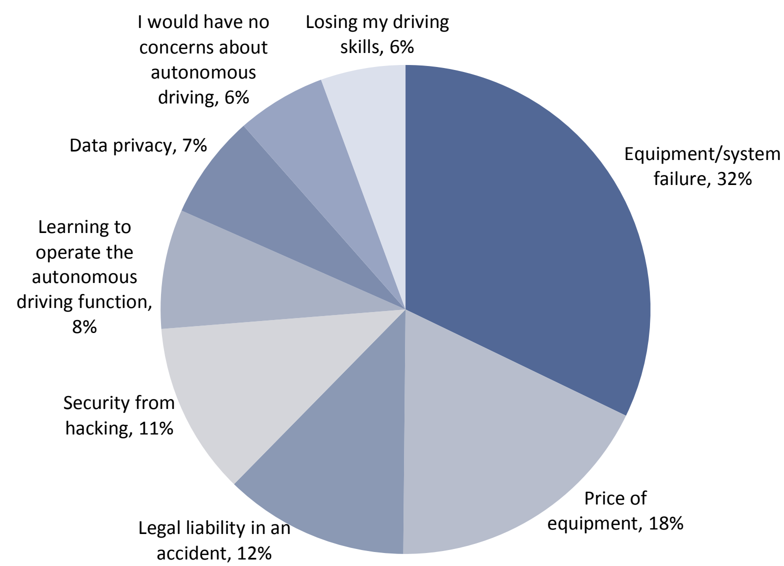
Concerns about data privacy and hacking, surprisingly, did not come at the top of the list for consumers in the survey. We point to the lack of general awareness on connected vehicles and its pros and cons. However, given the recent hacking incidents covered extensively in the media (involving Jeep and GM's OnStar among others), we believe that the responses could reflect a more skeptical picture if conducted now. Going forward, we see security concerns representing one of the most significant barriers for the automakers, apart from the lack of appropriate regulations, which could hinder the development and penetration of autonomous cars.

Exhibit 20: Value for money remains a consideration too…
When buying a car, how much extra would you be willing to pay for fully autonomous driving capabilities?



Source: Goldman Sachs Global Investment Research

Exhibit 21: ..with price coming back as a consideration after equipment reliability
What factor are you most concerned about regarding autonomous driving?



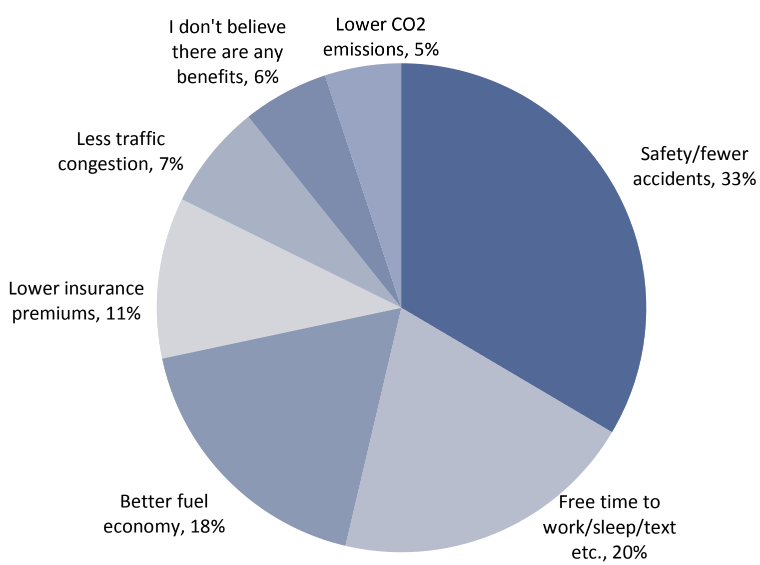
Source: Goldman Sachs Global Investment Research

Safer driving, free time are seen as the main benefits from autonomous driving

Our survey respondents were asked to identify in which feature of fully autonomous vehicles they were most interested in (**Exhibit 22**). Enhanced safety and fewer accidents topped the list, with 33% respondents identifying it as the most interesting benefit of autonomous vehicles. We believe that this is supported by the expected accident reduction and lower traffic fatalities versus the status quo highlighted by our analysis in the section "Why should we care about autonomous vehicles? Economic/societal benefits abound." More free time and better fuel economy came in second and third, respectively, in terms of attractive features for the customers. Interestingly, we were surprised by the low amount of respondents (approximately 11%) who cited lower insurance premiums as a key benefit.

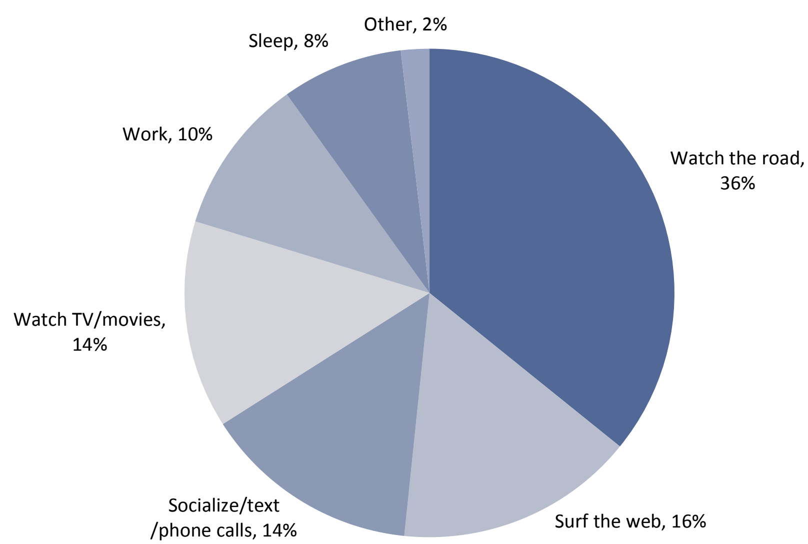
Honing in specifically on the question of free time, we sought to examine how customers would spend the extra time they had in their vehicle (**Exhibit 23**). Over one-third of the respondents indicated they would be "watching the road." We believe this response is potentially skewed given the aforementioned concern of autonomous driving system reliability – but further brings us back to necessary consumer education and technology validation. The next 16% of respondents indicated they would spend more time surfing the web – which could be a potential boost to m-commerce, and 14% indicated they would spend the time socializing (texting and phone calls), and another 14% would opt to watch TV/movies. We believe our survey results highlight the need for incremental infotainment and connectivity features within the vehicle, which we note could also be a differentiator for the automakers.

Exhibit 22: Fewer accidents and free time dominate as motivators for adoption…
What benefit of autonomous driving are you most interested in?



Source: Goldman Sachs Global Investment Research

Exhibit 23: …with free time filled occupied with being alert and leisure
How would you mainly use your free time in an autonomous vehicle, while the car is driving?



Source: Goldman Sachs Global Investment Research

When we distill this down, we believe that consumers' wariness of new autonomous driving technology, limited willingness to pay, and inclination towards infotainment features of a car, leaves the industry players in an interesting position. Even though our trajectory of autonomous vehicles suggests a launch around 2025, we believe that auto OEMs need to intensely focus on developing autonomous features that are automotive grade, in addition to driving the message about the advantages across to the consumers who are imperative to the success of the technology.

Enabler 6 – Cyber security: A cause for concern, though the industry is adapting

Main concerns

As vehicles become increasingly digital and automated, the possibility of hacking becomes an important issue. The more connected the car, the greater the vehicles' cyber-attack surface. One of the primary concerns when it comes to autonomous vehicles is the potential to hack into its data. Autonomous vehicles are essentially huge data collection devices that track the drivers' whereabouts and other personal customer information. Another concern that has attracted more attention in the press recently is safety. Many fear that hackers can take over and manipulate connected cars. The profile of this issue has been recently raised by a number of vehicle hacks presented on Youtube and in the press, most notably the recent wireless hack of a Jeep Cherokee featured in Wired.

A hacker can penetrate into a vehicle's network through either physical or wireless access. Physical access requires directly connecting to the OBD-II port (i.e., on-board diagnostics), inserting discs or connecting USBs, iPods, or other devices to the vehicle. Additionally, hackers can gain wireless access through Bluetooth, remote keyless entry, tire pressure monitoring systems, WiFi, RFID car keys, GPS, satellite radio, traffic message channel, or through the vehicle's telematics systems. To date, most car hacks have required direct access to the vehicle's systems, but more recent experiments like the Jeep Cherokee have successfully hacked into cars wirelessly and taken control.

Exhibit 24: Attack surfaces

Vulnerability class	Channel	Visible to User	Scale	Full Control	Cost
Direct physical	OBD-II port	Yes	Small	Yes	Low
Indirect physical	CDs, WiFi, connection to devices	Depends	Small-medium	Yes	Depends
Short range wireless	Bluetooth	No	Depends	Yes	Medium
Long range wireless	Cellular	No	Large	Yes	High

Source: AutoSec

Current solutions

There are a few key differences between the networks of computers versus those of cars. First, there is not one central point of communication in a vehicle. Each electronic control unit (ECU) needs to be protected. Second, commands to and from these units need to be acted on immediately in order for the vehicle to function property, which leaves limited time for complex authentication. Third, it is difficult to update the software on a vehicle without taking it to the dealership, unless it has OTA update capability.

In the past, cybersecurity had not been as much of a concern for vehicles given relatively low levels of connectivity and a very diffuse system of domains connected to the can-bus (controller area network interconnecting internal components) with a wide array of proprietary technologies. But increasing connectivity presents a challenge, as does the beefed up processing capability and embedded functionality of autonomous vehicles where the driver is increasingly being taken out of the process.

Current solutions in the market are firewalls, intrusion prevention/detection system solutions, penetration testing, cryptography, and other embedded security solutions. A firewall can be used to separate the control network from the communications and entertainment network, where many of the hacks can originate from. One of the newer solutions is IPS (intrusion prevention system), which scans all traffic in the vehicle's network with different algorithms to identify any abnormal activity or irregularities. Embedded security can protect the 80-100 ECUs in a vehicle often using cryptography. Another complementary method is penetration testing, which essentially allows researchers to use all possible methods to infiltrate the vehicle's network and report all vulnerabilities back. Having said that, the idea of automotive cybersecurity is still nascent and more work still needs to be done in order to better secure automotive networks.

As concerns rise with additional connected car hack demonstrations, most OEMs are expediting plans to secure their vehicles and have begun working with cybersecurity companies. For example, Volvo has partnered with CGI to improve authentication, GM has developed lockout codes for infotainment systems, Ford has built in firewalls, Toyota is working with Cisco to use its firewalls and gateways, and Tesla is using hackers to discover weaknesses in their systems. Additionally, the Alliance of Automobile Manufacturers and the Association of Global Automakers have recently announced their efforts to form a center to counter automotive cybersecurity threats. Significant strides are also likely to be made by designing vehicles and their interconnected domains with cybersecurity in mind.

Key players

Given that automotive cybersecurity is a relatively new phenomenon, there are only a few players in the market. We highlight some of the larger players below:

Argus uses its IPS solution to identify real-time threats on a car's network. It utilizes its deep packet inspection algorithms to scan all the traffic on the network and report any abnormal activity.

TowerSec offers intrusion prevention/detection system solutions that monitor internal and external communication channels in real-time. Its solution is easily integrated into the can-bus, telematics controllers, and infotainment unit.

Redbend offers connected car software management, firewalls between infotainment systems and other ECUs, risk assessments consulting, zero-day vulnerability mitigation, sandboxing, and ECU consolidation using virtualization technology. The company historically offered mobile software but has recently started offering automotive security solutions.

Arilou provides a type of firewall agent that integrates into the existing CAN network and blocks any attempts to send prohibited messages through the network.

Security Innovation, in addition to its main application security focus, offers Aerolink, its high speed communications security for connected vehicles. It is able to perform 450 verifications per second with crypto acceleration.

Utimaco offers a cryptographic, hardware-based solution that secures communication commands between the car's internal and external channels.

Escrypt provides embedded security solutions for the car, such as cryptographic software with high verification speeds and hardware modules at the ECU level.

Current estimates have costs of these cybersecurity solutions at around $10-$20 for the software, but we believe the cost will go up as the security needs rise with a package including encryption chips, gateways, and antivirus cards, among other things likely to cost well north of this. As we are in the very early innings of automotive cybersecurity, there will likely be more entrants into the market in the future. Existing, traditional cybersecurity players have recently focused on mobile and other new endpoint security solutions and may wish to move to automotive offerings afterwards.

Timeframe

Despite the recent efforts and initiatives by the auto OEMs, we believe the cybersecurity solutions being placed in vehicles fall short of what will be required on L3 and L4 vehicles and it is likely that some AVs will launch before being fully secure. Several experts we spoke with expected the OEMs to fix as they go, unless there is a government mandate or some new regulation in place. Therefore, while the need for cybersecurity is known among automakers, they will likely not see it as a barrier to production – unless the threat accelerates or regulation makes it a necessity.

A continuing shift in the balance of power towards suppliers/new entrants

While the timing of autonomous vehicle adoption may be uncertain, the one thing that is clear is that AVs will have a significant impact on the industry itself. As technology and software become a larger part of a vehicle's DNA, the supply base will have a larger and larger influence on the product, as this is where much of the innovation is coming from. And all of this will come at a time when the relevance of traditional OEMs brands could arguably diminish as 1) mobility moves from being a product to a service lessening the importance of certain performance characteristics that have differentiated nameplates in the past, 2) we could see disruption from new entrants like Apple and Google which are used to dealing with short product cycles demanded by a new generation of mobility consumer. As we have noted in the past, the OEMs are well aware of this challenge which was well summarized recently by Bill Ford, Executive Chairman of Ford, who was quoted in Automotive News (May 28, 2015) as saying "If we all collectively did nothing and we stayed with the current business model, we could just end up being assemblers of other people's stuff with a very low-margin, high fixed-cost business."

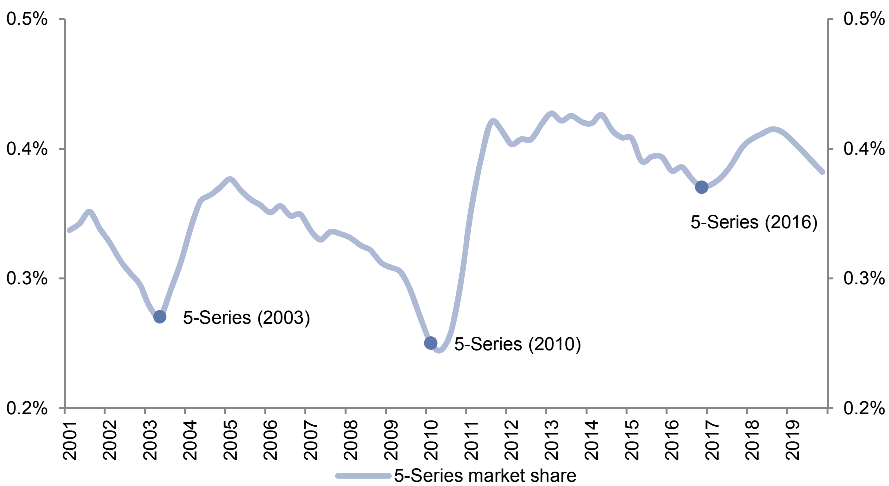
The car as a product and a service

We believe that the advent of autonomous driving will see cars becoming simultaneously both a product, and a service. From a product perspective, the car will primarily comprise the physical vehicle structure (like today), but with significantly upgraded capabilities in the areas of active safety, telematics and infotainment, and powertrain. The service elements will determine how we engage these vehicles, and while exactly how this works is yet to be determined, it is clear that the process will be managed via software that connects cars to users and to each other.

Software cycle runs faster than the hardware cycle

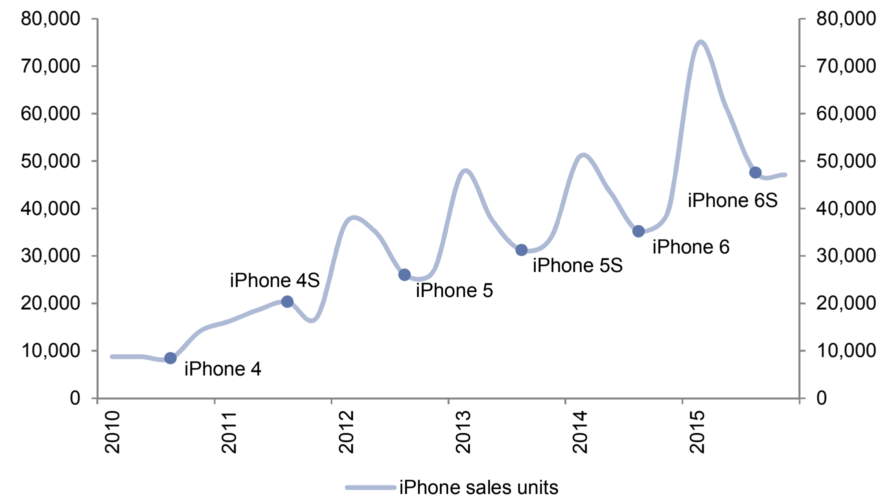
We expect the continued marriage of technology into new vehicles to create an interesting clash between product lifecycles. For instance, we think the software piece of the puzzle will continue to evolve at a significantly faster rate than the physical hardware that makes up the vehicle. Software (and some technological hardware) could move to a 12-24 month cycle, much like smartphones today. Here, the constantly declining cost of processing power and the low cost of rolling out (remotely) updates should permit the acceleration. Software will also grow in importance as a factor in differentiating manufacturers from one another. By contrast we see no reason to believe that the refresh rate for the physical vehicle (hardware) is likely to change dramatically: i.e., approximately seven years for a model – largely synchronized with the life of manufacturing equipment, and 1-2 model cycles for platforms and modular architectures).

Exhibit 25: Vehicle programs are typically replaced on a 7-year cycle…
5-Series market share against launch dates



Source: IHS Global Insight.

Exhibit 26: … while smartphone products are replaced on 1-2 year cycles
iPhone volumes against launch dates



Source: Goldman Sachs Global Investment Research.

Adapting to a dual-speed world

To remain competitive in this type of environment, manufacturers will need to adapt to a dual speed product refresh cycle.

- **Changes are already in motion:** Based on recent supplier conversations that we have had, we believe that some suppliers are over-specifying the processors in its microcontrollers to make them more easily upgradable mid-lifecycle. Daimler management already acknowledges that the industry will need to adapt to the challenge of a dual speed product cycle.
- **Other industries have been here before:** In aerospace, fighter jets illustrate that the physical hardware (some jets have been in service for decades) can be used through multiple equipment and software upgrades (e.g., the Panavia Tornado entered service in 1979 and began its latest upgrade cycle in 2008).
- **Beneficiaries: Suppliers and OEMs with scale.** The suppliers will benefit from this shift: largely since they are overwhelmingly responsible for the software content within vehicles currently. For the incumbent OEMs themselves, scale will be increasingly important as a basis for covering the fixed costs of managing the transition through intelligent modularization of software and hardware components.

How to invest in autonomous driving

While the revenue pool analysis shown earlier in this report suggests that the growth opportunity looks to be very large, we need a way to put it into terms for individual companies because, ultimately, it is through public equities that most investors will be able to monetize this theme.

Our approach looks at 35 individual companies with exposure to ADAS and takes each company's current market share in this subsector (either of the total ADAS market or of a particular component group within the market) and projects it out 5, 10, and 15 years. In most cases this will correspond to the current share, though in certain cases we tweak forward share assumptions – for instance if the entry/exit into a new component group will likely significantly change share. By doing this we arrive at the potential ADAS revenue for each company in 2020, 2025, and 2030 which we compare to the 2014 consolidated base of revenue for each company to calculate a CAGR. This represents the theoretical contribution that ADAS could have on the company's individual growth outlook over this time period each year.

The net result is that, for the group of 35 companies, ADAS is likely to be a quite meaningful tailwind. As we highlight in **Exhibit 27** below we estimate this could add an average of 110bp to top-line growth annually over the next five years. Looking out over 10 years the number rises to a staggeringly high 300bp driven by a threefold increase in revenue we project from 2020 to 2025. This is driven by the fact that we expect ADAS to reach 100% penetration in the US and Europe with about 14% and 23% L3 penetration, respectively. Looking out further to a 15-year CAGR, which takes us to 2030, suggests a 190bp contribution from ADAS, a slightly slower growth rate, but still a robust contribution driven by the continued rotation from ADAS to L3 and L4 automation. The detail surrounding the 2025 and 2030 CAGRs is shown in **Exhibit 28**. We note these averages exclude Mobileye so as to not overinflate the average given the company's unique status as an ADAS/AV pure play.

Keying off the five-year CAGR, which we think is the most investible of the three timeframes, we would put the company results into four buckets.

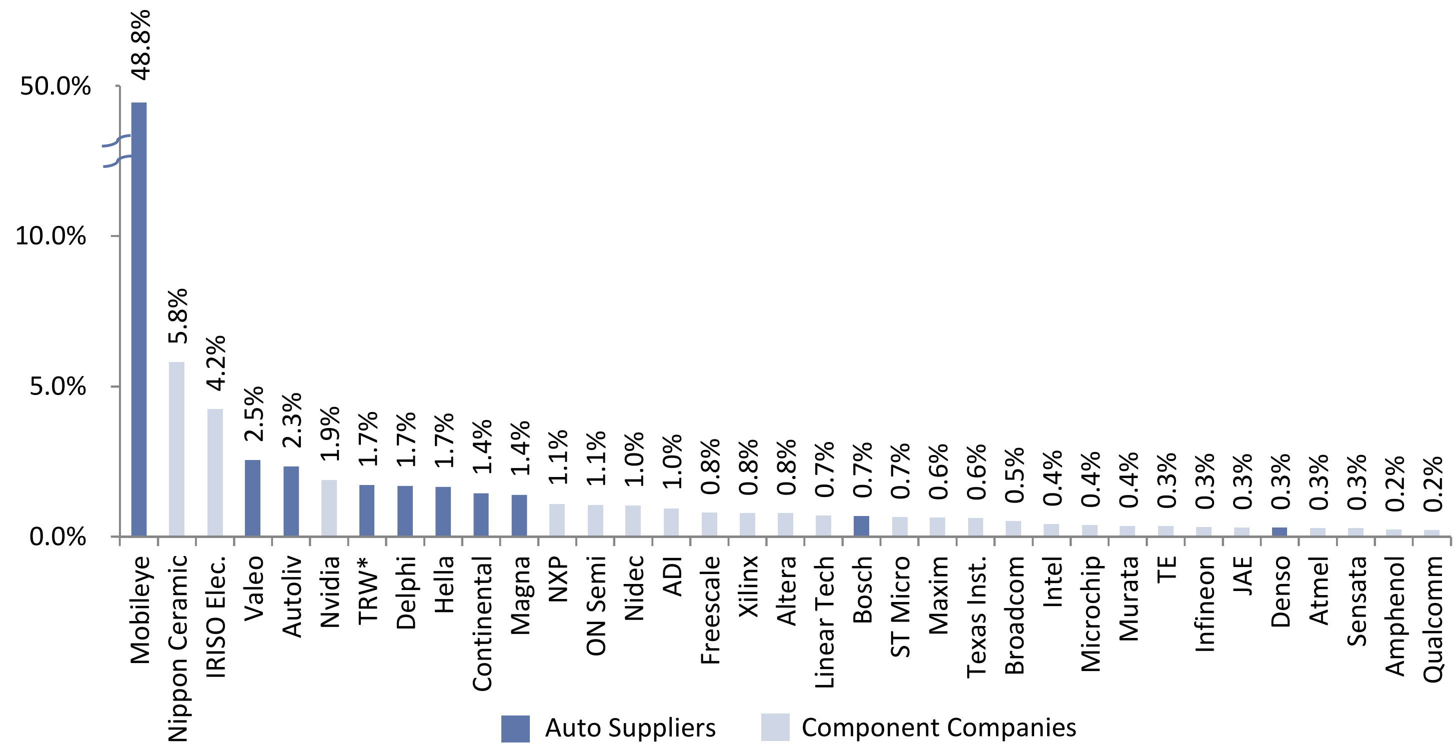
1) ADAS pure plays, of which there is only Mobileye, which not surprisingly sees the highest contribution with an implied revenue CAGR of nearly 50% over the next five years.

2) Among the listed traditional auto suppliers with exposure to ADAS/AVs, the most impacted are Valeo, Autoliv, and Delphi, which could see impacts of 250bp, 230bp, and 170bp over the same period, respectively.

3) Japan technology component makers Nippon Ceramic and IRSIO with tailwinds of 580bp and 420bp respectively.

4) The last bucket contains the more diversified semi component equipment manufacturers for which autos is just one of many end markets, with ADAS being a subset of that. But we note for companies like Nvidia, NXP, and ON Semi, ADAS/autonomous still has the potential to be meaningful with an estimated boost to top line of 190bp for Nvidia and approximately 100bp for the rest.

Exhibit 27: See an average of 110bp of annual revenue contribution from ADAS/AV over the next five years
Annual revenue contribution from ADAS – five-year CAGR



Note: TRW recently acquired by ZF Friedrichshafen.

Source: Goldman Sachs Global Investment Research.

Exhibit 28: If we look out to 2025 and 2030 the implied annual contribution to revenue growth rises to 300bp and 190bp

Annual revenue contribution from ADAS – 5-, 10- and 15-year CAGR

Company	5-Year Cagr	10-Year Cagr	15-Year Cagr	NTM P/E Multiple
Mobileye	48.8%	67.0%	22.4%	71.4x
Nippon Ceramic	5.8%	9.0%	4.6%	23.7x
IRISO Elec.	4.2%	4.4%	2.8%	15.2x
Valeo	2.5%	7.8%	5.0%	11.8x
Autoliv	2.3%	7.2%	4.6%	11.7x
Nvidia	1.9%	4.6%	2.4%	12.5x
TRW*	1.7%	5.4%	3.6%	21.9x
Delphi	1.7%	5.4%	3.6%	N/A
Hella	1.7%	5.3%	3.5%	12.6x
Continental	1.4%	4.7%	3.2%	11.9x
Magna	1.4%	4.5%	3.1%	9.3x
NXP	1.1%	3.2%	2.1%	14.2x
ON Semi	1.1%	3.0%	1.8%	10.0x
Nidec	1.0%	3.8%	2.6%	22.3x
ADI	1.0%	2.8%	1.7%	16.4x
Freescale	0.8%	2.4%	1.6%	20.5x
Xilinx	0.8%	2.6%	2.0%	36.5x
Altera	0.8%	2.6%	2.0%	17.4x
Linear Tech	0.7%	2.1%	1.3%	18.5x
Bosch	0.7%	2.3%	1.7%	N/A
ST Micro	0.7%	2.0%	1.3%	20.6x
Maxim	0.6%	1.9%	1.2%	17.4x
Texas Inst.	0.6%	1.8%	1.2%	18.1x
Broadcom	0.5%	1.7%	1.2%	18.0x
Intel	0.4%	1.1%	0.6%	13.0x
Microchip	0.4%	1.3%	1.0%	15.9x
Murata	0.4%	1.1%	0.6%	14.8x
TE	0.3%	1.0%	0.7%	8.4x
Infineon	0.3%	1.0%	0.7%	13.7x
JAE	0.3%	0.9%	0.6%	14.0x
Denso	0.3%	1.0%	0.8%	19.5x
Atmel	0.3%	1.0%	0.8%	14.0x
Sensata	0.3%	0.8%	0.5%	16.4x
Amphenol	0.2%	0.8%	0.5%	19.5x
Qualcomm	0.2%	0.8%	0.6%	11.5x
Average ex. Mobileye:	**1.1%**	**3.0%**	**1.9%**	**16.3x**

Note: TRW recently acquired by ZF Friedrichshafen.

Source: Goldman Sachs Global Investment Research.

So what could this mean in terms of actual equity value created? While any estimate will have flaws mostly because its impossible to tell what is currently discounted by the stocks, its informative to apply the individual average sector operating margins to the incremental ADAS/AV revenue and then use a simple EV/EBIT multiple (for the market) to get at what the potential EV creation could be. As we show in **Exhibit 29** below, the implied value creation could be substantial, worth $49bn of market cap in 2020, $161bn in 2025, and $312bn in 2030.

Exhibit 29: The potential EV creation from the ADAS/AV opportunity could be extensive
Implied value creation using market multiples

	2020				2025				2030			
	Revenue	EBIT Margin	EV/EBIT Multiple	Assumed EV	Revenue	EBIT Margin	EV/EBIT Multiple	Assumed EV	Revenue	EBIT Margin	EV/EBIT Multiple	Assumed EV
Global Auto Suppliers	$20,784.2	12.5%	13.0x	$33,774.39	$70,827.83	12.5%	13.0x	$115,095.23	$142,362.44	12.5%	13.0x	$231,338.96
US & European Component Companies	$5,315.6	20.0%	13.0x	$13,820.49	$15,730.43	20.0%	13.0x	$40,899.11	$27,624.18	20.0%	13.0x	$71,822.87
Japanese Component Companies	$917.3	12.0%	13.0x	$1,430.92	$3,031.03	12.0%	13.0x	$4,728.41	$5,814.61	12.0%	13.0x	$9,070.80
Total				**$49,025.8**				**$160,722.7**				**$312,232.6**
Current Market Cap				$701,196.8				$701,196.8				$701,196.8
% of Current Market Cap				7.0%				22.9%				44.5%

Note: Bosch & TRW excluded from market cap calculation.

Source: Goldman Sachs Global Investment Research

Exhibit 30: Snapshot of companies with ADAS/AV exposure included in our sensitivity analysis

Company	Ticker	Headquarters	Market Cap (mn US $)	Comments
Global Auto Suppliers				
Autoliv	ALV	Sweden	$10,226	Automotive supplier focusing on active and passive safety systems.
Continental	CONG.DE	Germany	$44,189	Automotive supplier specializing in tires, brake systems, automotive safety, and other components.
Bosch	n/a	Germany	n/a	Engineering and electronics company producing automotive components, industrial products, and building products.
Delphi	DLPH	U.K.	$23,167	Automotive supplier offering electrical distribution, powertrain, and electronics components.
Denso	6902.T	Japan	$38,191	Automotive supplier formerly a part of Toyota, producing a variety of systems components.
Hella	HLE.DE	Germany	$4,670	Automotive supplier focused on lighting and electronic components.
Magna	MGA	Canada	$20,781	Automotive supplier offering a full range of automotive components.
Mobileye	MBLY	Israel	$11,564	ADAS pureplay focused on vision algorithms.
TRW	n/a	U.S.	n/a	Automotive supplier specializing in safety and chassis components, recently acquired by ZF Friedrichshafen.
Valeo	VLOF.PA	France	$10,602	Automotive supplier providing a range of automotive components for thermal, visibility, powertrain, and driver assistance systems.
Global Component Companies				
Analog Devices, Inc.	ADI	U.S.	$18,598	Semiconductor manufacturer offering a portfolio of digital signal processing and integrated circuits.
Altera	ALTR	U.S.	$15,410	Semiconductor provider specializing in custom logic solutions.
Amphenol	APH	U.S.	$16,703	Provider of connectors, sensors, electronic components, and cabling to a broad set of end markets including automotive, consumer, and industrial.
Atmel	ATML	U.S.	$3,429	Semiconductor provider specializing in microcontrollers, touch solutions, logic, memory, and radio frequency components.
Broadcom	BRCM	U.S.	$32,802	Semiconductor company specializing in wireless and broadband communication.
Freescale	FSL	U.S.	$11,743	Semiconductor provider focused on processing and sensing solutions.
Infineon	IFXGn.DE	Germany	$12,970	Semiconductor company offering, previously a part of Siemens, offering solutions for automotive and industrial sectors.
Intel	INTC	U.S.	$146,290	Semiconductor manufacturer specializing in processors found in personal computers.
IRISO Elec.	6908.T	Japan	$556	Connectors provider headquartered in Japan offering solutions for a variety of applications such as board to board and sockets.
JAE	6807.T	Japan	$1,601	Connectors manufacturer headquartered in Japan providing electrical connectors such as HDMI, PCI express, and board to board.
Linear Tech	LLTC	U.S.	$10,067	Semiconductor company specializing in high performance analog integrated circuits for a variety of industries.
Maxim Integrated Products	MXIM	U.S.	$9,901	Semiconductor components maker which designs, develops, makes linear and mixed signal integrated circuits.
Microchip Tech.	MCHP	U.S.	$9,518	Designs and manufacturers microcontrollers, related mixed signal and memory products, and application development systems.
Murata	6981.T	Japan	$30,957	Electronics components manufacturer, based in Japan, which makes MLCC, filters, wireless modules among other things.
Nidec	6594.T	Japan	$22,565	Japan based precision motors manufacturer used in automotive, Industrial, appliances and HDD.
Nippon Ceramic	6929.T	Japan	$348	Japan based company engaged in the development and sale of electronic components including ultrasonic and infrared sensors, sensor lights.
Nvidia	NVDA	U.S.	$12,982	Semiconductor manufacturer involved in visual processing and also processors that allow running of high-performance applications.
NXP Semiconductor	NXPI	Netherlands	$22,125	Semiconductor company that provides high performance mixed signal and standard product signal solutions.
ON Semiconductor	ON	U.S.	$4,509	The company which offers a portfolio of analog, digital and mixed signal ics, image sensors and custom devices for specific electronic system solutions.
Qualcomm	QCOM	U.S.	$89,921	An American semiconductor company that provides wireless telecommunications products and services.
Sensata	ST	U.S.	$7,965	Manufacturer of sensors and controls with products for the automobile subsystems of engines, air conditioning, ride stabilization.
STMicroelectronics	STM	Switzerland	$6,401	Semiconductor company with a range of products used in telecom, automotive, consumer electronics and industrial sectors.
TE Connectivity	TEL	U.S.	$25,857	Provider of connectors, sensors and electronic components for the automotive, industrial, consumer, and data communications end markets.
Texas Instruments	TXN	U.S.	$51,184	A semiconductor design and manufacturing company that develops analog Ics and embedded processors.
Xilinx	XLNX	U.S.	$11,742	Technology company that offers complete programmable logic solutions.

Source: Company reports and GS research estimates.

Autonomous cars will cut auto insurance demand…but other dynamics are closer at hand

This section is authored by Goldman Sachs Insurance Analyst Michael Nannizzi.

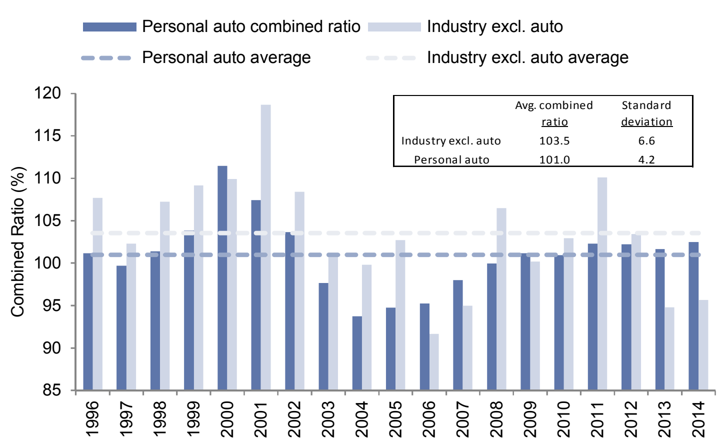
Autonomous cars are an ominous theme for auto insurers, as the prospect of removing human involvement in driving activity could effectively torpedo the concept of auto liability coverage, a market which represents almost $200bn in domestic annual premiums. However, the path to AV has more significance to insurers, as the business could materially change before AV goes mainstream.

Why does it matter? Auto insurance is a big business overall…and particularly for a select few

Auto insurance is a large component of the overall P&C market in the United States, representing nearly 40% of total net written premiums. But it is not only important because of its size; as we show in **Exhibit 31**, auto insurance has been not only more profitable than the rest of the industry but also much less volatile. This makes sense given that the auto insurance loss experience runs close to a normal distribution, where "tail" events are unlikely (i.e., people tend to drive away, not walk away from hurricanes and tornadoes). Homeowners insurance, by comparison, has 'fatter tails' as losses tend to be large when they happen and come in bunches, and homes cannot get out of the path of incoming weather. In addition, because auto insurance can be written with more operating leverage (three dollars of premiums for every dollar of capital vs. parity for most other products), the equity returns for profitable writers are even better. Certain underwriters, such as GEICO and Progressive (and to a lesser degree Allstate and State Farm), rely on auto insurance as the core element of enterprise profitability (**Exhibit 32**).

Auto insurers are disproportionately large advertisers and thus any impact to their profitability could have important knock-on impact on other elements of the insurance value chain (like agents) as well as those industries that benefit from the industry's substantial advertising budget. We note that ALL, PGR and GEICO represent 12% of the industry's aggregate written premiums (or 29% of industry auto premiums) but represent over 50% of the industry's nearly $5bn in annualized advertising dollars.

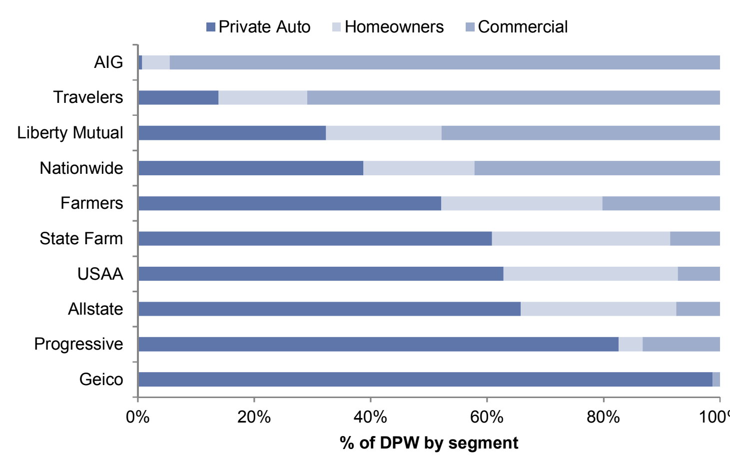
Exhibit 31: Auto insurance has a better profit profile than the industry
Auto combined ratios vs. the rest of the industry



	Avg. combined ratio	Standard deviation
Industry excl. auto	103.5	6.6
Personal auto	101.0	4.2

Source: SNL Financial, Goldman Sachs Global Investment Research

Exhibit 32: GEICO and Progressive rely the most on auto for profitability
Business lines of top underwriters by NPW



Source: SNL Financial, Federal Highway Administration

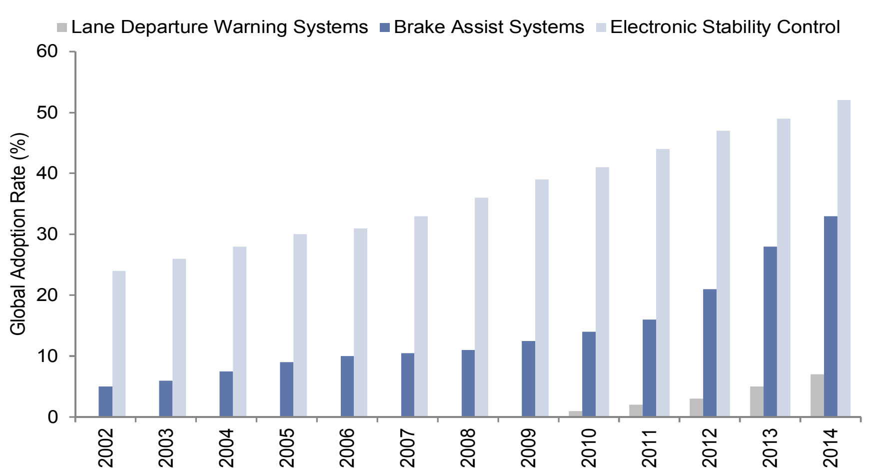
Better technology has resulted in fewer accidents, but today there appears to be an offset…

Vehicles are continuing to see safety improvements in the form of ADAS (Advanced Driver Assistance Systems), as components such as sensors that were previously reserved for luxury vehicles are now being offered as standard features on mainstream models. Frontal collision warnings and collision mitigation braking systems have shown potential 10%-15% and 23% reductions in crashes, respectively. Both technologies have becoming increasingly accessible, with over 25% of car models offering autobrake and over 50% offering front crash prevention in 2015. Since 2012, adoption is up 16% for autobrake, and 31% for front collision prevention. Adaptive cruise control, another technology that has so far been effective in preventing crashes, has been estimated to have reduced collisions by 17% on highways. Additionally, lane departure warnings have been shown to help drivers maintain their lanes by up to 34%, and are another area of ADAS which has potential to significantly reduce traffic accidents.

While auto safety technology continues to improve and become more common, many drivers remain unaware of some of these technologies, which imply there is room for further improvement. In a survey by the University of Iowa Public Policy Center, 65% of those questioned were unfamiliar with adaptive cruise control. Close to 42% of respondents indicated they did not know what a forward collision warning system does. This lack of consumer awareness could simply be a function of the relatively short amount of time these features have been on the market as well as slow adoption into mainstream models by auto manufacturers.

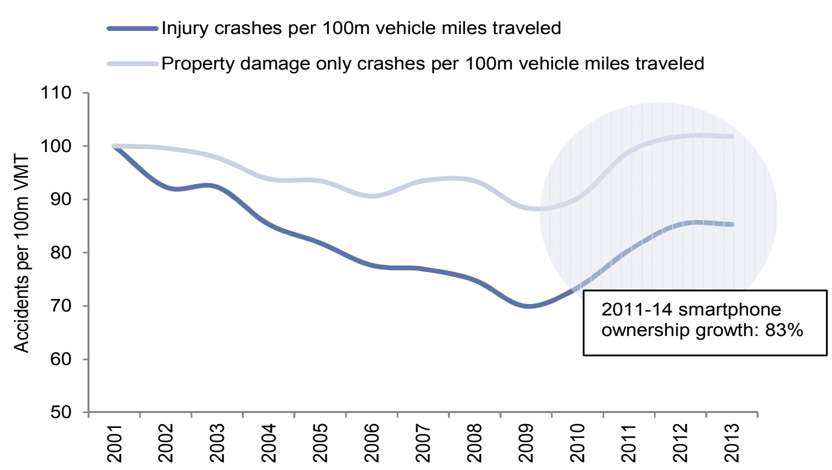
While new technologies such as ADAS are promising developments in preventing car crashes and reducing fatalities, distracted driving has emerged as a negative externality of a more connected world. As of 2014, 90% of American adults have a mobile phone which is up only modestly from 83% in 2011, but smartphone penetration among US adults rose from 35% to 64% over the same period. Smartphone penetration has also coincided with a significant uptick in social media usage and texting activity, and according to the National Safety Council, one in four crashes involves cell phone usage. According to a study from the Virginia Tech Transportation Institute, drivers that engage in "visual-manual subtasks" (e.g., reaching for a phone, texting) increased their chance of crashing by 3x. We believe this social development partially explains why continued improvement in safety features has not led to a consistent decline in accident frequency, and is likely to remain an issue so long as technology enables driver distraction.

Exhibit 33: Adoption of safety systems continues to increase…



Source: AD Little, Goldman Sachs Global Investment Research

Exhibit 34: …while vehicle crash rates have recently been on the rise



Source: Federal Highway Administration, Goldman Sachs Global Investment Research

…and the flip side of better technology has been consistently higher average accident cost

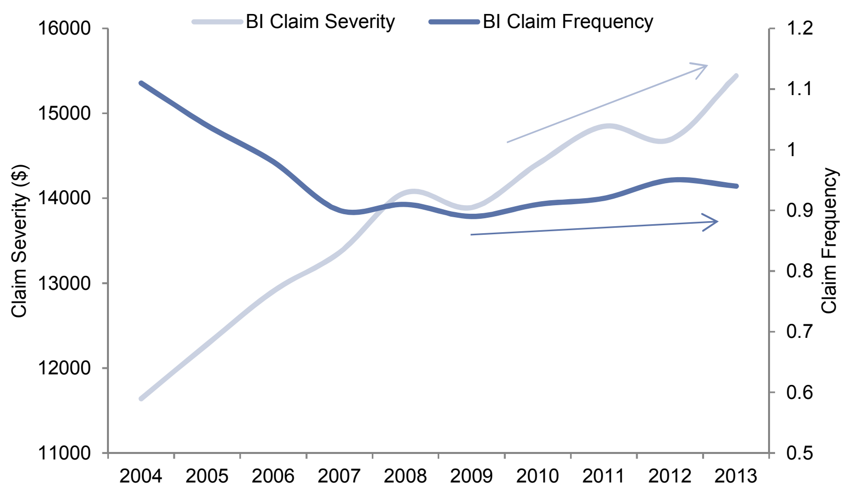
As the technological foundation of autonomous vehicles permeates the auto market, loss experience is likely to both improve and become more predictable, ultimately exerting downward pressure on insurance premiums. The path to adoption is likely to be slow, however. Our Autos analysts expect that fully autonomous cars will not begin to be available in North America for another 10 years and believe that full changeover of vehicles in operation is unlikely to occur before 2060. During this extended implementation period, we expect the impact on insurance will be a function of how improved technology will impact overall losses, including both frequency and severity.

1) **Frequency:** It is unclear how well driverless vehicles will interact with traditional drivers, and we expect that until Level 3 and Level 4 represent the majority of vehicles on the road, which we project not to occur until approximately 2035, accident frequency is unlikely to exhibit a step function decline but more likely follow the trend we have seen from improvements to-date.

2) **Severity:** As we pointed out earlier in this report, we expect Level 3-4 hardware to cost approximately $3,000. Given that average claim cost today is less than $16,000, the cost of hardware alone is likely to drive up future accident costs.

Supporting our view of the expected trend in severity is **Exhibit 35**, which shows that over the past decade severity has continued to rise. We attribute this trend to the fact that vehicle replacement cost has risen in part due to the fact that more advanced vehicles cost more to fix. As more manufacturers implement expensive technology we expect this trend to continue. The frequency trend is more nuanced, as in the mid 2000's we saw a precipitous decline in accident frequency abate in 2007 despite the fact that safety technology has continued to proliferate. But other factors may be contributing to the somewhat counterintuitive trend in auto frequency in recent years, and chief among them, in our view, is distracted driving. Therefore, overall we expect that until L3 and L4 proliferate, severity trends are likely to continue to rise while frequency trends are likely to be more unpredictable as benefits from technological advance may be offset by the negative impact of technological advance on driver distraction.

Exhibit 35: Frequency has flattened despite the continued roll-out of technology, while severity has continued to trend higher
For each 100 insured cars in 2013, there were 0.94 Bodily Injury (BI) claims at $15.4k average cost



Positive	Negative
+ Improved frequency	- Distracted driving
+ Driver safety	- Increased miles driven

Source: III, Goldman Sachs Global Investment Research

Near term, cultural shifts and connected cars will have a greater impact on insurance than AV…

Over the next 20 years, we see two trends that are likely to have a more immediate impact on insurers than autonomous cars: connectivity and cultural shifts.

Connected cars

Many auto insurers see connected cars as an interim goal that could broaden opportunities to gather better driving data and as a result provide more accurate pricing. The early pioneer in domestic usage-based insurance (UBI) remains Progressive, although more recently other insurers are bringing UBI solutions to market in an effort to better select the “best” drivers that are confident enough in their skill to have their driving activity monitored. On the hardware side, a shift towards mobile solutions (and away from physical ODBII port devices) is under way, which will reduce the UBI investment considerably for insurers that elect to roll out UBI solutions. But the shift away from dedicated devices and towards more ubiquitous connectivity for vehicles presents additional challenges for insurers. With connected cars, once they fully arrive, driving data will be procured by OEMs. This will reduce the cost of gathering the data for insurers, but that will cause them to cede control of data collection to the OEMs themselves. With connected cars insurers face two risks: 1) encroachment by the OEMs and 2) adverse selection of less sophisticated insurers that are unable to use the data to appropriately price their products.

On the first point, over time OEMs could become comfortable with the underlying UBI risk and choose to hold this risk themselves as opposed to partnering with insurance companies to provide the coverage. BMW, for example, announced last year that it planned to install UBI telematics devices into its vehicles in the UK and that it would partner with Allianz to provide the insurance coverage to customers that meet certain criteria. Over time if the loss experience is stable, BMW may consider taking a greater role in underwriting its customers' risk.

On the second point, insurers that develop the ability to analyze UBI data and price policies will be in the best position to benefit from greater availability of data, and clearly less sophisticated underwriters without these skills are likely to get adversely selected.

Cultural shifts

The role of insurance companies is likely to undergo substantial change over the next 5-10 years as a result of technological and cultural change. Although the trend towards "sharing economies" appears to be the catalyst of a cultural shift, there is more evidence that these new companies are simply responding to a desire by a growing category of consumers (e.g., Millennials) that prefer to "borrow" assets as opposed to owning them. With the advent of pure car-sharing services like Zipcar and the proliferation of ride-sharing services like Uber and Lyft, the incentive for millennials to own vehicles and drive them may recede, and this trend could place pressure on the demand for new vehicles. With regard to insurance there are two main considerations.

1) If households purchase fewer cars, that will likely result in a reduction in demand for personal auto insurance.

2) If consumers eschew driving altogether and rely more on livery services like Uber and Lyft to get around, the driving risk moves from personal to commercial and further cuts the pool of insurance available to pure auto writers.

…but longer-term, a full migration to AV will dramatically shift the pool of insurable auto risk

We expect that on the path to full implementation of automated vehicles, new safety technology will help to reduce accident frequency but as we have seen from technological advances, there is an offsetting impact on severity trends. We expect this "dance" will continue as it has over the previous several years, however there is a risk that a more stable loss profile combined with real-time loss data made available via connected cars will drive greater price competition and thus downward pressure on auto margins.

But once we reach full autonomy, it is likely that much of the premiums that consumers currently pay for auto insurance will move from the personal auto market to the commercial liability market, specifically into the product liability category. We expect that consumers will likely end up paying for the coverage indirectly as auto manufacturers will need to pass through the insurance costs that will become part of their overhead for their autonomous vehicles. Although the liability associated with pure driving is likely to decline, we would expect that liability coverage for other aspects of the risk – i.e. cyber, product defect, and software error – will be substantial and may serve to offset the decline in overall insurance premiums.

The exhibit below attempts to quantify the profit impact of risk migrating out of the personal auto market and into the commercial market at different levels of profitability. If 30% of premiums move out of the personal auto market at a 96% combined ratio, for example, that would imply $1.3bn in auto industry profits moving into the commercial market. Although the timeline to this scenario analysis is extremely long, we believe insurers need to think about this potential outcome and find ways to deliver value to consumers to offset the risk of premium declines in a world where autonomous vehicles become the industry standard. Clearly, pure auto and pure personal lines writers are the most exposed to this risk (**Exhibit 36**).

Exhibit 36: Auto insurers have a lot to lose if autonomous vehicles cause a shift from personal to commercial insurance policies
Sensitivity of auto industry profitability based on 2014 NEP for auto insurers ($mn)

Percentage of Personal Auto Net Premiums

Combined Ratio	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
90%	1,110	2,220	3,330	4,441	5,551	6,661	7,771	8,881	9,991	11,101
92%	888	1,776	2,664	3,552	4,441	5,329	6,217	7,105	7,993	8,881
94%	666	1,332	1,998	2,664	3,330	3,997	4,663	5,329	5,995	6,661
96%	444	888	1,332	1,776	2,220	2,664	3,108	3,552	3,997	4,441
98%	222	444	666	888	1,110	1,332	1,554	1,776	1,998	2,220

Source: SNL Financial, Goldman Sachs Global Investment Research

Case study on cultural shifts: closing in on a solution to the ride-sharing “insurance gap”

As we wrote in our Internet of Things v.4 report in September 2014, ride-sharing services like UberX, Sidecar, and Lyft that permit individuals to drive commercially were resulting in a growing insurance gap. We identified this gap as an area of concern for incumbent insurers, consumers, and drivers, that would likely require explicit resolution, as incumbent insurers were actively looking to incorporate or enforce ‘livery exclusions’ and non-renew policies where these activities were occurring.

Earlier this year, Uber, in conjunction with regulators and insurance companies, developed an insurance model that began to seek approval in a few key states including the largest ride-sharing state (California). This model is summarized in **Exhibit 37** but essentially designates three distinct periods: Period 1, personal driving; Period 2, en route to a fare; and Period 3, driving a passenger commercially. The ride-sharing companies now provide explicit insurance with appropriate limits during Period 3, and Period 1 should be covered by a driver’s personal policy, leaving only Period 2 unaddressed (in Uber’s case, James River is the insurance company that provides the Period 3 coverage).

In recent months, insurers have begun offering policies to cover the combination of Period 1 and 2, so that drivers can ensure they have coverage throughout the entire driving spectrum. We note, however, that there remains some concern on behalf of drivers that incumbent personal insurers may still drop part-time drivers should they expose the fact that they are driving for hire. There remain only a small handful of companies offering coverage which we discuss below, and although it is likely that there are some small gaps within this approach, should more states and insurance companies follow suit the uninsured risk associated with ride-sharing should materially decline.

Exhibit 37: The three-period insurance model for ride-sharing companies
Uber’s rideshare insurance structure for UberX drivers

<table>
<tr><th>UberX Insurance Structure</th><th>Active when…</th><th>Provides…</th></tr>
<tr><td>Period 1</td><td>Driver is online and available</td><td>Liability when applicable insurance not maintained
$50,000 injury, $100,000 total, $25,000 property</td></tr>
<tr><td>Period 2</td><td>Driver is en route to passenger</td><td rowspan="2">$1m liability
$1m uninsured motor injury
Contingent collision and comprehensive coverage (alongside collision coverage from insurer)</td></tr>
<tr><td>Period 3</td><td>Driver is driving with passenger</td></tr>
</table>

Source: Uber, Goldman Sachs Global Investment Research

Exhibit 38: Auto insurers have introduced offerings that fit the ‘new’ model
Summary of rideshare insurance offered by third-party insurers

Other insurance providers	Insurance structure	States available
Allstate	Extends existing personal policy	CO, IL, TX, VA
Erie	Covered under business policy	IL, IN
Farmers	Extends existing personal policy	AR, CO, UT
GEICO	Integrated with GEICO commercial	CT, GA, MD, TX, VA
Metromile	Uber-specific, pay-by-mile	CA, IL, OR, PA, VA, WA
Progressive	Lyft-specific, rates adjusted by mile	PA
USAA	Extends existing personal policy	CO, TX

Source: PolicyGenius, Goldman Sachs Global Investment Research

Why should we care about autonomous vehicles? Economic/societal benefits abound

Part of what makes us confident that Autonomous Driving will be achieved is that the economic and social benefits are manifold. We highlight four in particular: (1) accident reduction, (2) congestion reduction, (3) increased productivity, and (4) mobility expansion. In our analysis, we look into each aspect and quantify potential gross economic benefits that we could expect with the adoption of autonomous vehicles. In **Exhibit 39**, we summarize our findings which suggest savings of approximately $3.5 trillion (equivalent to 5% of current global GDP) that could be achieved with adoption of autonomous vehicles globally. Asia Pacific, in particular, stands to benefit the most from broad autonomous vehicle adoption given its high population of drivers and growing vehicles in use. While we believe that autonomous driving will begin to provide benefits with each additional vehicle, we expect that the full benefits we outline below would be recognized gradually over time as penetration ramps up.

Exhibit 39: We estimate global gross benefits $3.5trn from fully autonomous vehicles
Global Economic Benefits from Autonomous Driving, $ in bn

Global Economic Benefits from Autonomous Driving

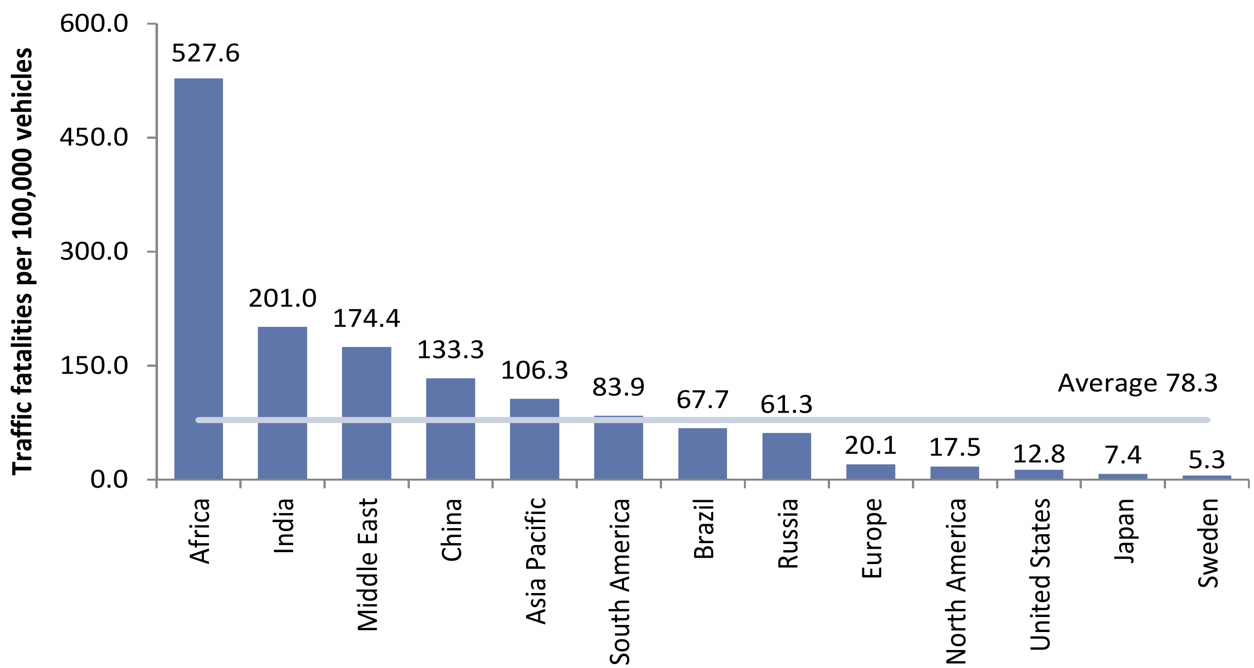
	Accident Reduction	Congestion Reduction	Increased Productivity	Additional Drivers	Total Benefits
United States	$249	$7	$195	$331	**$782**
North America	$261	$10	$199	$352	**$821**
South America	$81	$4	$67	$90	**$242**
Europe	$348	$13	$262	$282	**$904**
Asia Pacific	$439	$15	$321	$499	**$1,275**
Middle East/Africa	$74	$4	$72	$114	**$264**
Global	**$1,202**	**$47**	**$921**	**$1,337**	**$3,506**

Source: Goldman Sachs Global Investment Research.

Lower fatalities/lower accidents

One key benefit from autonomous vehicles is the impact from lower fatalities and lower accidents. As autonomous cars are expected to eliminate roughly 90% of all auto accidents, most of which stem from human error, the benefits we could see are substantial both in terms the reduction of lives lost and in economic terms. In **Exhibit 40**, we see that developing and emerging countries have the most to gain from reduced traffic fatalities. In areas such as Africa, India, and China, transportation could be significantly safer than today, given that auto accidents and fatalities are drastically higher there than in developed countries. We also perform an analysis looking at the economic benefit autonomous vehicles would provide by taking the NHTSA's assumptions for economic costs per accident and applying them to the appropriate vehicles in operation (VIO), fatalities per vehicle, and scaling this by the cost of living for each region to find the economic savings (**Exhibit 41**). The Asia Pacific region stands to gain the most given its high VIO and fatality rate. Globally, we estimate roughly $1.2 trillion in economic savings from reduced accidents and fatalities.

Exhibit 40: Developing countries and emerging markets have the most to gain from reduced traffic fatalities
Traffic Fatality per 100,000 Vehicles



Source: WHO, Goldman Sachs Global Investment Research.

Exhibit 41: We expect savings of $1.2trn globally from a 90% crash reduction rate stemming from fully autonomous vehicles
Global Economic Savings from Accident Reduction, $ in bn

Region	Vehicles in Service	Traffic Fatalities	Fatalities per 100,000 Vehicles	Fatalities per Crash	Total Crashes Annually	Crash Reduction Rate	Average Economic Cost per Crash	Total Economic Savings
North America	309,806,790	52,009	16.8	0.0032	16,320,481	90.0%	$17,751	$260.7
South America	111,520,731	93,604	83.9	0.0159	5,874,861	90.0%	$15,229	$80.5
Europe	400,297,839	79,551	19.9	0.0038	21,087,508	90.0%	$18,320	$347.7
Asia/Pacific	625,014,013	664,580	106.3	0.0202	32,925,454	90.0%	$14,812	$438.9
Africa	40,466,010	213,495	527.6	0.1002	2,131,731	90.0%	$14,423	$27.7
Middle East	64,057,456	111,744	174.4	0.0331	3,374,518	90.0%	$15,266	$46.4
Total	**1,551,162,839**	**1,214,983**	**78.3**		**81,714,553**			**$1,201.9**

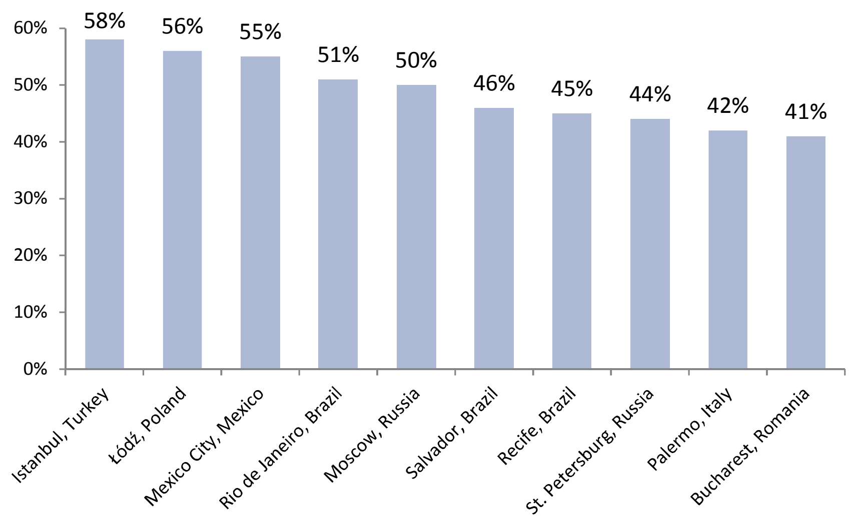
Source: NHTSA, WHO, Goldman Sachs Global Investment Research.

CO2 and fuel saving

We also expect fuel economy savings and CO2 reductions from autonomous driving due to a reduction of auto accidents, smoother traffic flows, and increased lane capacity with the use of platooning. According to the Eno Center of Transportation Research, autonomous cars are expected to increase fuel economy by 31% due to smoother traffic flows and approximately 89% increase in lane capacity. We also factored in the causes of delays, of which 50% were due to normal traffic patterns, 25% due to traffic incidents, 15% due to weather, and 10% due to roadwork.

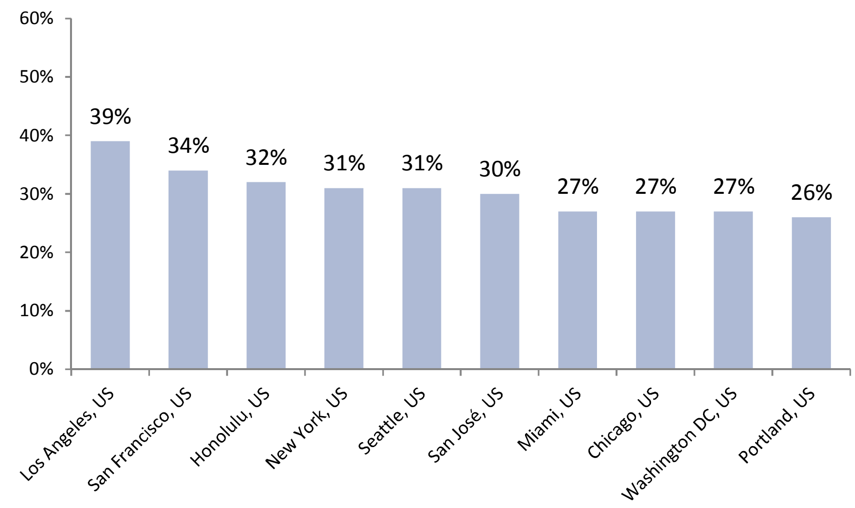
Looking at congestion levels globally using the TomTom traffic index, we see that emerging economies see the most congestion globally as travelers can see delays over 50% of the estimated travel time sans traffic. In the United States, the results are not surprising with its largest cities like Los Angeles, San Francisco, and New York ranking highest for traffic delays, with travelers experiencing delays of 30%-40% (**Exhibits 42 and 43**. Based on our analysis (**Exhibit 44**), we believe that autonomous vehicles could save consumers $46.5bn in wasted fuel costs each year globally and we would emit 212 billion pounds fewer in CO2 from congestion reduction. We expect Asia to benefit the most from both a CO2 and fuel savings standpoint with over $15bn in fuel savings and approximately 70bn pounds of CO2 savings annually (**Exhibit 45**).

Exhibit 42: Emerging economies suffer the most congestion
TomTom traffic index – global top 10



Source: TomTom.

Exhibit 43: Large metropolitan cities in the US experience the most congestion
TomTom traffic index – US top 10



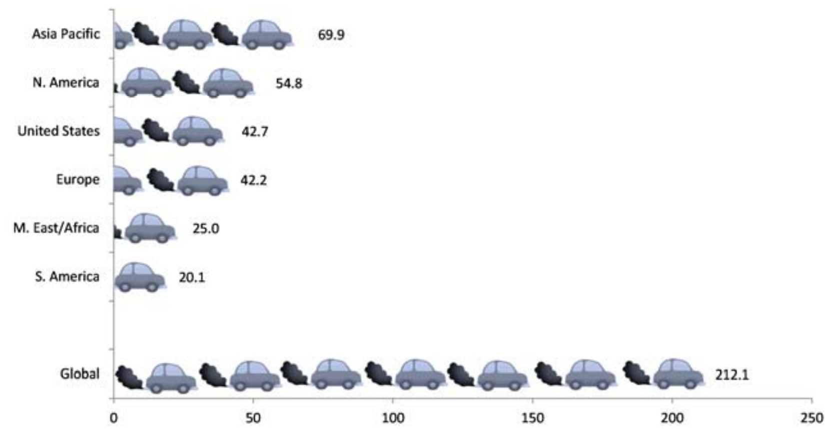
Source: TomTom.

Exhibit 44: Autonomous vehicles could reduce over 212bn lbs. of CO2 emissions globally and generate over $45bn in fuel savings annually
CO2 savings by region

	United States	North America	South America	Europe	Asia Pacific	Middle East/Africa	Global	Comments
Average Fuel Economy (mpg)	18.0	18.0	18.7	22.3	18.2	18.7	19.1	Estimated relative to the US, based on car/truck/diesel mix
Annual Vehicle miles traved (billions)	2,938.5	3,551.5	878.5	2,856.1	3,209.9	1,349.9	11,845.9	Derived from MPG
Gallons of Fuel Consumed (billions)	**163.2**	**197.0**	**47.0**	**128.4**	**176.2**	**72.2**	620.7	Derived from CO2 emission
CO2 (lb) per gallon	19.1	19.1	19.1	19.1	19.1	19.1	19.1	Similar CO2 content for gas and diesel
Total CO2 Released (lb bn)	**3,115.1**	**3,759.1**	**896.2**	**2,449.8**	**3,363.6**	**1,378.8**	**11,847.3**	From IEA
Annual Wasted Fuel from Congestion (gal bn)	**2.9**	**3.7**	**1.4**	**2.9**	**4.7**	**1.7**	**14.4**	US from the Urban Mobility Report, regional data calculated based on US figure
As % of Total Fuel Consumed	**1.8%**	1.8%	1.8%	1.8%	1.8%	1.8%	1.8%	
Congestion index	**100**	**106**	**163**	**126**	**152**	**132**	**136**	From TomTom Traffic Index, indexed to the US at 100
Adjusted %	**1.8%**	**1.9%**	**2.9%**	**2.2%**	**2.7%**	**2.4%**	**2.4%**	
CO2 Released from Congestion(lb bn)	**55.3**	**71.0**	**26.0**	**54.7**	**90.6**	**32.4**	**274.8**	
Average Price of fuel	$2.91	$3.47	$4.18	$5.78	$4.12	$3.24	$4.18	Average taken from globalpetrolprices.com
Wasted Fuel Annually ($bn)	**$8.4**	**$12.9**	**$5.7**	**$16.6**	**$19.6**	**$5.5**	**$60.2**	
Causes of Delays:								From Rand Corporation research
Nonrecurrent Delays due to Roadwork	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	
Nonrecurrent Delays due to Weather	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	
Nonrecurrent Delays due to traffic incidents	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%	
Recurrent Delays due to Travel patterns	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%	
Autonomous Vehicle Benefits:								
Reduction of Auto Accidents	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%	Average of related articles and Wall Street Journal
Improvement in MPG from smoother traffic flows	31.0%	31.0%	31.0%	31.0%	31.0%	31.0%	31.0%	From Eno Center for Transportation Research
Increased Lane Capacity	88.9%	88.9%	88.9%	88.9%	88.9%	88.9%	88.9%	From Eno Center for Transportation Research
Wasted Fuel by Cause with Autonomous Vehicles (gal bn):								
Wasted Fuel due to Roadwork (gal bn)	0.2	0.3	0.1	0.2	0.3	0.1	1.0	
Wasted Fuel due to Weather (gal bn)	0.3	0.4	0.1	0.3	0.5	0.2	1.5	
Wasted Fuel due to Traffic Incidents (gal bn)	0.1	0.1	0.0	0.0	0.1	0.0	0.2	
Wasted Fuel due to recurrent traffic patterns (gal bn)	0.1	0.1	0.1	0.1	0.2	0.1	0.6	
Total Wasted Fuel with Autonomous (gal bn)	**0.7**	**0.8**	**0.3**	**0.7**	**1.1**	**0.4**	**3.3**	
Wasted Fuel Annually ($bn)	**$1.9**	**$2.9**	**$1.3**	**$3.8**	**$4.5**	**$1.3**	**$13.7**	
CO2 (lb bn) from Wasted Fuel with Autonomous	**12.6**	**16.2**	**5.9**	**12.5**	**20.7**	**7.4**	**62.7**	
Annual Fuel Savings ($bn)	**$6.5**	**$10.0**	**$4.4**	**$12.8**	**$15.1**	**$4.2**	**$46.5**	
Annual CO2 Reduction (lb bn)	**42.7**	**54.8**	**20.1**	**42.2**	**69.9**	**25.0**	**212.1**	

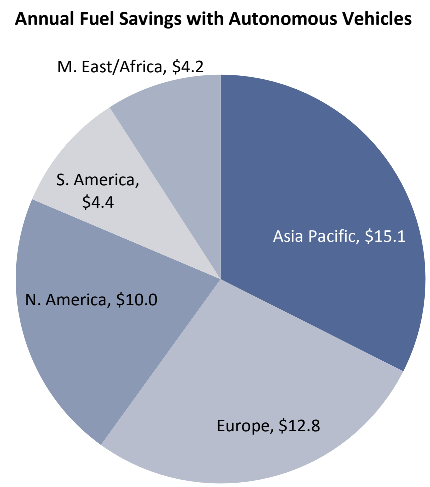
Source: IEA, UT Urban Mobility Report, TomTom, globalpetrolprices.com, Rand Corporation, Eno Center of Transportation Research, WSJ, and Goldman Sachs Global Investment Research.

Exhibit 45: We expect to see the largest reduction in Asia Pacific…
Annual CO2 Reduction by Region, in CO2 bn lbs.



Source: IEA, UT Urban Mobility Report, TomTom, globalpetrolprices.com, Rand Corporation, Eno Center of Transportation Research, WSJ, and Goldman Sachs Global Investment Research.

Exhibit 46: …driving $15.1bn in annual fuel savings in the region
Annual Fuel Savings by Region, $ in bn



Source: IEA, UT Urban Mobility Report, TomTom, globalpetrolprices.com, Rand Corporation, Eno Center of Transportation Research, WSJ, and Goldman Sachs Global Investment Research.

We believe that CO2 and fuel savings are directly impacted by the rise of mega-cities. As we continue to see large metropolitan cities bloom up in developing regions, existing infrastructure in many cases is struggling to cope with the large influx of people and automobiles. We think that that the adoption of autonomous vehicles will ultimately be a very important tool to manage some of these congestion issues making cities cleaner and more efficient and significantly improving the quality of life in the process.

Increased productivity

Autonomous vehicles would also allow occupants to use their time on other activities, as L4 autonomous driving would not require interaction by the driver other than typing in the coordinates of his or her destination. As a result, we believe there could be a lot of value created by people spending their time performing other activities rather than paying attention to the road. In order to estimate this, we segmented the potential activities into three categories: working, sleeping/resting/other, and leisure. We then applied the percentage of time spent on average per person each day based on data from the US Department of Labor and allocated it into the three categories (**Exhibit 48**). Afterwards, we determined the total number of hours spent per year in a vehicle per driver and allocate the total number of hours to each category, breaking out the percentage of workers who cannot perform their job duties in a vehicle (i.e., construction, hospitality, et cetera). In order to find the economic benefit from autonomous vehicles, we assigned a dollar value for each hour of each category. From most impactful to least, we applied $31.10 per hour for working based on the average hourly wage in industries where employees can work remotely, $0.70 per hour of leisure based on the industry sizes of US online advertising, e-commerce, and m-commerce – adjusted for the number of hours spent per year on digital media, and finally $0.00 for sleeping. This analysis yields us an approximate $195bn benefit due to having additional time in the car for other activities other than driving (**Exhibit 47**). The majority of this stems from the ability to work remotely in a vehicle, which represents a benefit of $177bn.

Exhibit 47: Multitasking while operating a vehicle could bring significant value to the US economy
US Productivity gains with Autonomous Vehicles

	Value	Comments
Annual Hours Driving per Person	293.8	Average from Mckinsey, AAA, and KPMG Reports
US Drivers	212,159,728	DOT data from 2013
Total Annual Driving Hours (bn)	**62.3**	
% of U.S. workers able to work remotely	30.5%	US Department of Labor Industry Categorization
Dollar Value of Each Activity per Hour		
Sleeping/Resting	$0.0	
Leisure	$0.7	Based on total industry revenue and time spent on digital media
Working	$31.1	Average wage provided by the US Department of Labor of workers

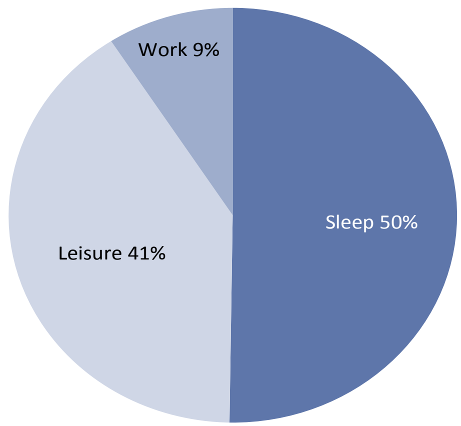
	Able to Work Remotely		Unable to Work Remotely	Comments
Time Split During Autonomous Transportation	Weekdays	Other Days	All Days	
Sleeping/Resting/Other	42%	56%	52%	Sleeping hours from the American Time Use Survey
Leisure	18%	37%	48%	Leisure hours less sports from the American Time Use Survey
Working	40%	8%	0%	Working hours from the American Time Use Survey
Hours spent Annually by Activity (bn)				
Sleeping/Resting/Other	5.5	3.3	22.5	
Leisure	2.3	2.2	20.9	
Working	5.2	0.5	0.0	

Value Generated from Additional Productivity	
Sleeping/Resting	$0.0
Leisure	$18.1
Working	$177.2
Total ($ bn)	**$195.2**

Source: US Department of Labor, D.O.T., McKinsey, AAA, KPMG, Goldman Sachs Global Investment Research.

Globally, we expect a $921bn annual economic benefit, or roughly 1.8% higher GDP, calculated by adjusting our US estimates for the number of registered vehicles in each region and the cost of living in each region (**Exhibit 49**). As we have seen with our other analyses, Asia Pacific would benefit the most given the region's high VIO, which offsets the lower cost of living in the region.

Exhibit 48: Most travel time is expected to be used sleeping or on leisure activities
Drivers' Use of Time with Autonomous Vehicles



Source: US Department of Labor, Goldman Sachs Global Investment Research

Exhibit 49: Asia Pacific drivers stand to gain the most globally
Productivity gains with Autonomous Vehicles

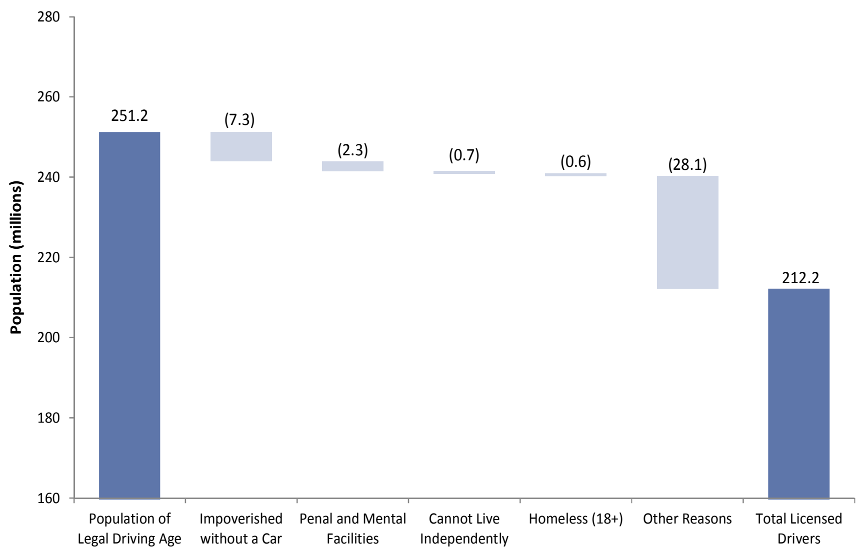
	Number of Registered Vehicles	Cost of Living Index	Productivity gains ($bn)
US	257,514,999	76.5	$195.2
North America	309,806,790	66.5	$199.0
South America	111,520,731	57.1	$67.3
Europe	400,297,839	68.7	$261.6
Asia Pacific	625,014,013	55.5	$321.4
Middle East	64,057,456	57.2	$43.1
Africa	40,466,010	54.1	$28.7
Total	**1,551,162,839**		**$921.0**

Source: US Department of Labor, WHO, Numbeo, Goldman Sachs Global Investment Research.

Lengthening the tails of mobility

Lastly, we believe that autonomous cars would provide mobility to millions around the world who could previously not drive due to age, disability, or other reasons. In the US, we break down the number of potential drivers who are of age and then perform a walk to the number of licensed drivers on the road today (**Exhibit 50**). As we can see, a portion of the population is unable to drive due to economic factors, incarceration, and disabilities– among other reasons. However, when looking at the benefits from autonomous driving, we believe that (1) some of the previously excluded driver population will now be able to operate an autonomous vehicle (i.e., those with disabilities, too busy to obtain a license) and (2) there will be an expansion of mobility by widening the age group of those who can operate a vehicle. In our analysis, we assumed that children 10 years old and up would be allowed to operate a L4 autonomous vehicle. Given these assumptions, we performed a similar walk (**Exhibit 51**) to the potential number of operators of autonomous vehicles. We estimate an increase from 212 million drivers to 244 million, or a roughly 15% increase, primarily driven by the aforementioned demographic shift. We also note that those who have a disability or were too busy/disliked driving would be added to the driver pool, as the L4 autonomous vehicles would not require the passengers to engage in driving at any time.

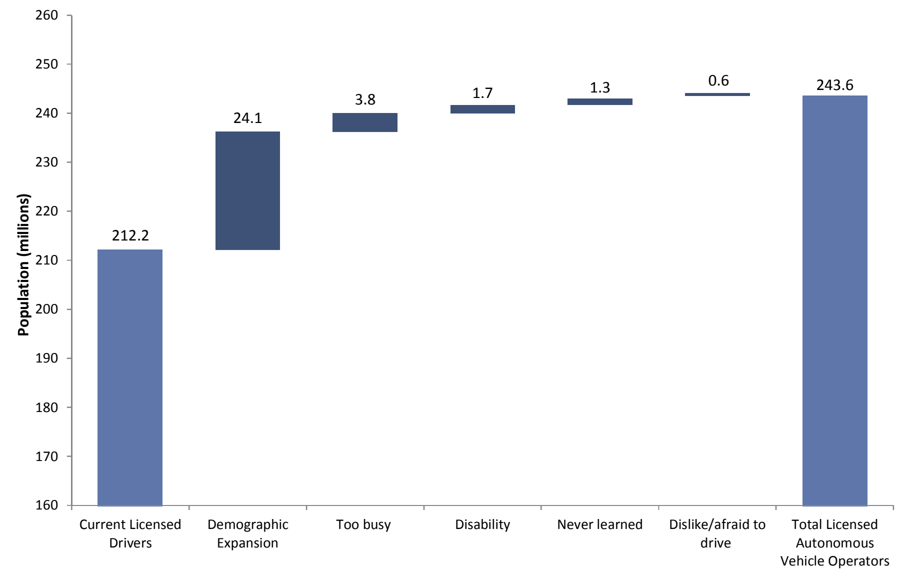
Exhibit 50: Walk from driving age population in the US licensed drivers



Source: CDC, US Census, US BLS, US DOT, Goldman Sachs Global Investment Research.

Exhibit 51: Autonomous vehicles could provide mobility for over 30mn new operators

US driver breakdown with autonomous vehicles



Source: CDC, US Census, US BLS, US DOT, Goldman Sachs Global Investment Research.

With this data, we looked at the economic benefit that these additional drivers could bring. We assumed that the percentage of new drivers would be the same for every region and used average fuel costs to estimate the average vehicle miles traveled (VMT) per person. Next, we used personal consumption expenditure per VMT and adjusted the results by the cost of living in each region. By this we concluded that additional drivers due to autonomous vehicles could add approximately $1.3 trillion in economic benefits, or 1.8% to overall global GDP (**Exhibit 52**).

Exhibit 52: Economic Gains from Additional Drivers
Globally, over $1.3tn in economic gains would be generated by additional drivers

	Driver Increase	VMT per Person	Additional VMT	PCE/VMT	Additional PCE
United States	31,406,930	14,214	223,208	$1.5	$330,556
North America	45,862,051	11,909	273,076	$1.3	$351,564
South America	16,508,900	9,884	81,590	$1.1	$90,118
Europe	59,257,835	7,161	212,158	$1.3	$281,888
Asia/Pacific	92,523,551	10,043	464,611	$1.1	$499,114
Africa	5,990,360	12,022	36,007	$1.0	$37,666
Middle East	9,482,705	14,523	68,857	$1.1	$76,237
Total	229,625,402		1,136,300		$1,336,586

Source: US Census, World Bank, Goldman Sachs Global Investment Research.

Based on our analysis, we believe that autonomous vehicles have the opportunity to bring significant economic benefits globally through fewer accidents, fuel savings, increased productivity, and additional drivers. In particular, we believe the Asia Pacific region would benefit the most compared to other regions given its high population and growing motorization. Given the lack of infrastructure and the congestion issues in developing regions, we reason that they should ultimately be receptive and supportive to autonomous vehicle adoption. Though as we discuss in our volume forecast at the beginning of this report, ADAS and AVs will likely role out initially more quickly in the developed markets where vehicle mix is richer and the take rate on new technology is higher.

Appendix 1: Glossary of terms

Abbreviation	Term	Definitions
ACC	Adaptive Cruise Control	Follows the flow of traffic and adjusts the vehicle speed to maintain a safe distance from vehicles ahead
ADAS	Advanced Driver Assistance System	Specific application of active safety technology such as lane departure warning and collision mitigation braking, for example
AEB	Autonomous Emergency Braking	Detects critical traffic situations and ensures optimum braking
AHC	Adaptive High Beam Control	Adjusts the headlamp range to the prevailing traffic situation and provides for the best possible illumination
CACC	Cooperative Adaptive Cruise Control	ACC with information sharing with other vehicles and infrastructure to adjust speed and for navigation reducing congestion
CAFE	Corporate Average Fuel Economy	Annual mpg standards set for an OEM’s vehicle fleet manufactured for sale in the US for each model year
CCC	Car Connectivity Consortium	A consortium among the carmakers and consumer electronics companies, which established an open industry standard for in-car smartphone integration called MirrorLink
DSRC	Dedicated Short Range Communication	A 2-way short-to-medium range radio for data transmission dedicated for vehicle safety and mobility applications
ECU	Electronic Control Unit	An embedded module that controls one or more electrical systems or subsystems
ESC/ESP	Electronic Stability Control/ Electronic Stability Program	An electronic braking system which helps drivers maintain control of their vehicle during extreme steering maneuvers
FCW	Forward Collision Warning	Warns the driver in situations where the vehicle is approaching a preceding vehicle at a high speed
FLC	Forward Looking Camera	Camera designed to be attached at front of a vehicle and aid applications like lane departure warning and emergency braking
FLR	Forward Looking Radar	Radar placed at front of the vehicle to aid other applications, such as emergency braking
HMI	Human Machine Interface	Interface between the user and the car stereo/infotainment system (includes steering wheel, displays)
HUD	Head Up Display	Shows information directly in the line of sight of the driver, reduces the need to look down at the instrument cluster
ITS	Intelligent Transportation Systems	Technologies that aim to increase and improve transportation via non-traditional means like CACC
LBS	Location Based Services	In-car location-based services (like suggesting restaurants) through location determined from GPS hardware and connectivity features
LDW	Lane Departure Warning	Alerts the driver with acoustic or haptic warnings before the vehicle is about to leave the lane
LIDAR	Light Detection and Ranging	Remote sensing method that uses light in the form of a pulsed laser to create 3D images of vehicle surroundings
NCAP	New Car Assessment Program	Provides consumers with a measure of the relative safety of vehicles to aid in their purchasing decisions
NHTSA	National Highway Traffic Safety Administration	Responsible for setting and enforcing safety performance standards for motor vehicles
OAA	Open Automotive Alliance	Global alliance of technology and auto industry participants working to bring the Android platform to cars
OBD	Onboard Diagnostics	Monitors the performance of the vehicle's major components, providing early warnings of malfunctions
OEM	Original Equipment Manufacturer	Refers to automobile manufacturing companies
OS	Operating System	Main programing on a computer, controls the way it works and makes functionality of other programs possible
PAYD	Pay As You Drive	Telematics solution correlating the cost of auto insurance directly to vehicle use based on time and distance traveled
PHYD	Pay How You Drive	Correlating motor insurance to time, distance, place and driving behavior
PCW	Pedestrian Collision Warning	Warns the driver about a potential collision with pedestrians ahead
RVC	Rear View Camera	Camera attached at rear of a vehicle and aids in reverse maneuvers and cross-traffic detection
TSR	Traffic Sign Recognition	With the help of a forward looking camera, detects speed limit and other roadside traffic signs
UBI	Usage Based Insurance	Insurance companies offer usage-based fees based on driver behavior
V2V	Vehicle to Vehicle	Wireless exchange of data among nearby vehicles, offering an opportunity for significant safety improvements
V2I	Vehicle to Infrastructure	Wireless exchange of critical safety and operational data between vehicles and roadway infrastructure
V2X	Vehicle to External Environment	Wireless exchange between vehicles and its surroundings

Appendix 2: Company profiles

Company	Headquarters	Select Products	Description & Highlights
New Entrants			
Apple	California	**- Infotainment Platform** **- Possible Autonomous Vehicle**	Apple offers an in-car infotainment platform named Carplay. The company has been working on its own autonomous car and is in talks with carmakers and automotive suppliers.
Baidu	China	**- Autonomous Driving Platform**	Baidu recently announced its intention to make a foray into driverless cars. The company has made a $10mn acquisition of a Finnish mapping technology provider, IndoorAtlas. In addition, Baidu is also developing Baidu Brain, an artificial intelligence tool which could have autonomous vehicle applications.
Google	California	**- Software** **- Infotainment Platform** **- Maps**	Google offers an in-car infotainment platform, Android Auto, which competes with Apple's Carplay. The company announced its plan for driverless cars in 2008 and subsequently revealed a self-driving low-speed vehicle. Currently, the company is actively testing its L4 vehicle in the streets of California. Google also provides mapping and route guidance services through Google Maps.
Tencent	China	**- Autonomous Driving Platform**	WeChat messaging app provider Tencent announced earlier this year its plans to develop autonomous cars. Tencent has teamed up with Taiwan's Foxconn Technology Group for its manufacturing capabilities and Chinese luxury auto dealer China Harmony Auto Holding for its dealership network to explore opportunities in this area.
Semiconductors			
Altera	California	**- Programmable Logic Devices** **- Integrated Circuits**	Altera offers programmable chips technology which allows users to configure the chips after purchase and upgrade them through real-time software updates. The company provides solutions for a variety of industries including automotive, consumer, embedded vision, industrial, and medical. Altera was recently acquired by Intel.
Atmel	California	**- Microcontroller** **- Capacitive Touch Technology Solutions** **- Logic**	Atmel provides microcontrollers, capacitive touch, and other system solutions. The company offers a broad range of automotive solutions with applications including window switches, infotainment, actuators, pump systems, and stability control systems.
Analog Devices	Massachusetts	**- Integrated Circuits**	Analog Devices manufactures integrated circuits used in analog and digital signal processing. The company's analog chips are used in wireless network equipment and can be found in the advanced semiconductor content in connected cars and trucks.
Broadcom	California	**- Telematics/Connectivity Hardware** **- Infotainment**	Broadcom offers telematics and in-vehicle networks technology such as Near Field Communication (NFC), Wi-Fi, Bluetooth, and Ethernet solutions. The company's products allow for the connectivity of ADAS system as well as improves in-car connectivity.
Freescale	Texas	**- Processors**	The semiconductor company's ADAS portfolio includes a variety of microcontrollers, integrated circuits, and sensors solutions, with applications in rear view cameras, park assist, radar, and front view camera solutions, etc.
Infineon	Germany	**- Processors** **- ECUs** **- Other Semiconductors**	Infineon offers a range of semiconductor applications for vehicles. In particular, the company offers processors for radar, camera, and in-cabin sensing systems.
Intel	California	**- Processors** **- Software Platform** **- Connectivity/Telematics Hardware**	Although more widely known as a semiconductor provider for PCs and mobile devices, Intel also provides processors and a software platform for on-board connectivity and multimedia. The company has invested in the automotive space with emphasis on autonomous driving.
Linear Technology	California	**- Battery Management Systems** **- Telematics/Connectivity Hardware** **- Hybrid/Electric Vehicle Systems** **- Processors**	The company manufactures a broad line of integrated circuits for automotive purposes including telematics, infotainment, ADAS systems, electric vehicles, and battery management systems.
Maxim Integrated	California	**- Integrated Circuits**	Maxim Integrated provides linear and mixed signal integrated circuits for a variety of industries including automotive, computing, medical, consumer, and industrial. The company partnered with NVIDIA on its Drive CX and PX platforms.
Microchip Technology	Arizona	**- Microcontrollers** **- Analog**	Microchip Technology enables the use of technology to network audio, video and safety information in connected cars. The company recently announced that it has joined the Linux Foundation and to develop software for the connected car. Microchip Technology products can be found in Mercedes, Toyota, Volkswagen, and GM vehicles.

Company	Headquarters	Select Products	Description & Highlights
Semiconductors (continued)			
Nvidia	California	- Processors - Autonomous Driving Platform - Infotainment Platform	NVIDIA specializes in graphic processing capabilities for car infotainment, headrest displays, etc. The company also provides a computing platform utilizing its hardware, onto which automakers can develop autonomous driving systems, incorporating sensor data.
NXP Semiconductors	Netherlands	- Telematics/Connectivity Hardware - V2X	Specializing in in-vehicle networks, telematics, 802.11p solutions, logic, interface systems, sensors, and MOSFETs, NXP produces hardware components for autonomous technology such as V2X solutions, a variety of sensors, and in-vehicle networks.
ON Semiconductor	Arizona	- Logic - Integrated Circuits - Analog	ON Semiconductor Corporation supplies analog, standard logic, and discrete semiconductors for data and power management. The company's products include integrated circuits, and analog ICs. ON's products can be found in a variety of automotive applications including braking, infotainment, cameras, and throttle control.
Qualcomm	California	- Processors - Telematics/Connectivity Hardware - Electric Vehicle Hardware	Qualcomm's portfolio of automotive products primarily relate to infotainment systems, providing processors and connectivity hardware. However, the company also provides a LTE chipset with DSRC capabilities for V2X functions.
STMicroelectronics	Switzerland	- Microcontrollers - Processors - Power switches	STMicroelectronics manufactures semiconductor integrated circuits and discrete devices. The company's products are used in the telecommunications, consumer electronics, automotive, computer, and industrial sectors. STM is partnered with Mobileye to provide the vision-processor.
Texas Instruments	Texas	- Analog and Connectivity Solutions - DLR Displays - ADAS and Infotainment Processors - MCUs	Texas instruments offers a wide range of solutions for the automobile industry with applications in infotainment, active and passive safety, ADAS, solutions for hybrid/electric power train systems, wireless connectivity technology.
Xilinx	California	- Logic	Xilinx offers complete programmable logic solutions. Its automotive platforms is focused on image processing and recognition, graphics, and vehicle networking and connectivity.
Software			
Elektrobit Automotive	Germany	- Software - Human Machine Interface	Elektrobit Automotive provides embedded software solutions primarily for the connected vehicle infrastructure, human machine interface, navigation, driver assistance, and ECUs.
IAV	Germany	- Software	IAV offers a diverse range of automobile products including software and algorithms for autonomous driving and a host of ADAS technologies.
Ottomatika	Pennsylvania	- Software	Ottomatika technology is featured in autonomous vehicles currently being tested on the road. The company provides a variety of modules and sensors that allow for automated highway driving with lane changing, traffic jam assist, pedestrian detection, and V2X communications. Ottomatika was recently acquired by Delphi.
Red Bend	Israel	- Security - Software	Redbend is a software company with diverse software solutions. The company's vehicle software focuses on car cyber security, head unit virtualization, ECU consolidation, and over-the-air (OTA) updates.
Safran	France	- Infrared Imaging - Mapping	Safran, a French defense contractor, recently partnered with Valeo to showcase autonomous driving technology. The self-driving cars utilized the infrared imaging, algorithms, and dynamic mapping used in drones made by Safran.

Company	Headquarters	Select Products	Description & Highlights
Sensing Technology			
Ambarella	California	- **Cameras** - **Processors**	The camera solutions provider has a variety of ADAS/autonomous vehicle camera applications including 360 degree cameras, crash avoidance, and lane departure warning with an emphasis on video processing and HD quality imagery.
ibeo	Germany	- **LIDAR**	Ibeo offers laser scanners for use in LIDAR systems, particularly wide angle lasers with a 145 degree horizontal field-of-view. The company is currently partnered with Valeo.
Leddartech	Canada	- **Sensors**	The company offers detection and ranging technology, offering collision avoidance sensors and blind spot detection.
Mobileye	Israel	- **Vision Algorithms** - **Processing Platform**	Widely established ADAS and autonomous vehicle leader providing camera vision algorithms for active safety and autonomous driving functions. The company works with numerous OEMs on autonomous functions/driving.
Quanergy	California	- **LIDAR**	Quanergy produces next-gen LIDAR systems for L3 and L4 autonomous driving. The company has developed a solid state LIDAR, requiring no moving parts which is significantly smaller and cheaper than the systems on offer today.
SoftKinetic	Belgium	- **Sensors** - **Cameras**	Softkinetic is a provider of 3D vision technology for consumer electronics as well as industrial applications. The company provides sensing hardware for infotainment, as well as ADAS products for pedestrian detection and autonomous parking.
TriLumina	New Mexico	- **LIDAR**	Trilumina is a semiconductor laser company, specializing in LIDAR, user interface systems including eye tracking, and optical wireless communications. The company provides a scalable illumination source for LIDAR applications.
Velodyne	Colorado	- **LIDAR**	Velodyne manufactures LIDAR systems and produces the system used in the Google autonomous vehicle. Earlier versions were rather expensive with a large distinctive spinning device on the roof of the vehicle. However, a smaller, more cost-effective model has been announced.
Operating System			
Linux	n/a	- **Operating System**	Linux is a free and open-source operating system platform. Tesla utilizes Linux for the software on its Model S.
Microsoft	Washington	- **Operating System**	In addition to its successful PC operating system, Microsoft also offers software for automotive platforms, namely for connectivity and infotainment use.
QNX	Canada	- **Operating System**	QNX is an operating system provider and a subsidiary of Blackberry. The company provides an automotive operating system with ADAS, driver information, infotainment, and connectivity features.
Human Machine Interface			
Lemoptix	Switzerland	- **Human Machine Interface**	Lemoptix, a human machine interface provider, offers laser scanning micro projection technology for head up displays and 3D sensing. The company was acquired by Intel in 2015.
Luxoft	Switzerland	- **Human Machine Interface** - **Telematics/Connectivity Hardware** - **Software**	Luxoft offers software integration and solutions for automakers. The company offers a wide range of embedded software for in-vehicle infotainment and telematics, digital instrument clusters, head up displays, and ADAS/autonomous driving.
Seeing Machines	Australia	- **Human Machine Interface** - **Eye Tracking Sensors**	Seeing Machines offers image-processing technology dedicated to eye tracking and facial recognition. The company offers solutions for automotive, aerospace, fleet, mining, rail, and consumer electronics applications.
Tobii	Sweden	- **Human Machine Interface** - **Eye Tracking Sensors**	Tobii is a provider of eye tracking technology. The company offers human machine interface solutions for a variety of applications in the consumer technology, advertising, academic research, automotive, and medical industries. Recently, the company partnered with MSI to provide eye tracking technology for MSI's laptops.

Company	Headquarters	Select Products	Description & Highlights
Auto Suppliers (Integrators)			
Autoliv	Sweden	- Sensors - Cameras - Radar - ECU	Autoliv is a large provider of active safety market (sensors, ECUs, etc.). The company's autonomous driving component portfolio includes: sensors, stereo and night vision cameras, and radar components including forward-looking radar. V2V components and LIDAR are areas Autoliv is looking to enter. In addition, the company is expected to come out with its own camera algorithms by the end of the year.
Bosch	Germany	- Telematics/Connectivity Hardware - Cameras - Radar - Human Machine Interface - ECU	Bosch supplies auto components and systems including body electronics, chassis and powertrain products, telematics, and infotainment hardware. The company has built up a broad portfolio of sensor and ECU capabilities with strong aggregation capabilities. The company has also developed its own vision algorithms that compete with Mobileye.
Continental	Germany	- ECU - Radar - Camera - Human Machine Interface - Telematics/Connectivity Hardware	Continental specializes in tires, safety, powertrain & chassis components, and a variety of other automotive components. In August, the company showcased its highly automated vehicle which can handle stop-and-go traffic, highway cruising and steering, and handle safety maneuvers.
Delphi	UK	- Control Modules - Multi-Domain Controllers - Human Machine Interface - Telematics/Connectivity Hardware - Powertrain Components	Delphi is a Tier 1 supplier with a focus on powertrain, infotainment, active safety, and electrical distribution. Within ADAS the company has a diverse portfolio including broad array of sensors, domain controllers, HMI application. The company recently acquired software company Ottomatika and took a stake in Lidar developer Quanergy.
Denso	Japan	- ECU - Sensors - Radar - Human Machine Interface - V2X	Denso offers powertrain control, electronic, thermal, information and safety systems as well as a variety of other consumer and industrial products. The company supplies the Safety Sense P package to Toyota, which plans to progressively install this ADAS system in mid-sized sedans and other larger models. Continental supplies the Safety Sense C, a more affordable ADAS system. Toyota plans to sharply increase the number of models featuring ADAS over the next few years and this could increase Denso's sales in this business to around ¥100-¥200 bn a year.
Hella	Germany	- Lighting - Sensors - Radar	Hella offers lighting and electronics systems as well as aftermarket products. The company's radar systems have been implemented in various ADAS applications such as blind spot monitoring, lane change assist, and rear cross-traffic alert.
Magna International	Canada	- ECU - Cameras - Ultrasonic Sensors	Magna manufactures a variety of automotive components ranging from body & chassis, powertrain, exteriors, seating, closures and roof systems, as well as ADAS. Within ADAS, Magna is strongest in cameras where it has paired with Mobileye to provide the vision capability on the GM Supercruise. We estimate active safety revenue of roughly $400mn which includes domain controllers and ultrasonic sensors.
TRW	Michigan	- ECU - Radar - Cameras	TRW offers a suite of automotive safety, electronics, steering, and braking solutions. The company was recently acquired by ZF Friedrichshafen AG. TRW primarily supplies radar, camera, and ECU hardware for active cruise control, forward collision warning, and other ADAS functions.
Valeo	France	- Telematics/Connectivity Hardware - Infotainment - Sensors - Cameras - Radar - ECU	Valeo offers thermal, visibility, powertrain, and comfort & driving assistance systems to global OEMs. Management believes that autonomous driving features will be a main growth driver for the company by 2020.
Mapping			
HERE (formerly Nokia Maps)	Finland	- Mapping	Recently acquired by Audi, BMW, and Daimler, HERE is a mapping provider based on a cloud-computing model in which location data and services are stored on remote servers so that users have access regardless of device. The company announced that its mapping and drive guidance will be incorporated in 2016 Jaguar vehicles.
TomTom	Netherlands	- Mapping	TomTom offers navigation and mapping products for both consumer use as well as automotive. The company provides OEMs with real-time maps and a platform onto which companies may integrated selected components into the interface.

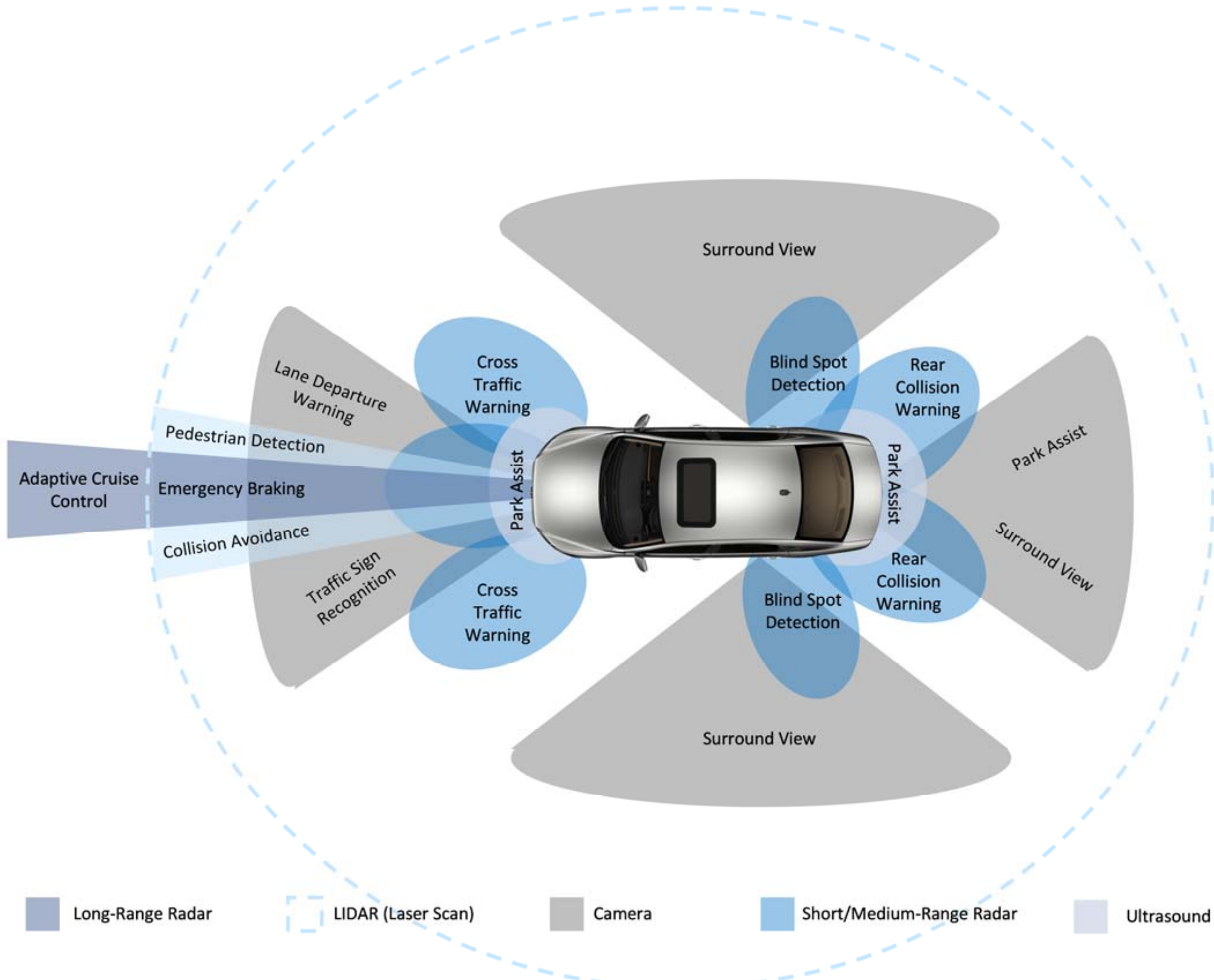
Company	Headquarters	Select Products	Description & Highlights
V2X/Connectivity			
Airbiquity	Washington	**- Connected Car Platform**	Airbiquity's connected car platform, Choreo, enables connected car programs with safety and infotainment applications. Airbiquity's cloud platform integrates apps and content into vehicle systems and provides automatic crash notification and vehicle tracking.
Autotalks	Israel	**- V2X**	A semiconductor company focusing on V2X communication technology offering V2X hardware including both transceiver and processor, software, and security products.
Cisco Systems	California	**- V2X - Data Management & Analytics**	Cisco, the networking giant, has been exploring the relevance of networking for vehicle connectivity and autonomous driving for some time. The company focuses on cybersecurity, reliable network connectivity, big data management and the integration of services and processes across enterprise systems and partner ecosystems.
Cohda Wireless	Australia	**- V2X**	Cohda Wireless specializes in V2V communication systems and provides both on-board units as well as road side units. In addition, the company offers a software development kit which allows users to run applications on Cohda's platform.
Flextronics	Singapore	**- Cameras - V2X - Lighting - In-Vehicle Connectivity - Infotainment Hardware**	Flextronics offers V2X hardware, advanced connectivity modules, and integrated gesture recognition.
IBM	New York	**- V2X - Data Management & Analytics**	IBM has several solutions for the automotive market including V2X technology, vehicle monitoring and data services, and vehicle security. The company is focused on vehicle to cloud as a stepping stone for full V2X implementation.
Sierra Wireless	Canada	**- Connectivity Hardware**	Sierra Wireless offers 2G, 3G, and 4G embedded modules and gateways, providing vehicles with wireless communications for telematics, infotainment, and location-aware applications.
Telecom Carriers			
AT&T	Texas	**- LTE Networks - Connected Car Platform**	In early 2014, AT&T announced initiatives including a connected car center in Atlanta GA, and a modular, global automotive platform called AT&T Drive. The AT&T Drive platform adds to the company's proprietary SIM platform to provide mobile internet access in vehicles and allows automakers to develop connected car solutions.
Sprint	Kansas		Sprint offers its own Sprint Velocity connected vehicle platform, which provides diagnostics, connectivity and infotainment options.
T-Mobile	Washington		T-Mobile provides connectivity services for on-board telematics and infotainment systems.
Verizon	New York		Verizon's telematics division works with auto manufacturers to embed software directly to vehicles. The system collects data from the vehicle to provide roadside assistance or in-vehicle security.
Aftermarket Solutions			
Cruise Automation Inc.	California	**- Aftermarket Autonomous Driving - Hardware**	Cruise sells an aftermarket highway autopilot product for specific vehicles in production. The system currently works on highways in California and uses a combination of sensors, radar, and cameras to provide autonomous driving features.
Vinli	Texas	**- Aftermarket Telematics/Connectivity - Hardware**	Vinli produces a ODB II port device which connects to the user's device through Bluetooth and offers on-board Wi-Fi, young driver safety , diagnostics, and remote locking applications.

Company	Headquarters	Select Products	Description & Highlights
Other Components			
Amphenol	Connecticut	**- Connectors - Cables - Interconnect Systems**	Amphenol manufactures interconnect products for use in cellular, television, aerospace, automotive, and other industrial applications. The company provides interconnect systems for automotive safety devices and in-car electronics.
Bendix	Ohio	**- Braking Systems - Fuel Control Systems**	Bendix develops and supplies active safety technologies, air brake charging, and control systems & components for commercial vehicles. The company produces its Wingman line of active safety systems including active cruise control with braking, collision mitigation technology, and full-stability control.
IRISO Electronics Co.	Japan	**- Connectors**	IRISO produces precision metal pins and connectors for printed circuit boards used in a range of electrical equipment. The company is involved in the development of connectors in the automotive industry, particularly for safety, HVAC, and infotainment applications.
Japan Aviation Electronics	Japan	**- Connectors - Sensors - Touch panels**	Japan Aviation Electronics manufactures electronic devices and parts such as connectors, switches, system equipment, fiber optic devices, and aerospace electronic devices. The Company's products include PC cards, sockets, fiber optic couplers, LCDs, and acceleration sensors.
Murata Manufacturing	Japan	**- MLCC (Capacitors) - Radio frequency components - Sensors**	Murata is a Japanese manufacturer of electronic components including MLCCs, filters and wireless modules. It is a leading player in smartphone components and is currently expanding its automotive business.
Nidec Corporation	Japan	**- Precision Motors - Sensors - Cameras - Radar - ECU**	Nidec produces a wide range of precision motors in automotive, industrials, appliances and HDD. The company has extended its focus to ADAS and offers motors, cameras, sensors and radars.
Nippon Ceramic Co.	Japan	**- Sensors**	Nippon Ceramic offers various types of ultrasonic and pyroelectric infrared sensors. The company provides ultrasonic sensors for ADAS applications and has No.1 mkt share in Japan.
Sensata Technologies	Massachusetts	**- Sensors - Controls**	Sensata offers sensors and controls for use in automotive, aerospace, military, telecommunications, and other industrial applications. The company's products are used in a variety of systems including transmission control, vehicle stability, acceleration sensing, among others.
TE Connectivity	Pennsylvania	**- Connectors - Sensors**	TE Connectivity is a provider of engineered electronics components, network solutions, and wireless systems. The company provides automotive solutions for signals, sensors, and electrical and electronics connectors.
Car Sharing Technology			
Lyft	California	**-Car Sharing Platform**	Lyft, a mobile ride-sharing service provider, competing with Uber. The company could also become a player in the robo-taxi provider market.
Uber	California	**-Car Sharing Platform -Autonomous Driving Platform**	Uber is a mobile ride-sharing service provider. It has been vocal about embracing autonomous vehicles with the ultimate goal of using them for their cab-sharing services. The company has established its Advanced Technologies Centre in Pittsburgh to help develop autonomous driving technology recruiting heavily from the Carnegie Mellon University robotics program.
Vulog	France	**- Car Sharing Platform**	Vulog offers in-car technology, service management software, and user applications for car sharing companies. Vulog's platform allows for flexibility between different car sharing services.

Company	Headquarters	Select Products	Description & Highlights
Security			
Argus	Israel	**- Intrusion and Penetration Testing**	Argus is an automotive cyber security provider, helping car manufacturers, their Tier 1 suppliers and aftermarket connectivity providers protect connected cars and commercial vehicles from car-hacking. It provides a ready-to-embed, cyber security solution suite for automobiles and aftermarket connectivity platforms.
Arilou Technologies	Israel	**- Security Solutions for the CAN Bus** **- Hacking and Penetration testing**	Arilou provides security solutions for the automotive industry focused on protecting the CAN bus, hacking and penetration testing. It is aimed at preventing cyber-attacks while ensuring connectivity of the vehicle.
ESCRYPT	Germany	**- Embedded Security Products and Solutions**	Escrypt provides embedded security solutions, offering products and services at all levels, including security system designs, and implementation of security mechanisms in software and hardware. It also offers customized software and customized hardware (e.g. for secure boot of ECUs), code testing and PKI & key management.
Security Innovation	Massachusetts	**- Application and Embedded Security**	Security Innovation focuses mainly on application security and has developed products for embedded security. The company has partnered with NXP and with Cohda Wireless. In February, it launched a center of excellence to provide penetration services to the automobile industry. Aerolink, its communication security protocol, is set to be released in partnership with GM.
TowerSec	Israel	**- Hacker Detection**	TowerSec is a solutions provider in the automotive space providing on-board cyber security products for manufacturers and suppliers aimed at current and future vehicles including autonomous versions. TowerSec products prevent and detect malicious attacks. It is currently working with US and European OEMs with products that are currently being integrated into existing and future architectures.
Utimaco	Germany	**- Hardware Security Modules**	Utimaco is a manufacturer of hardware-based security solutions. It provides hardware security modules (HSM) to manage cryptographic keys and prevent third-party breaches. The HSM is scalable and customizable and works to provide key security to enable connected and automated driving solutions.

Appendix 3: Autonomous vehicle sensor suite & functionality

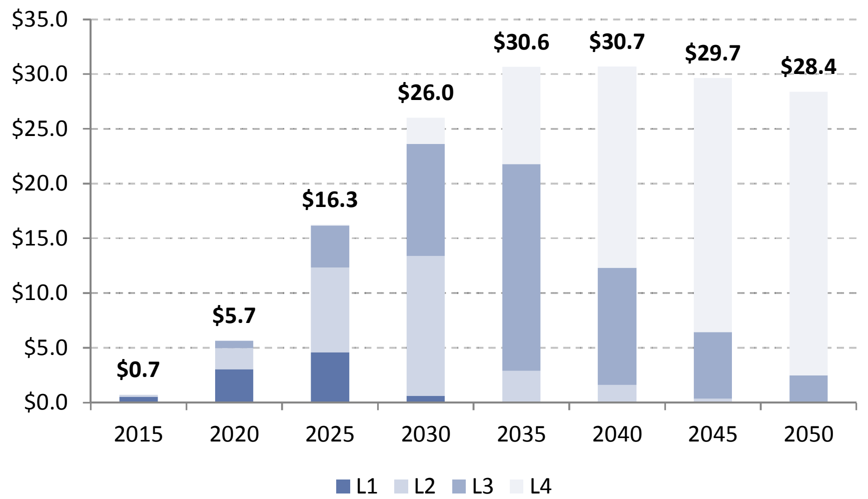
Exhibit 53: Snapshot of autonomous vehicle sensors



Source: Goldman Sachs Global Investment Research

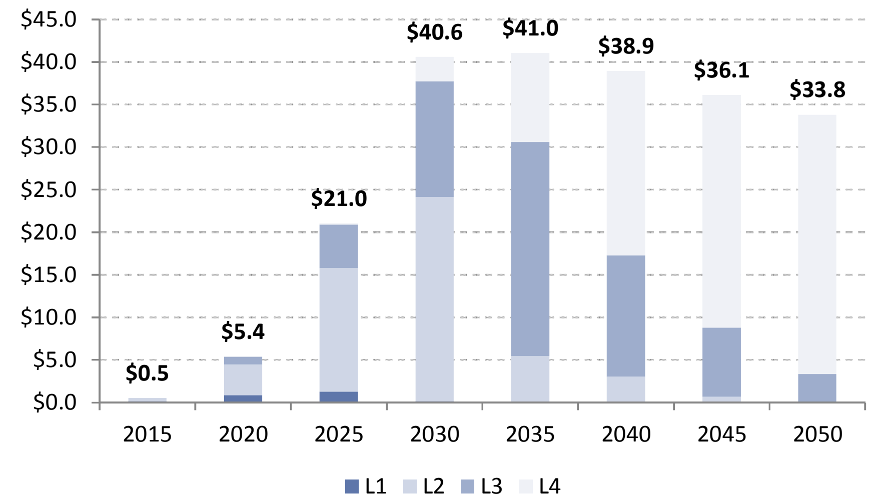
Appendix 4: Component content forecasts by automation level

Exhibit 54: Cameras' forecast to plateau at $30bn in 2035
Component content forecast, $ in bn



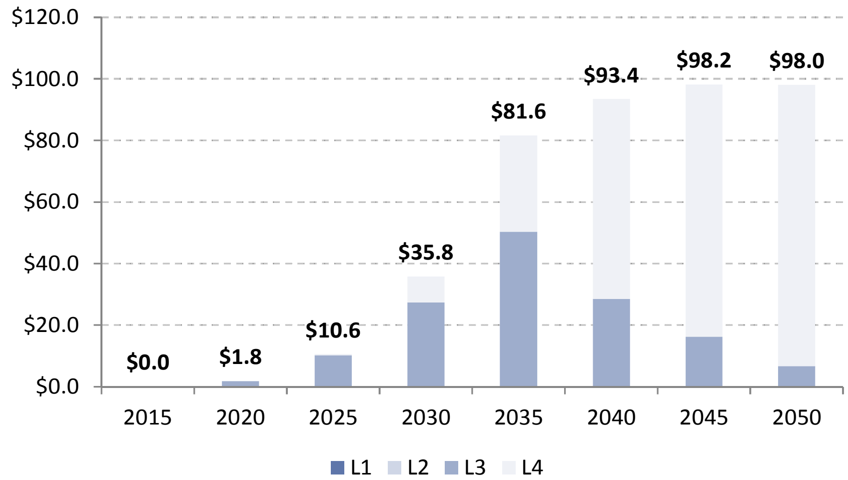
Source: Goldman Sachs Global Investment Research

Exhibit 55: Radar components expected to reach $41bn by 2035
Component content forecast, $ in bn



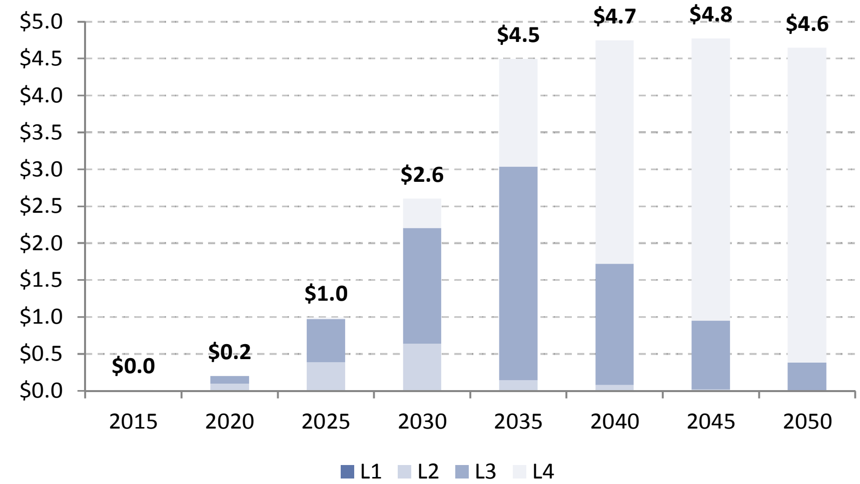
Source: Goldman Sachs Global Investment Research

Exhibit 56: LIDAR expected to grow to $98bn by 2050 as L4 penetration grows
Component content forecast, $ in bn



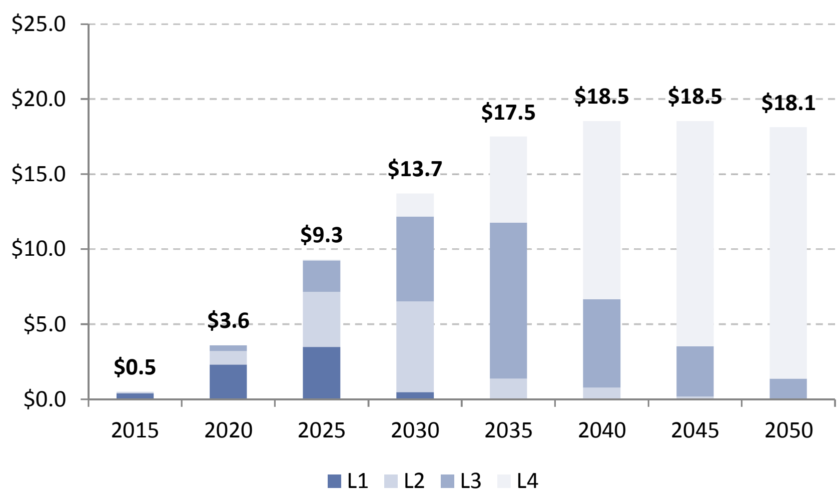
Source: Goldman Sachs Global Investment Research

Exhibit 57: Comm Semis a $4.5bn market by 2035
Component content forecast, $ in bn



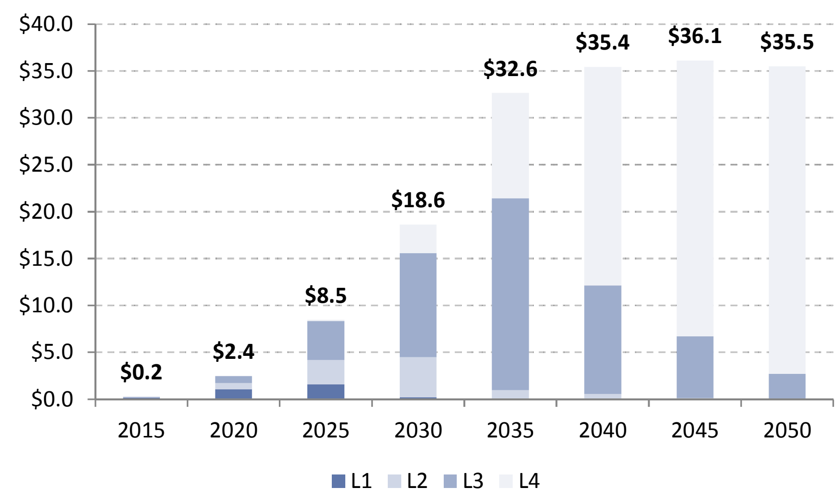
Source: Goldman Sachs Global Investment Research

Exhibit 58: Processor content expected to grow to $18.5bn by 2040
Component content forecast, $ in bn



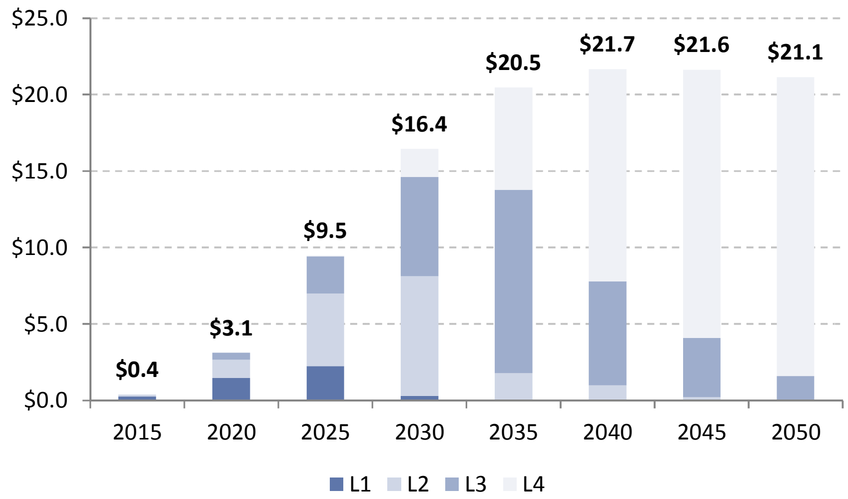
Source: Goldman Sachs Global Investment Research

Exhibit 59: Logic content expected to growth to $36bn by 2045
Component content forecast, $ in bn



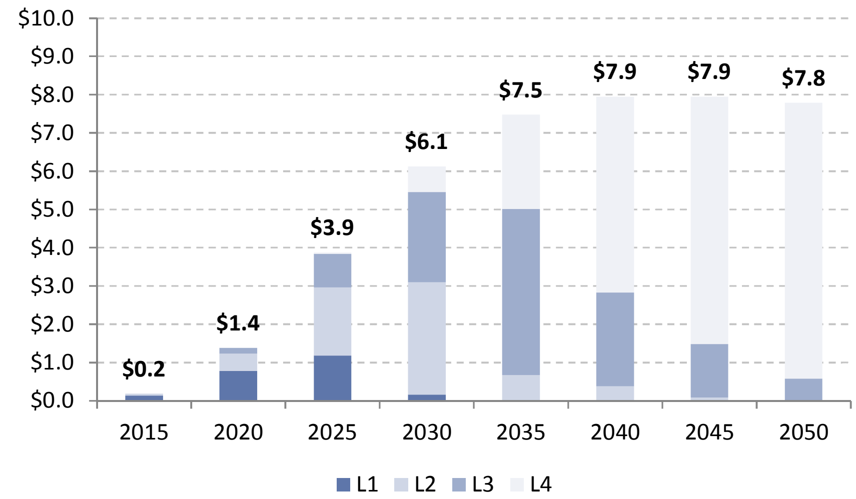
Source: Goldman Sachs Global Investment Research

Exhibit 60: Analog componentry should grow to $21bn by 2050
Component content forecast, $ in bn



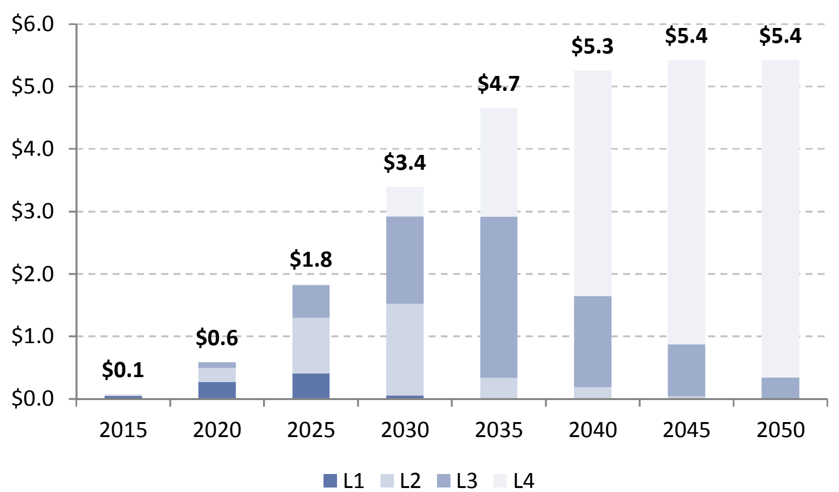
Source: Goldman Sachs Global Investment Research

Exhibit 61: Sensors/MEMS expected to grow to $8bn market size by 2040
Component content forecast, $ in bn



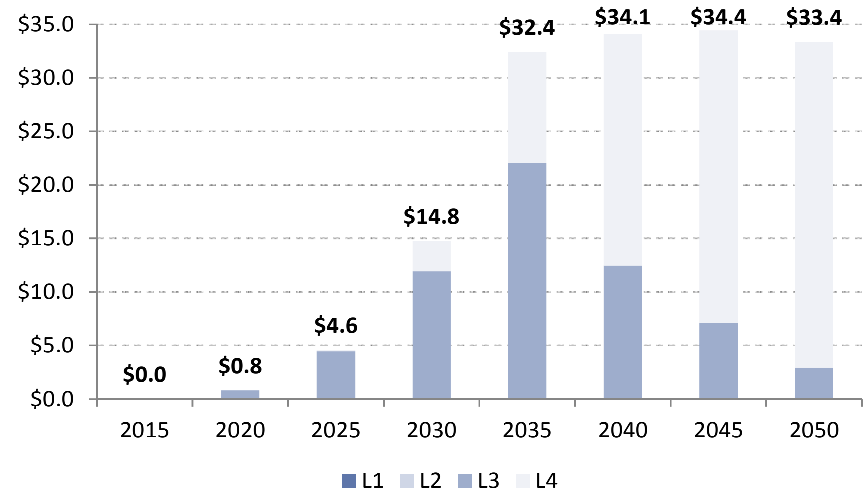
Source: Goldman Sachs Global Investment Research

Exhibit 62: Connectors content expected to grow above $5bn through 2050
Component content forecast, $ in bn



Source: Goldman Sachs Global Investment Research

Exhibit 63: V2V and V2I content expected to grow to over $30bn by 3035
Component content forecast, $ in bn



Source: Goldman Sachs Global Investment Research

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Reg AC

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