Goldman Sachs | Research

The Evolution of ADAS

Assessing the semiconductor opportunity underpinning the next level of automotive safety and convenience

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Advanced driver assistance system (ADAS) features encapsulated in the L2 level of automation, which include functionality in cars to alert and automatically avoid potential accidents, are progressively becoming a standard in newly released vehicle models, driven by regional star rating regimes. Further penetration gains, alongside new regulatory-mandated features, are set to drive rapid proliferation of sensing and processing, all of which are powered by semiconductor chips. While the timeline to higher levels of autonomy (i.e. self-driving in a broader array of conditions) has shifted to the right, the emergence of more sophisticated levels of functionality (L2+), including enhanced safety and quasi-autopilot features, offers an increasingly rich semis content opportunity. Our scenario analysis suggests that by 2025E, average ADAS semis value per car could be roughly equivalent to that seen in an average xEV, with scope for the ADAS semiconductors market to increase by at least a 44%/27% CAGR out to 2025/2030E.

In this report we explain the required semiconductor technologies for each level of automation, lay out success factors for chip players in each domain, and provide a scenario analysis of market size and potential impact for key players. While the main focus of this report is ADAS, we also investigate bottlenecks for the roll out of higher levels of autonomy as well as potential content opportunities. Key impacted companies in our semis coverage include Infineon, STMicro, Intel, Nvidia, NXP and Renesas.

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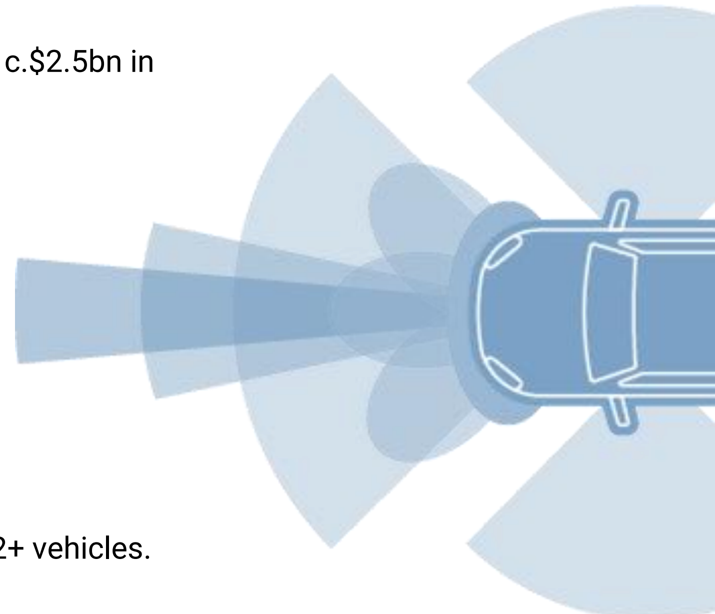
Did you Know ???

$400/$873

Incremental semis content in L2+/L4-L5 cars (and higher if GPU included) in 2025E; in comparison, estimated incremental semis content in xEV/BEV/Mild Hybrid vs ICE cars is $207/$441/$111.

$2.5bn/$11bn

GS forecast for ADAS semis TAM to grow from c.$2.5bn in 2021 to c.$11bn in 2025.



38%/35%

Infineon/STM 2020-25E ADAS revenue CAGRs.

30%/54%/51%

Total L1 & L2 penetration in 2021/25E/30E.

5-6/2-6/12-14

Number of radars/cameras/MCUs needed in L2+ vehicles.

2030

The year GS expects L4/L5 ADAS penetration to reach 5% of the auto market.

70mn

Number of EyeQ chips that Mobileye has shipped to date, growing at 39% 2014-20 CAGR, with 19mn units shipped in 2020. Significant portion is L1/L2, but moving toward L2+ onwards.

91%

Percentage of NCAP 4 and 5-Star passenger cars sold in the EU in 2020. NCAP rating regimes give credit for L1/L2 features that enable higher safety ratings.

77Ghz

Radar frequency that offers more accuracy and higher object detection resolution vs 24Ghz.

$3,000

Estimated GPU content per L4/L5 vehicle. We believe GPUs are most useful for higher levels of autonomy (L4/L5), albeit some market participants believe their own custom logic chips are enough for running driving policy.

Note: All estimates are Goldman Sachs Global Investment Research.
Source: Company data, EURO NCAP, Goldman Sachs Global Investment Research

PM Summary

Our US Autos team also published a report on ADAS today focusing on key sensor technologies such as LiDAR; see "Autos & Industrial Tech: Expect robust growth in ADAS; Competition may weigh on LiDAR fundamentals".

Advanced driver assistance system (ADAS) features encapsulated in the L2 level of automation, which include functionality in cars to alert and automatically avoid potential accidents, are progressively becoming a standard in newly released vehicle models, driven by regional star rating regimes. Further penetration gains, alongside new regulatory-mandated features, are set to drive rapid proliferation of sensing and processing, all of which are powered by semiconductor chips. While the timeline to higher levels of autonomy (i.e. self-driving in a broader array of conditions) has shifted to the right, the emergence of more sophisticated levels of functionality (L2+), including enhanced safety and quasi-autopilot features, offers an increasingly rich semis content opportunity. Our scenario analysis suggests that by 2025E, average ADAS semis value per car could be roughly equivalent to that seen in an average xEV, with scope for the ADAS semiconductors market to increase by at least a 44%/27% CAGR out to 2025/2030E.

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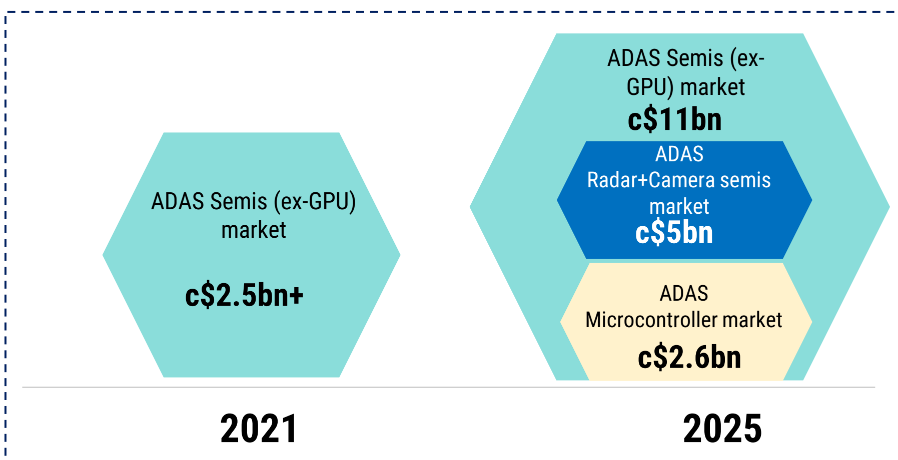
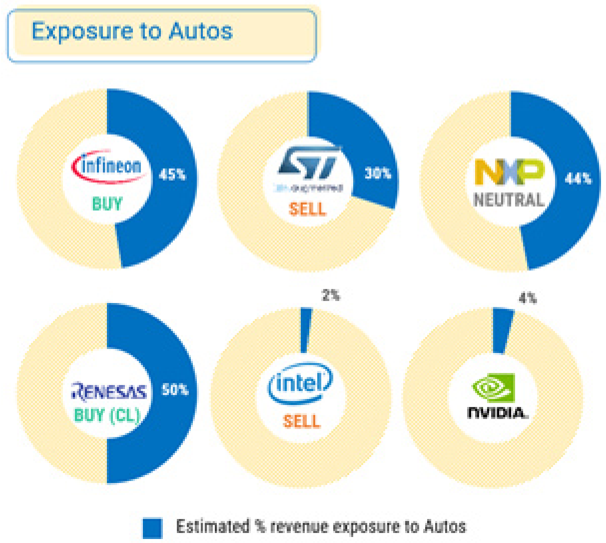
Exhibit 1: We expect the ADAS semis TAM to grow from $2.5bn to $11bn by 2025, with Microcontrollers and sensors (cameras and radars) forming the largest share
GS ADAS semis TAM base case forecasts



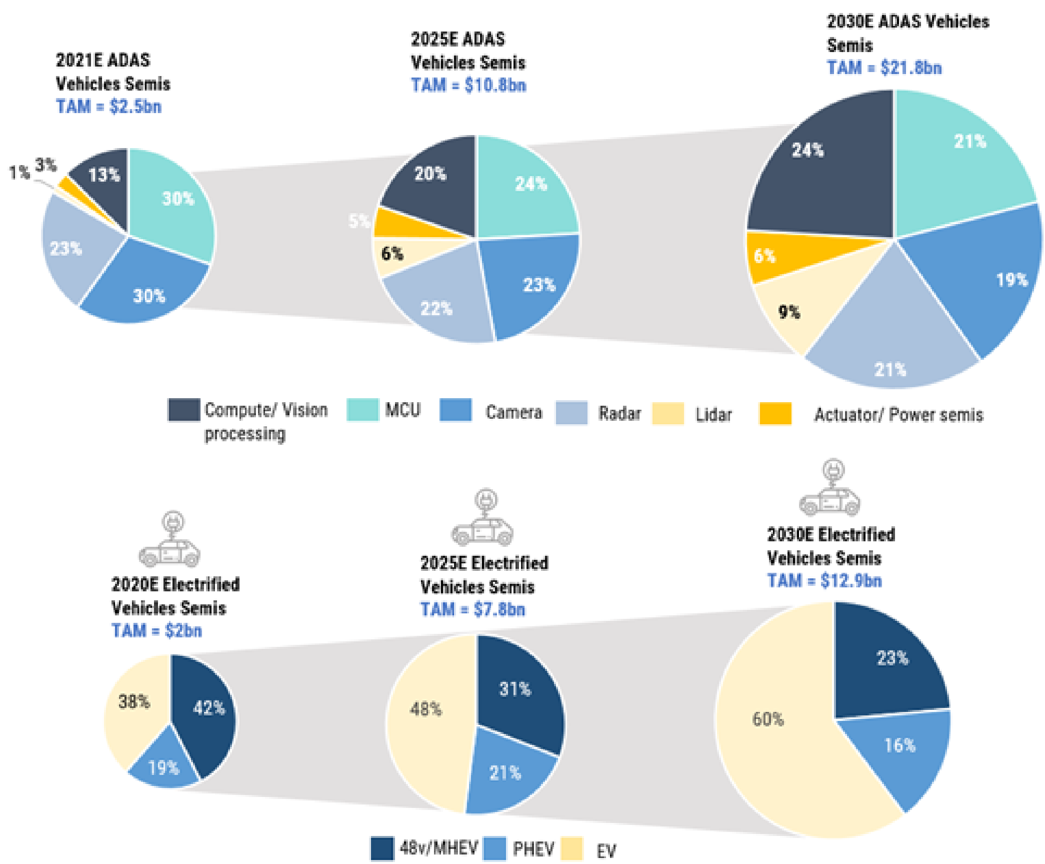
Source: Goldman Sachs Global Investment Research

Exhibit 2: Key impacted semis companies
% of revenue exposure to automotive end markets, 2020E



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 3: ADAS Semis TAM set to expand c.9x vs 2021 to $22bn by 2030 on our base case forecasts
ADAS and xEV Semis TAM base case



The ADAS semis TAM is ex-GPU; see scenario analysis for our TAM value estimates including GPU.

Source: Goldman Sachs Global Investment Research

Advanced driver assistance system (ADAS) features such as AEB, encapsulated in the L2 level of automation (e.g., the car can do simple tasks like automatic

emergency breaking but the driver still performs main driving actions), are progressively becoming standard in newly released vehicle models, driven by regional star rating regimes.

- **ADAS in cars perform detailed interpretations of the area around the car to anticipate possible collisions with vehicles, pedestrians or other objects, and warn the driver** (or prompt the car to manoeuvre/respond in certain ways). Examples of the functionality include **Lane Departure Warnings, Forward Collision Warnings, Automatic Emergency Braking and Adaptive Cruise Control.**

- The importance of ADAS from an economic perspective stems from two factors: First, an estimated **90% of casualties in the EU and injuries on the road are due to human error according to the European Commission, with over one million deaths per year globally due to road accidents, per WHO (at an estimated cost of $300bn per year in North America alone** (2011 data), per the American Automobile Association). Second, research by the **European Commission suggests ADAS technology could reduce crash fatalities by 19%-28%** in voluntary systems, and between 26%-50% in a regulated scenario.

Exhibit 4: ADAS offers several safety benefits through the use of sensor and compute technology, addressing a significant source of injuries and casualties and economic damage due to driving accidents

ADAS in a nutshell	
What is ADAS?	• ADAS, or advanced driver-assistance systems, are technological features designed to **increase the safety of driving a vehicle** • These systems use a **human-machine interface to improve the driver's ability to react to dangers on the road**, through early warnings and automated systems • Some of these systems are built standard to certain vehicles, while aftermarket features and even entire systems are available to add at a later date to personalize the vehicle to the driver
Examples of ADAS applications	• **Automatic Emergency Braking**: Use sensors to detect whether the driver is in the process of hitting other objects on the road. Take preventive safety measures, such as tightening seat belts, reducing speed, and adaptive steering to avoid a collision • **Automatic Parking**: Help inform drivers of blind spots so they know when to turn the steering wheel and stop. Some systems can even complete parking automatically without the driver's help by combining the input of multiple sensors • **Adaptive Cruise Control (ACC)**: ACC can automatically accelerate, slow down, and stop the vehicle, depending on the actions of other actions of surrounding objects

Why is it important?	• **Safety on roads is a primary concern**
	  • 1.35 million people die in road accidents worldwide every year – **3,700 deaths a day** (World Health Organisation)
	  • Road traffic crashes cost most countries **3% of their gross domestic product** (World Health Organisation)
	  • **90% of European fatalities and injuries** on the road are due to **human error** (European Commission)
	• **ADAS could reduce human error and reduce number of car accidents**
	  • ADAS could prevent **40% of all accidents, 37% of injuries and 29% of deaths** (AAA Foundation for Traffic Safety)
	  • Forward collision warning systems could **lower front-to-rear crashes by 27%** (Insurance Institute for Highway Safety)
	  • Rear automatic braking systems could **reduce crashes by c.80%** (Insurance for Highway Safety)

How is ADAS evolving?	• ADAS **features such as AEB in the L2 level of automation are progressively becoming a standard** in newly released vehicle models, driven by regional star rating regimes. • **L2+/L2++ combine higher levels of safety functionality and quasi auto-pilot features** (driver still has responsibility). • Longer term, **L4/L5 will have high to full automation with vehicles performing driving tasks** and no human attention required.

Source: Company data, World Health Organisation, European Commission, AAA Foundation for Traffic Safety, Insurance Institution for Highway Safety, Goldman Sachs Global Investment Research

Regional NCAPS (new car approval schemes) have directly linked star ratings to certain ADAS features in the last 5+ years, including in Europe and the US. For example, in Europe, 4-star and 5-star safety ratings for newly launched/facelifted vehicles are linked to having active safety features such as Automatic Emergency Braking.

- Given that **in the EU, for example, 75%/16% of new cars sold in 2020 had a 4-star / 5-star rating according to Euro NCAP**, the underpinning of the market for

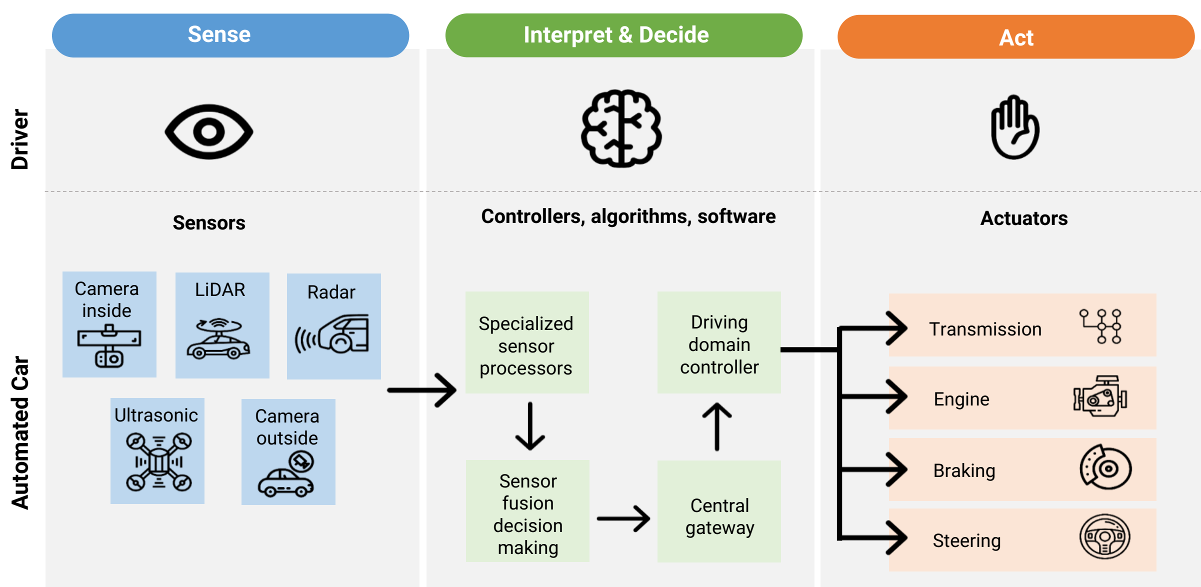
ADAS technology is clear. We note that Mobileye (owned by Intel), a key provider of processing software/systems in conjunction with STMicro used for ADAS, **shipped 70mn chips cumulatively by 2020 (since 2014)**, with a strong increase in yearly production over the period, as shown in the exhibit below.

We believe further penetration of L1/L2 ADAS, alongside new regulatory-mandated features, will drive rapid proliferation of sensing and processing in the car, and hence semiconductor growth.

- **We expect continued penetration gains of L1/L2 ADAS systems, as a function both of increasing proliferation in established markets and increased prevalence in new markets, as per our US Autos Team's report [LINK]. L2 is becoming a standard for many car makers,** and our industry discussions suggest OEMs find it difficult to sell new models without L2 in key markets, suggesting that **car makers will continue to increase L2 adoption to achieve future EU NCAP 5-star ratings**, for example.
- In essence, **ADAS systems incorporate intelligence into the car that allows it to sense, decide and act, all of which require semiconductors,** driving a strong market opportunity for semis. **Sensing can take the form of-sensors such as a camera** (which contain semis, and are typically coupled with an array of processing chips); **processing of an environmental model** (or other facets of the decision-making process); or complex software that runs on chips, such as Mobileye's vision-based **processing chip**, co-designed with STM (the final direction to act in a particular way is provided by a **microcontroller**). **Thus, as ADAS proliferates, it drives a need for chips.**

Exhibit 5: Replacing human actions with ADAS systems requires multiple sensors and associated semis, alongside chip content for interpretation, processing and actuation

ADAS systems schematic

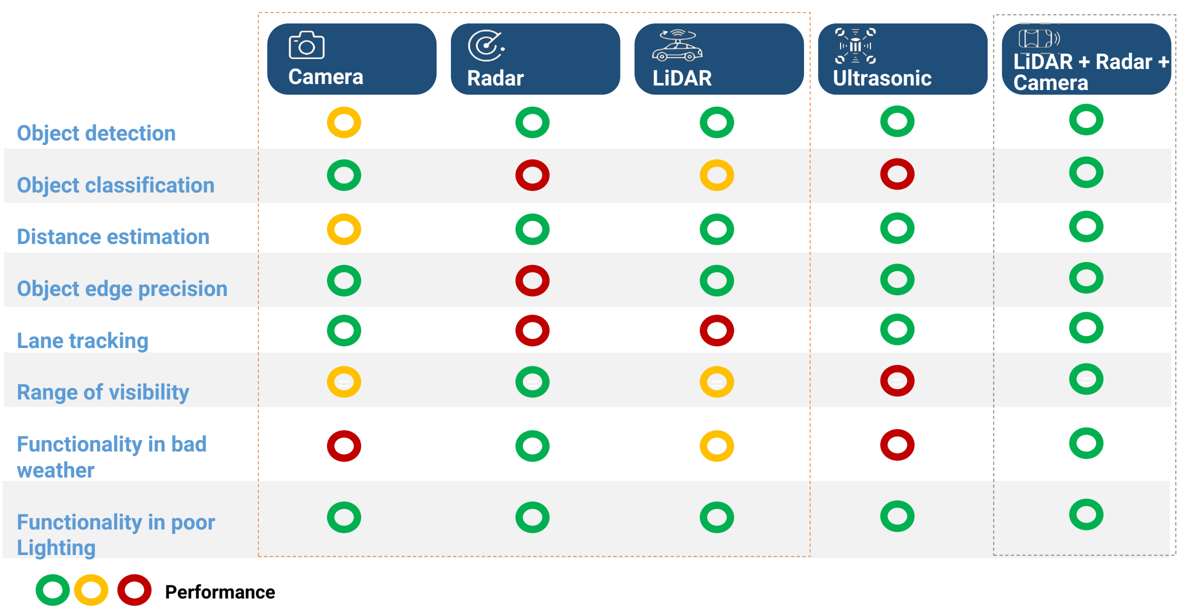


Source: Infineon, Goldman Sachs Global Investment Research

- Importantly, aside from penetration gains, **we expect further semis content growth per car associated with the use of more and more sensors for L1-L2 ADAS** (as opposed to higher levels of automation). Our industry discussions suggest a **trend towards incorporation of different types of sensors, even at lower levels of autonomy.** In the past few years, the advantages of camera-based sensing have become well established; companies now see scope to leverage sensors such as **radar** additionally to add extra redundancy/robustness (e.g. for L2 emergency braking functions, **given that different types of sensors have different advantages** (as illustrated below)). Importantly, **radars also require semiconductor chips, both on board the device, and also in the form of microcontrollers for pre-processing before feeding information into a central processing chip** where decisions are made (the latter will run algorithms related to perception and driving policy, etc.).
- Furthermore, the **ADAS landscape remains fluid; extra features continue to be incorporated into NCAPs, regardless of any push from OEMs for full autonomy.** For example, the latest **European NCAP incorporates mandatory in-cabin monitoring by 2022 on new homologated cars,** driving **a need for optical sensing chips within such systems**. Europe is leading the implementation of this feature, and our industry discussions suggest a **100% attachment rate in new cars produced by 2026/2027.**
- Thus, **while L1-L2 ADAS only form part of the semis opportunity, we see strong associated semis content growth opportunities**, even as levels of automation are set to progress to L2+ and beyond, as shown below.

Exhibit 6: Radars, cameras and lidars each have strengths and weaknesses, meaning a combination of each can help optimise performance/redundancy, even at lower levels of ADAS, e.g. L2

Performance levels suggest camera-only systems are less optimal vs. diverse solutions

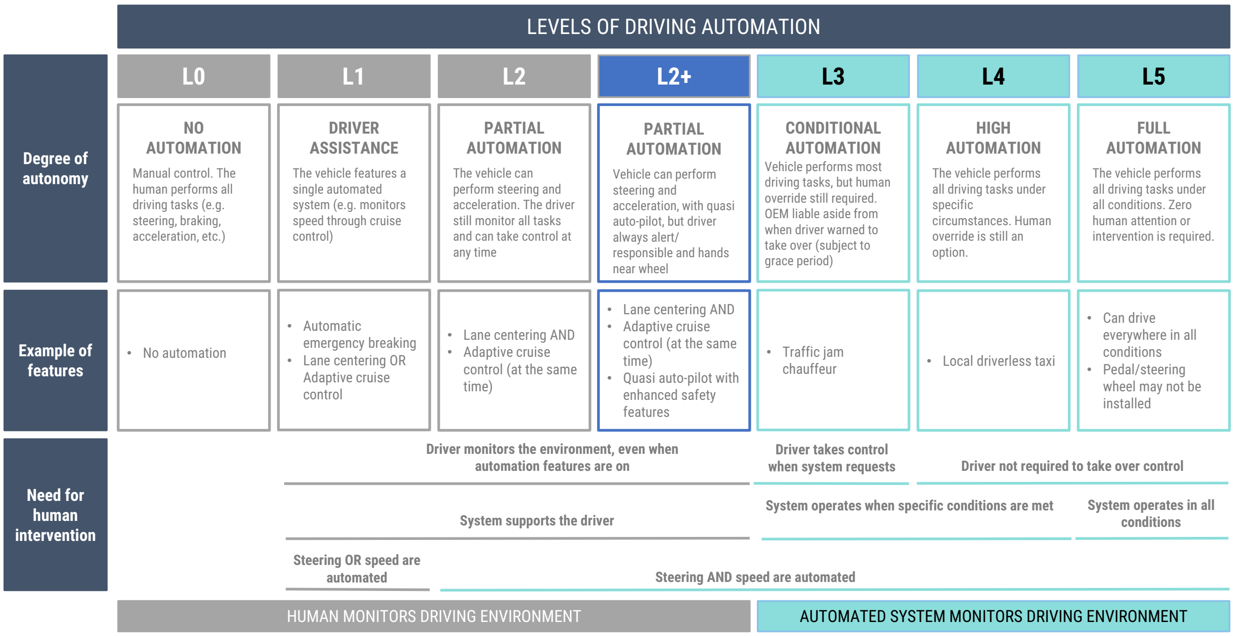


Source: STMicroelectronics, Goldman Sachs Global Investment Research

We define the different levels of autonomy, per the Society of Automotive

Engineers (SAE), below. Industry participants also refer to additional levels such as L2+ (which is a vehicle that is technically capable of L3 but the driver still needs to be prepared to take over if alerted, even if this is only a legal/regulatory distinction).

Exhibit 7: L2+ offers some of the convenience features of L3; L3-L5 face regulatory and technological bottlenecks
Overview of the ADAS levels

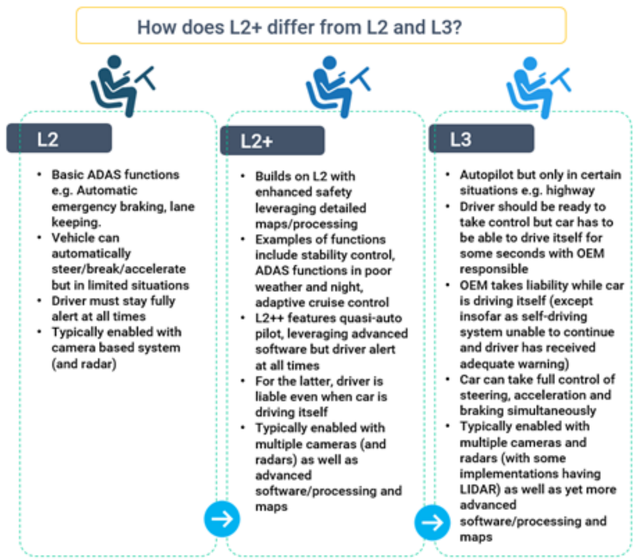


Source: Society of Automotive Engineers, company data, Goldman Sachs Global Investment Research

While the timeline to higher levels of autonomy has shifted to the right in recent years, L2+ functionality, including both enhanced safety and autopilot features, offers an increasingly rich semis content opportunity, in our view.

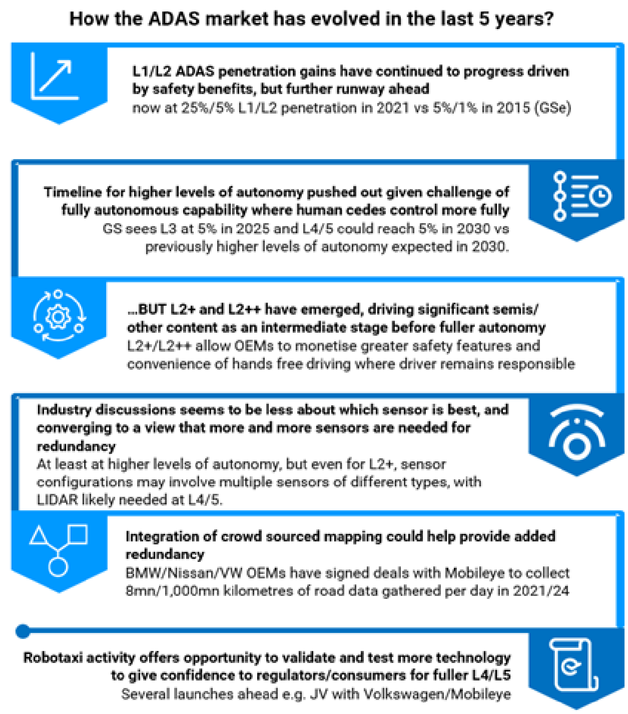
- In recent years, **the timeline for higher levels of autonomy (L3-L5), whereby the car drives itself to varying extents and under different conditions, has been delayed somewhat,** as per our industry discussions. For example, **for L3, which involves the car being able to drive itself in certain conditions**, subject to providing a warning to a driver to take over (but with a grace period of a certain number of seconds where the OEM is liable), **the required level of reliability/redundancy and the challenge of dealing with the handover have led to true L3 being delayed**.
- That said, we note the **emergence of L2+ and L2++ (broadly L2+), which build on L2 and offer advanced functions that stop short of L3 autonomy, but which we expect should see strong market uptake**. These are a) **enhanced safety** (e.g. electronic stability, road path planning) and b) **quasi-autopilot functions** (where the driver remains responsible at all times, even though the car drives itself under certain conditions, e.g. on motorways). We illustrate below some of the differences between L2+ and L3, as well as how L2+ differs from L2.

Exhibit 8: L2+ enhances numerous safety and convenience features from L2, without making OEMs fully liable for automated features (which L3 does)



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 9: The timeline for higher levels of autonomy has been pushed out, but L2+ — which has some similar features — has emerged in the meantime, which in our view should drive significant associated semis content

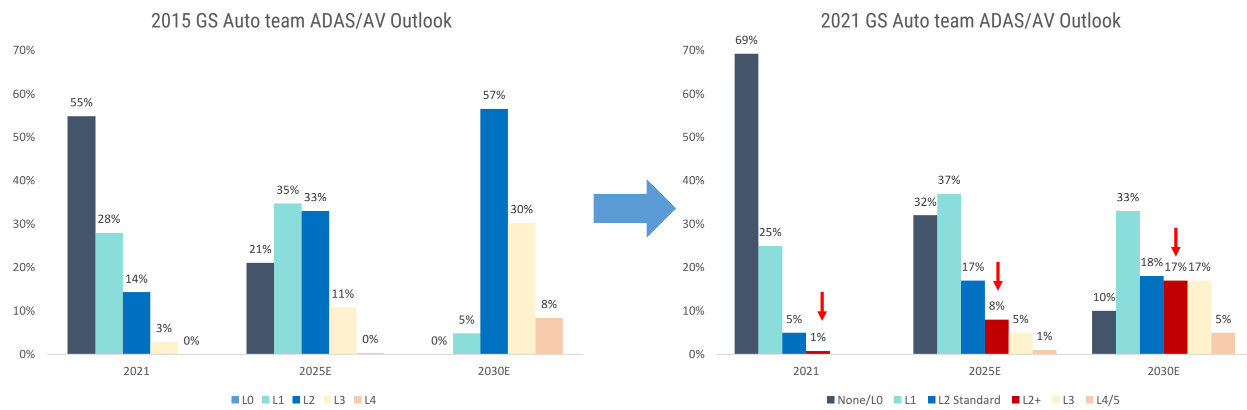


Source: Company data, Goldman Sachs Global Investment Research

L2+ offers many of the benefits of L3, especially as they pertain to the quasi-autopilot functionality, even though it does not offer the same degree of autonomy.

- **Several premium OEMs such as Tesla, Daimler, Audi and Porsche offer various versions of L2+**, with a more **advanced L2++ system from Geely set to launch in 4Q21**, powered by Intel/Mobileye/STM. We expect **demand to be driven by consumer convenience**, a **desire by OEMs to use L2+ to differentiate** and some features potentially becoming part of regulations over time given safety benefits. We see better comfort, convenience and safety features all driving a **greater willingness of consumers to pay more for the vehicle, which could be monetised by OEMs.**

Exhibit 10: The timeline for the adoption of high levels of autonomy has been pushed out, but L2+ has emerged (with a significant semis content opportunity) as L3-L5 face bottlenecks



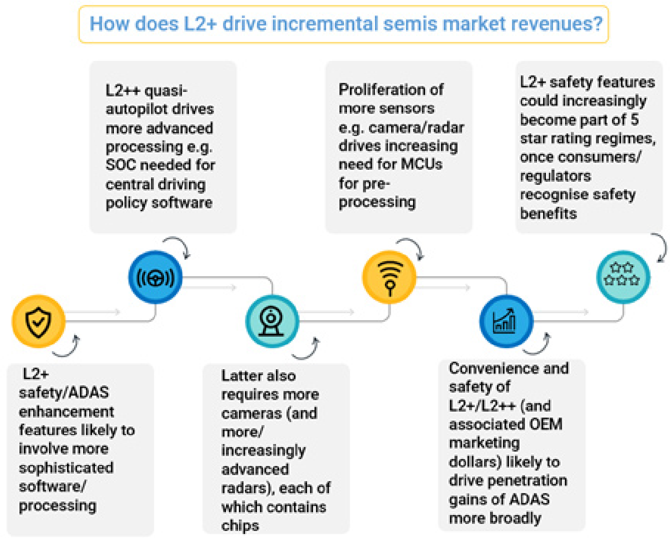
See "US Autos & Industrial Tech: Expect robust growth of ADAS" (April xx, 2021). Note that the ranges we present for 2030 are moderate adoption scenarios rather than a forecast.

Source: Goldman Sachs Global Investment Research

- **L2+ and especially L2++ drive increased opportunities for semi content per car.** This is because, typically, the **L2+ functions pertaining to enhanced safety require additional processing.** For example, the **driving policy will need to factor in inputs from live crowdsourced maps that are sent to the car to help with path planning and build in extra redundancy,** e.g. to help the car drive in poor weather conditions. Moreover, to the extent that **quasi-auto pilot** is deployed, it **will require a higher level of computational capability** as well as robustness. This can partly be achieved with more powerful processing, but **will also involve higher numbers of radars and cameras sensors** (and potentially also LiDARs). These **drive proliferation of chips as part of the sensors, and also typically are associated with larger numbers of MCUs,** e.g. for pre-processing, as highlighted below.

- Given the semis content associated with L2+ (as explained below) that is already on the road in 2021, **we believe the ADAS semis market should see strong double digit growth not only out to 2025, but also to 2030, even if L3 and higher levels of automation are delayed indefinitely. We estimate that an L2+ car on average has semis content worth $253-610 (ex GPU) vs. a regular ICE at $396 and L2 average at $110-$260. To the extent that a GPU is added, we see this as further boosting semis content per car.**

Exhibit 11: L2+ can drive semis market revenues by driving demand for more advanced processing, safety enhancement features and proliferation of more sensors



Source: Goldman Sachs Global Investment Research

Exhibit 12: There are numerous bottlenecks to higher L3 penetration in the short term; in our view this create an opening for L2+ vehicles, which offer many of the benefits/features without the OEM having as high a level of responsibility

1 Safety
- **L3 requires multiple (sometimes triple) redundancies in the sensor suite and actuators**, alongside with central processing of multiple sensor inputs, per SAE, which presents a significant technical challenge.
- It must be guaranteed that the **AV software won't have a lapse of judgement** (quite apart from following driving rules of the road to the letter), and it is necessary to **mathematically define what safe driving is**, while **working with industry bodies to standardise** this.
- **Car must be able to drive itself and park safely** in event driver is incapacitated and can't take over when a warning signal is given**, a large technical challenge**

2 Regulation
- As **liability shifts to the OEM in L3 (from the driver in L2),** and the ADAS system takes primary control of the vehicle, **higher levels of redundancy and even higher mean time between failure (MTBF) are required.**
- **Regulatory validation of L3 vehicles is harder** than isolated functions like AEB, that are incorporated into star rating regimes.
- L3 systems are **more complex to test** and verify by safety regulators/control agencies **(especially to get a 5 star rating)**

3 Costs
- OEMs must **scale up production of ADAS vehicles in order to spread fixed R&D costs across a larger volume** to **reduce costs to consumers**, and drive demand.
- Eg **L1 77Ghz radars used to be very expensive**, but the technology has matured with **SiGe radars significantly reducing cost**

4 Standardisation
- **Proprietary software developed by OEMs is much more difficult to standardise than Tier 1 innovations** (as these can be offered to multiple OEM car ranges/models).
- **A fragmented array of approaches could result in slower validation/ regulatory acceptance**

5 Consumer utility
- **Latest regulatory drafts in some regions appear to limit L3 to certain speeds**, contexts etc, with the **driver required to take over** subject to a grace period
- To the extent that the **driver's freedom to focus on things other than driving is curtailed**, there may be a relatively **limited delta between consumer utility of L2++ and L3,** meaning the industry focuses on the former and waits for L4.

Source: Company data, Goldman Sachs Global Investment Research

By 2025E, average incremental ADAS semis value per car could be roughly equivalent to that seen in an average xEV, we estimate.

- Our analysis suggests **average incremental semis content (ex GPU) in a L2+ car of $253-$610, higher than in an L1 car at $44-$98 or an L2 at $110-$260.** To the extent that GPUs are incorporated, we see this as significantly boosting the content opportunity per vehicle, providing a strong opportunity for semi companies (see our scenario analysis). Assuming that the **main delta between L2+ and L3 is defined by software rather than semis content**, albeit this area is fluid, and further semis could be included, we estimate that **L4/L5 consumer implementations could range from $705-$1,381 excluding GPUs, and $3,450-$4,170 including these** (albeit the main focus of this report is assisted driving, rather than full autonomy).

- Based on our US auto team's ADAS penetration assumptions, this translates into **ex-GPU blended average ADAS semis content of $91 in 2021E, rising to $163 in 2025E** (as **L2+/L3 rise in the mix**) and **$230 in 2030E** (**when we assume L4/L5 enters the mix** at low levels). For context, we estimate that a **regular ICE has semis content of $396, and on average an xEV has extra content of $207 (with a BEV at $441). Thus it is clear that ADAS represent an important opportunity for semis players in the auto space.**
- Our forecasts for successive increases in value of $ semis content per car for each of the various levels of automation are, broadly speaking, driven by factors including: 1) **greater prevalence of sensors, e.g. camera, radar** and (at the highest levels) lidar; 2) **greater processing capabilities for running more sophisticated software,** e.g. pertaining to environmental models and driving policy (including for L2+, but especially in L4/L5); 3) more **microcontrollers;** and 4) other semiconductors such as **optical sensors** (for driver monitoring). We summarise the **semis content requirements of each level below.**

Exhibit 13: We see the semis opportunity expanding materially as more sensors and processing are required for higher levels of automation, with the ADAS semis (ex-GPU) BoM even for L2+ vehicles similar to that found in BEVs

Estimated breakdown of semis content per vehicle for ADAS levels in 2025E

	Level 1 L1 vehicles in 2021: 22m	Level 2 L2 vehicles in 2021: 4m	Level 2+ L2+ in 2025: 8m	Level 3 L3 vehicles in 2025: 5m	Level 4/L5 L4/L5 vehicles in 2030: 4m-23m
Semis Content (ex-GPU)	**$44-$98**	**$110-$260**	**$253-$610**	**$253-$610**	**$705-$1,381**
Camera modules	$16-$21	$27-$88	$22-$84	$22-$84	$66-$169
Radar modules	$10-$14	$41-$54	$64-$100	$64-$100	$157-$260
Sensor Fusion/ Vision Processing	$3-$12	$3-$20	$105-$126	$105-$126	$215-$246
Others(e.g. Actuators)	$0	$7-15	$16-$28	$16-$28	$66-$97
Microcontrollers	$15-$50	$32-$82	$46-$134	$46-$134	$128-$268
GPUs	$0	$0	$457-$465	$915-$930	$2,745-$2,790
Lidar	$0	$0	$0-$139	$0-$139	$73-$340
Semis Content (with GPU)	**$44-$98**	**$110-$260**	**$711-$1,075**	**$1,168-$1,540**	**$3,450-$4,170**

The above does not include software, e.g. pertaining to driving policy, environmental models. Number of L4/L5 vehicles is a scenario range for 2030.

Source: Goldman Sachs Global Investment Research

We assume more sensors are required at each successive level, as these are important in adding increased redundancy/robustness to systems.

- This is especially the case at the higher levels of autonomy, but even at L2+. While the focus of our report is ADAS, we also discuss below why extremely high sensing capabilities are needed for L4/L5 automation. Note that **at each successive level of automation, we assume more cameras and radars are required** (as well as LiDARS for L2+ onwards, given their advantage of higher resolution and better performance at night /in bad weather). **We assume LiDAR semis content of $0/$0/$0-$139/$73-340 for this category for L1/L2/L2+/L4+.** We illustrate below some of the more advanced sensor configurations at various levels of autonomy, and highlight Exhibit 14, in which we detail a range of numbers of sensors needed per level of ADAS/automation.
- **Greater processing capabilities are required as one progresses from lower levels of automation to higher levels.** This is because **more sophisticated processing is required to run ever more complex software**. For example, **L2+ systems running autopilot need to run software that can leverage data from**

crowd source mapping systems (to help the car drive safely even when weather conditions impact the visual field) and to **run more advanced environmental (and driving policy) models** (even if the human driver needs to be ready to take control). Furthermore, as higher levels of automation such as L3 are approached, the **car needs to be able to drive itself entirely without human intervention during a certain grace period of a number of seconds on a highway** (pending the human taking control post a warning signal), again **requiring even greater computational power** (to achieve driving capabilities that are greater even than a human could deliver).

- This is **especially so for L4/L5 (see below), where such capabilities are required for a much bigger window of time** (and much wider circumstances). **We assume total semis content of \$44-\$98/\$110-\$260/\$253-\$610/\$705-\$1,381 for L1/L2/L2+/L4+ if GPUs are excluded** (and \$3,450-\$4,170 for L4+ where they are included). Typically, **such processing will either be run on a custom chip, such as that provided by Mobile/STM/Intel, and/or a GPU** from a manufacturer such as Nvidia.

Exhibit 14: Higher levels of autonomy require higher levels of redundancy, driving demand for sensors and associated MCUs (alongside greater processing requirements)
Illustrative sensor/MCU setup for various ADAS levels

HARDWARE AND SOFTWARE EVOLUTION TOWARDS AUTONOMOUS DRIVING

	L1	L2	L2+/L3	L4/L5
Degree of autonomy	DRIVER ASSISTANCE	PARTIAL AUTOMATION	CONDITIONAL AUTOMATION	HIGH/FULL AUTOMATION
Sensors	1 – 2 Sensors + Optional Sensor Fusion Box	5 – 8 Sensors + Sensor Fusion Box	7 – 12 Sensors + Sensor Fusion Box, Driver Monitoring	15 – 24 Sensors + Sensor Fusion Box, Driver Monitoring
# of MCUs	2 – 5 MCUs	5 – 8 MCUs	10 – 16 MCUs	18 – 24 MCUs
Total semis content per vehicle (ex-GPU) (GSe)	\$44 – \$98	\$110 – \$260	\$253 – \$610	\$705 – \$1,381

RAPIDLY INCREASING SENSORS AND CONTENT PER VEHICLE (HARDWARE & SOFTWARE)

Some premium car makers are already integrating less advanced LiDARs at lower levels of autonomy and based on our industry conversations we understand that many (but not all) OEMs envisage LIDAR at L4/L5.

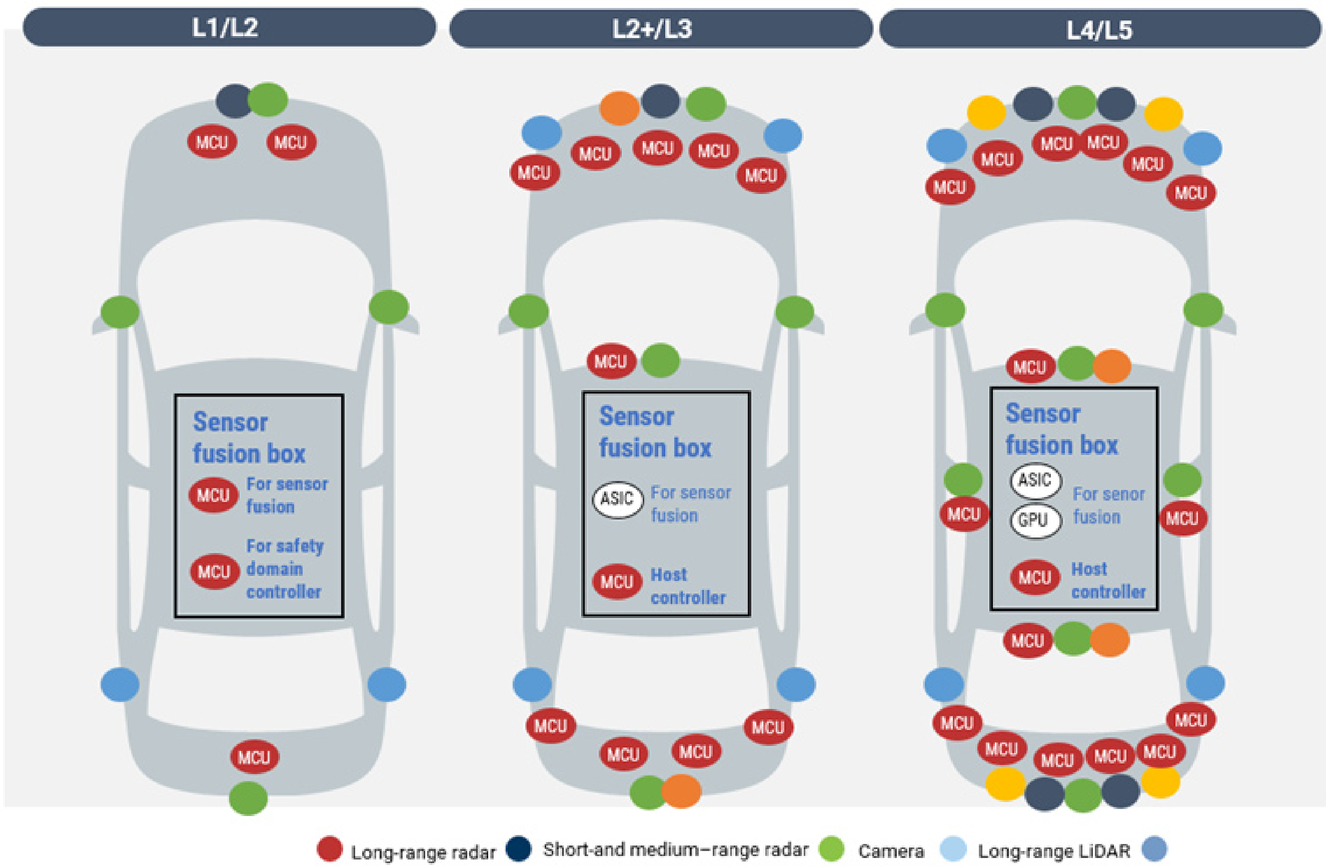
Source: Company data, Goldman Sachs Global Investment Research

The increasing number of sensors drives greater need for microcontrollers (MCUs).

- This is because **such sensors will tend to be attached to MCUs that do**

pre-processing before information goes to a central sensor fusion box containing custom chip(s) for processing and/or a GPU. This is where decisions on driving policy and environmental perception are made. Note, however, that **in L1/L2, an MCU may actually be the centralised processing chip doing this.** Independent to the number of sensors, after such a decision stage, **an MCU (e.g. an AURIX MCU from Infineon) will then run software that tells various domains of the car what to do,** e.g., brake, steer, etc. This will be **ASIL-D certified** for automotive grade. **We assume semis content of $15-$50/$32-$82/$46-$134/$128-$268 for MCUs for L1/L2/L2+/L4+, as per Exhibit 13**. We explain this further in Exhibit 51 and discuss various factors that could lead to consolidation of the number of MCUs in our scenario section.

Exhibit 15: Higher levels of automation to drive demand for associated MCUs for pre-processing and safety domain controller functions
Illustrative MCU setup for various ADAS levels

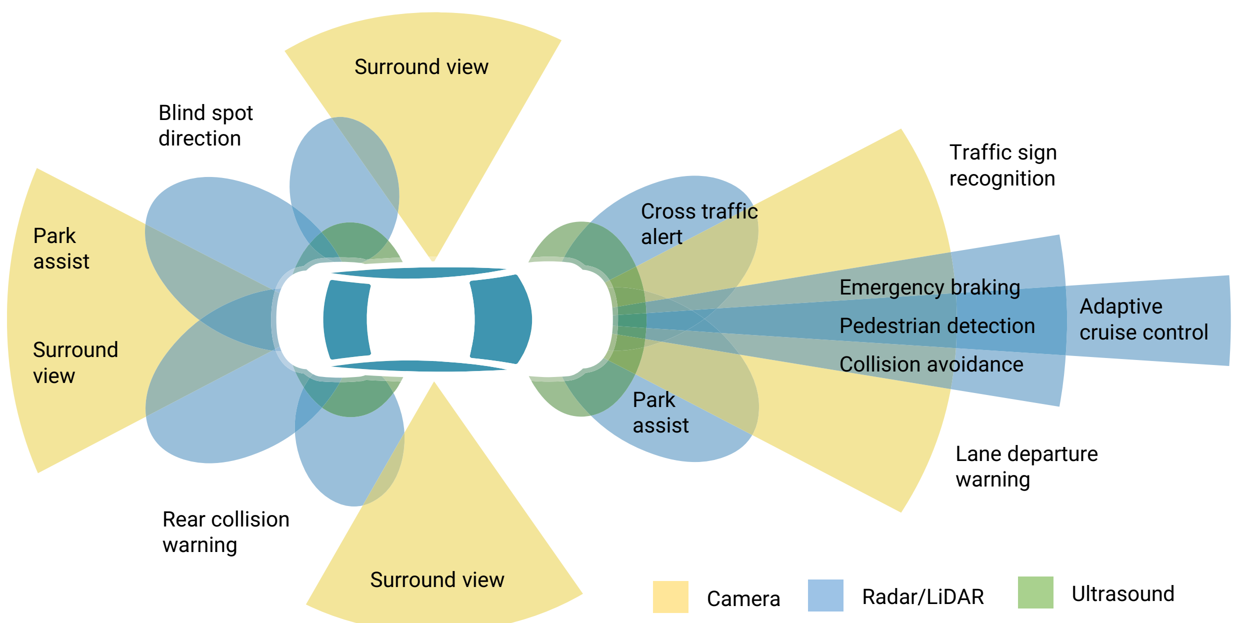


Source: Company data, Goldman Sachs Global Investment Research

- **Other semis of importance include power management ICs, driver monitoring optical semis and V2V chips.** Power semis are needed for managing the power voltages of an ADAS system of very high computational power. The **increasing presence of driver monitoring systems is driven by the requirement that drivers remain alert and prepared to re-take control when prompted in L2+/L3 autonomous systems**. Driver monitoring systems track head position, gaze, attention and alertness. **Europe NCAP has incorporated driver monitoring systems.**

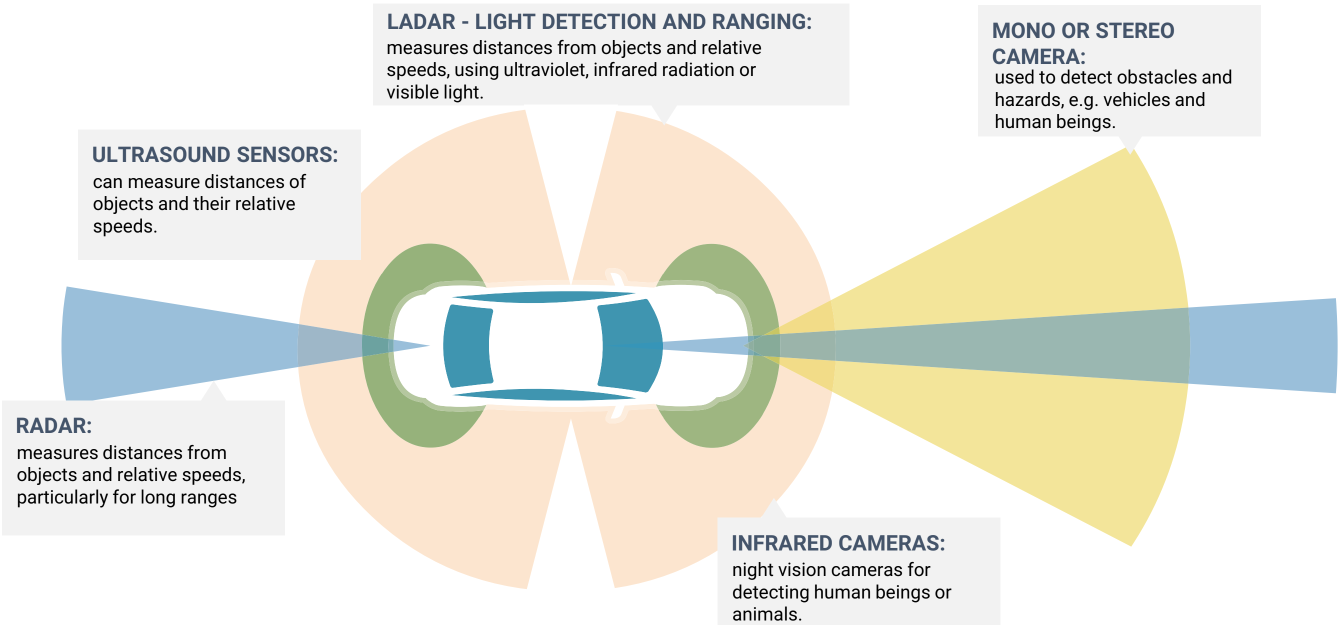
- **We see various success factors for the different types of semis.** For processing chips such as those provided by STM/Mobileye and Nvidia, these include **processing power, ability to conserve power (especially as EVs will need to run on batteries) and form factor efficiency**. **Some industry players believe that SOCs/ASICs *could* substitute for GPUs in the longer term, given power consumption issues.** For radar chips, key factors include the ability to **improve resolution** and potentially the move from a more analog approach to an approach that uses digital modulation (we note this a fluid area). For MCUs, key aspects include reputation for **reliability (e.g. ISO 26262 certification)**, auto domain level expertise and integration of memory with the MCU. Although we believe **ability to integrate processing with memory may lead to some advantages near term**, over time, **having sufficient processing power may be a gating factor for MCUs to do the more advanced functions** beyond L2 (e.g. computation functions, rather than purely pre-processing). We highlight the key players and success factors for a broader array of domains in Exhibit 62.

Exhibit 16: ADAS offers a range of automated driving features...
Illustrative features of certain levels of ADAS



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 17: ...enabled by a broad array of sensors and underlying semis processors
Illustrative different sensor types that can be appropriate for various levels of ADAS



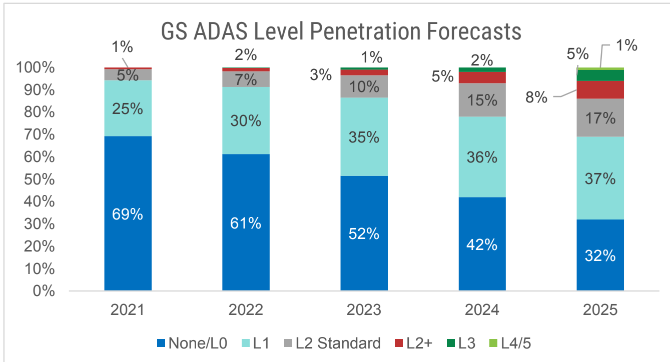
Source: Company data, Goldman Sachs Global Investment Research

We forecast the semiconductors market (ex-GPU) for ADAS to increase at 44%/27% CAGRs out to 2025E/2030E (from 2021E) in our base case, with even faster growth in our bull case as we flex up our assumptions for the extent of GPU usage and ASP.

- **Overall, we see rapid growth in the semis opportunity associated with ADAS out to 2025/2030 even if L4/L5 gets further pushed out than assumed in our scenarios (we run a separate sensitivity on penetration rates). We estimate an ADAS semis (ex-GPU) market size of $10.8bn by 2025E and $21.8bn by 2030E on our base case.**
- **Note that the absolute numbers we present for 2030 penetration are scenarios rather than an explicit forecast. We also acknowledge that further scenarios could be possible on other parameters, e.g. scope for L4/L5 to boost or inhibit overall auto units, which is beyond the scope of this report. The US Autos team's 2030 scenarios for penetration we use as one input into our semis scenarios are based on the inputs of leading auto tier 1 suppliers (Magna, Valeo, Veoneer).**

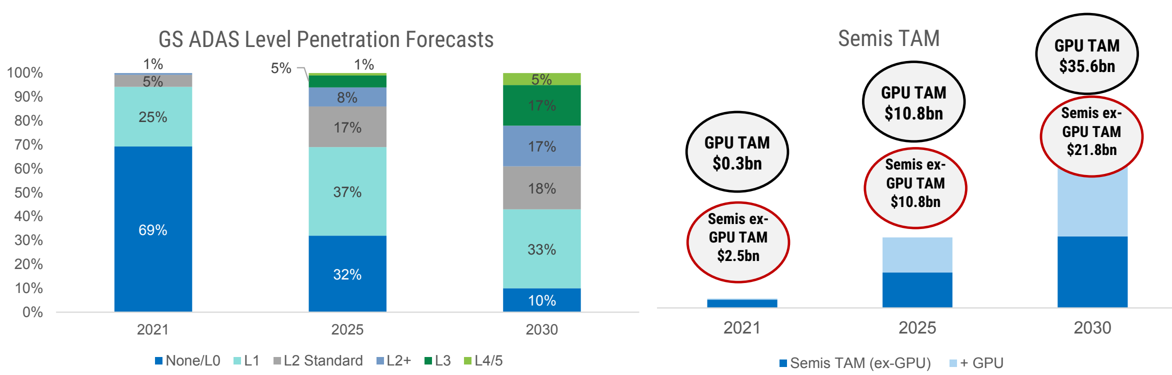
Exhibit 18: Our scenarios are based on our US auto team's forecasts for L2+ penetration to expand from <1% in 2021E to 6% by 2025E, with L1-L2 prevalence to more than double over the period, which would help drive up semis content

GS ADAS level penetration forecasts



Source: Goldman Sachs Global Investment Research

Exhibit 19: Proliferation of L2+ and L3 to drive semis ex-GPU TAM to c$22bn by 2030E in our base case scenario



Note that the ranges we present for 2030 are scenarios rather than a forecast

Source: Goldman Sachs Global Investment Research

We believe the factors most likely to impact the size/growth of the ADAS semis market are:

- The **penetration rates of higher levels of autonomy** (e.g. L2+ to L5), which require greater semis content given higher compute needs.
- The **degree to which the number of MCUs consolidates as the number of sensors rises**. At lower levels of autonomy, each sensor requires a dedicated MCU for pre-processing, but **we expect a degree of centralisation and consolidation in MCUs as higher power GPUs and ASICs are utilised in the sensor fusion box**.
- We are cognisant of the **risks that semis become commoditised and components experience greater/weaker-than-expected cost curve deflation in future years.**
- The **number of radar/cameras/lidars is likely to impact the size and growth of the ADAS market for semis**, and the **number of sensors derives the number of processing chips required** within ADAS vehicles. We note that per our industry

discussions **there is a broad array of views as to the number of components needed, especially as regard to the number of sensors/MCUs needed,** particularly at higher levels of autonomy.

To derive our TAM estimates, we flex three variables: (1) the number of semis units per vehicle (radar/camera/lidar chips, MCUs, power semis, compute/vision processing chips); (2) ASP (specifically the associated ASP deflation in these units); and (3) market share for Infineon/STM in their respective component areas. We use the same GS forecast penetration rates in all three scenarios, but run a separate set of sensitivities flexing this variable as discussed below**.**

Exhibit 20: We flex the number of units, ASP and Infineon/STM market share to arrive at our bear/base/bull forecasts for semis content per ADAS vehicle

Bull/base/bear case semis content by ADAS level

Semis Content ($) - Bull case							
	Camera	Radar	Lidar	MCU	Others	Compute	GPU
L1	21	14	0	50	0	12	0
L2	88	54	0	82	15	20	0
L2+	84	100	139	134	28	126	465
L3	84	100	139	134	28	126	930
L4/L5	169	260	340	268	97	246	2,790

Semis Content ($) - Base case							
	Camera	Radar	Lidar	MCU	Others	Compute	GPU
L1	19	12	0	19	0	7	0
L2	48	48	0	51	11	11	0
L2+	73	76	42	72	22	115	461
L3	73	76	42	72	22	115	922
L4/L5	83	172	145	161	81	231	2,767

Semis Content ($) - Bear case							
	Camera	Radar	Lidar	MCU	Others	Compute	GPU
L1	16	10	0	15	0	3	0
L2	27	41	0	32	7	2	0
L2+	22	64	0	46	16	105	457
L3	22	64	0	46	16	105	915
L4/L5	66	157	73	128	66	215	2,745

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 21: We see a sizeable semis content opportunity even at the lower levels of autonomy, such as L2+ which is in production today

2025E ADAS Semis content per car

2025E Content per car - excl GPUs (in $)					
	L1	L2	L2+	L3	L4/L5
Bear	44	110	253	253	705
Base	57	169	400	400	873
Bull	98	260	610	610	1,381

2025E Content per car - incl GPUs (in $)					
	L1	L2	L2+	L3	L4/L5
Bear	44	110	711	1,168	3,450
Base	57	169	861	1,323	3,640
Bull	98	260	1,075	1,540	4,170

Source: Goldman Sachs Global Investment Research

In our bear/base/bull case scenarios, we estimate a $7.3bn/$10.8bn/$16.9bn overall ADAS semis (ex-GPU) TAM in 2025E, rising to $14.7bn/$21.8bn/$34.2bn in 2030 (Exhibit 22). This implies an ADAS semis (ex-GPU) market 2021-2030E CAGR of 26%/27%/27% across our bear/base/bull scenarios.

- As mentioned above, our third variable is to **flex individual company market share** for STM and Infineon (within their respective sub-segments of the ADAS semis market). **In our bull case scenario ($16.9bn ADAS semis ex-GPU TAM in 2025E), Infineon sees a +56% CAGR (2020-25E)** in its ADAS revenues (vs 27%/38% bear/base case CAGRs). We estimate that in a bull case, STM realises a +51% CAGR (2020-25E) (22%/35% bear/base case CAGRs).
- Our bull case valuations imply 15%/16% upside to our PTs for STM/IFX (-7%/-7% downside in bear case).
- We present our conclusions for semis market TAM and IFX/STM ADAS revenues (flexing these three variables) in a series of tables below.

Exhibit 22: We see the semis (ex-GPU) TAM rising to $34bn in our bull case by 2030E (vs $15bn/$22bn in our bear/base case)
ADAS Semis TAM 2025/2030E

Semis SAM - inc GPUs (in USD mn)	2025	2030
Bear	17,975	49,640
Base	21,557	57,444
Bull	27,738	70,493

Semis SAM - excl GPUs (in USD mn)	2025	2030
Bear	7,290	14,687
Base	10,785	21,842
Bull	16,878	34,232

Source: Goldman Sachs Global Investment Research

Exhibit 23: In our scenarios, we see higher ADAS revenues for Infineon vs STMicro in 2025E and 2030E
IFX and STM ADAS Revenues and TAM for 2025E/2030E

STM ADAS TAM ($ mn)	2025	2030
Bear	5,830	12,348
Base	7,633	15,614
Bull	11,348	22,293

STM ADAS Revenue ($ mn)	2025	2030
Bear	825	1,399
Base	1,326	2,360
Bull	2,388	4,438

IFX ADAS TAM (€ mn)	2025	2030
Bear	4,161	7,843
Base	5,501	10,357
Bull	8,747	16,259

IFX ADAS TAM (€ mn)	2025	2030
Bear	959	1,730
Base	1,459	2,729
Bull	2,645	5,017

Source: Goldman Sachs Global Investment Research

Below we run a series of sensitivities on the three scenarios above on the degree to which ADAS penetration could accelerate faster ('hyper-adoption') or slower ('lower adoption') than the rate used in the scenarios above ('neutral'), holding all other variables (semis content/ASPs/market share) equal.

For our base case, assuming a lower adoption sensitivity in which we model that the timeline for L4/L5 penetration is pushed out beyond 2030 (vs neutral sensitivity of 1% in 2025E) has only a marginal impact — the strong semis content associated with L2+ drives a semis (ex-GPU) TAM of $19.6 in 2030E vs the neutral scenario of $21.8bn. We see the greatest driver of semis content over the mid term the emergence of the rich content opportunity associated with L2+. Our hyper-adoption sensitivity suggests a semis TAM of $30.2bn by 2030E.

- **In our hyper-adoption sensitivity, we assume L4/L5 penetration reaches 20% by 2030E (vs 5% in the Neutral case). Success factors** for this rate of penetration include **rapid adoption of advanced safety functionality by NCAP regulators**, **quick cost curve reductions** to ensure commercial viability and faster-than-expected **technological breakthrough.**

- In **our lower adoption sensitivity, we assume that there is still no L4/L5 penetration in 2030E, but that rapid acceleration of L2+ offsets this.** Therefore, **we assume 39% penetration of L2+ in 2030E** in **our lower adoption sensitivity** (vs 17% on our neutral sensitivity). We see risks that this could materialise **including regulatory or technological barriers to block mass production of L4/L5**, with L2+ presenting an attractive alternative, given that **L2+ offers many similar advanced features at a price point that is commercially viable** even today.
- **For our base case**, under lower adoption/neutral/hyper-adoption ADAS level penetration sensitivities, **we estimate a $10.3bn/$10.8bn/$10.8bn overall ADAS semis (ex-GPU) TAM in 2025E, rising to $19.6bn/$21.8bn/$30.2bn in 2030E.**

Exhibit 24: For our base case, our hyper-adoption sensitivity implies 20% L4/L5 consumer car adoption in 2030E, whereas lower adoption assumes L3-L5 are delayed but is replaced by L2+
ADAS level penetration rate for hyper-adoption/neutral/lower adoption sensitivities on base case scenario

Penetration rate - Hyperadoption case	2021E	2022E	2023E	2024E	2025E	2030E
L0	69%	61%	52%	42%	32%	10%
L1	25%	30%	35%	36%	37%	30%
L2 Standard	5%	7%	10%	15%	17%	15%
L2+	1%	2%	3%	5%	8%	10%
L3	0%	0%	1%	2%	5%	15%
L4/L5	0%	0%	0%	0%	1%	20%

Penetration rate - Neutral case	2021E	2022E	2023E	2024E	2025E	2030E
L0	69%	61%	52%	42%	32%	10%
L1	25%	30%	35%	36%	37%	33%
L2 Standard	5%	7%	10%	15%	17%	18%
L2+	1%	2%	3%	5%	8%	17%
L3	0%	0%	1%	2%	5%	17%
L4/L5	0%	0%	0%	0%	1%	5%

Penetration rate - Lower adoption case	2021E	2022E	2023E	2024E	2025E	2030E
L0	69%	61%	52%	42%	32%	10%
L1	25%	30%	35%	36%	37%	33%
L2 Standard	5%	7%	10%	15%	17%	18%
L2+	1%	2%	4%	7%	14%	39%
L3	0%	0%	0%	0%	0%	0%
L4/L5	0%	0%	0%	0%	0%	0%

Source: Goldman Sachs Global Investment Research

Exhibit 25: We see the ADAS semis (ex-GPU) TAM rising to $48bn by 2030 in our most positive sensitivity (bull case on advanced autonomy adoption rates)
ADAS semis (ex-GPU) TAM sensitivities in 2025E/2030E

2025E Semis SAM - excl GPUs (in USD mn)	Lower Adoption	Neutral	Hyper adoption
Bear	6,850	7,290	7,290
Base	10,325	10,785	10,785
Bull	16,128	16,878	16,878

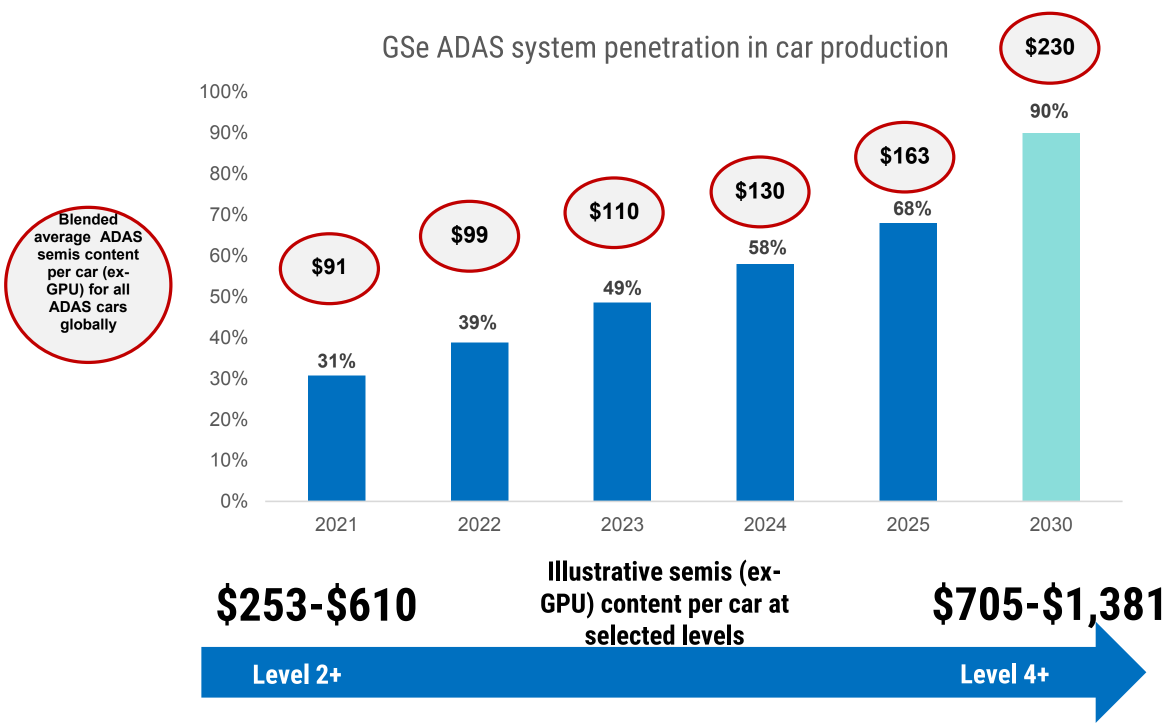
2030E Semis SAM - excl GPUs (in USD mn)	Lower Adoption	Neutral	Hyper adoption
Bear	12,555	14,687	22,082
Base	19,588	21,842	30,244
Bull	30,524	34,232	47,850

Source: Goldman Sachs Global Investment Research

While the key focus of this report is ADAS, we also investigate enablers, semis content and bottlenecks for *higher* levels of autonomy (L4-5), as well as potential content opportunities.

- While the focus of this report is assisted driving (i.e. <L3 ADAS), **we highlight that the highest levels of autonomy (i.e. L4-L5) will bring greatly increased semis content opportunities, as show in the exhibit below**. Moreover, even if we believe that **true consumer L4/L5 will not become large scale before 2030 onward**, **some of the features developed for this could become part of levels such as L2+ earlier on**, driving further semi content opportunities.
- **L4 is defined as highly automated driving, where the vehicle can perform all driving tasks under specific conditions**. **L5** is defined as fully automated driving where the vehicle **performs all driving tasks under all conditions**, with human intervention not required as automated features even perform well in all locations and weathers (**some L5 cars may be designed without a steering wheel/pedals)**.
- **L2+ vehicles offer some L3 features (such as quasi auto-pilot on highways) but the driver remains liable in the event of an accident** and **must remain alert at all times** (whereas the driver may disengage with the road environment for temporary periods in L3 vehicles, as the OEM is liable).

Exhibit 26: Higher levels of penetration of more advanced autonomy (i.e. L4/L5) drive average blended incremental ADAS semis (ex-GPU) content per car to be similar to that of an xEV by 2025E
GSe ADAS system penetration, incremental content for L2+/L4-L5 and blended average incremental ADAS semis content (ex-GPU) across all vehicles globally



Source: Goldman Sachs Global Investment Research

In essence, while we assume that it is relatively simple given today's computational and engineering capabilities to build a car that can drive itself in a certain defined area, the key bottleneck (among others) for a *consumer* owned car to be able to drive beyond prescribed maps is to ensure the car can do so to a

standard that is significantly statistically better than human ability in terms of safety (and to do so at a reasonable hardware cost (note Robotaxis operate under different cost constraints).

- In other words, the **mean time between failures must be demonstrably an order of magnitude better than a human driver such that consumers and regulators deem it acceptable.** We include this bottleneck in the exhibit below, as well as others, e.g. the **need for the car to be able to follow regional driving practices** (which may not be defined specifically in legal rules) and therefore may require an official method of validation for safety.
- Another potential bottleneck, as per our industry discussions, is that **cost curves for L4/L5 need to fall significantly before being commercially viable for consumer purchase**. Therefore, we believe **early adoption of L4/L5 technology could be limited to Robotaxis/fleet vehicles (rather than consumer owned vehicles),** for which the ROI of a constantly driving vehicle is higher than an often idle consumer vehicle.
- That said, we note progress is being made in a number of these areas. **In driving policy, Mobileye is already working with regulators, while China has introduced an industry alliance to formally approved RSS based standards.**

Exhibit 27: We highlight several key bottlenecks that could prevent widespread adoption of consumer L4/L5 by regulators and consumers; that said, we believe progress is already being made on a number of these

Key bottlenecks to L4/L5 ADAS penetration	
Lower ROI for consumer AV	• **Incremental cost of L4/L5 ADAS systems has not yet fallen low enough to be economically viable for consumers,** given **current cost of hardware/sensors** required to get to sufficient level of mean time between failure • We believe there could be a **scenario where early adoption of L4/5 is limited to Robotaxis/fleet vehicles**, for which **the ROI of a constantly driving (and earning) vehicle is higher** than an often idle consumer vehicle. • We believe there could be a **scenario where Robotaxis could proliferate before consumer L4/5** in order to validate confidence in advanced systems. • **Momenta** (provider of AI software backed by Daimler) pledged that **Robotaxis will be fully driverless and profitable by 2024.** • **MBLY announced partnership with VW to run MAAS/robotaxi in Israel** (launched in 2019, fully commercialised by 2022) • Long-term, we est. the **incremental semis (ex-GPU) content can be c.$900 for L4/L5 vehicles**, on top of other ADAS software/hardware
Consumer acceptance	• We believe that **widespread consumer acceptance of AV systems will require failure rates to fall significantly below that of human-driven vehicles** in order to establish sufficient consumer confidence in ADAS products. • **ADAS fatalities are high profile** and lower consumer confidence (even if the failure rate is lower than human-driving) • That said, we believe that **as technical capabilities improve**, it will be **possible in the long term to demonstrate failure rates which are significantly better** than those of human drivers.

Redundancy	• **L4/L5 vehicles require higher levels of redundancy** and lower mean time before failure as **driver is not engaged with the road**
	• **Lidar sensors could become necessary** to facilitate long-range high-speed sensing.
	    • Issues of cost must be resolved, with **LIDAR sensors around 10x the cost of radar sensors**.
	• **Most testing is performed in perfect conditions** (e.g. Arizona/California, where is it **sunny, little traffic and wide roads)**
	    • AI trained exclusively in perfect conditions will **fail in harsher climates** e.g. Scandinavia or **more traffic** e.g. Asia.
	• **More progress is required on training AI using global scenarios** if OEMs want to sell cars globally
	• That said, we note that prices are coming down. For example, we note that **some cheaper lidars are now being included in some L2+ cars in the premium market segment.**
	• **Moreover, sensor innovation is improving** e.g. incrasing radar resolution

Mapping	• **L2+ to L5 vehicles rely to a degree on high definition mapping** which enables autonomous features in poor conditions. • Current technology enables maps to be updated every few months, **but real-time updates are required to ensure max safety**. • While **geo-fenced Robotaxis only need regional mapping**, consumer L4/L5 vehicles need **large-scale maps** to drive anywhere. • **Mobileye made progress** on data collection. Already gathering **8mn km per day, rising to 1bn km per day by 2024.**
Algorithms	• **More advanced software algorithms are required** to optimise L4/L5 driving behaviour • E.g. System must **understand how fast to drive on a road** due to social norms, even if it is less than the speed limit • **Different countries have varying cultures** which **software must be programmed** for (ie. software must account for behaviours and not just rules). • E.g. cameras must look for traffic light cameras in different locations (i.e. LHS vs RHS driving) • That said, **Mobileye has made progress crystallising its RSS (RSS is its proposal for standardised driving policy) approach with regulators** (which seeks to codify standards of safe driving, beyond a pure rules based approach).

Source: Company data, Goldman Sachs Global Investment Research

We highlight a number of key enablers for full L4-L5 Autonomous driving.

- First, **given the need to demonstrate a mean time between failure that is better than that of a human driver, there is a need to integrate multiple systems based in different sensors, e.g.** radar, lidar and ADAS that are independent of each other. By doing so, this builds true redundancy into the system. **The number of sensors in more autonomous vehicles is expected to be more numerous than seen in lower levels of automation to provide the required robustness/redundancy** and full view around the vehicle, which in our view should drive semis content.

- Second, **we believe the computational complexity will be especially advanced.** We believe a **set up involving custom processing chips and/or GPUs will need to be able to ensure critical computing power for advanced central sensor fusion processing.** Clearly this will be associated with a rich semiconductor opportunity.

Exhibit 28: A broad array of semis is required to underpin higher levels of automation (e.g. L4/L5), with a number of key players competing
Illustrative key enablers for ADAS functionality and key semis providers

KEY ENABLER	TYPE OF SEMIS	DESCRIPTION	PERFORMANCE	SELECTION OF SEMIS PLAYERS
Camera	Image Sensor	Vision system used for **detecting colours and textures of objects**, road environments (e.g. traffic signs, traffic lights) and road paths. Coverts light emitted from objects to form images of surrounding environments	**Has advantage of seeing texture and colour perception (e.g. traffic lights). Performs worse in poorer weather** and light conditions, which means it is **best complemented by other systems such as radar/lidar** sensors, or a high definition AV map.	Sony, Melexis, ON
Radar	Radar processing chip	**Longer range vision system that measures object speeds and distances in relation to the movement of the vehicle,** by emitting electromagnetic waves into surrounding area which are reflected back to the sensor. Used in all-weather conditions and complements camera-sensing systems.	Performs well in bad weather and **specialises in long-range detection of objects,** giving it a critical role in ADAS sensing, but has poor object detection. **Advancements in chip technology have enabled 4D imaging radar** and digital radar (using digital modulation).	Infineon, STM, TI, NXP, ADI, Freescale, Bosch
LIDAR	ASIC/ Logic chip	**Light detection and ranging sensing system that emits light and use returned data for object detection, creating a 3D maps of the area** with a 360 degree field of view. **Used in higher levels of automation** where higher detection accuracy is required.	**Strong performance at night** time and bad weather (adding redundancy to cameras). **LIDARs tend to be much more expensive than radars (and more precise)**. Detects long-ranges does object classification well	Osram, Hamamatsu
Embedded Controls	ECU/MCU	**MCUs used for pre-processing of signals from sensors, central processing of driving policy in lower levels of automation, and final action signal** e.g. to brake, ("domain or host controller")	**ECUs/ MCUs are critical in pre-processing of software and sensing data inputs** in the sensor fusion box (for L0-L2). Domain control is performed by ISO 26262 certified MCUs in all ADAS levels. **Pre-processing means less bandwidth taken up** on car's Ethernet and/or central compute	Infineon, STM, NXP, Renesas
Processing/ Sensor fusion	ASIC/ SOC/ FGPA	**Central compute takes inputs from sensor/MCU pre-processing and analyses environment/decides what to do High definition mapping software to enable autonomous features** to operate in poor conditions (in which cameras performance falls)	**Semis need to balance performance vs power consumption/size. Necessary to ensure autonomous functionality continues in poor weather** conditions (when cameras might perform worse). Without an integrated mapping system, human override is likely to be required more often.	STM, Intel, Mobileye
GPU	GPU chip	**Highly specialised processing chip for central processing of radar/camera/lidar input data** for decision making, but not domain control of powertrain, braking, transmission etc	GPUs can be **used to run software that analyses and decides on sensing data inputs** in the sensor fusion box. This **task can be performed by MCUs in L0-L2, but GPUs are required in L2+ to L5 due to higher processing performance.**	Nvidia
Driver Monitoring System	Optical sensors	**Use of sensors to monitor driver's head position, gaze, attention** and alertness. High attach rate due to legislation	Most **commonly used in L2+ systems**, which offer quasi-auto pilot features, but **require the driver to remain constantly alert** in the event that they need to take control. We expect future systems to monitor all occupants in the vehicle	STM, Bosch, NXP
V2X	Wireless connectivity chips	Provides **vehicle to vehicle communications** and vehicle to infrastructure communications	**Rollout of 5G networks should help provide low enough latency** that is required for secure and mission-critical communication	Broadcom, STM, Infineon, NXP, Qualcomm
Actuation / Power semis	Power semis	**Send final decision signals to physical controls for processes such as electronic braking**, throttle power and gear shifting	**Physical mechanisms are essential to operate the vehicle autonomously**. Mission-critical functionality that performs in all conditions (both autonomous and human driving).	Infineon, STM
Mapping	Coupled with ASIC/ SOC/ FGPA	**Map data enables ADAS features (e.g. lane centering) to remain effective even in areas where sensors have difficulty in accurately identifying** the road environment. For example, in **areas without visible lane marks**, or poor weather/light conditions.	**Effective mapping requires crowd-sourced road data to be aggregated before producing the mapping software**. Mobileye is currently gathering **8mn km of road data per day**, which is expected to scale to **1bn km per day by 2024.**	Mobileye
Driving Policy Software	Coupled with ASIC/ SOC/ FGPA	**Required in order to ensure vehicle follows societal norms alongside road rules**. This **software must clearly define the assumptions that humans make** about other drivers (e.g. that vehicles in adjacent lanes won't turn into your lane)	**Mobileye has made progress crystallising its RSS (RSS is its proposal for standardised driving policy) approach with regulators** (which seeks to codify standards of safe driving, beyond a pure rules based approach).	Mobileye

Source: Company data, Goldman Sachs Global Investment Research

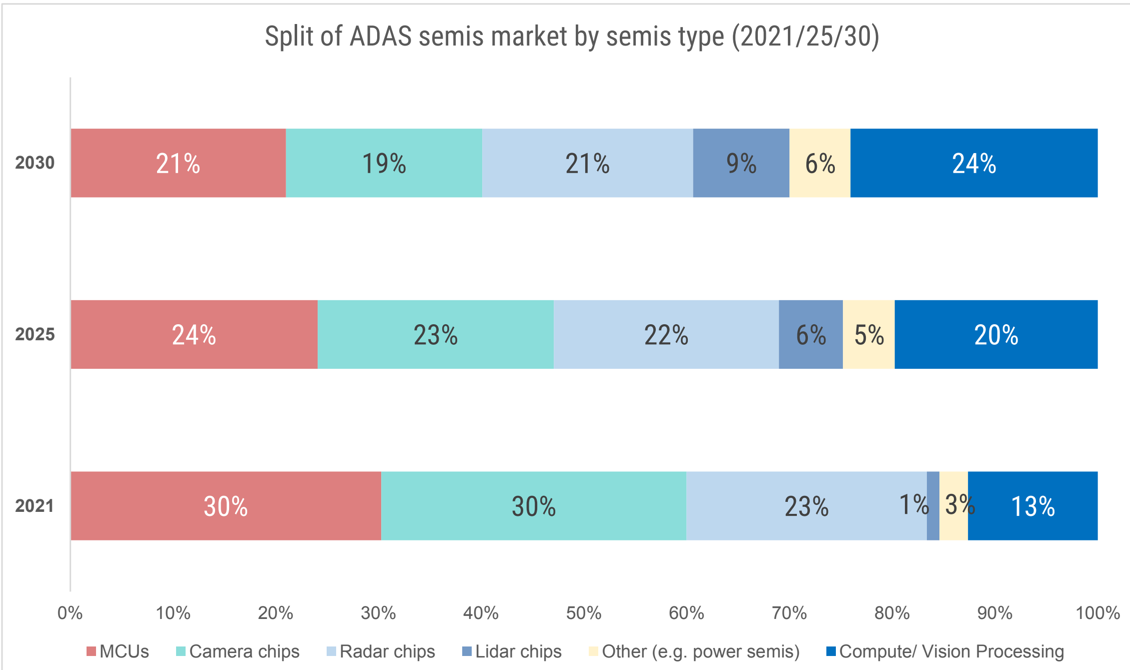
- Third, **high definition maps enable ADAS features (e.g. lane centering) to remain effective even in areas where sensors have difficulty in accurately identifying the road environment.** (e.g. in areas without visible lane marks, or poor weather/light conditions, where camera or radar sensors may perform suboptimally).
- **We provide further detail on a number of enablers and their implications for semis in the below exhibit.** This is a non exhaustive list and the enablers will evolve over time, just as content expected to be deployed on L1-L3 continues to evolve.

Multiple semiconductor companies have scope to benefit from ADAS, and we estimate an overall semis TAM of $21.8bn by 2030 in our base case. For context, we put the size the Auto semis market at c$38bn today.

- **Multiple companies in our coverage could benefit from the increased need for various types of semiconductor content in ADAS** as this technology evolves and penetrates more cars in coming years. Overall, in our base case, **we see a total ADAS-related semiconductor TAM of $10.8bn by 2025E (with our bull case at $16.9bn) and $21.8bn by 2030E (bull case at $34.2bn), which compares to the estimated overall Automotive semi market of c.$38bn today.**
- **For overall Microcontrollers, our base case analysis suggests a semis TAM of $2.6bn/$4.6bn in 2025/30E, and we believe Infineon (Buy), STM (Sell), Renesas (Buy, on CL) and NXP (Neutral) could all benefit to different degrees**. We consider **Infineon the leader on MCUs with its AURIX MCU for radar signal pre-processing** (alongside other host controller applications), where STM also holds a strong position (albeit with smaller market share). That said, we expect Infineon to further strengthen its position over time. **Renesas and NXP are also notable players in this space, with strong positions on 32-Bit MCUs.** These players are namechecked in our industry discussions as having the highest computing performance MCU chips when compared with some other players, per our industry discussions, which we believe is due to a strategic choice to pursue compute power.
- **In radar chips, our base case analysis suggests a semis TAM of $2.4bn/$4.5bn in 2025/30E. We see Infineon as a broad player that competes on all radar frequencies, and in our base case we assume strong +25% market share when considering all types of radars** (i.e. long-range, mid-range, short-range, 77 GHz, 24 GHz, SiGe, CMOS, front, rear, corner, etc.). **STM holds a market leading position on 24 GHz short-range radar** (while Infineon leads on 77 GHz long-range radar using SiGe technology) per company disclosure. That said, we expect Infineon to also offer CMOS radar technology in the future, in line with the company's plans. **We note that NXP also offers a leading solution on CMOS short-range and 77 GHz radar.**
- **Lidar chips offer advantages in terms of precision and resolution in comparison to radar sensors,** and our US Autos analyst Mark Delaney **expects 0.33/0.75/3 lidars on average for L2+/L3/L4-L5 vehicles in 2025.** However, **the extent to which lidars are used is fluid and may depend on the extent to which camera/radar capabilities can be improved** (something the industry is focused on

given the expensive nature of lidars relative to other sensors). Per our US Auto team, they see **lidars becoming more prevalent with L3 and then L4/L5**. Lidars tend to comprise a laser, receiver and scanner, with the receiver having an ASIC. **We estimate a lidar semis TAM of $0.7bn/$2.1bn in 2025/30E (base case). Key players include Velodyne, Aptiv and Magna.**

Exhibit 29: We see a broad opportunity set for semis content spanning semiconductors for compute, sensing and MCUs
Split of ADAS semis market by type of semis (2021/25/30E base case)



Note this does not include GPU

Source: Goldman Sachs Global Investment Research

- **Perception and decision making/policy software for more advanced ADAS (and especially for AVs) needs to run (at least for L3 onward) on powerful compute chips, rather than purely MCUs.** These could be an SOC/ASIC and/or GPU (at higher levels of autonomy). **Key players include Nvidia, which specialises in graphics processing capabilities through its GPUs for sensor fusion processing for in-car compute in higher autonomy (L4/L5) and car infotainment system.** Nvidia states that its solutions offer an end-to-end solution of both semis processing and accompanying software. For in-car compute, **the primary hardware solution is an SoC, which can also be sold with GPUs at higher levels of autonomy. We estimate the GPU semis TAM for ADAS expanding to $11bn/$36bn by 2025/30E in our base case.**
- **Mobileye also offers a full suite of software for various levels of automation, ranging for ADAS L1/L2, where it is the market leader.** This includes **algorithms not only for perception and driving policy**, but **also for integrating data from its crowd sourced mapping platform**, whereby it sources data from a broad array of OEMs using cameras on board cars that use its ADAS systems. Furthermore, it

collaborates with STM to co-design a custom chip that serves as a central compute option that can run such algorithms. Historically Mobileye/STM have been **strong on vision processing but over time it can run more and more sophisticated driving policy/perception software** and the company has expressed an intention to integrate inputs from independent sensors of various types e.g. radar. As such, we see the central processing **semis TAM (ex-GPU) for ADAS expanding to $2.1bn/$5.3bn by 2025/30E in our base case.**

- **In power management, both Infineon and STMicro offer a range of power management ICs tailored for ADAS.** These semis play an important role in managing voltages in an ADAS system of very high computational power. **We see the actuation/power semis TAM for ADAS expanding to $0.5bn/$1.3bn by 2025/30E in our base case.**
- STM offers optical sensing solutions to address **Driver monitoring (DMS) and occupant monitoring (OMS)** applications in which it holds a market leading position **(we estimate its market share is trending towards 25% on DMS).**
- We provide further details on these and other technologies, including other manufacturers and potential success factors for semis players in Exhibit 28, and detailed company profiles at the end of this report.

We list below the most important arguments that could run counter to our thesis that ADAS will over time drive significantly increased semis content, and our view as to mitigants to such arguments. These counter arguments include incorporating safety features into NCAP ratings, significant semis content associated with L2+ (given advantages of this to consumers/OEMs) and progress on standardising driving policy/behavioural elements for more advanced automation levels (in the longer term).

Exhibit 30: Cynics view - there are various arguments against our thesis but we see counter-arguments

1

Higher levels of redundancy required

- L3 requires much higher levels of redundancy/accuracy to be a reality and so could potentially be delayed.
- L2++ delivers many of the benefits to consumers and there is a very large semis opportunity in any case due to more sophisticated processing/sensing needs vs L2; hence even if L3 were skipped, L2++ would drive a lot of tech adoption in the car.

2

Regulation for L2+ onwards is lacking

- L2+ will not be driven by regulation so may not have as fast uptake as L1/L2 (which is driven by star rating regimes)
- Our industry discussions suggest premium car makers will want to have L2+/L2++ given attractiveness to consumers of safety features and/or convenience of quasi self driving. Furthermore, we believe it is possible the safety components could be included into star rating regimes (effectively regulation).

3

Consumer confidence is sensitive to higher profile ADAS crashes

- If there are crashes, this could retard the uptake of all types of automated vehicles
- We certainly believe this could set back adoption of L3 onwards, but see L2++ as a major driver and note the driver rather than the OEM is responsible at this level
- Moreover technology can be introduced to monitor the driver's alertness.

4

AI developments must overcome cultural challenges

- Autonomy requires understanding of driving behaviour, not just road rules; machines will struggle to achieve this.
- While the focus of the report is up to L2+, out to 2030, we acknowledge the potential for more advanced autonomous functions to trickle down and benefit the content within the ADAS sphere, suggesting progress in greater automation is a driver indirectly.
- That said, we note that work is ongoing to standardise/quantify what can count as "safe" driving at higher levels of autonomy (e.g. in scenarios where it is not just about following specific rules and where regional differences in driver behaviour are paramount).

5

Mean time before failure not sufficiently high yet

- L4/L5 requires such a high mean time before failure that it should not be relied upon to drive semis uptake.
- Our focus on this report is thus mainly on L1-L2++ out to 2030 and we think even without L4 onwards the semis TAM will expand by c9x vs 2020. However, we see potential for robotaxis to be a useful means of validating more advanced levels of automation and see independent sensor systems as a potential avenue for achieving sufficiently high mean time before failure.

Source: Company data, Goldman Sachs Global Investment Research

Summarised single-stock implications

BUY Infineon

- Infineon provides microcontrollers, radar processing chips and power semis for L1-L5 ADAS technologies.
- The company is primarily exposed to the ADAS market through its portfolio of MCUs, which are used for pre-processing of sensor data (camera/radar/lidar) before central processing in the sensor fusion box, but also as ISO 26262-certified safety domain controllers that send signals for the final actuation of the vehicle physical parts (e.g. steering wheel, brakes).
- We estimate IFX has c.30% global market share in MCU today, based on the company's comments that its ISO 26262-certified AURIX MCU is gaining traction and achieve 30%+ market share in the ADAS segment (it already has 30%+ market share for motor management and transmission, albeit this refers to the domain drivetrain).
- Infineon has achieved a solid position on long-distance 77 GHz radar chip, but is also working on the shorter-range 24 GHz frequency. We estimate c.25% market share for IFX in radar chips, when taking into account all types of radar.
- Our ADAS base case scenario analysis suggests IFX will grow its ADAS revenues at a 38% CAGR (2020-25E) but in a bull case scenario in which MCU uptake is greater (where it holds a strong market share), this drives a 56% CAGR (2020-25E).
- We are Buy rated on Infineon in the context of positive xEV, ADAS and Renewables tailwinds.

SELL ST life.augmented

- STMicro supplies vision-based processing chips, short-range radar processing chips, MCUs and power semis to the ADAS market. STM has been a co-developer of vision-based camera EyeQ chips with Mobileye for the past 15 years. To date, over 70m EyeQ chips have been shipped, with the majority of those delivered for L2 vehicles. STM's processing chips currently garner a dominant market share, especially viz-a-vis vision-based processing as it has co-developed its chips with leading vendor Mobileye.
- STM offers a comprehensive portfolio of ADAS IC's for power management, and holds a leading market position in short range 24 GHz radar sensor chips.
- STM offers optical sensing solutions for driver and occupant monitoring systems, which are required in L2+ vehicles that monitor to ensure drivers remain alert in the event that ADAS systems prompt require human control.
- Our ADAS scenario analysis suggests STM will grow its ADAS revenues at a 35%

CAGR (2020-25E) in our base case and in bull case scenario at a 51% CAGR (2020-25E).

N/R NVIDIA

- Nvidia is a market share leader in graphics processing unit (GPU) production for devices ranging from tablets to workstations and gaming PCs, alongside programmable GPUs for high-power compute applications, e.g. in the automotive end market.
- Nvidia specialises in graphics processing capabilities through its GPUs for sensor fusion processing for in-car compute in higher autonomy (L4/L5) and car infotainment system. Nvidia's solutions offer an end-to-end solution of both semis processing and accompanying software. For in-car compute, the primary hardware solution is an SoC, which can also be sold with GPUs at higher levels of autonomy.
- In 2019, the company talked to a TAM of $30bn with $25bn from driving (e.g. for L2+ to L4 systems), $3bn related to training software/development (e.g. training models, mapping, analysing data) and $2bn pertaining to validation (e.g. simulation).
- We note that perception and decision making/policy software for more advanced ADAS (and especially for AVs) needs to run (at least for L2+ onwards) on powerful compute chips, rather than purely MCUs. These could be an SOC/ASIC and/or GPU (at higher levels of autonomy), which are offered by Nvidia.
- Nvidia also offers a software stack for perception, localisation, mapping, planning and control for a complete autonomous drive platform (which the company believes can support L5 autonomy in time)

SELL intel

- In 2017 Intel acquired Mobileye, a provider of camera vision subsystems and processing chips for active safety and autonomous driving functions.
- Mobileye is a technological leader in the area of software algorithms, system-on-chips and customer applications that are based on processing visual information for Advanced Driver Assistance Systems (ADAS). Mobileye believes its camera subsystems are highly efficient as a result of the tight integration of hardware and software design (chips co-designed with STM), which allows for smaller sizer and greater compute power.
- While it has been highly successful on camera based processing, increasingly it is working on incorporating other sensors in order to achieve higher levels of autonomy (given redundancy needs for super human driving capabilities at such levels). These will be processed on its custom chips (EyeQ range) that it co-designs with STM, and which continue to evolve in terms of functionality and sophistication.
- Mobileye's advanced vision based system is due to launch in Geely L2++ vehicles in

4Q21, with quasi-autopilot functionality. This product will include algorithms not only for perception and driving policy, but also for integrating data from Mobileye's crowd-sourced mapping platform, whereby it sources road data form a broad array of OEMs using cameras on board cars that use its ADAS systems.

BUY - CL RENESAS

- Renesas Electronics Corporation is a key player in microcontrollers, analog, power and SoC products and serves several key end markets such as automotive, industrial (FA and others), infrastructure (e.g. Data center, Base station) and IoT (e.g. PC, tablets, wireless charger.
- Renesas is primarily leveraged to ADAS through its R-Car SoCs. Renesas started shipping R-Car V3U for L2+ (and L3, using multiple V3Us) in December 2020, and guides for mass production to start from the June quarter in 2023.
- Renesas offers products which balance calculation ability, cost and power consumption according to the OEMs' needs.
- To the extent that there are increasing levels of autonomy, such as L3, we see a potential benefit to Renesas, given the requirement for higher processing capabilities and MCUs in a sensor fusion setting for ADAS.
- Renesas acquired Intersil (completed in 2017) and IDT (completed in 2019), which it has brought together to offering what it describes as a "winning combination" of MCU, Analog and Power.
- Renesas has said it plans to focus on software (development programs/tools) as well as hardware, to secure long/mid-term competitiveness.

NEUTRAL NXP

- NXP Semiconductors is a market leader in automotive semiconductors (including infotainment) in recent years, and has high revenue exposure to automotive (c50%).
- The company is a major player in auxiliary functions within the car, such as body & comfort, infotainment and functional safety, and has a solid position in ADAS-related semis.
- Specific to ADAS, NXP focuses on 77 GHz long-range radar processing chips, using CMOS technology (rather than the SiGe technology that Infineon currently utilises, despite also transitioning towards CMOS). We see NXP as well positioned for the future uptick in ADAS adoption given the company's offering in long-range radar chips, which we see scaling in content as autonomy develops.

ADAS features driven by regional star rating regimes

Automated driver assist system (ADAS) features such as AEB, encapsulated in the L2 level of automation (e.g., the car can do simple tasks like automatic emergency breaking but the driver still performs main driving actions), are progressively becoming standard in newly released vehicle models, driven by regional star rating regimes.

Exhibit 31: ADAS offers several safety benefits through the use of sensor and compute technology, addressing a significant source of injuries and fatalities and economic damage

Why is ADAS important?	
Safety on roads is a major concern, as it bears considerable human and economic costs…	
Human costs	• **1.35 million people die in road accidents worldwide every year – 3,700 deaths a day** (World Health Organisation) • **20-50 million suffer non-fatal injuries**, often resulting in long-term disabilities • In 2018, around 23 400 people were killed in road accidents in the EU: 45% of the fatalities were passenger car drivers or passengers; 21% were pedestrians (EU) • Road traffic injuries are the **leading cause of death among young people aged 5-29**. Young adults aged 15-44 account for more than half of all road deaths (World Health Organisation)
Economic costs	• Road traffic crashes cost most countries **3% of their gross domestic product** (World Health Organisation) • The Lancet estimates that **road injuries will cost the world economy US$1-8 trillion in 2015–30**, equivalent to an annual tax of **0-12% on global GDP** • Low and middle income countries will experience approximately $834 billion dollars (in 2010 USD) in economic losses from 2015–2030 due to fatal and nonfatal crash injuries (The Lancet)
…ADAS can reduce these costs substantially by improving safety with ever-evolving technologies.	

Impact of ADAS	• **90% of fatalities and injuries** on the road are due to **human error** (European Commission)**. ADAS can reduce human error and drastically reduce number of car accidents…**
	  • ADAS could prevent **40% of all accidents, 37% of injuries and 29% of deaths** (AAA Foundation for Traffic Safety)
	  • Forward collision warning systems **lower front-to-rear crashes by 27%** (Insurance Institute for Highway Safety)
	  • Rear automatic braking systems **reduces crashes by c.80%** (Insurance for Highway Safety)
	• **…and generate meaningful cost savings as a consequence.**
	  • Potential to reduce car accident frequencies up to 25% and **cut car insurance premiums by $20bn** (SwissRe)
	  • That said, safety systems can add an **extra $3,000 in repair costs** due to higher technological complexity (AAA)

Source: Company data, World Health Organisation, AAA Foundation for Traffic Safety, Insurance Institute for Highway Safety, The Lancet, Goldman Sachs Global Investment Research

- **ADAS in cars perform detailed interpretations of the area around the car to anticipate possible collisions with vehicles, pedestrians or other objects, and warn the driver** (or prompt the car to manoeuvre/respond in certain ways). Examples of the functionality include **Lane Departure Warnings, Forward Collision Warnings, Automatic Emergency Braking and Adaptive Cruise Control.**

- The importance of ADAS from an economic perspective stems from two factors: First, an estimated **90% of casualties in the EU and injuries on the road are due to human error according to the European Commission, with over one million deaths per year globally due to road accidents, per WHO (at an estimated cost of $300bn per year in North America alone** (2011 data), per the American Automobile Association). Second, research by the **European Commission suggests ADAS technology could reduce crash fatalities by 19%-28%** in voluntary systems, and between 26%-50% in a regulated scenario.

- **Regional NCAPS (new car approval schemes) have directly linked star ratings**

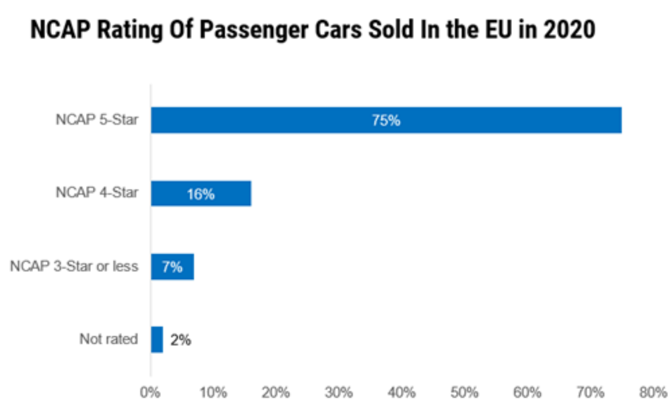
to certain ADAS features in the last 5+ years, including in Europe and the US. For example, in Europe, 4-star and 5-star safety ratings for **newly launched/facelifted vehicles are linked to having active safety features such as Automatic Emergency Braking.**

Exhibit 32: We see a strong regulatory impetus driving L1/L2 adoption, as basic automated safety features are increasingly made mandatory for 4/5 star NCAP ratings
Overview of key global regulations on ADAS

Global ADAS regulatory landscape	
US	• **US regulator NHTSA announced 20 automakers** have made commitments to make front-crash protection and automatic emergency breaking universal features across all passenger models by September 2022. • **US NHTSA is driving massive adoption of DMS (driver monitoring systems),** which is expected to be a standard soon based on our industry checks and accelerate in the next 5 years.
Europe	• NCAP requires **new cars to be equipped with In-Cabin monitoring functions in Europe by 2022**, and is expected to reach a **100% equipment rate of new cars produced by 2026/2027.** • As of **2022, new advanced safety (ADAS) technologies will be mandatory in all European** motor vehicles • Includes intelligent **speed assist**, driver attention/distraction warning systems and **emergency braking.** Mandatory features by 2022: • **For cars, vans, trucks and buses:** Warning of driver drowsiness and distraction (e.g. smartphone use while driving), intelligent speed assistance, reversing safety with camera or sensors, and data recorder in case of an accident ('black box') • **For cars and vans:** Lane-keeping assistance, advanced emergency braking, and crash-test improved safety belts. • **For trucks and buses:** Requirements to improve the direct vision of bus and truck drivers and remove blind spots. Front and side systems to detect/warn of vulnerable road users, especially when making turns. • European Commission suggests this will help save over 25k lives and avoid at least 140,000 serious injuries by 2038
China	• The Chinese government **aims for 80% of vehicles to be L1-L3 by 2025.** • The National Development and Reform Commission (NDRC) published a report on smart vehicles **development strategy targeting mass production of L3 autonomous vehicles by 2025.**
Global	• Since January 2021, UN announced Automated Lane Keeping Systems (ALKS) regulation **applies to 60 countries (not United States), which enables safe introduction of L3 vehicles in certain traffic conditions** • **ASKS includes performance-based requirements for vehicles to be sold as L3 systems** (e.g. maximum speeds under 60km/h, and on roads without cyclists/pedestrians, must have driver-monitoring system technology)

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 33: Most new car models sold in 2020 exceeded legal safety requirements as currently required by law to be in place in 2020 and offer better ADAS functionality than required by law from 2022



Source: Euro NCAP

- Given that **in the EU, for example, 75%/16% of new cars sold in 2020 had a 4-star / 5-star rating in according to Euro NCAP,** the underpinning of the market for ADAS technology is clear. We note that Mobileye (owned by Intel), a key provider of processing software/systems in conjunction with STMicro, **shipped 70mn chips cumulatively by 2020 (since 2014)**, with a strong increase in yearly production over the period, as shown below.

Exhibit 34: We see 10 key autonomous features present in L1 to L2+ vehicles, each of which drive a requirement for sensors and associated semis content

10 key ADAS applications
For L1 to L2+ vehicles

1 Automatic Emergency Braking

Use sensors to **detect whether the driver is in the process of hitting other objects on the road**. Take preventive safety measures, such as tightening seat belts, reducing speed, and adaptive steering to avoid a collision

2 Automatic Parking

Help **inform drivers of blind spots so they know when to turn the steering wheel and stop**. Some systems can even complete parking automatically without the driver's help by combining the input of multiple sensors

3 Adaptive Cruise Control (ACC)

ACC can **automatically accelerate, slow down, and stop the vehicle**, depending on the actions of other actions of surrounding objects

4 Adaptive Light Control

Adaptive light **control adapts the vehicle's headlights to external lighting conditions**. It changes the strength, direction, and rotation of the headlights depending on the vehicle's environment and darkness.

5 Navigation System

Provide on-screen instructions and voice prompts to help drivers follow a route while concentrating on the road. Some navigation systems can display exact traffic data and, if necessary, plan a new route to avoid traffic jams.

6 Night Vision

Night vision systems enable drivers to **see things that would otherwise be difficult or impossible to see at night** (e.g. detection of thermal energy from cars, animals, and other objects in the night)

7 Blind Spot Monitoring

Provide drivers with important information that is otherwise difficult or impossible to obtain (e.g. sound an alarm when they detect an object in the driver's blind spot, such as when the driver tries to move into an occupied lane)

8 Crosswind Stabilization

Supports the vehicle in counteracting strong crosswinds. The sensors in this system can detect strong pressure acting on the vehicle while driving and apply brakes to the wheels affected by crosswind disturbance.

9 Driver Drowsiness Detection

Warn drivers of sleepiness or other road distractions. Sensors can analyse the movement of the driver's head, and heart rate to determine whether they indicate drowsiness

10 Driver Monitoring System

Measure the driver's attention by analysing whether the driver's eyes are on the road or drifting. Driver monitoring systems can alert drivers with noises, vibrations in the steering wheel, or flashing lights.

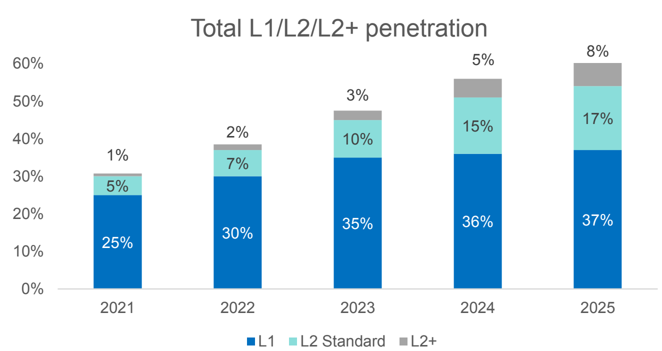
Source: Company data, Goldman Sachs Global Investment Research

Further penetration of L1/L2 to drive semis content growth

We believe further penetration of L1/L2 ADAS, alongside new regulatory-mandated features, will drive rapid proliferation of sensing and processing in the car, and hence semiconductor growth.

- **We expect continued penetration gains of L1/L2 ADAS systems, as a function both of increasing proliferation in established markets and increased prevalence in new markets. L2 is becoming a standard for many car makers,** and our industry discussions suggest OEMs find it difficult to sell new models without L2 in key markets, suggesting that **car makers will continue to increase L2 adoption to achieve future EU NCAP 5-star ratings**, for example.
- In essence, **ADAS systems incorporate intelligence into the car that allows it to sense, decide and act, all of which require semiconductors,** driving a strong market opportunity for semis. **Sensing can take the form of-sensors such as a camera** (which contain semis, and are typically coupled with an array of processing chips); **processing of an environmental model** (or other facets of the decision-making process); or complex software that runs on chips, such as Mobileye's vision-based **processing chip**, co-designed with STM (the final direction to act in a particular way is provided by a **microcontroller**). **Thus, as ADAS proliferates, it drives a need for chips.**

Exhibit 35: We forecast L1 to L2+ (i.e. lower levels of autonomy) to grow from 31% penetration in 2021 to 65% by 2025
Total L1/L2/L2+ penetration



Source: Goldman Sachs Global Investment Research

Importantly, aside from penetration gains, we expect further semis content growth per car, associated with use of multiple sensors for L1-L2 ADAS (as opposed to higher levels of automation).

- Our industry discussions suggest a **trend towards incorporation of different types of sensors, even at lower levels of autonomy.** In the past few years, the advantages of camera-based sensing have become well established; companies now see scope to leverage sensors such as **radar** additionally to add extra redundancy/robustness (e.g. for L2 emergency braking functions, **given that different types of sensors have different advantages** (as illustrated below)).

Importantly, **radars also require semiconductor chips, both on board the device, and also in the form of microcontrollers for pre-processing before feeding information into a central processing chip** where decisions are made (the latter will run algorithms related to perception and driving policy, etc.).

- Furthermore, the **ADAS landscape remains fluid; extra features continue to be incorporated into NCAPs, regardless of any push from OEMs for full autonomy.** For example, the latest **European NCAP incorporates mandatory in-cabin monitoring by 2022 on new homologated cars,** driving **a need for optical sensing chips within such systems**. Europe is leading the implementation of this feature, and our industry discussions suggest a **100% attachment rate in new cars produced by 2026/2027.**

- Thus, **while L1-L2 ADAS only form part of the semis opportunity, we see strong associated semis content growth opportunities**, even as levels of automation progress to L2+ and beyond, as shown below. In the short term, we see this driven by the increase in total penetration of L1 to L2+ vehicles from 31% in 2021 to 62% in 2025 on our forecasts (note that companies such as Mobileye have stated that we could see penetration increases in geographies such as India).

- **Semis content will also be driven by the need to utilise multiple different types of sensors within ADAS vehicles, given that radars, cameras and lidars each have strengths and weaknesses. Radar and lidar cannot detect textures** (whereas cameras can), but these can perform better in poorer weather conditions or low light visibility. Furthermore, **radar is less susceptible to ice/debris**. Meanwhile, **lidar can give a higher level of detail than cameras**, including in various weather/light conditions, and can also be effective in seeing objects at farther distance at high speed (albeit radars and cameras are currently less expensive, despite the fact that lidar costs are coming down). That said, **our industry discussions indicate that a combination of each could help optimise performance/redundancy, even at lower levels of ADAS, e.g. L2, but some players such as Tesla are seeking to reach fully autonomy without lidar or radar.**

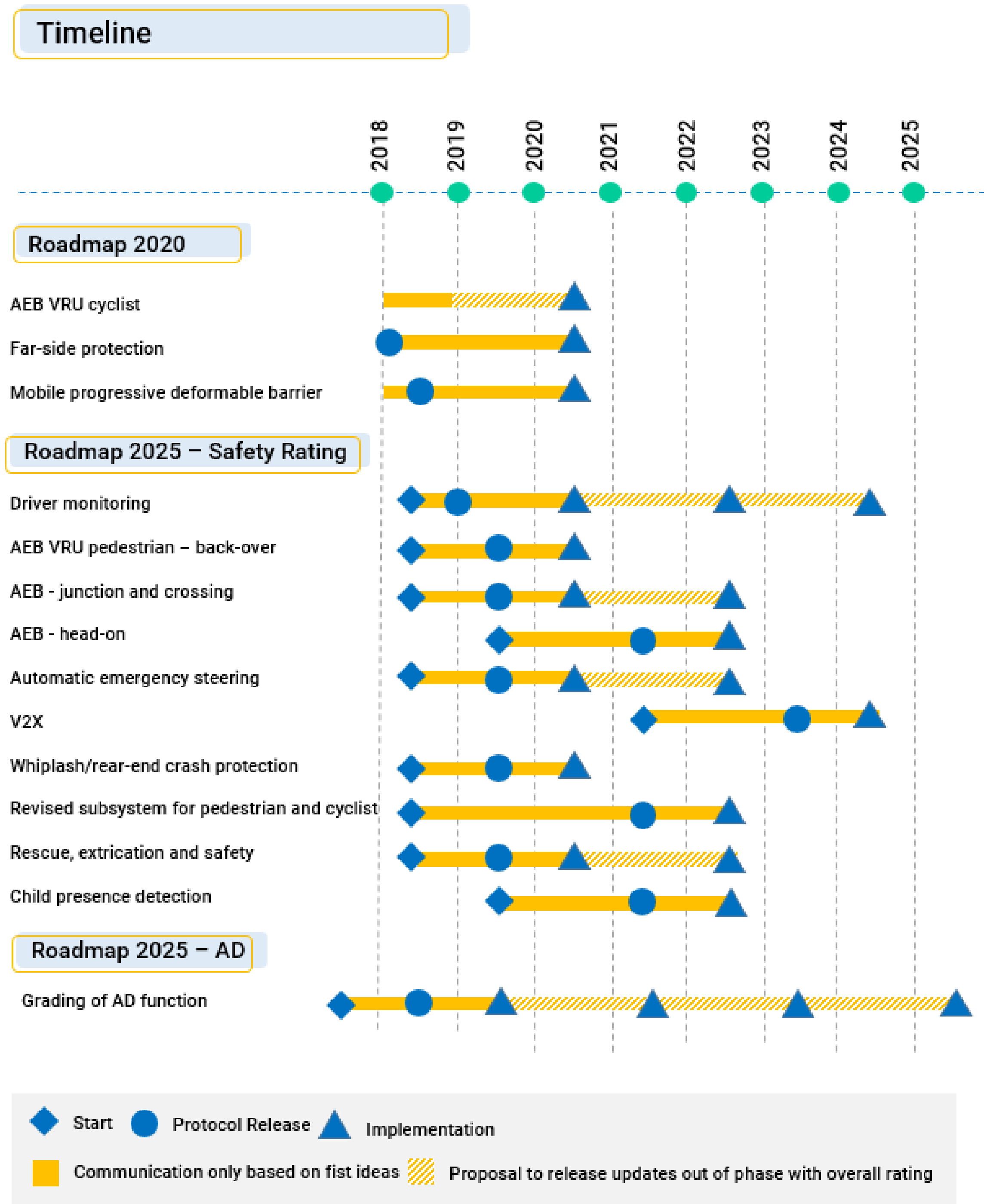
- **We define the different levels of autonomy, per the Society of Automotive Engineers (SAE), below.** Industry participants also refer to additional levels such as L2+ (which is a vehicle that is technically capable of L3 but the driver still needs to be prepared to take over if alerted, even if this is only a legal/regulatory distinction).

Exhibit 36: L2+ functionality has emerged as the timeline for rollout of automation beyond L3 faces bottlenecks
Breakdown of functionality and content opportunity across L1-L5

	L0	L1	L2	L2+	L3	L4	L5
Type of automation	No Automation	Driver Assistance	Partial Automation	Conditional Automation	Conditional Automation	High Automation	Full Automation
What it does	No automation. The human driver performs all tasks (e.g. steering, braking acceleration etc)	The vehicle features a single automated system (e.g. monitors speed through cruise control)	The vehicle can perform steering and acceleration simultaneously . The driver still monitor all tasks and can take control at any time	Vehicle can perform steering and acceleration, with quasi auto-pilot, but driver always alert/ responsible and hands near wheel. Often uses AV maps to perform autonomous tasks even in poor conditions (e.g. bad weather or hidden road markings)	Environmental detection capabilities. The vehicle can perform most driving tasks, but human override still required. OEM liable in event of crash, necessitating higher redundancy levels and lower mean time between failure	Vehicle performs most driving tasks, but human override still required. OEM liable aside from when driver warned to take over (subject to grace period)	The vehicle performs all driving tasks under all conditions. Zero human attention or intervention is required. L5 vehicle may be designed without a steering wheel/pedals
Example of features		Automatic emergency breaking, blind spot warning, lane departure warning, adaptive cruise control	Lane centering AND adaptive cruise control simultaneously	Quasi auto-pilot Lane centering AND adaptive cruise control simultaneously, even in poor conditions	Traffic jam chauffeur, highway autonomy	Robotaxi in geofenced area	Robotaxi in all locations and conditions
Penetration expectation in 2021/25 (GSe)	69%/32%	25%/37%	5%/17%	1%/8%	0%/5%	0%/1%	0%/1%
Driver responsibility	Full control and responsibility	Driver monitors and largely controls the environment, even when automation features are on	Driver monitors and largely controls the environment, even when automation features are on	Driver must constantly monitor the environment and take control when system requests	Driver does not need to constantly monitor the environment, but takes control when system requests	Driver not required to take control, expect in very poor conditions	Driver not required to take control
System responsibility		System supports the driver	System supports the driver	System operates when specific conditions are met	System operates when specific conditions are met	System operates when specific conditions are met	System operates in all conditions
System functionality		Steering OR speed are automated	Steering and speed are simultaneously automated	Steering and speed are simultaneously automated	Steering and speed are simultaneously automated	Steering and speed are simultaneously automated	Steering and speed are simultaneously automated
	Human monitors driving environment (ADAS)				Automated systems monitor driving environment (AD)		
What sensors are needed (GSe)	No sensors	1 camera, 1 radar	5 cameras, 3 radars	6 cameras, 5 radars,	6 cameras, 5 radars, 0-1 lidar	6 cameras, 5 radars, 0-1 lidar	8 cameras, 7 radars, 3 lidars
What semis are needed (GSe)	1 MCU	2 MCU	6 MCU	11 MCU, ASIC/SOC/GPU	11 MCU ASIC/SOC/GPU	18 MCU ASIC/SOC/GPU	18 MCU ASIC/SOC/GPU
Catalysts for adoption		Regulation/ NCAP Star Ratings	Regulation/ NCAP Star Ratings	Consumer Safety Push	Consumer Convenience and safety	Consumer Convenience/ As a service company demand (Robotaxi)	Consumer Convenience/ As a service company demand (Robotaxi)

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 37: European NCAP evolves to incorporate new functions, thus driving semis content, for example driver monitoring



Source: Euro NCAP, NCAP, compiled by Goldman Sachs Global Investment Research

L2+ functionality has emerged, with rich semis content opportunity

While the timeline to higher levels of autonomy has shifted to the right in recent years, L2+ functionality, including both enhanced safety and autopilot features, offers an increasingly rich semis content opportunity, in our view.

- In recent years, **the timeline for higher levels of autonomy (L3-L5), whereby the car drives itself to varying extents and under different conditions, has been delayed somewhat,** as per our industry discussions. For example, **for L3, which involves the car being able to drive itself in certain conditions**, subject to providing a warning to a driver to take over (but with a grace period of a certain number of seconds where the OEM is liable), **the required level of reliability/redundancy and the challenge of dealing with the handover have led to true L3 being delayed**.

Exhibit 38: L2+ offers many of the benefits of L3, especially as they pertain to the quasi-autopilot functionality, even though it does not offer the same degree of autonomy

What is L2+?	

L2 vs L3	• **The jump from L2 to L3 is the largest gap** in the 6 ADAS levels (L0 to L5).
	  • It involves the **cross over from driver assist technology to partial automation technology**
	  • **L2 drivers must maintain constant situational awareness**; In L3, driver engagement not needed (but must remain alert)
	  • Ie. **Human must always look at traffic in L2+,** but has freedom to do something else in L3 vehicles.
	• **L2+** vehicles often use an **internal surveyor camera** that checks driver is always alert

Why L2+ emerged	• **L2+ offers highly sought consumer features at affordable price,** including e.g. **quasi auto-pilot** and added **convenience/ safety features**
	• **Liability in the event of an accident lies with the driver in L2, but shifts to the OEM in L3.**
	• Therefore, **OEMs have begun to introduce some L3 features into L2 cars** (as there is high customer demand), but with driver remaining liable. These **L2 cars with more advanced features are called L2+.**
	  • **We do not expect a significant increase in semis content in L3 vs L2+** (but meaningful software upgrades), meaning **that L2+ will be a greater driver of incremental revenues until 2030 vs L3** in our view.
	• **Higher levels of redundancy are required in L3/L4/L5 vehicles**, as drivers may not be fully aware of road situations and as the **failure rates must be extremely low** vs human standard of driving in order for such types of automation to **be accepted by regulators society**
	  • Any failures could lead to fatalities, with the **OEMs being liable.**

L2+/L2++ technologies	• **L2+ enhances L2 with extra safety** features e.g. adaptive cruise control, while **L2++ goes further with more advanced features** such as **quasi-autopilot with mapping software** (but driver still responsible)
	• In **L2++, the use of high-definition maps enable vehicles to perform driver assist functions in sub-optimal scenarios**
	  • E.g. poorly marked roadways, bad visibility/ driving conditions.
	• **L2++ vehicles use crowd-sourced location data** to perform ADAS manoeuvres in more complex driving environments.
	• For example, **L2++ vehicles continue lane cantering processes even in areas with low quality lane markings** or poor visibility
	  • Traditional sensor-only systems perform poorly in these scenarios

Penetration	• **L2+ vehicles are already on the market in 2021** and will **reach a high single-digit % penetration by 2025.** • **Multiple premium OEMs already offer L2++ features that include e.g. quasi autopilot, such as Tesla, Audi, BMW, Porsche.** • **Geely Auto Group** (China carmaker) to use Mobileye in **new L2++ EV model to launch in late 2021.**

Source: Company data, Goldman Sachs Global Investment Research

- That said, we note the **emergence of L2+ and L2++ (broadly L2+), which build on L2 and offer advanced functions that stop short of L3 autonomy, but which we expect should see strong market uptake**. These are a) **enhanced safety** (e.g. electronic stability, road path planning) and b) **quasi-autopilot functions** (where the driver remains responsible at all times, even though the car drives itself under certain conditions, e.g. on motorways). We illustrate below some of the differences between L2+ and L3, as well as how L2+ differs from L2.

- **Autopilot functionality comprises the ability for the car not only to achieve the correct speed**, but also to **steer and control speed based on sensors perceiving**

and interpreting signs, markings and other vehicles and typically leveraging map technology.

Exhibit 39: L2+ systems offer similar functionality to L3 vehicles under certain scenarios, but are much easier to test and verify by safety regulators

L2+ vs L3 in 2021

Cons

- L3 offers a higher level of driver convenience, as the passenger is allowed to disengage from the driving environment and perform other tasks, which should drive higher customer demand. In L2+, drivers must maintain constant situational awareness (L2+ vehicles often use an internal surveyor camera that checks driver is always alert)
- In the event of an L3 accident, liability lies with the OEM, which could drive higher consumer adoption of L3 vs L2+

Pros

- L3 systems are more complex to test and verify by safety regulators/control agencies (especially to get a 5 star rating). It is easier to verify a L2+ system.
- As liability shifts to the OEM in L3 (from the driver in L2), and the ADAS system takes primary control of the vehicle, higher levels of redundancy and even higher mean time between failure (MTBF) are required, which poses technological challenges and makes L2+ relatively easier to produce
- OEMs must scale up production of L3 vehicles in order to spread fixed R&D costs across a larger volume. L2+ vehicles are cheaper to produce.
- L3 requires multiple (sometimes triple) redundancies in the sensor suite and actuators, alongside with central processing of multiple sensor inputs, per SAE, which presents a significant technical challenge (with L2+ relatively easier to produce)
- L2+ has a very similar feature set to L3 cars, but comes at a significantly lower cost. Both levels can perform adaptive cruise control with lane centering on motorways. L3 drivers can disengage with the driving environment, while L2+ drivers must be alert to take control if prompted.

Source: Company data, Goldman Sachs Global Investment Research

L2+ offers many of the benefits of L3, especially as they pertain to the quasi-autopilot functionality, even though it does not offer the same degree of autonomy.

- **Several premium OEMs such as Tesla, Daimler, Audi and Porsche offer various versions of L2+**, with a more **advanced L2++ system from Geely set to launch in 4Q21**, powered by Intel/Mobileye/STM. We expect **demand to be driven by consumer convenience**, a **desire by OEMs to use L2+ to differentiate** and some features potentially becoming part of regulations over time given safety benefits. We see better comfort, convenience and safety features all driving a **greater willingness of consumers to pay more for the vehicle, which could be monetised by OEMs.**

- **A prevalent view in our industry discussions with semis names is that OEMs selling vehicles priced >€60k will have L2+ functionality of some type integrated into their cars. For example, some Chinese players currently manufacture L2+ cars for the domestic market, while Tesla's solution is a very advanced L2+ offering.**
- **Mobileye has highlighted its role in providing certain types of L2+ technology for the Nissan Propilot 2.0, VW Travel Assist, Cadillac Supercruise and BWM KaFAS. Our industry conversations suggest that L2+ over time will likely be integrated into NCAP star rating regimes for 5 star vehicles, at least once costs of technology are significantly low, and as such will become increasingly adopted (this is separate from the consumer pull factors of convenience and the OEMs' incentive to sell L2+ to drive incremental revenues).**
- We note **Toyota has two commercially available L2+ models** the Lexus LS (hybrid) and Mirai (fuel cell vehicle). Our Japan auto team has highlighted **good performance even in rainy conditions in highway self drive functionality,** and we believe this shows how **extra technology and software on board such implementations can enhance convenience.** Moreover, the **system will be upgradeable over the air** to unlock further features in the future. See more here).
- **L2+ and especially L2++ drive increased opportunities for semi content per car.** This is because, typically, the **L2+ functions pertaining to enhanced safety require additional processing.** For example, the **driving policy will need to factor in inputs from live crowdsourced maps that are sent to the car to help with path planning and build in extra redundancy,** e.g. to help the car drive in poor weather conditions. Moreover, to the extent that **quasi-auto pilot** is deployed, it **will require a higher level of computational capability** as well as robustness. This can partly be achieved with more powerful processing, but **will also involve higher numbers of radars and cameras sensors** (and potentially also LiDARs). These **drive proliferation of chips as part of the sensors, and also typically are associated with larger numbers of MCUs,** e.g. for pre-processing, as highlighted below.
- **Our industry discussions indicate mapping databases will become a standard feature soon for L2/L2+**, and will not only be for higher ADAS levels (L3/4/5). Managing and interpreting the data from the map and from sensor inputs, and deciding what to do with it, will be a driver of computational processing needs.

Exhibit 40: High definition AV maps can help improve safety features in L2+ vehicles and provide extra redundancy for L2++ quasi-autopilot

What is AV mapping and why is it helpful for L2+/L2++?

- **AV maps help to improve safety in conditions where other sensors can't see lane markings** (e.g. if low light or snowy etc), which means there is more processing needed to integrate maps with sensor inputs
- Maps **give more redundancy for quasi-autopilot in L2++** (e.g. by identifying which lane has priority), which **also drives processing content**
- **Help improve vehicle path selection** by **identifying which traffic light controls pertain to which lane**
- Also helps with various other subtle driving questions which are **unwritten in law e.g. one-way/bidirectional rural roads**)

Source: Company data, Goldman Sachs Global Investment Research

We note that a number of features included in the broader L2+ definition were developed for L3-L5 but have been subsumed into the L2++ category.

- For current **L2++ setups, OEMs cannot guarantee the mean time between failure for when the car is driving itself to be good enough to call it L3,** as in the latter case the car needs to be able to drive itself without any human input for a certain number of seconds pending the human taking over once a warning signal given (and to park safely totally on its own if the human is unable to do so). Hence, **car makers classify this as L2++ as it incorporates multiple features of L3 and a significant part of the value-add, i.e. quasi-autopilot.** We think that the additional features can **drive higher customer adoption and willingness to pay for L2+, given added safety and convenience.**
- **Mobileye's L2++ setup includes 11 cameras (7 long range and 4 short range cameras), with 2 eyeQ5 chips. That said, other players may use configurations which are more reliant of radar and less reliant on camera. Mobileye has said that it wants to improve the capabilities of radars (e.g. dynamic range, better accuracy, higher resolution), which could mean that radar will be able to detect hazards in the future. We estimate that a software/chip package from various tech providers could be towards the $40-100 range for basic ADAS, with L2 in the hundreds, and L2++ in high hundreds to thousands. Of these, we estimate 20-30% could be the chip cost. Our industry discussions suggest many car makers have multiple L2+ programs in the pipeline.**
- Given the semis content associated with L2+ (as explained below) that is already on the road in 2021, **we believe the ADAS semis market should see strong double digit growth not only out to 2025, but also to 2030, even if L3 and higher levels of automation are delayed indefinitely. We estimate that an L2+ car on average has semis content worth $253-610 (ex GPU) vs. a regular ICE at $396 and L2 average at $110-$260. To the extent that a GPU is added, we see this as further boosting semis content per car.**

Exhibit 41: How do we see ADAS and higher levels of autonomy driving the semis market revenues in the next 5-10 years?

How do we see ADAS and higher levels autonomy driving the semis market revenues in the next 5-10 years?

- Penetration to rise to 54% for L1/L2 globally by 2025E vs 30% today (GSe)
- L1/L2 to continue rolling out in developed markets, driven by 4/5 star ratings incorporating ADAS functions. Also driven by emerging market adoption
- New features within L1 could evolve
- Car safety regimes could start to incorporate some L2+ safety features for 4/5 star ratings, driving OEMs to adopt (on top of L2 features)
- Certain enhancements to radar technology e.g. higher resolution radar could drive proliferation and become standard
- L2+ enhanced safety features to drive extra processing/software (and maps integration)
- L2++ style quasi-autopilot to drive higher processing needs for more advanced software, and more sensors, as well as associated higher MCU needs
- L2+/L2++ OEM adoption starting already, with broader category reaching 8% penetration by 2025E (GSe)
- L3 to see 5% penetration in 2025E (GSe), with likely jump in software capabilities (and potentially associated semis), but still only 17% penetration by 2030E in our moderate scenarios (GSe)
- Robotaxi a key L4/L5 autonomy use case to battle test consumer L4/L5 in smaller volumes, but will require yet higher semis processing, sensors and associated MCUs (inter alia)
- Towards 2030, consumer L4/L5 to drive significantly higher processing needs (for more sophisticated software that runs e.g. driving policy), as well as even more sensors (and associated MCUs, power semis etc)

Source: Goldman Sachs Global Investment Research

We note that L3 (under a strict definition) is not on the road currently and our industry discussions suggest that launches of L3 have been pushed out by some OEMs, with factors including the need a) to gain regulatory approval and b) to have capabilities that guarantee a sufficient level of mean time between failure such that the OEM can take liability (at a reasonable cost).

- **For L3, the car must be able to drive several seconds completely autonomously** for several speeds without requiring the driver to take control, representing a **meaningful challenge**. Hence, **computational capability and redundancy must be at a higher level vs L2+.** These and other bottlenecks are detailed in below.
- We note that the **latest proposals regarding L3 regulations in Europe include several parameters under which automated lane keeping systems can operate for highway roads in L3 vehicles**. We believe that to the extent that L3 only ends up being allowed under certain conditions in certain regions, this could impact the extent to which it is **more compelling to consumers than L2++**. Thus, it is possible that the **industry could potentially skip L3 and go straight to L4.** That said, from a semis perspective, **we do not see a large gap between L2++ and L3**, but we believe **L3 requires more sophisticated technology for software driving policy and mapping.**
- Our forecasts assume L3 becomes more meaningful around 2025 in terms of penetration, at 5%, which we expect to **grow to 17% penetration by 2030.**

Exhibit 42: We see several bottlenecks to higher L3 penetration in the short term, catalysing adoption of L2+ vehicles, and believe there could be a scenario where the industry skips directly to L4/L5
Bottlenecks to further L3 penetration

1 **Safety**
- As **liability shifts to the OEM in L3 (from the driver in L2),** and the ADAS system takes primary control of the vehicle, **higher levels of redundancy and even higher mean time between failure (MTBF) are required.**
- **L3 requires multiple (sometimes triple) redundancies in the sensor suite and actuators**, alongside with central processing of multiple sensor inputs, per SAE, which presents a significant technical challenge.
- The **car must be able to drive itself and park safely in the event the driver is incapacitated** and can't take over when a warning signal is given, a large technical challenge
- It must be guaranteed that the **AV software won't have a lapse of judgement**, (quite apart from following driving rules of the road to the letter) and it is necessary to **mathematically define what safe driving is**, while **working with industry bodies to standardise** this.

2 **Regulation**
- **Level of robustness and redundancy required is high**, with ability to demonstrate high mean time between failure (vs human).
- **Regulatory validation of L3 vehicles is harder** than isolated functions like AEB, that are incorporated into star rating regimes.
- OEMs **may develop their own software/system algorithms**, whereas **standardization would potentially make validation and adoption faster for the industry.**
- To the extent there are many **limitations imposed by regulators on the usage of L3** (which appears likely in several regions), it is **possible it will make more sense for OEMs to focus more on L2+/L2++ given L3 may not incrementally deliver a very large benefit** (e.g. if there are many conditions for usage and/or a need to frequently take control
- L3 systems are **more complex to test** and verify by safety regulators/control agencies **(especially to get a 5 star rating)**

3 **Costs**
- OEMs must **scale up production of ADAS vehicles in order to spread fixed R&D costs across a larger volume**.
    - This should **reduce costs to consumers**, driving demand.
- Eg **L1 77Ghz radars used to be very expensive**, but the technology has matured with **SiGe radars significantly reducing cost**

4 **OEMs**
- **Audi reversed initial plans to introduce L3 features** into A8 sedan in Europe/US due to regulatory issues (April 2020).
- **Ford pledged in 2017 to deliver a L4 car in 2021** without pedals/steering wheel. **CEO stated in 2021 it would focus on self driving in geo fenced areas** due to technical complexity
- BMW backs away from L3 features in its iX model

5 **Consumer utility**
- **Latest regulatory drafts in some regions appear to limit L3 to certain speeds**, contexts etc, with the **driver required to take over** subject to a grace period
- To the extent that the **driver's freedom to focus on things other than driving is curtailed**, there may be a relatively **limited delta between consumer utility of L2++ and L3,** meaning the industry focuses on the former and waits for L4.

6 **Standardisation**
- **Significant work is being done at OEMs to innovate L3 driving technologies**. **Proprietary software developed by OEMs is much more difficult to standardise than Tier 1 innovations** (as these can be offered to multiple OEM car ranges/models).
- A **fragmented array of approaches could result in slower validation/regulatory** acceptance

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 43: There are several examples of L2+ vehicles on the road today, and we see a significant associated semis content opportunity given added safety (and quasi-autopilot) functionality

Roadmap for L2+/L2++

Roadmap for L2+/L2++

1	What does it do?	• **L2+ enhances L2 with extra safety** features e.g. adaptive cruise control, stability control **tend to leverage crowd sourced maps** • **L2++ goes further with more advanced features** such as **quasi-autopilot with mapping software** (but driver still responsible) • **L2+ vehicles may have the ability to deliver conditional automation**, in which the vehicle can self-drive in specific conditions. This is quasi-autopilot. • **Drivers must remain aware** of the driving environment, and **be alert** to take back driving immediately when prompted.
2	Liability	• **Liability remains with the human driver**. L2+ vehicles often have **internal surveyor cameras** to ensure driver is continuously alert.
3	L2+/L2++ cars on the road	• **Tesla** Model 3/X/S/Y (with quasi-autopilot) • **Cadillac** Supercruise launched in 2018 (with quasi-autopilot) • **Nissan** ProPilot 2.0 to come with quasi-autopilot on Nissan Ariya SUV in 2021 • **VW** Travel Assist launched in Nov 2019 • **Geely** L2++ vehicles to launch in 4Q21 • We believe all OEMS with cars priced >$60k will offer L2+ functionality per industry discussions

4	Key technologies	• **Illustrative setup:**
		    • 2-6 cameras, 5-6 radars, 0-1 lidar chips
		    • 10-16 MCUs
		    • 0-1 GPUs
		    • Custom ASIC chip for environmental processing/driving policy
		    • Driver monitoring semis

5	Semis value	• We estimate the incremental ***average*** **ADAS semis (ex-GPU) content per L2+ car is $253-$610.** • Note that different OEMs and different implementations will have different levels of semis/number of sensors/processors. • We expect **L2+/L2++ semis TAM (ex-GPU) to grow to $3bn/$6bn by 2025/30** in base scenario
6	Key features	• **High-definition maps** enable driver assist functions to perform in sub-optimal scenarios • E.g. **Lane centering** is still effective without visible lane markings (so camera not functioning) • L2++ cars offer **qusai autopilot** (with driver still alert and ready to take control when prompted)
7	Success Factors	• We believe **consumers are already showing a willingness to pay for L2+, and OEMs/ Tier 1's already showing desire to monetise** • Further **penetration gains could hinge on price reductions overtime** and further OEMs productising L2++
8	Bottlenecks/Challenges	• No show-stopping bottlenecks/challenges

Source: Company data, Goldman Sachs Global Investment Research

ADAS semis content to be roughly equivalent to average xEV by 2025E

By 2025E, average incremental ADAS semis value per car could be roughly equivalent to that seen in an average xEV, we estimate.

- Our analysis suggests **average incremental semis content (ex GPU) in a L2+ car of $253-$610, higher than in an L1 car at $44-$98 or an L2 at $110-$260.** To the extent that GPUs are incorporated, we see this as significantly boosting the content opportunity per vehicle, providing a strong opportunity for semi companies (see our scenario analysis). Assuming that the **main delta between L2+ and L3 is defined by software rather than semis content**, albeit this area is fluid, and further semis could be included, we estimate that **L4/L5 consumer implementations could range from $705-$1,381 excluding GPUs, and $3,450-$4,170 including these** (albeit the main focus of this report is assisted driving, rather than full autonomy).
- Based on our US auto team's ADAS penetration assumptions, this translates into **ex-GPU blended average ADAS semis content of $91 in 2021E, rising to $163 in 2025E** (as **L2+/L3 rise in the mix**) and **$230 in 2030E** (**when we assume L4/L5 enters the mix** at low levels). For context, we estimate that a **regular ICE has semis content of $396, and on average an xEV has extra content of $207 (with a BEV at $441). Thus it is clear that ADAS represent an important opportunity for semis players in the auto space.**
- Our forecasts for successive increases in value of $ semis content per car for each of the various levels of automation are, broadly speaking, driven by factors including: 1) **greater prevalence of sensors, e.g. camera, radar** and (at the highest levels) lidar; 2) **greater processing capabilities for running more sophisticated software,** e.g. pertaining to environmental models and driving policy (including for L2+, but especially in L4/L5); 3) more **microcontrollers;** and 4) other semiconductors such as **optical sensors** (for driver monitoring). We summarise the **semis content requirements of each level below.**

Exhibit 44: We see the semis opportunity expanding materially as more sensors and processing are required for higher levels of automation, with the ADAS semis (ex-GPU) BoM even for L2+ vehicles similar to that found in BEVs

Estimated breakdown of semis content per vehicle for ADAS levels in 2025

	Level 1 L1 vehicles in 2021: 22m	Level 2 L2 vehicles in 2021: 4m	Level 2+ L2+ in 2025: 8m	Level 3 L3 vehicles in 2025: 5m	Level 4/L5 L4/L5 vehicles in 2030: 4m-23m
Semis Content (ex-GPU)	**$44-$98**	**$110-$260**	**$253-$610**	**$253-$610**	**$705-$1,381**
Camera modules	$16-$21	$27-$88	$22-$84	$22-$84	$66-$169
Radar modules	$10-$14	$41-$54	$64-$100	$64-$100	$157-$260
Sensor Fusion/ Vision Processing	$3-$12	$3-$20	$105-$126	$105-$126	$215-$246
Others(e.g. Actuators)	$0	$7-15	$16-$28	$16-$28	$66-$97
Microcontrollers	$15-$50	$32-$82	$46-$134	$46-$134	$128-$268
GPUs	$0	$0	$457-$465	$915-$930	$2,745-$2,790
Lidar	$0	$0	$0-$139	$0-$139	$73-$340
Semis Content (with GPU)	**$44-$98**	**$110-$260**	**$711-$1,075**	**$1,168-$1,540**	**$3,450-$4,170**

The above does not include software, e.g. pertaining to driving policy, environmental models. Number of L4/L5 vehicles is a scenario range for 2030

Source: Goldman Sachs Global Investment Research

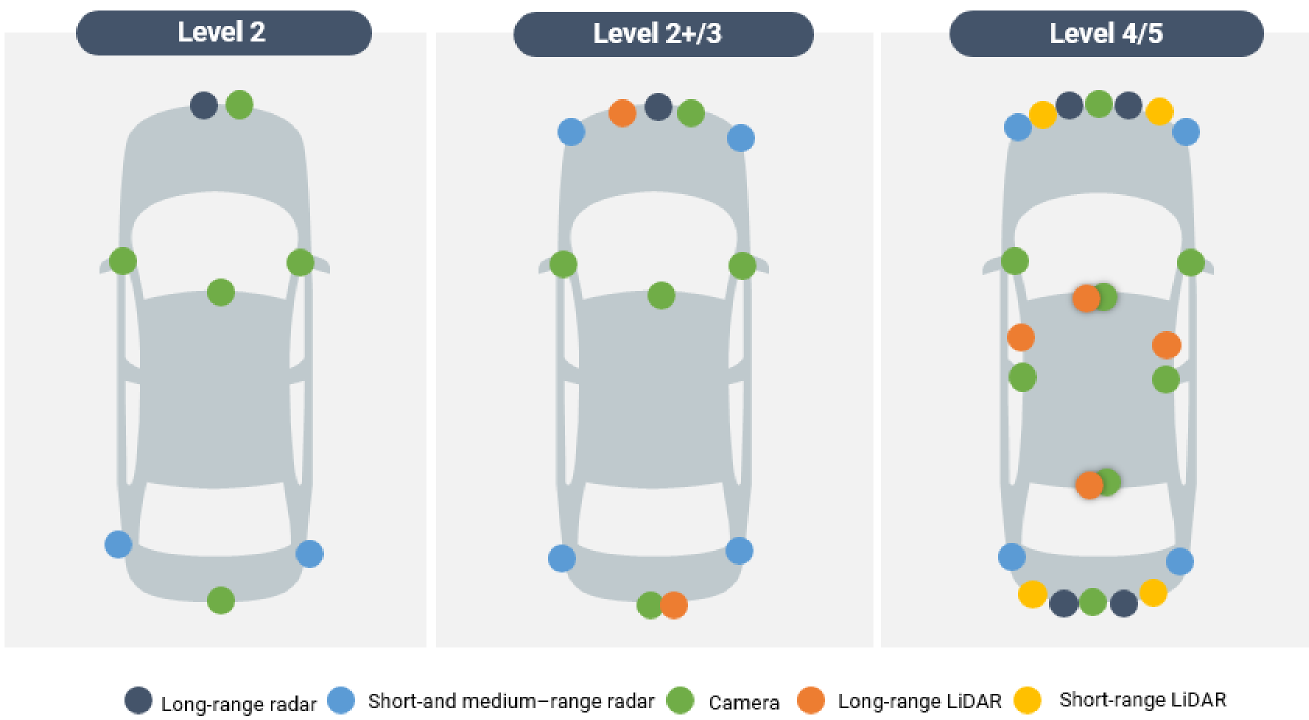
We assume more sensors are required at each successive level, as these are important in adding increased redundancy/robustness to systems.

- This is especially the case at the higher levels of autonomy, but even at L2+. While the focus of our report is ADAS, we also discuss below why extremely high sensing capabilities are needed for L4/L5 automation. Note that **at each successive level of automation, we assume more cameras and radars are required** (as well as LiDARS for L2+ onwards, given their advantage of higher resolution and better performance at night /in bad weather). **We assume LiDAR semis content of $0/$0/$0-$139/$73-340 for this category for L1/L2/L2+/L4+.** We illustrate below some of the more advanced sensor configurations at various levels of autonomy, and highlight Exhibit 14, in which we detail a range of numbers of sensors needed per level of ADAS/automation.
- **Greater processing capabilities are required as one progresses from lower levels of automation to higher levels.** This is because **more sophisticated processing is required to run ever more complex software**. For example, **L2+ systems running quasi-autopilot need to run software that can leverage data**

from crowd source mapping systems (to help the car drive safely even when weather conditions impact the visual field) and to **run more advanced environmental (and driving policy) models** (even if the human driver needs to be ready to take control). Furthermore, as higher levels of automation such as L3 are approached, the **car needs to be able to drive itself entirely without human intervention during a certain grace period of a number of seconds on a highway** (pending the human taking control post a warning signal), again **requiring even greater computational power** (to achieve driving capabilities that are greater even than a human could deliver).

- This is **especially so in the case of L4/L5 (see below), where such capabilities are required for a much bigger window of time** (and much wider circumstances). **We assume total semis content of \$44-\$98/\$110-\$260/\$253-\$610/\$705-\$1,381 for L1/L2/L2+/L4+ if GPUs are excluded** (and \$3,450-\$4,170 for L4+ where they are included). Typically, **such processing will either be run on a custom chip, such as that provided by Mobile/STM/Intel, and/or a GPU** from a manufacturer such as Nvidia.

Exhibit 45: Higher levels of autonomy require more sensory input and greater levels of redundancy...
Illustrative sensor setup for various ADAS levels



Source: Company data, Goldman Sachs Global Investment Research

The increasing number of sensors drives greater need for microcontrollers (MCUs).

- This is because **such sensors will tend to be attached to MCUs that do pre-processing before information goes to a central sensor fusion box containing custom chip(s) for processing and/or a GPU.** This is where decisions on driving policy and environmental perception are made. Note, however, that **in L1/L2, an MCU may actually be the centralised processing chip doing this.** Independent to the number of sensors, after such a decision stage, **an MCU (e.g. an AURIX MCU from Infineon) will then run software that tells various domains of the car what to do,** e.g., brake, steer, etc. This will be **ASIL-D certified** for automotive grade. **We assume semis content of $15-$50/$32-$82/$46-$134/$128-$268 for MCUs for L1/L2/L2+/L4+, as per Exhibit 44**. We explain this further in Exhibit 51 and discuss various factors that could lead to consolidation of the number of MCUs in our scenario section.

- **Other semis of importance include power management ICs, driver monitoring optical semis and V2V chips.** Power semis are needed for managing the power voltages of an ADAS system of very high computational power. For L1, L2, L2+ and L3, power semiconductors required include gate driver ICs and PMICs. **For L4 and L5, we assume a higher percentage of the total BoM goes into power semis, which include gate driver ICs, PMICs and high-power MOSFETs**. In L4/L5, a higher level of redundancy of the mechanical systems (braking, steering) is also needed (i.e. power failure cannot happen) and hence power semi BoM will go substantially up as a result of that. The **increasing presence of driver monitoring systems is driven by the requirement that drivers remain alert and prepared to re-take control when prompted in L2+/L3 autonomous systems**. Driver monitoring systems track head position, gaze, attention and alertness, with the industry considering **optical sensing solutions the best technology to enable the interpretation of complex actions and situations within the vehicle** (which we note further drives semis content). Furthermore, in Europe NCAP has evolved to incorporate driver monitoring as a mandatory feature by 2022. At higher levels of autonomy, we note the potential for data connection semis to be used for vehicle-to-vehicle communications. **The connectivity system, in terms of software and hardware architecture supporting the upcoming features in L2+/L3/L4/L5, can be a significant differentiator,** depending on the vehicle class (standard/premium) and car maker.
- **We see various success factors for the different types of semis.** For processing chips such as those provided by STM/Mobileye and Nvidia, these include **processing power, ability to conserve power (especially as EVs will need to run on batteries) and form factor efficiency**. **Some industry players believe that SOCs/ASICs *could* substitute for GPUs in the longer term, given power consumption issues.** For radar chips, key factors include the ability to **improve resolution** and potentially the move from a more analog approach to an approach that uses digital modulation (we note this a fluid area). For MCUs, key aspects include reputation for **reliability (e.g. ISO 26262 certification)**, auto domain level expertise and integration of memory with the MCU. Although we believe **ability to integrate processing with memory may lead to some advantages near term**, over time, **having sufficient processing power may be a gating factor for MCUs to do the more advanced functions** beyond L2 (e.g. computation functions, rather than purely pre-processing). We highlight the key players and success factors for a broader array of domains in Exhibit 62.

Exhibit 46: We see a broad opportunity set spanning semiconductors for compute, sensing and MCUs
Base case forecasts

Semis TAM by component ($, mn)						
	2021E	2022E	2023E	2024E	2025E	2030E
Camera	747	1,016	1,377	1,868	2,478	4,173
Radar	588	825	1,159	1,655	2,362	4,480
Lidar	31	73	145	288	674	2,055
MCUs	760	1,035	1,404	1,907	2,597	4,583
Actuation/ Power Semis	70	114	185	314	542	1,294
GPUs	336	909	2,045	4,056	10,772	35,602
Compute/ Vision Processing	317	493	761	1,210	2,132	5,257
Total semis TAM (ex-GPU)	2,512	3,556	5,032	7,242	10,785	21,842
Total semis TAM (with-GPU)	2,849	4,465	7,078	11,298	21,557	57,444

Source: Goldman Sachs Global Investment Research

Scenario analysis suggest 44%/27% ADAS semis ex-GPU market CAGR out to 2025/30E (vs 2021E)

We forecast the semiconductors market (ex-GPU) for ADAS to increase at 44%/27% CAGRs out to 2025E/2030E (from 2021E) in our base case, with even faster growth in our bull case as we flex up our assumptions for the extent of GPU usage and ASP.

- Overall, **we see rapid growth in the semis opportunity associated with ADAS out to 2025/2030 even if L4/L5 gets further pushed out than assumed in our scenarios (we run a separate sensitivity on penetration rates). We estimate an ADAS semis (ex-GPU) market size of $10.8bn by 2025E and $21.8bn by 2030E on our base case.**
- **Note that the absolute numbers we present for 2030 penetration are scenarios rather than an explicit forecast. We also acknowledge that further scenarios could be possible on other parameters, e.g. scope for L4/L5 to boost or inhibit overall auto units, which is beyond the scope of this report. The US Autos team's 2030 scenarios for penetration we use as one input into our semis scenarios are based on the inputs of leading auto tier 1 suppliers (Magna, Valeo, Veoneer).**

We believe the factors most likely to impact the size/growth of the ADAS semis market are:

- The **penetration rates of higher levels of autonomy** (e.g. L2+ to L5), which require greater semis content given higher compute needs.
- The **degree to which the number of MCUs consolidates as the number of sensors rises**. At lower levels of autonomy, each sensor requires a dedicated MCU for pre-processing, but **we expect a degree of centralisation and consolidation in MCUs as higher power GPUs and ASICs are utilised in the sensor fusion box**.
- We are cognisant of the **risks that semis become commoditised and components experience greater/weaker-than-expected cost curve deflation in future years.**
- The **number of radar/cameras/lidars is likely to impact the size and growth of the ADAS market for semis**, and the **number of sensors derives the number of processing chips required** within ADAS vehicles. We note that per our industry discussions **there is a broad array of views as to the number of components needed, especially as regard to the number of sensors/MCUs needed,** particularly at higher levels of autonomy.

To derive our TAM estimates, we flex three variables: (1) the number of semis units per vehicle (radar/camera/lidar chips, MCUs, power semis, vision processing chips); (2) ASP (specifically the associated ASP deflation in these units); and (3) market share for Infineon/STM in their respective component areas. We use the same GS forecast penetration rates in all three scenarios, but run a separate set of sensitivities flexing this variable as discussed below.

- **While we assume 7 radars as our base case for L4/L5, we note that some industry participants see a higher number of radars (e.g. double digit figures). However, note our base case number is a blend of L4 and L5. Furthermore, we see the situation as fluid, and will to some extent depend on the capabilities of camera systems (and LIDAR). In our bull case we assume 10 radars for L4/L5.**
- We view **Infineon as a broad player** that competes on all radar frequencies, **and assume +25% market share in our base case, considering all types of radars** (e.g. long-range, mid-range, short-range, 77 GHz, 24 GHz, SiGe, CMOS, front, rear, corner). **STM holds a market leading position on 24 GHz short-range radar** (while Infineon leads on 77 GHz long-range radar using SiGe technology).
- **In our base case, we assume IFX has c.30% market share in MCU based on company comments that its ISO 26262-certified AURIX MCU is gaining traction and should achieve 30%+ market share in the ADAS segment** (it already has 30%+ market share for motor management and transmission, albeit this refers to the domain drivetrain).
- **In our base case, we assume STM has c.15% market share in MCUs** (across all applications such as parking sensors, radars and cameras) given that it is **present in both the microcontroller used for radar processing and in the MCU that sits beside Mobileye processing chips**. We assume that **STM's processing chips (co-developed with Mobileye) have a dominant market share**, especially viz-a-vis vision based processing.

Exhibit 47: We flex our assumptions on the number of semis per vehicle...
Bull/base/bear case semis units by ADAS level

Units - Bull case						
	Camera	Radar	Lidar	MCU	Others	l Compute
L1	1	1	0	5	0	1
L2	5	3	0	8	2	2
L2+/L3	6	6	2	16	3	2
L4/L5	14	10	8	24	8	3

Units - Base case						
	Camera	Radar	Lidar	MCU	Others	l Compute
L1	1	1	0	2	0	1
L2	3	3	0	6	2	2
L2+/L3	6	5	1	11	3	2
L4/L5	8	7	3	18	8	3

Units - Bear case						
	Camera	Radar	Lidar	MCU	Others	l Compute
L1	1	1	0	2	0	1
L2	2	3	0	5	2	2
L2+/L3	2	5	0	10	3	2
L4/L5	8	7	2	18	8	3

Source: Goldman Sachs Global Investment Research

Exhibit 48: ...alongside the associated ASPs of these semis
Bull/base/bear case semis ASPs by ADAS level

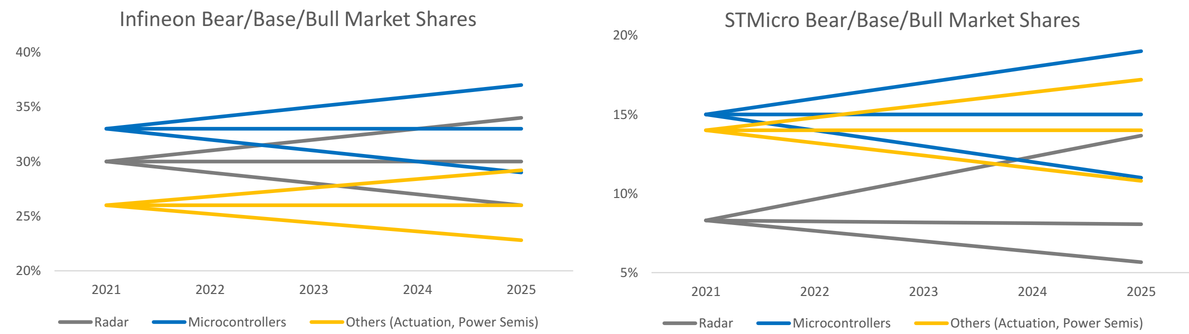
ASP - Bull case						
	Camera	Radar	Lidar	MCU	Others	Compute
L1	22	15	0	12	0	13
L2	19	19	0	11	8	11
L2+/L3	16	18	110	9	10	68
L4/L5	13	28	60	12	13	88

ASP - Base case						
	Camera	Radar	Lidar	MCU	Others	Compute
L1	20	13	0	10	0	8
L2	17	17	0	9	6	6
L2+/L3	14	16	100	7	8	63
L4/L5	11	26	50	10	11	83

ASP - Bear case						
	Camera	Radar	Lidar	MCU	Others	Compute
L1	18	11	0	8	0	3
L2	15	15	0	7	4	1
L2+/L3	12	14	90	5	6	58
L4/L5	9	24	40	8	9	78

Source: Goldman Sachs Global Investment Research

Exhibit 49: We flex IFX/STM market share in our bear/bull/base scenarios
Bull/base/bear case IFX/STM market shares



Source: Goldman Sachs Global Investment Research

Exhibit 50: We flex three variables to arrive at our bear/base/bull forecasts for semis content per ADAS vehicle
Bull/base/bear case semis content by ADAS level

Semis Content ($) - Bull case							
	Camera	Radar	Lidar	MCU	Others	Compute	GPU
L1	21	14	0	50	0	12	0
L2	88	54	0	82	15	20	0
L2+	84	100	139	134	28	126	465
L3	84	100	139	134	28	126	930
L4/L5	169	260	340	268	97	246	2,790

Semis Content ($) - Base case							
	Camera	Radar	Lidar	MCU	Others	Compute	GPU
L1	19	12	0	19	0	7	0
L2	48	48	0	51	11	11	0
L2+	73	76	42	72	22	115	461
L3	73	76	42	72	22	115	922
L4/L5	83	172	145	161	81	231	2,767

Semis Content ($) - Bear case							
	Camera	Radar	Lidar	MCU	Others	Compute	GPU
L1	16	10	0	15	0	3	0
L2	27	41	0	32	7	2	0
L2+	22	64	0	46	16	105	457
L3	22	64	0	46	16	105	915
L4/L5	66	157	73	128	66	215	2,745

Source: Goldman Sachs Global Investment Research

Exhibit 51: We see the number of MCUs per sensor consolidating at higher levels of autonomy (albeit higher absolute numbers vs L1-L3 given higher sensing/processing requirements)

Why could the number of MCUs consolidate in higher levels of autonomy?

- **At lower levels of autonomy (L1 to L2+), we see the number of MCUs scaling close to 1:1** with the number of sensors, as each requires an **MCU for signal pre-processing** before feeding information into a central processing chip where decisions are made.
- This is because the **main central compute and internal vehicle Ethernet may have finite bandwidth**.
- However, to the extent that these latter two **become able to handle more processing/bandwidth over time**, this could **limit the need for these MCUs that are deployed close to the sensors.**
- **Multiple benefits to OEMs** of moving towards centralized intelligence including **weight, cost of ownership, standardization and managing upgrades** during the vehicle's lifetime.

Source: Company data, Goldman Sachs Global Investment Research

In our bear/base/bull case scenarios, we estimate a $7.3bn/$10.8bn/$16.9bn overall ADAS semis (ex-GPU) TAM in 2025E, rising to $14.7bn/$21.8bn/$34.2bn in

2030 (Exhibit 56). This implies an ADAS semis (ex-GPU) market 2021-2030E CAGR of 26%/27%/27% across our bear/base/bull scenarios.

- As mentioned above, our third variable is to **flex individual company market share** for STM and Infineon (within their respective sub-segments of the ADAS semis market). **In our bull case scenario ($16.9bn ADAS semis ex-GPU TAM in 2025E), Infineon sees a +56% CAGR (2020-25E)** in its ADAS revenues (vs 27%/38% bear/base case CAGRs). We estimate that in a bull case, STM realises a +51% CAGR (2020-25E) (22%/35% bear/base case CAGRs).
- Our bull case valuations imply 15%/16% upside to our PTs for STM/IFX (-7%/-7% downside in bear case).

Exhibit 52: We see a sizeable semis content opportunity at ever the lower levels of autonomy, such as L2+, which is in production today
2025E ADAS Semis Content per car based on our scenario analysis

2025E Content per car - excl GPUs (in $)	L1	L2	L2+	L3	L4/L5
Bear	44	110	253	253	705
Base	57	169	400	400	873
Bull	98	260	610	610	1,381

2025E Content per car - incl GPUs (in $)	L1	L2	L2+	L3	L4/L5
Bear	44	110	711	1,168	3,450
Base	57	169	861	1,323	3,640
Bull	98	260	1,075	1,540	4,170

Source: Goldman Sachs Global Investment Research

Exhibit 53: We see the semis TAM (ex-GPU) rising to $34bn in our bull case by 2030E (vs $15bn/$22bn in our bear/base case)
ADAS Semis TAM 2025E/2030E

Semis SAM - inc GPUs (in USD mn)	2025	2030
Bear	17,975	49,640
Base	21,557	57,444
Bull	27,738	70,493

Semis SAM - excl GPUs (in USD mn)	2025	2030
Bear	7,290	14,687
Base	10,785	21,842
Bull	16,878	34,232

Source: Goldman Sachs Global Investment Research

Exhibit 54: We see higher ADAS revenues for Infineon vs STMicro in 2025E and 2030E
ADAS semis (ex-GPU) TAM sensitivities in 2025E/2030E

STM ADAS TAM ($ mn)	2025	2030
Bear	5,830	12,348
Base	7,633	15,614
Bull	11,348	22,293

STM ADAS Revenue ($ mn)	2025	2030
Bear	825	1,399
Base	1,326	2,360
Bull	2,388	4,438

IFX ADAS TAM (€ mn)	2025	2030
Bear	4,161	7,843
Base	5,501	10,357
Bull	8,747	16,259

IFX ADAS TAM (€ mn)	2025	2030
Bear	959	1,730
Base	1,459	2,729
Bull	2,645	5,017

Source: Goldman Sachs Global Investment Research

Below we run a series of sensitivities on the three scenarios above on the degree to which ADAS penetration could accelerate faster ('hyper-adoption') or slower ('lower adoption') than the rate used in the scenarios above ('neutral'), holding all

other variables (semis content/ASPs/market share) equal.

For our base case, assuming a lower adoption sensitivity in which we model that the timeline for L4/L5 penetration is pushed out beyond 2030 (vs. neutral sensitivity of 1% in 2025E) has only a marginal impact — the strong semis content associated with L2+ drives a semis (ex-GPU) TAM of $19.6 in 2030E vs the neutral scenario of $21.8bn. We see the greatest driver of semis content over the mid term the emergence of the rich content opportunity associated with L2+. Our hyper-adoption sensitivity suggests a semis TAM of $30.2bn by 2030E.

- **In our hyper-adoption sensitivity, we assume L4/L5 penetration reaches 20% by 2030E (vs 5% in the neutral case). Success factors** for this rate of penetration include **rapid adoption of advanced safety functionality by NCAP regulators**, **quick cost curve reductions** to ensure commercial viability and faster-than-expected **technological breakthrough.**
- In **our lower adoption sensitivity, we assume that there is still no L4/L5 penetration in 2030E, but that rapid acceleration of L2+ offsets this.** Therefore, **we assume 39% penetration of L2+ in 2030E** in **our lower adoption sensitivity** (vs 17% on the neutral sensitivity). We see risks that this could materialise **including regulatory or technological barriers to block mass production of L4/L5**, with L2+ presenting an attractive alternative, given that **L2+ offers many similar advanced features at a price point that is commercially viable** even today.
- **For our base case**, under lower adoption/neutral/hyper-adoption ADAS level penetration sensitivities, **we estimate a $10.3bn/$10.8bn/$10.8bn overall ADAS semis (ex-GPU) TAM in 2025E, rising to $19.6bn/$21.8bn/$30.2bn in 2030E.**

Exhibit 55: Under our base case, our hyper-adoption sensitivity implies 20% L4/L5 consumer car adoption in 2030E, whereas our lower adoption case assumes L3-L5 are delayed but replaced by L2+

ADAS level penetration rate for hyper-adoption/neutral/lower adoption cases

Penetration rate - Hyperadoption case	2021E	2022E	2023E	2024E	2025E	2030E
L0	69%	61%	52%	42%	32%	10%
L1	25%	30%	35%	36%	37%	30%
L2 Standard	5%	7%	10%	15%	17%	15%
L2+	1%	2%	3%	5%	8%	10%
L3	0%	0%	1%	2%	5%	15%
L4/L5	0%	0%	0%	0%	1%	20%

Penetration rate - Neutral case	2021E	2022E	2023E	2024E	2025E	2030E
L0	69%	61%	52%	42%	32%	10%
L1	25%	30%	35%	36%	37%	33%
L2 Standard	5%	7%	10%	15%	17%	18%
L2+	1%	2%	3%	5%	8%	17%
L3	0%	0%	1%	2%	5%	17%
L4/L5	0%	0%	0%	0%	1%	5%

Penetration rate - Lower adoption case	2021E	2022E	2023E	2024E	2025E	2030E
L0	69%	61%	52%	42%	32%	10%
L1	25%	30%	35%	36%	37%	33%
L2 Standard	5%	7%	10%	15%	17%	18%
L2+	1%	2%	4%	7%	14%	39%
L3	0%	0%	0%	0%	0%	0%
L4/L5	0%	0%	0%	0%	0%	0%

Source: Goldman Sachs Global Investment Research

Exhibit 56: We see the ADAS semis (ex-GPU) TAM rising to $48bn by 2030E in our most positive sensitivity (i.e. hyper-adoption on advanced autonomy adoption rates)

ADAS semis (ex-GPU) TAM sensitivities in 2025E/2030E based on penetration scenarios

2025E Semis SAM - excl GPUs (in USD mn)	Lower Adoption	Neutral	Hyper adoption
Bear	6,850	7,290	7,290
Base	10,325	10,785	10,785
Bull	16,128	16,878	16,878

2030E Semis SAM - excl GPUs (in USD mn)	Lower Adoption	Neutral	Hyper adoption
Bear	12,555	14,687	22,082
Base	19,588	21,842	30,244
Bull	30,524	34,232	47,850

Source: Goldman Sachs Global Investment Research

Exhibit 57: We see a 35% 2021-30E revenue CAGR for STMicro in our most positive sensitivity (vs 13%/22% in bear/lower adoption / neutral/base case)

STM ADAS revenues and 2021-30E CAGR

STM 2025 ADAS revenues (in USD mn)	Lower Adoption	Neutral	Hyper adoption
Bear	778	825	825
Base	1,266	1,326	1,326
Bull	2,296	2,388	2,388

Source: Goldman Sachs Global Investment Research

Exhibit 58: We see a 38% 2021-30E revenue CAGR for Infineon in our most positive sensitivity (vs 16%/24% in our bear/lower adoption / neutral/base case)

IFX ADAS revenues and 2021-30E CAGR

Infineon 2025E ADAS revenues (in EUR mn)	Lower Adoption	Neutral	Hyper adoption
Bear	910	959	959
Base	1,397	1,459	1,459
Bull	2,541	2,645	2,645

Source: Goldman Sachs Global Investment Research

L4/L5 to provide even greater potential semis content opportunities, but this could be longer term as progress continues to address bottlenecks

While the key focus of this report is ADAS, we also investigate enablers, semis content and bottlenecks for *higher* levels of autonomy (L4-5), as well as potential content opportunities.

- While the focus of this report is assisted driving (i.e. <L3 ADAS), **we highlight that the highest levels of autonomy (i.e. L4-L5) will bring greatly increased semis content opportunities**. Moreover, even if we believe that **true consumer L4/L5 may under some scenarios not become large scale before 2030 onward**, **some of the features developed for this could become part of levels such as L2+ earlier on**, driving further semi content opportunities.
- **L4 is defined as highly automated driving, where the vehicle can perform all driving tasks under specific conditions**. **L5** is defined as fully automated driving where the vehicle **performs all driving tasks under all conditions**, with human intervention not required as automated features even perform well in all locations and weathers (**some L5 cars may be designed without a steering wheel/pedals)**. The US Census Bureau has shown that the average American spends over 50 minutes a day commuting, meaning that **higher levels of autonomy can ensure both a safer commute but also allow drivers to focus on productivity and leisure instead.**
- **L2+ vehicles offer some L3 features (such as quasi auto-pilot on highways) but the driver remains liable in the event of an accident** and **must remain alert at all times** (whereas the driver may disengage with the road environment for temporary periods in L3 vehicles, as the OEM is liable).

Exhibit 59: Our industry discussions suggest Robotaxi could gain a foothold before consumer AVs, helping validate and 'test drive' higher levels of automation before they are incorporated into consumer vehicles

1

Penetration

- **Our discussions suggest that Robotaxis with L4/L5 have good chance of gaining a foothold in the upcoming years, and that they could have earlier success than private vehicles (with such a level of autonomy).**
- To the extent that private vehicles with L4-5 are deployed, this could potentially be more towards 2030, although this could be earlier, potentially with a limited deployment and mainly restricted to geo-fenced areas.

2

Robotaxi vs Consumer L4/L5

- The **extent of Robotaxi deployment** will depend on **public acceptance** and **local regulation** openness.
- **Autonomous vehicles for ride sharing could come sooner than L4/L5 consumer vehicles** because it is **possible to amortise the high cost of hardware** required to get to a sufficient mean time between failures over 24/7 usage/earnings
- Robotaxi has no driver and runs all the time, which **improves return on investment spend**, while **consumer AVs are often idle**
- It is **feasible to limit Robotaxis to a smaller area** (ie geo-fenced in one city/region); this is **not commercially viable** for consumer AV

3

Progress and drivers

- **Mobileye is working with OEMs to integrate autonomous vehicle AI into Robotaxi**
- Player such as **Moovit (per Mobileye) could be responsible for other layers** e.g. payment and mobile intelligence
- **Mobileye previously stated it would target deployment of JV with VW in 2021**; early riders program start 2021 and target **commercial driverless pilot in 2022 post regulatory approval.**
- Robotaxi **helps test and certify** autonomous vehicle technology globally and **gain regulatory/market credibility for L4/L5**

Source: Company data, Goldman Sachs Global Investment Research

In essence, while we assume that it is relatively simple given today's computational and engineering capabilities to build a car that can drive itself in a certain defined area, the key bottleneck (among others) for a *consumer* owned car to be able to drive beyond prescribed maps is to ensure the car can do so to a standard that is significantly statistically better than human ability in terms of safety (and to do so at a reasonable hardware cost (note Robotaxis operate under different cost constraints).

- In other words, the **mean time between failures must be demonstrably an order of magnitude better than a human driver such that consumers and regulators deem it acceptable.** We include this bottleneck in the exhibit below, as well as others, e.g. the **need for the car to be able to follow regional driving practices** (which may not be defined specifically in legal rules) and therefore may require an official method of validation for safety.
- Another potential bottleneck, as per our industry discussions, is that **cost curves for L4/L5 need to fall significantly before being commercially viable for consumer purchase**. Therefore, we believe **early adoption of L4/L5 technology could be limited to Robotaxis/fleet vehicles (rather than consumer owned vehicles) in some scenarios,** for which the ROI of a constantly driving vehicle is higher than an often idle consumer vehicle. **Auto Tier 1 suppliers expect L3-L5 to be a relatively small part of the industry mix through 2025,** although some L3/L4 deployments are scheduled to occur sooner (note that over-the-air updates could allow for quicker roll-out of these features). We note that **our US auto team believes that L4/L5 adoption could be potentially higher than this,** and therefore discusses the **2030 market opportunity using scenario analysis.** We note that certain **Tier 1 suppliers such as Continental, Bosch, Valeo and Magna** are currently working to **commercialize advanced driver assist platforms** for highway autonomy.

- That said, we note progress is being made in a number of these areas. **In driving policy, Mobileye is already working with regulators, while China has introduced an industry alliance to formally approved RSS based standards.**

Exhibit 60: We see several bottlenecks to L4/L5 penetration but note meaningful progress in a number of areas

Key bottlenecks to L4/L5 ADAS penetration	
Lower ROI for consumer AV	• **Incremental cost of L4/L5 ADAS systems has not yet fallen low enough to be economically viable for consumers,** given **current cost of hardware/sensors** required to get to sufficient level of mean time between failure • We believe there could be a scenario where **early adoption of L4/5 is limited to Robotaxis/fleet vehicles**, for which **the ROI of a constantly driving (and earning) vehicle is higher** than an often idle consumer vehicle. • We believe there could be a **scenario where Robotaxis proliferate before consumer L4/5 to validate confidence in AV.** • **Momenta** (provider of AI software backed by Daimler) pledged that **Robotaxis to be fully driverless and profitable by 2024.** • **MBLY announced partnership with VW to run MAAS/robotaxi in Israel** (launched in 2019, fully commercialised by 2022). • Long-term, we est. the **incremental semis (ex-GPU) content can be c.$900 for L4/L5 vehicles**, on top of other ADAS software/hardware
Consumer acceptance	• We believe that **widespread consumer acceptance of AV systems will require failure rates to fall significantly below that of human-driven vehicles** in order to establish sufficient consumer confidence in ADAS products. • **ADAS fatalities are high profile** and lower consumer confidence (even if the failure rate is lower than human-driving) • That said, we believe that **as technical capabilities improve**, it will be **possible in the long term to demonstrate failure rates which are significantly better** than those of human drivers.

Redundancy	• **L4/L5 vehicles require higher levels of redundancy** and lower mean time before failure as **driver is not engaged with the road**
	• **Lidar sensors will become necessary** to facilitate long-range high-speed sensing.
	    • Issues of cost must be resolved, with **LIDAR sensors around 10x the cost of radar sensors**.
	• **Most testing is performed in perfect conditions** (e.g. Arizona/California, where is it **sunny, little traffic and wide roads)**
	    • AI trained exclusively in perfect conditions will **fail in harsher climates** e.g. Scandinavia or **more traffic** e.g. Asia.
	• **More progress is required on training AI using global scenarios** if OEMs want to sell cars globally
	• That said, we note that prices are coming down. For example, we note that **some cheaper lidars are now being included in some L2+ cars in the premium market segment.**
	• **Moreover, sensor innovation is improving** e.g. incrasing radar resolution

Mapping	• **L2+ to L5 vehicles rely to a degree on high definition mapping** which enables autonomous features in poor conditions. • Current technology enables maps to be updated every few months, **but real-time updates are required to ensure max safety**. • While **geo-fenced Robotaxis only need regional mapping**, consumer L4/L5 vehicles need **large-scale maps** to drive anywhere. • **Mobileye made large progress** on data collection. Already gathering **8mn km per day, rising to 1bn km per day by 2024.**
Algorithms	• **More advanced software algorithms are required** to optimise L4/L5 driving behaviour • E.g. System must **understand how fast to drive on a road** due to social norms, even if it is less than the speed limit • **Different countries have varying cultures** which **software must be programmed** for (ie. software must account for behaviours and not just rules) • E.g. cameras must look for traffic light cameras in different locations (i.e. LHS vs RHS driving) • That said, **Mobileye has made progress crystallising its RSS (RSS is its proposal for standardised driving policy) approach with regulators** (which seeks to codify standards of safe driving, beyond a pure rules based approach). • **China has introduced an industry alliance to formally approved RSS based standards**.
Cyber threats	• **ADAS vehicles become increasingly vulnerable to cyber attacks as levels of connectivity increase** and greater reliance is placed on digital data transfer for mission critical processes. • **Cybersecurity controls must be applied to prohibit malicious agents** from gaining control of one of several vehicles. • This presents a challenge as **vehicles beyond L2+ often critically rely on external data** e.g. sensory inputs, positioning data, cloud maps. • In L4/L5, **malicious connectivity attacks might not be able to be overridden** by a driver **(can't assume the driver is fully alert).** • In L1/L2, drivers must remain alert, so **safety focuses on performance of electronic actuators** eg. braking/transmission.

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 61: Software and sensing capabilities are required to be significantly more robust to enable full autonomous driving features, but progress is being made on L4 testing and implementation

Why must software, computational and/or sensing capabilities be so much more robust for L3-L5 vs L1-L2?

- **Mean time before failure (MTBF) is 1mn - 10mn hours of driving for human**. Fully autonomous driving **must be at least as good as human.**
- **Automatic emergency breaking fails 1 in a few tens of thousand activations**.
- So getting to 1mn - 10mn MTBF for autonomous systems is an **order of magnitude harder than current technological capabilities**
- BUT if you have multiple separate subsystems working together where one system spots a target and both work on the target, then the **capabilities of AV tech systems might reach human levels**
- **Mathematically each of e.g. 3 independant systems could have MTBF of 1 in 10,000 hrs, which would be technically feasible**

The industry is already working on implementations of L4, albeit these are typically in the mobility as a services (MAAS) category rather than broad based consumer L4/L5

- **Consumer L4/L5 is the most challenging implementation** of AV to adopt
- However, **Robotaxis/MAAS, where the service is limited to certain physical areas, could be more feasible**
- **Economic model** (24/7 utilisation of a car) **can justify much higher cost of hardware/sensing** vs what is economical on consumer L4/L5 vehicle
- **Nio to use MBLY for consumer L4 AV** in China in 2022
- Mobileye to work **with VW to offer L4 mobility as a service/AV in Israel** (launched in 2019, to be fully commercialised by 2022)
- Mobileye to start to test, scale and **roll-out MAAS in France in 2022 and the US in 2023**

Source: Company data, Goldman Sachs Global Investment Research

We highlight a number of key enablers for full L4-L5 Autonomous driving.

- First, **given the need to demonstrate a mean time between failure that is better than that of a human driver, there is a need to integrate multiple systems based in different sensors,** e.g. radar, lidar and ADAS that are independent of each other. By doing so, this builds true redundancy into the system. **The number of sensors in more autonomous vehicles is expected to be more numerous than seen in lower levels of automation to provide the required robustness/redundancy** and full view around the vehicle, which in our view should drive semis content.
- Second, **we believe the computational complexity will be especially advanced.** We believe a **set up involving custom processing chips and/or GPUs will need to be able to ensure critical computing power for advanced central sensor fusion processing.** Clearly this will be associated with a rich semiconductor opportunity.
- Third, **high definition maps enable ADAS features (e.g. lane centering) to remain effective even in areas where sensors have difficulty in accurately identifying the road environment.** (e.g. in areas without visible lane marks, or poor weather/light conditions, where camera or radar sensors may perform suboptimally). **Mobileye has started the process of collecting road data** (through a variety of partnerships with OEMs such as BMW, Nissan and VW). This data is **automatically integrated into a high definition map by software in the cloud**, and relayed back to L2+ cars on the road. We see **key success factors being frequent updates of maps** (approaching real-time ideally), **accuracy** (as GPS not precise enough) and **scalable data sets** (to ensure software is capable of handling unlikely events).

Notably, **Mobileye has already stated it is collecting 8mn km of road data per day, with ambitions to increase to 1bn km per day by 2024.**

- Furthermore, we see **software as a key enabler of L4/L5 automation technology.** We contrast the ***decision*** **software that is integrated with a processing chip** (often provided by Mobileye) against **software that is involved in *perception* of objects** around the car. We highlight that a variety of *independent* subsystems are needed in order to produce the levels of redundancy required. For example, a **camera based, radar based and lidar based systems that can each individually and independently perform full end to end autonomous driving** to the same performance level and can be **combined to create a product with sufficiently high mean time between failure**.
- **We provide further detail on a number of enablers and their implications for semis in the below exhibit.** This is a non exhaustive list and the enablers will evolve over time, just as content expected to be deployed on L1-L3 continues to evolve.

ADAS semis market TAM of $21.8bn by 2030E, driven by MCUs, radar and camera chips

Multiple semiconductor companies have scope to benefit from ADAS, and we estimate an overall semis TAM of $21.8bn by 2030 in our base case. For context, we put the size the Auto semis market at c$38bn today.

- We see **multiple companies in our coverage that could benefit from the increased need for various types of semiconductor content in ADAS** as this technology evolves and penetrates more cars in coming years. Overall, in our base case, **we see a total ADAS-related semiconductor TAM of $10.8bn by 2025 (with our bull case at $16.9bn) and $21.8bn by 2030 (bull case at $34.2bn), which compares to the estimated overall Automotive semi market of c.$38bn today.**

For overall Microcontrollers, our base case analysis suggests a semis TAM of $2.6bn/$4.6bn in 2025/30E, and we believe Infineon (Buy), STM (Sell), Renesas (Buy, on CL) and NXP (Neutral) could all benefit to different degrees.

- We consider **Infineon the leader on MCUs with its AURIX MCU for radar signal pre-processing** (alongside other host controller applications), where STM also holds a strong position (albeit with smaller market share). That said, we expect Infineon to further strengthen its position over time. **Renesas and NXP are also notable players in this space, with strong positions on 32-Bit MCUs.** These players are namechecked in our industry discussions as having the highest computing performance MCU chips when compared with some other players, per our industry discussions, which we believe is due to a strategic choice to pursue compute power.
- **In radar chips, our base case analysis suggests a semis TAM of $2.4bn/$4.5bn in 2025/30E. We see Infineon as a broad player that competes on all radar frequencies, and estimate strong +25% market share when considering all types of radars** (i.e. long-range, mid-range, short-range, 77 GHz, 24 GHz, SiGe, CMOS, front, rear, corner, etc.) **STM holds a market leading position on 24 GHz short-range radar** (while Infineon leads on 77 GHz long-range radar using SiGe technology), per company disclosure. That said, we expect Infineon to also offer CMOS radar technology in future in line with the company's plans. **We note that NXP also offers a leading solution on CMOS short-range and 77 GHz radar.**

- We see **lidar chips offering advantages in terms of precision and resolution in comparison to radar sensors,** and our US Autos analyst Mark Delaney **expects 0.33/0.75/3 lidars on average for L2+/L3/L4-L5 vehicles in 2025.** However, we note that **the extent to which lidars are used will be fluid and may depend on the extent to which camera/radar capabilities can be improved** (something the industry is focused on given the expensive nature of lidars relative to other sensors). Per our US Auto analyst's ADAS report, **we see Lidars becoming more prevalent with L3 and then L4/L5**. Lidars tend to comprise a laser, receiver and scanner, with the receiver having an ASIC. Some companies are seeking to integrate multiple functions on a single chip, which is sometimes referred to as a lidar-on-a-chip. **We**

see a lidar semis TAM of $0.7bn/$2.1bn in 2025/30E. Key players include Velodyne, Aptiv, Magna and Luminar.

- **We note a variety of new approaches on LiDAR**, for example**, Abax is developing flash LiDAR technology which illuminates an entire field of view with laser beams** (without mechanical spinning), which could **significantly reduce LiDAR costs**, as highlighted in our China team's note **here**. **Furthermore, MEMS LiDAR offers a lower cost solution than mechanical LiDAR, at a smaller size.** Key challenges include enlarging the scanning range, extending the light distance and widening the angle of scanning (see more here). Separately, the team has a **Buy rating on SMIC/Hua Hong (foundries for CIS, LiDAR, radar chips), which could benefit from expanding LiDAR penetration,** while it highlights that Will Semi expects CMOS image sensor units to grow from 2 units currently to 6 units in 3-5 years (more here).

Exhibit 62: We see a variety of success factors for key semis components, with scope for technologies to further evolve

ADAS Semis Success Factors	

Radar semis	• **77Ghz offers more accuracy** and allows for **higher resolution of object detection vs 24Ghz** (hence, 24Ghz is cheaper)
	• Regulations mean that **24Ghz is no longer allowed in Europe after 2030**.
	• **European OEMs are increasingly switching to 77Ghz only** (for both short, medium and long range radar)
	  • But China is still using 24Ghz and **there is a growing market for 24Ghz in China** (whereas it is shrinking in US/Europe)
	• **Silicon Germanium (SIGE) technology is good for long range, but will soon transition to CMOS**, which will have advantages for short and medium range.
	  • **SIGE will still be the first choice for long range radar**, because CMOS has a weaker signal. But, **CMOS will be first choice for short and medium range.**
	• **Ability to combine the radar chips with MCUs intelligently** could be an advantage e.g. alongside the radar chip
	  • **IFX offers its Aurix MCU** for radar signal pre-processing
	• Some players **looking to move from analog approach to digital modulation**; we believe this could be a differentiator.
	• More broadly, **radar chips are improving in terms of resolution**.

Lidar semis	• **Lidars have advantages in terms of precision and accuracy** vs other sensors (particularly in bad weather) • There are **efforts to evolve lidar technology**; Mobileye is working FMCW lidar (which goes beyond time of flight (TOF) as it is 4D sampling because it can also measure velocity). We see a broad range of scenarios as to implementations of LIDAR. • This could help **improve velocity measurement, give higher range and immunity to interference** e.g. sunlight • While we assume multiple Lidars on L4, our industry discussions suggest that **improvements in camera/radar could mean the latter substitute to some extent for LIDARs.**

MCUs	• **Reputation for reliability/ISO26262 certification**
	  • Key for usage as **domain controller** (gives final signal to e.g. brakes)
	  • Also important to have a **power IC capability which is ASIL-D certified**
	  • E.g. IFX AURIX product often found in these roles given that OEMs want products to have this certification
	• **Auto domain level expertise**
	  • Helps gain market share at OEMs e.g. pre processing for corner radars
	• **Integration of Memory with MCU**
	  • Can help in terms of **convenience/better form factor** to OEM but may come at the cost of processing power and thus suitability in sensor fusion
	  • E.g. IFX has this approach and would be suitable for L1/L2 sensor fusion, and potentially L2+, but **unlikely for more sophisticated implementations.**
	• **Processing power of MCU**
	  • **Trade off with memory integration**; Higher compute power could mean more scope to be in sensor fusion function beyond L2.
	  • E.g. **Renesas/NXP focus more on compute power vs memory**, which could give more applicability in this area.

Source: Company data, Goldman Sachs Global Investment Research

- **Perception and decision making/policy software for more advanced ADAS (and especially for AVs) needs to run (at least for L3 onwards) on powerful compute chips, rather than purely MCUs.** These could be an SOC/ASIC and/or GPU (at higher levels of autonomy). **Key players include Nvidia, which specialises in graphics processing capabilities through its GPUs for sensor fusion processing for in-car compute in higher autonomy (L4/L5) and car infotainment system.** Nvidia's solutions offer an end-to-end solution of both semis processing and accompanying software. For in-car compute, **the primary hardware solution is an SoC, which can also be sold with GPUs at higher levels of autonomy. We forecast the GPU semis TAM for ADAS expanding to $11bn/$36bn by 2025/30E.**

- **Mobileye offers a full suite of software for various levels of automation, ranging for ADAS L1/L2, where it is the market leader.** Mobileye's packages include EyeQ chips that it co-designs with STM. We believe that **success factors include the ability to co-design hardware and software algorithms that such chips are designed to run on**. The Supervision L2++ from Mobileye runs on 2 Eye Q5 chips. According to the company, in the future this will evolve towards the EyeQ6 that will continue to build on that efficiency. These are very efficient chips due to the hardware/software co-design and allow for **smaller size/power, which we believe will continue to be important, especially as the industry transitions towards EVs.** Mobileye's offering also includes **algorithms for perception and driving policy** as well as for **integrating data from its crowd sourced mapping platform**, whereby it sources data from a broad array of OEMs using cameras on board cars that use its ADAS systems. Furthermore, it **collaborates with STM to co-design a custom chip that serves as a central compute option that can run such algorithms**. Historically Mobileye/STM have been **strong on vision processing but over time it can run more and more sophisticated driving policy/perception software** and the companies have expressed an intention to integrate inputs from independent sensors of various types e.g. radar. We note that **software for perception/decision making will require in-depth domain knowledge so that corner cases can be dealt with,** and that over time algorithms can be trained so the vehicle can react in such situations (based on very significant amounts of data being collected). **We see the central processing semis (ex-GPU) TAM for ADAS expanding to $2.1bn/$5.3bn by 2025/30E.**
- **In power management, both Infineon and STMicro offer a comprehensive range of power management ICs tailored for ADAS.** These semis play an important role in managing voltages in an ADAS system of very high computational power. **We see the actuation/power semis TAM for ADAS expanding to $0.5bn/$1.3bn by 2025/30E.**
- STM offers optical sensing solutions to address **driver monitoring (DMS) and occupant monitoring (OMS)** applications and holds a market leading position **(we estimate its market share is trending towards 25% on DMS).** We also note that ON Semis participates in the ADAS image sensing space.
- We provide further details on these and other technologies, including further players and success factors in Exhibit 28, and detailed company profiles at the end of this report.

The Cynics view

We list below the most important arguments that could run counter to our thesis that ADAS will over time drive significantly increased semis content, and our view as to mitigants to such arguments. These counter arguments include incorporating safety features into NCAP ratings, significant semis content associated with L2+ (given advantages of this to consumers/OEMs) and progress on standardising driving policy/behavioural elements for more advanced automation levels (in the longer term).

Exhibit 63: The Cynics View

1 Commoditisation of features
- L1/L2 may have fast uptake, but over time will simply become commoditised
- Over time, greater safety features and convenience features will drive adoption of next levels of autonomy e.g. better radars for safety, more precise algorithms running on better hardware and this will drive semis content.
- These improvements may also be incorporated into NCAP star ratings/regulation over time as well.

2 Regulation for L2+ onwards is lacking
- L2+ wont be driven by regulation so may not have as fast uptake as L1/L2 (which was driven by star rating regimes)
- Our industry discussions suggest all premium car makers will want to have L2+/L2++ given attractiveness to consumers of safety features and/or convenience of quasi self driving. Furthermore, we believe it is possible the safety components could be included into star rating regimes (effectively regulation).

3 Higher levels of redundancy required
- L3 requires much higher levels of redundancy/accuracy to be a reality and so could potentially be delayed.
- L2++ delivers many of the benefits to consumers and there is a very large semis opportunity in any case due to more sophisticated processing/sensing needs vs L2.
- Hence even if L3 were skipped, L2++ would drive a lot of tech adoption in autonomous vehicles.

4 Advanced autonomous driving timeframe has been pushed out
- L4/L5 has been pushed out by around 5 years, so the semis opportunity should not be overstated.
- Our base case is that the semis market for ADAS will largely be driven by L1-L2+ out to 2030
- We see a semis (ex-GPU) market of $20bn by 2030 even if L4-L5 never happens.

5 Mean time before failure not sufficiently high yet
- L4/5 requires such a high mean time before failure that it should not be relied upon to drive semis uptake.
- Our focus on this report is thus mainly on L1-L2++ out to 2030 and we think even without L4 onwards the semis TAM will expand by c8x vs 2020. However, we see potential for robotaxis to be a useful means of validating more advanced levels of automation and see independent sensor systems as a potential avenue for achieving sufficiently low mean time before failure.

6 Consumer confidence is sensitive to higher profile ADAS crashes
- If there are crashes, this could retard the uptake of all types of automated vehicles
- We certainly believe this could set back adoption of L3 onwards, but see L2++ as a major driver and note the driver rather than the OEM is responsible at this level; moreover technology can be introduced to monitor the driver's alertness.

7 AI developments must overcome cultural challenges
- Autonomy requires understanding of driving behaviour, not just following rules; a machine will struggle to achieve this.
- While the focus of the report is up to L2+, out to 2030, we acknowledge the potential for more advanced autonomous functions to trickle down and benefit the content within the ADAS sphere, suggesting progress in greater automation is a driver indirectly.
- That said, we note that work is ongoing to work is already underway to standardise/quantify what can count as "safe" driving at higher levels of autonomy (e.g. in scenarios where it is not just about following specific rules and where regional differences in driver behaviour are paramount).

Source: Company data, Goldman Sachs Global Investment Research

Single Stock Implications

Infineon (covered by Alexander Duval)

What does it do?

Infineon is a semiconductor manufacturer based in Munich, Germany, which provides chips for the Automotive, Industrial, Smartphone/PC and Smartcard markets. The company has 40+ years of experience in the Auto and Industrial end markets and is the global market leader in power semis (c.55% of group revenues) with c.20% market share based on 2019, >2X that of the number two player.

How is it leveraged to ADAS?

Infineon provides microcontrollers, radar processing chips and power semis for L1-L5 ADAS technologies. The company is primarily exposed to the ADAS market through its portfolio of MCUs, which are used for pre-processing of sensor data (camera/radar/lidar) before central processing in the sensor fusion box, but also as ISO 26262-certified safety domain controllers that send signals for the final actuation of the vehicle physical parts (e.g. steering wheel, brakes). We estimate that IFX has c.30% global market share in MCU based on our industry discussions that ISO 26262-certified AURIX MCU is gaining traction and that it could achieve 30%+ market share in the ADAS segment (it already has 30%+ market share for motor management and transmission, albeit this refers to the domain drivetrain). Infineon has also achieved a strong position on long-distance 77 GHz radar chip, and announced that it is working on the shorter-range 24 GHz frequency. We estimate that it has c.25% market share for IFX in radar chips, when taking into account all types of radar (e.g. long-range, mid-range, short-range, 77 GHz, 24 GHz, SiGe, CMOS, front, rear, corner). Infineon's presence in power semis as provides it with exposure to the trend of increasing levels of redundancy in mechanical systems (e.g. braking, steering) as the levels of autonomy rise (towards L4/L5), and hence we expect a substantial increase in the power semis BoM over the next 5 years.

Valuation and key risks

We are Buy rated on IFX with a 12m price target of €42.3 based on a target multiple of 15x CY22E EV/EBITDA (85% weighting) alongside an M&A component at 20x CY22E EV/EBITDA (15% weighting), consistent with precedent transaction multiples. Key risks to our view and price target include weaker end markets, worsening semi cycle and negative macro dynamics.

STMicro (covered by Alexander Duval)

What does it do?

STMicro is a semiconductor producer headquartered in Geneva, Switzerland, with significant operations in Italy and France. The company supplies chips for the Automotive, Industrial, Smartphone and Consumer Devices markets, with particular expertise in power semis and microcontrollers. The company is a top 5 player in Automotive semis, power discretes and modules, and smart cards segments.

How is it leveraged to ADAS?

STMicro supplies vision-based processing chips, short-range radar processing chips, MCUs and power semis to the ADAS market. STM has been a co-developer of vision-based camera EyeQ chips with Mobileye for the past 15 years. To date, over 70m EyeQ chips have been shipped, with a significant portion of these being used in L1-L2 vehicles, but increasing usage in L2+. We believe that STM's processing chips (co-developed with Mobileye) currently garner a dominant market share, especially viz-a-vis vision based processing. STM offers a comprehensive portfolio of ADAS ICs for power management, and according to the company holds a leading market position in short range 24 GHz radar sensor chips. Furthermore, STM offers optical sensing solutions for driver and occupant monitoring systems, which are required in L2+ vehicles that monitor to ensure drivers remain alert in the event that ADAS systems prompt require human control. We assume in our TAM sensitivities STM has c.10% market share on radar chips, which reflects the fact that STM is a leader on 24 GHz (one particular radar frequency), with this frequency primarily used for short-range radar. We assume STM has c.15% market share in MCUs, with the company present in both the microcontroller used for radar processing in high volume production and in the housekeeping MCUs that sit beside-Mobileye processing chips. Our assumption for STM's MCU market share in ADAS factors in all mentioned applications from parking sensors, radar, and camera.

Valuation and key risks

We are Sell rated on STM, with a 12m price target of €30/ADR $37.0 based on 13x CY22E EV/EBITDA. Key risks to our view and price target relate to market-share gains, better-than-expected industrial/auto trends and positive semi cycle dynamics.

Nvidia (covered by Toshiya Hari)

What does it do?

Nvidia is a market share leader in graphics processing unit (GPU) production, headquartered in Santa Clara, California. The company sells graphics solutions for devices ranging from tablets to workstations and gaming PCs, alongside programmable GPUs for high-power compute applications, e.g. in the automotive end market. Nvidia's chips are known for their applicability in areas such as deep learning, neural networks and training of algorithms.

How is it leveraged to ADAS?

Nvidia specialises in graphics processing capabilities through its GPUs for sensor fusion processing for in-car compute in higher autonomy (L4/L5) and car infotainment system. Nvidia's solutions offer an end-to-end solution of both semis processing and accompanying software. For in-car compute, the primary hardware solution is an SoC, which can also be sold with GPUs at higher levels of autonomy. For example, the Pegasus solution comprises 2 Xavier SoCs with 2 Turing GPUs, which the company believes does not require further external FPGA/CPUs for computing. Nvidia's DRIVE platform is an L2+ solution that's powered by two SOCs and includes a sensor suite

(Nvidia Hyperion; 7-8 external cameras, 5-8 radars, 12 ultrasonic sensors, and 1-3 internal cameras for driver/occupant monitoring). Nvidia also offers a software stack for perception, localisation, mapping, planning and control for a complete autonomous drive platform (which the company believes can support L5 autonomy in time). This platform also includes a simulation platform to test and validate AV algorithms, and a training platform to train neural networks for AV perception. In 2019, the company talked to a TAM of $30bn with $25bn from driving (e.g. for L2+ to L4 systems), $3bn related to training software/development (e.g. training models, mapping, analysing data) and $2bn pertaining to validation (e.g. simulation). We note that perception and decision making/policy software for more advanced ADAS (and especially for AVs) needs to run (at least for L2+ onwards) on powerful compute chips, rather than purely MCUs. These could be an SOC/ASIC and/or GPU (at higher levels of autonomy).

Valuation and key risks

We are Not Rated on Nvidia.

Intel (covered by Toshiya Hari)

What does it do?

Intel Corporation develops and manufactures devices for the consumer, data center, IoT, automotive, and communications infrastructure end markets. It acquired Mobileye in 2017 for $14.7bn, which provides camera vision subsystems and processing chips for active safety and autonomous driving functions.

How is it leveraged to ADAS?

Intel is primarily leveraged towards ADAS through its subsidiary Mobileye. Mobileye is a technological leader in the area of software algorithms, system-on-chips and customer applications that are based on processing visual information for ADAS. Mobileye's camera subsystems are considered highly efficient as a result of the tight integration of hardware and software design (chips co-designed with STM), which allows for smaller sizer and greater compute power. We believe that success factors for these chips include the ability to co-design hardware and software algorithms that such chips are designed to run, which Mobileye has evidenced throughout its partnership with STM. Mobileye's L4 camera subsystem contains two Eye Q5 chips, with the upcoming Eye Q6 expected to continue efficiency improvements, as per company comments, and which we believe will continue to be important, especially as the industry transitions towards EVs.

While to date it has been successful with camera based processing, increasingly it is working on incorporating other sensors in order to achieve higher levels of autonomy (given redundancy needs for super human driving capabilities at such levels). Mobileye's advanced vision based system is due to launch in Geely L2++ vehicles in 4Q21, with quasi-autopilot functionality. This product will include algorithms not only for perception and driving policy, but also for integrating data from Mobileye's crowd-sourced mapping platform, whereby it sources road data form a broad array of OEMs using cameras on board cars that use its ADAS systems. We see mapping as a key enabler for automated driving, with importance at L2+ onwards, and note Mobileye's role in collecting vast amount of data given its relationships with multiple OEMs.

We see Mobileye as at the forefront of work to drive progress on L3 and beyond. Its roadmap includes not only L4/L5 consumer solutions, but also mobility-as-a-service solutions, where it has announced work on standardisation of RSS driving policy. For example, it announced a partnership with VW to run MAAS/robotaxi in Israel (launched in 2019, to be fully commercialised by 2022), which we believe could be important in driving regulatory acceptance of L4/L5 technology on the journey towards L4/5 consumer AV. Mobileye's L2+/L2++ capabilities include everywhere (e.g. urban) and all speed lane centering as well as everywhere and all speed conditional hands-free driving, but we expect further advances towards fuller levels of automation given its strong track record of innovation.

Valuation and key risks

We are Sell rated on Intel, with a 12-month price target of $57, based on 13x our normalized EPS estimate of $4.40. Key upside risks to our view and PT include: 1) stronger-than-expected PC/server demand; 2) better execution on process node transitions, and, as a result, higher market share than what we assume in our base case; 3) business portfolio optimization, 4) early/significant success in foundry; and 5) timing/magnitude of government incentives related to the on-shoring of semiconductor manufacturing.

Renesas (covered by Daiki Takayama)

What does it do?

Renesas Electronics Corporation is a Japanese semiconductor manufacturer headquartered in Tokyo. It has manufacturing, design and sales operations in around 20 countries. It is a key player in microcontrollers, analog, power and SoC products, and serves several key end markets such as automotive, industrial (FA and others), infrastructure (Data center, Base station etc.) and IoT (PC, tablets, wireless charger, etc.).

How is it leveraged to ADAS?

Renesas is primarily leveraged to ADAS through its R-Car SoCs. Renesas has been shipping R-Car V3U for L2+ (and L3, using multiple V3Us) since December 2020, and has guided for mass production to start from June Q 2023. It offers products which balance calculation ability, cost and power consumption according to the OEMs' needs. To the extent that we see increasing levels of autonomy, such as L3, we see a potential benefit to Renesas, given the requirement for higher processing capabilities and MCUs in a sensor fusion setting for ADAS. Renesas has also been realising synergies between acquisitions Intersil (completed in 2017) and IDT (completed in 2019), which it describes as a "winning combination" of MCU, Analog and Power. The company announced plans to focus on software (development programs/tools) as well as hardware to secure long/mid-term competitiveness in its product portfolio.

Valuation and key risks

We are Buy rated (on Conviction List), with a 12-month target price of ¥1,400, based on FY12/22E EV/DACF, applying the electronic components sector average multiple of 8X, and implies FY12/22E EV/EBITDA of 7X. Key risks include a decline in auto production volume, weaker machine tool orders, yen appreciation, and a potential INCJ stake sale.

NXP (covered by Toshiya Hari)

What does it do?

NXP Semiconductors N.V. is a global semiconductor manufacturer headquartered in the Netherlands and US. The primary markets NXP addresses relate to Automotive, Industrial & IoT, Mobile and Communication Infrastructure. The company has been a market leader in automotive semiconductors (including infotainment) in recent years, noting its strong revenue exposure to automotive (c.50%).

How is it leveraged to ADAS?

The company is a major player in auxiliary functions within the car such as body & comfort, infotainment and functional safety, and has a solid position in ADAS-related semis. Specific to ADAS, NXP focuses on 77 GHz long-range radar processing chips using CMOS technology (rather than the SiGe technology that Infineon currently utilises, despite also transitioning towards CMOS). We see NXP as well positioned for the future uptick in ADAS adoption given the company's market-leading position in long-range radar chips, which we see scaling in content as autonomy develops.

Valuation and key risks

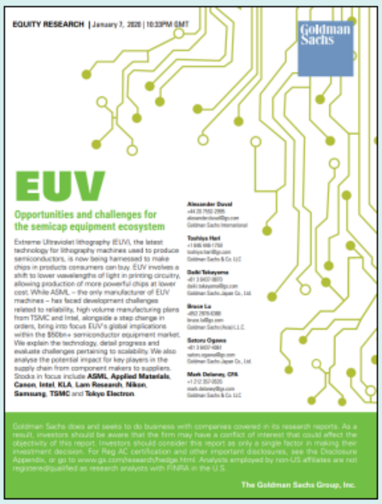
We are Neutral rated, with a 12-month price target of $179, based on 19x our normalized EPS estimate of $9.40. Key upside/downside risks to our PT and investment thesis include: 1) renewed deterioration in Automotive/Industrial end-demand or faster than expected recovery in Automotive; 2) margin execution; 3) increased competition in the MCU market; and 4) M&A that is accretive/dilutive to growth, margin and/or returns.

Related Research on Semiconductors

Assessing the EV opportunity for the semiconductor supply chain: Mid-term content tailwinds in focus

April 15, 2020

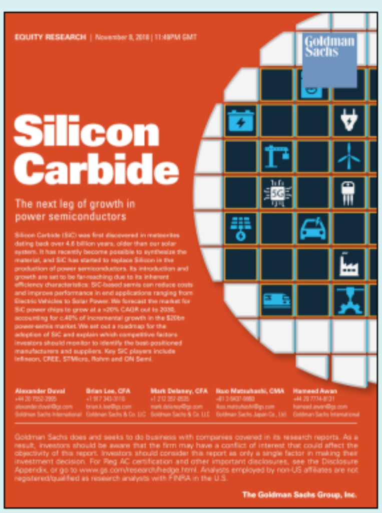
Electrified Vehicles (EVs) are set to gain critical mass in coming years -- while overall auto units are likely to fall sharply this year, we see the EU regulations requiring reductions in CO2 over the next few years driving up global EV units almost 4X by 2025 vs 2019. Our analysis of the types of semiconductor chips required for EVs suggests semis content per car could rise up to 3X for a full Battery EV (BEV), with the semis revenue pool set to grow at a 24% CAGR (2019-25E). Importantly, our industry work makes us increasingly confident that Silicon Carbide (SiC) can be a crucial enabling technology given cost and range benefits, driving SiC uptake in mid-end cars.



EUV: Opportunities and challenges for the semicap equipment ecosystem

Jan 7, 2020

Extreme Ultraviolet lithography (EUV), the latest technology for lithography machines used to produce semiconductors, is now being harnessed to make chips in products consumers can buy. EUV involves a shift to lower wavelengths of light in printing circuitry, allowing production of more powerful chips at lower cost. While ASML – the only manufacturer of EUV machines – has faced development challenges related to reliability, high volume manufacturing plans from TSMC and Intel, alongside a step change in orders, bring into focus EUV's global implications within the $50bn+ semiconductor equipment market. We explain the technology, detail progress and evaluate challenges pertaining to scalability. We also analyse the potential impact for key players in the supply chain from component makers to suppliers.



Silicon Carbide: The next leg of growth in power semis

Nov 8, 2018

Silicon Carbide (SiC) was first discovered in meteorites dating back over 4.6 billion years, older than our solar system. It has recently become possible to synthesize the material, and SiC has started to replace Silicon in the production of power semiconductors. Its introduction and growth are set to be far-reaching due to its inherent efficiency characteristics: SiC-based semis can reduce costs and improve performance in end applications ranging from Electric Vehicles to Solar Power. We forecast the market for SiC power chips to grow at a >20% CAGR out to 2030, accounting for c.40% of incremental growth in the $20bn power-semis market. We set out a roadmap for the adoption of SiC and explain which competitive factors investors should monitor to identify the best-positioned manufacturers and suppliers. Key SiC players include Infineon, CREE, STMicro, Rohm and ON Semi.

Disclosure Appendix

Reg AC

We, Alexander Duval, Toshiya Hari, Mark Delaney, CFA, Daiki Takayama, George Galliers, Allen Chang and James Saunders, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

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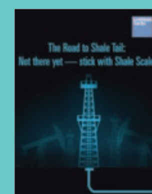

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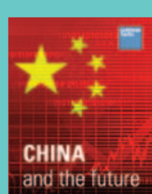

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