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Initiation

Autos & Industrial Tech

Expect robust growth in ADAS; competition may weigh on LiDAR fundamentals

Initiate INVZ, VLDR at Neutral

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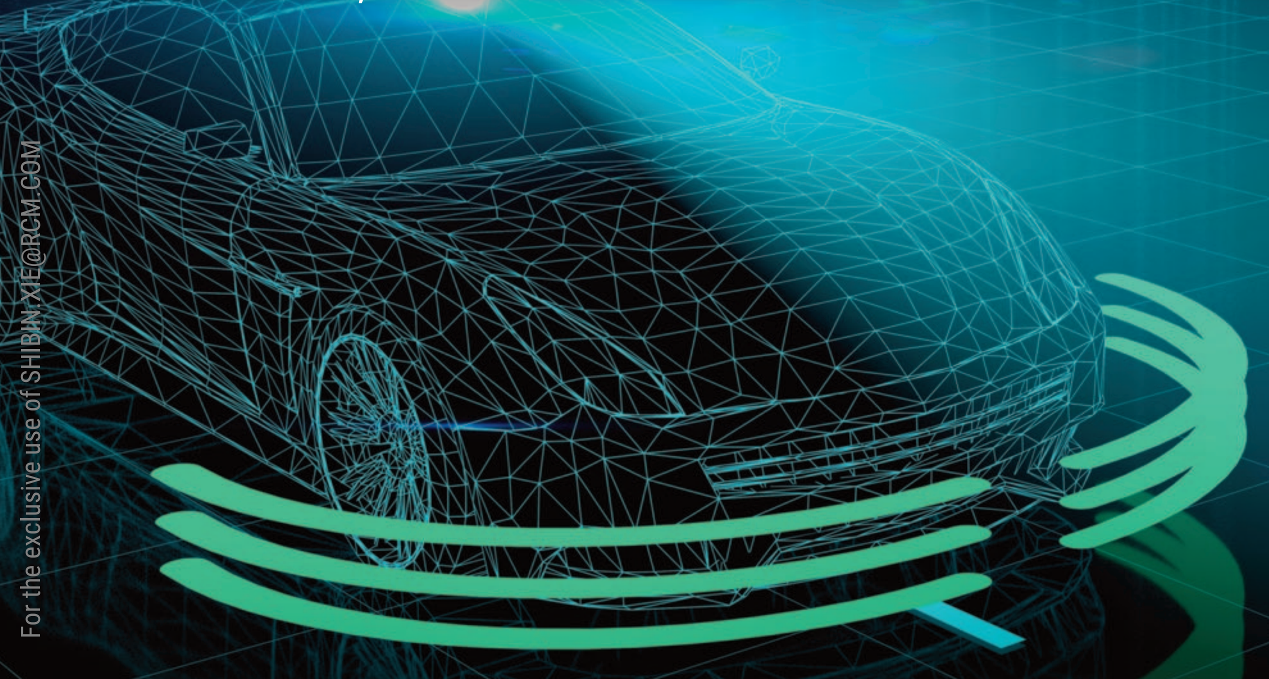

We expect robust growth of advanced driver assistance systems (ADAS), which enable safety features such as automatic lane changes and emergency breaking. These features mark a step toward reducing the over 1 mn annual traffic fatalities that occur globally per the WHO. We believe that the attach rate of L2/L2+ ADAS systems could reach 25% by 2025, and we estimate that the market for camera, radar and LiDAR ADAS systems in total could grow to more than $60 bn by 2025.

While we see a substantial long-term market opportunity for LiDAR, the fact that most of the industry growth in ADAS in the near-term is from L2/L2+ solutions that often don't use LiDAR could limit near-term industry volumes, and in the long-term competition could weigh on margins. We initiate coverage of LiDAR providers **Velodyne** and **Innoviz** at Neutral. We believe tier 1 suppliers such as **Aptiv, Denso,** and **Magna,** and OEMs including **Tesla, GM, Ford, Li Auto, Toyota, VW, BMW,** and **Daimler** are companies that can benefit from this transition.

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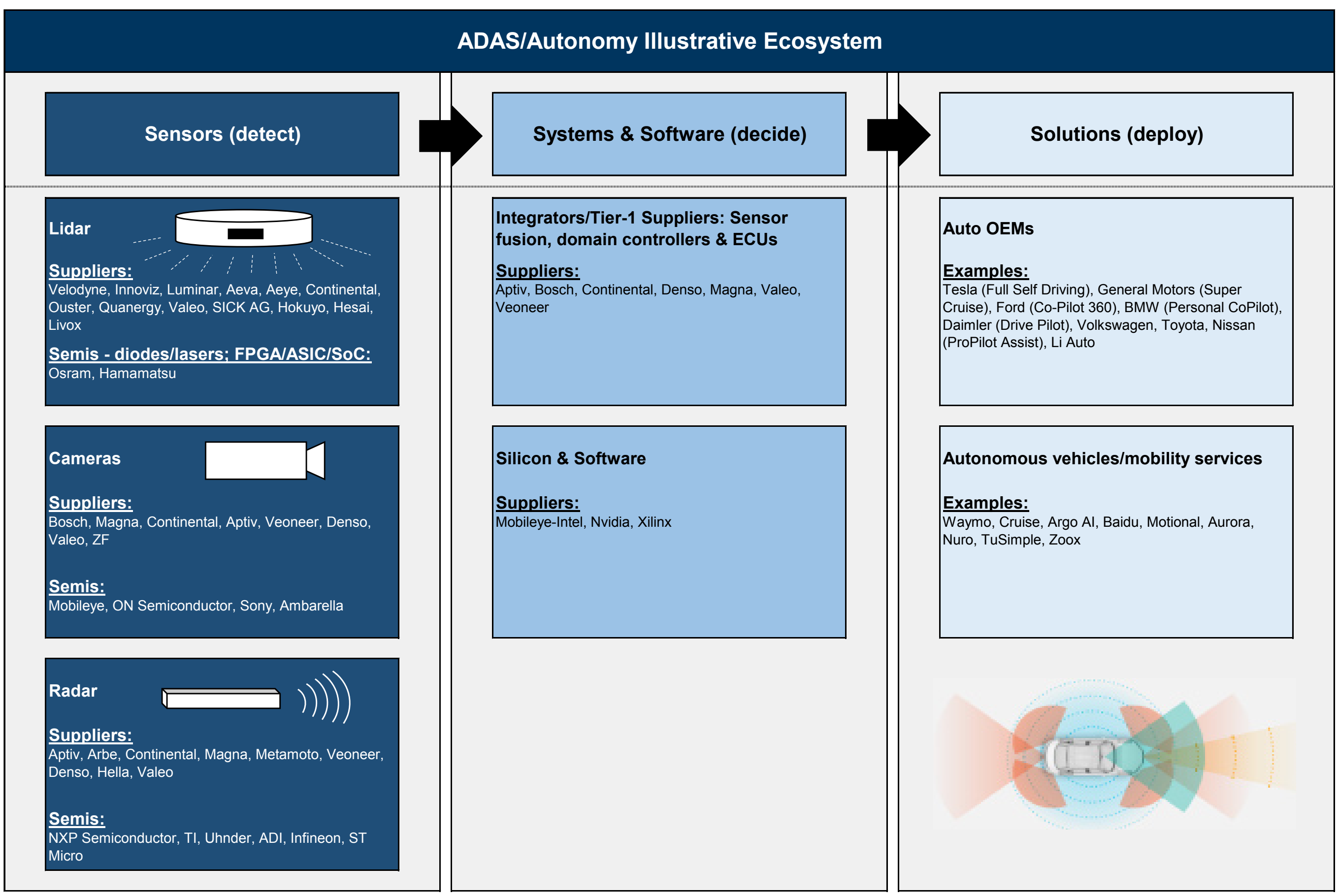
We expect robust growth in the near- to intermediate-term of advanced driver assistance systems (ADAS), which enable safety features such as automatic lane changes, lane keeping, and emergency breaking. These features mark a step toward reducing the over 1 mn annual traffic fatalities that occur globally per the WHO and also represent a substantial business opportunity for both the auto tech industry and auto OEMs.

ADAS features enable Level 2 autonomy (e.g., the car can do complex tasks like change lanes and keep distance on the highway, but the driver needs to be alert and prepared to take over), Level 3 (the driver can disengage completely in certain settings like the highway but be prepared to take over within a certain amount of time if prompted), or L2+ (the vehicle is capable of more complex tasks and potentially could be L3 or higher technically, but the driver is still required to stay alert, and the risk of an accident lies with the driver).

While we focus mostly on ADAS and key sensor technologies such as LiDAR in this report, we believe that it is important to understand the full autonomous technology landscape to assess the opportunity especially as many of the ADAS technologies are the building blocks for full autonomy. We show an illustrative overview of the ecosystem in Exhibit 1.

Exhibit 1: ADAS/Autonomy Illustrative Ecosystem Map
Representative but not an exhaustive list



Source: Goldman Sachs Global Investment Research

Exhibit 2: ADAS in a nutshell

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 movement 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 Organization)
	  • Road traffic crashes cost most countries **3% of their gross domestic product** (World Health Organization)
	  • **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.

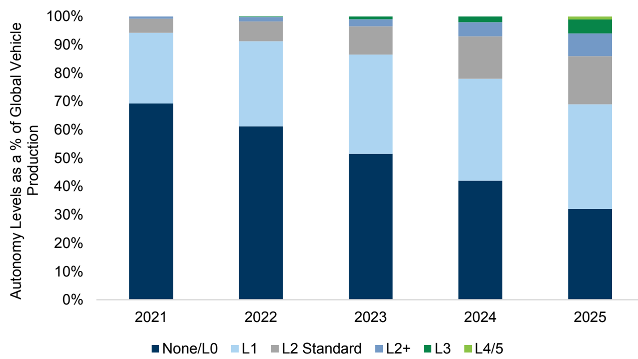
Source: Company data, Goldman Sachs Global Investment Research

Several auto and auto tech companies are expecting robust growth in ADAS systems in the next few years, and based on the projections of leading auto tier 1 suppliers, L2/L2+ technology could reach 25% adoption on light vehicles by 2025, up from about 5% presently (Exhibit 3). The increased adoption of L2/L2+ ADAS systems is being driven by new safety regulations (see the regulatory section of this report), consumer demand, and the opportunity for OEMs to sell ADAS systems at attractive margins.

There could also be more advanced systems deployed in the next few years that allow features like highway driving at full speed that in some locations could be classified as L3 (when the driver can conditionally disengage).

While the auto supply chain expects only limited deployments of L4 autonomy in the next few years (L4 is when the vehicle can drive itself broadly in a geofenced area), we'd note that there are lots of companies working to bring this technology to market and it could therefore occur more quickly than tier 1s are typically projecting. L4 could also roll out on a staggered basis with deployments in select locations based on technology requirements and regulations, rather than being a binary event, which is how some AV companies have addressed the market so far (e.g. with targeted deployments and/or testing in select cities). We'd also note that the increasing use of over the air updates in the auto industry (an approach that Tesla has helped popularize) makes it possible to deploy L4 autonomy more rapidly to at least some fleets when the technology is ready (to the extent the hardware can support higher levels of automation).

Exhibit 3: L2 (inc L2+) ADAS could reach 25% adoption by 2025 per the auto industry



Source: Company data, Goldman Sachs Global Investment Research

Autonomous driving (both partial automation or ADAS, and full autonomy) relies on several sensors to gauge the environment. Sensor types include cameras, radar, ultrasonic, and lidar. We estimate that the total addressable market for camera, radar, and lidar hardware in ADAS/AVs will grow at a ~40%+ CAGR to ~$60+ bn in 2025 from ~$15 bn today. The market for these types of sensors could reach between $90 bn to $160 bn in 2030, depending on global vehicle production and the mix of L2/L3/L4/L5 autonomy. We further estimate that there could be a $15 bn+ software opportunity in ADAS/AVs in 2025 (e.g., for object classification, sensor fusion, and path planning), and potentially a $100 bn+ TAM (and potentially significantly more than $100 bn) opportunity in 2030 (depending on L4/L5 mix, which we expect to carry significantly higher software content than L3 and below), although many OEMs plan to address this software opportunity with internal solutions, and the dollar value autonomous software will have is debated by investors.

We consider Buy-rated **APTV** and Buy rated **Denso** (on CL) to be good ways to invest in this theme. Aptiv has a 1.3 bn+ ADAS business in 2020 growing at a ~30% CAGR and serving several key auto OEMs, as well as with its full autonomy Motional JV. Denso has a broad range of key autonomous technologies including lidar. Neutral rated **MGA** has a roughly $550 mn ADAS business currently, which it expects to grow to over $1 bn in 2023 and $2 bn by 2027, and we consider it to be a beneficiary of this shift. We also see ADAS as an opportunity for OEMs including **TSLA, GM, F, Li Auto, VW, BMW** and **Daimler** as their offerings are typically sold as add-on options with high incremental margins. Separately, **our semis colleagues have published a related report with ways to invest in ADAS (LINK)**.

We believe that LiDAR sensors ("light detection and ranging" or lidar, which are sensors that emit light and use the return data for object classification and can be more precise than radar and work in different environmental conditions/add redundancy to cameras) will develop from a roughly $1 bn market currently to a substantial multi-billion dollar market over time, driven by both the transportation industry (e.g., passenger cars, trucking, robo-taxis) and also last-mile delivery and industrial/IoT applications.

We expect lidar companies to operate in a highly competitive and difficult environment, even though the long-term market size could be substantial. Most auto OEMs plan to use lidar to reach full autonomy (i.e., L4/5). However, we expect relatively moderate lidar adoption in the automotive industry in the near term as we expect that most OEMs will be deploying primarily L2/L2+ solutions in the next few years without lidar. Longer term, there could be margin headwinds for lidar industry participants given that: **1)** ADAS systems do not necessarily require lidar. While Tesla has been in the minority among auto OEMs with its view that it can achieve full autonomy without lidar, most L2 and some L2+ designs do not use lidar, and Aptiv has even seen select customers develop L3 platforms without Lidar. **2)** There are well over 50 lidar companies per our industry discussions, in addition to companies with internal lidar efforts, which along with competition from camera/radar solutions will weigh on industry margins, in our view. **3)** While we believe several lidar companies have made considerable technical progress, there remains a causality dilemma between lowering sensor costs to levels that could support volume adoption, and lidar suppliers simultaneously needing high volumes to reach their cost objectives. The potential for lidar volumes to be relatively moderate in the next few years could limit cost reductions and, in turn, margins for the industry.

There are a handful of lidar companies that are technical leaders per our industry discussions (based on characteristics such as the range, resolution, and reflectivity performance of the sensors), and we consider both Velodyne and Innoviz to be in that group. However, we expect that our margin concerns about the lidar industry broadly will apply to these two companies as well. We believe that investors should look to the ability to ramp into volume production with scalable solutions, gain traction in software, and progress with customers (including with automotive grade qualifications) as ways to gauge which companies in the lidar industry may have the most long-term commercial success.

We expect full autonomous driving solutions (e.g., L4/5) to come to market, despite the delays that the industry has faced to date, as there are a significant number of companies looking to solve this issue given the material human and business opportunity (potentially $7 trillion USD for moving people and items autonomously per GM). For the purposes of this report, we built the ADAS TAM through 2025 using what we consider to be a bottom-up aggregation of projections from leading automotive integrators/tier-1s. These companies are consistently expecting the most near-term growth in L2-L2+ type systems. However, there are already trials in select cities underway for L4 vehicles/robotaxis and there could be additional targeted deployments in the coming few years. Furthermore, definitions between L2+ and L3/L4 could blur if mainstream vehicles can meet L4 capability from a technology perspective, but the risk still lies with the driver, or if vehicles are L4 but only for drivers in a narrow set of geographic locations. Lastly, with the auto industry shifting to use over-the-air (OTA) updates, we note that it is possible to deploy higher degrees of autonomy to an installed base of vehicles relatively fast once the technical and/or legal milestones are met.

We initiate coverage of Velodyne Lidar (ticker VLDR) with a Neutral rating and a

12-month price target of $13, and we initiate coverage of Innoviz Technologies (ticker INVZ) with a Neutral rating and a 12-month price target of $11.

Velodyne Lidar is an early mover in lidar with a broad product portfolio. Velodyne has shipped over 50k lidar units since its inception to automotive OEMs, Tier 1 suppliers, and autonomy players (e.g., GM, Ford, Toyota, VW, Aptiv, Argo, Zoox, and Uber) as well as to customers in last-mile delivery, precision agriculture, industrial robotics, advanced security, and smart city initiatives. Velodyne has manufacturing partnerships with Fabrinet, Nikon, and Veoneer, and the company estimates that its project pipeline could yield a total of 9 mn units shipped across diverse end markets by 2025 (roughly half outside of auto). Velodyne has historically had relatively high-cost rotational lidar solutions, and its 2020 ASP was about $5K per unit, but the company has also developed lower cost solid-state products targeting the ADAS market (including the Velarray with a $500 target ASP and the Velabit with a $100 target ASP). The company also has reduced its bill of materials with the use of custom ASICs and its micro-lidar arrays. Velodyne shipped over 700 Velarray units in 4Q20. Velodyne also generates license revenue.

Innoviz Technologies is a solid-state lidar supplier that is targeting various end market applications, including consumer vehicles, shuttles, robotaxis, trucking, logistics, drones, and heavy machinery. Innoviz's offerings include the InnovizOne (an automotive-grade MEMS lidar sensor) and perception software. Innoviz has commercial agreements, including with BMW and Magna (its partner for the BMW program) as well as relationships with Aptiv, Harman, and Hirain. Innoviz expects to be shipping to BMW starting in 2022 as part of an L3 add-on option for BMW's iX, and this could then scale to other models (such as the 7 Series and 5 series). The company estimates its order book from BMW will generate $2 bn in revenue by the end of the decade. Innoviz expects its InnovizOne to reach a roughly $1K price point, followed by a roughly $500 price point for its next-generation InnovizTwo. Innoviz products can achieve up to 250 meters of range, per the company.

The Road Ahead in Numbers

NOW

~5%

2025

25%

By 2025, we think **25% of light duty vehicles will have L2 or L2+ ADAS technology**, meaning they can handle complex tasks like lane changes but with a driver at the ready to take over.

NOW

$15bn

2025

$60bn

To support increased adoption of ADAS features in vehicles, we estimate **the total addressable market for camera, radar, and LiDAR systems** will grow at a 40%+ CAGR to ~$60+ bn in 2025. We also see a $15bn+ software opportunity by 2025.

NOW

$1bn

2025

$6bn

The **market for LiDAR sensors** could grow at a 60% CAGR through 2025 driven by ADAS as well as other end markets (e.g. last mile delivery, industrial, mapping).

NOW

~$2k

2025

$400

We expect **typical prices for LiDAR** to decline significantly by 2025, driven by cost reductions with the technology and competition.

Source: Company data, Goldman Sachs Global Investment Research.

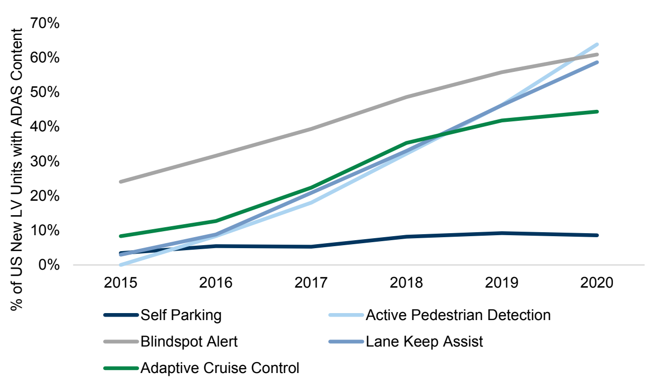
Robust ADAS growth to drive expanding TAM for sensors

Key drivers and obstacles to ADAS/AV adoption

We believe that there are significant societal benefits from ADAS and autonomous vehicles (AVs) technology, and potentially a $7 trillion USD business opportunity. For example, about 40k people die in traffic fatalities in the US annually per NHTSA and over 1 million people die each year globally in accidents, per the WHO. ADAS and AV technology has the potential to meaningfully reduce road injuries and deaths, and we believe there is increasing regulatory momentum, particularly in Europe, to require ADAS features in new vehicles. Active safety measures (e.g., L1 and above) are critical for further progress in curbing roadway deaths, especially with the increased prevalence of distracted driving.

In addition, the average American spends over 50 minutes per day commuting, per the US Census Bureau. Higher levels of autonomy can not only ensure a safer commute but return time to drivers who can focus on productivity and leisure instead. As a result, we believe there will be strong consumer and societal demand for autonomous technology, and as we show in Exhibit 4, attach rates for ADAS features are already increasing. Furthermore, we believe OEMs, suppliers, and other non-automotive players (e.g., large tech companies) are motivated to overcome the technological barriers to higher levels of autonomy given the significant economic opportunity (e.g., the TAM for moving people autonomously could be $5 trn USD and moving items autonomously could be $2 trn per GM).

Exhibit 4: ADAS features per vehicle are rising steadily
ADAS features as a percent of total US new vehicles



Source: Wards, Goldman Sachs Global Investment Research

Levels of autonomy explained

We define the different levels of autonomy, per the Society of Automotive Engineers (SAE) in Exhibit 5. Industry participants also refer to additional levels such as L2+ (which is a vehicle that is able to perform more complex tasks and may be technically capable of L3, but the driver still needs to be alert, and the driver is still responsible for an accident).

Exhibit 5: Levels of autonomy

LEVELS OF DRIVING AUTOMATION

	L0	L1	L2	L2+	L3	L4	L5
Degree of autonomy	**NO AUTOMATION** Manual control. The human performs all driving tasks (e.g. steering, braking, acceleration, etc.)	**DRIVER ASSISTANCE** The vehicle features a single automated system (e.g. monitors speed through cruise control)	**PARTIAL AUTOMATION** The vehicle can perform steering and acceleration. The driver still monitors all tasks and can take control at any time	**PARTIAL AUTOMATION** Vehicle can perform steering and acceleration, with quasi auto-pilot, but driver always alert/ responsible and hands near wheel	**CONDITIONAL AUTOMATION** Vehicle performs most driving tasks, but human override still required. OEM liable aside from when driver warned to take over (subject to grace period)	**HIGH AUTOMATION** The vehicle performs all driving tasks under specific circumstances. Human override is still an option.	**FULL AUTOMATION** The vehicle performs all driving tasks under all conditions. Zero human attention or intervention is required.
Example of features	• No automation	• Automatic emergency breaking • Lane centering OR Adaptive cruise control	• Lane centering AND Adaptive cruise control (at the same time)	• Lane centering AND Adaptive cruise control (at the same time) • Quasi auto-pilot with enhanced safety features	• Traffic jam chauffeur	• Local driverless taxi	• Can drive everywhere in all conditions • Pedal/steering wheel may not be installed
Need for human intervention		Driver monitors the environment, even when automation features are on			Driver takes control when system requests	Driver not required to take over control	
		System supports the driver			System operates when specific conditions are met		System operates in all conditions
		Steering OR speed are automated	Steering AND speed are automated				
	HUMAN MONITORS DRIVING ENVIRONMENT				AUTOMATED SYSTEM MONITORS DRIVING ENVIRONMENT		

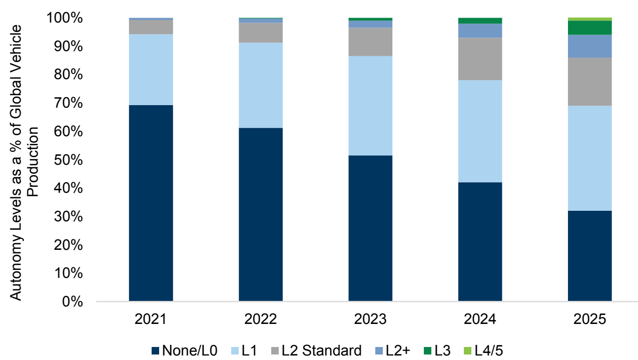
Source: SAE, NHTSA, Company data, Goldman Sachs Global Investment Research

We note that there is not a consensus about what sensor configuration will be necessary at each level. While most companies are planning to use a range of sensors (e.g., camera, radar, and lidar) at higher levels of automation, Tesla is seeking to reach full autonomy without lidar (and Tesla has recently commented that the company could also limit its use of radar sensors). In addition, the number of sensors required at each level of autonomy varies by vehicle type (e.g., a heavy-duty truck would require more lidar sensors than a passenger vehicle). Lastly, some companies plan to rely on mapping, and others believe this is a less scalable approach.

We expect robust growth in ADAS, and L2/L2+ attach rates could reach 25% by 2025

In exhibit Exhibit 6, we show potential ADAS/AV adoption through 2025, which is based on the estimates of leading automotive tier 1 suppliers (such as Magna, Veoneer, and Valeo). Aggregating the projections of these companies, we expect L2/L2+ adoption to grow steadily from about 5% today to 25% in 2025. The auto tier 1 suppliers expect L3-5 to be a relatively small part of the industry mix through 2025, although some L3/L4 deployments are scheduled to occur sooner, and OTA updates have the potential to allow for a quicker roll-out of more advanced features.

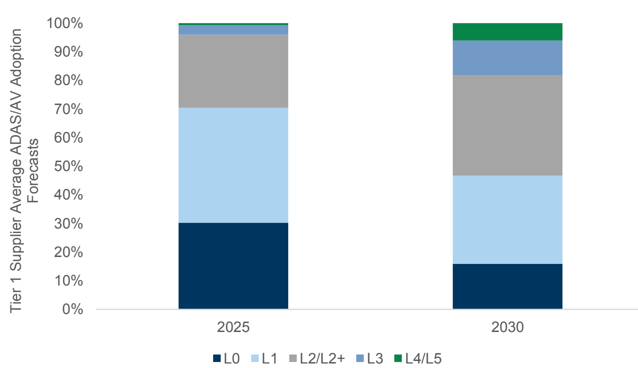
Exhibit 6: L2 (inc L2+) ADAS could reach 25% adoption by 2025 per the auto industry
Autonomy levels as a percent of global vehicle production CY21E-CY25E



Source: Company data, Goldman Sachs Global Investment Research

Magna, Valeo, and Veoneer are expecting L4/5 adoption to be relatively low even by 2030 (Exhibit 7), and we appreciate that this technology has faced delays broadly that could continue, although we believe that L4/5 adoption could potentially be higher than this by 2030, and we therefore discuss the 2030 market opportunity for sensors using scenario analysis.

Exhibit 7: Key auto Tier 1s on average expect L2/L2+ adoption will grow from ~25% in 2025 to ~35% in 2030
Average of ADAS/AV adoption forecasts from Magna, Valeo, Veoneer



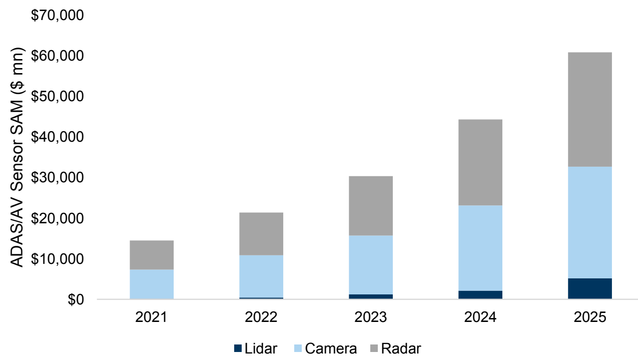
Source: Company data, Goldman Sachs Global Investment Research

ADAS/AV adoption curve implies 2030 TAM could exceed $50+ bn for automotive lidar and $160 bn for total auto tech sensors

Regardless of the L2/L3/L4/L5 mix the automotive industry achieves, we believe there is a robust business opportunity for auto tech sensors — including cameras, radar, and lidar — over the next five to ten years. We based our TAM analysis for auto tech sensors on our AV/ADAS adoption expectations outlined above, and what we believe are representative sensor configurations and pricing.

We estimate the total TAM for cameras, radar, and lidar hardware in ADAS/AV passenger and commercial vehicles could grow at a 40%+ CAGR from about $15 bn in 2021 to over $60 bn in 2025 (Exhibit 8).

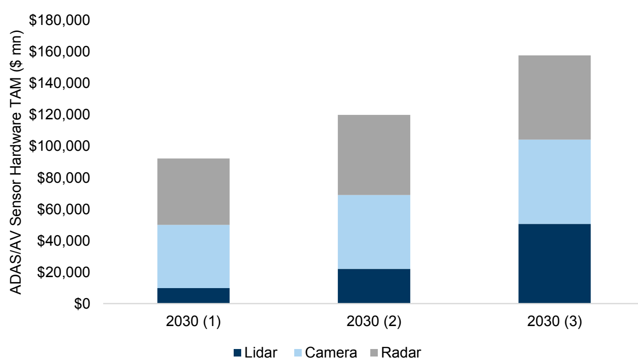
Exhibit 8: We forecast the TAM for the ADAS sensor suite could exceed $60 bn in 2025, growing at a 40+% CAGR



Source: Company data, Goldman Sachs Global Investment Research

In 2030 — depending on global auto production, sensor attach rates, and the L2 through L5 mix — we believe the total TAM could reach between about $90 bn and $160 bn across cameras, radar, and lidar.

Exhibit 9: Our sensitivity analysis suggests a TAM between ~$90 bn and ~$160 bn for ADAS/AV sensors in 2030



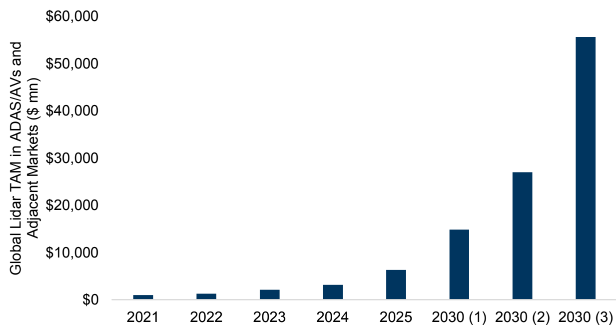
Source: Company data, Goldman Sachs Global Investment Research

Cameras and radar: Specifically, we estimate the TAM for cameras and radar in ADAS/AV applications could reach about $28+ bn each in 2025, and reach between $40 bn and $55 bn each in 2030. We assume that content per passenger vehicle ranges from about 1 radar and 1 camera at L1 to about 7 radars and 8 cameras at L4/L5. We consider these configurations to be representative of a typical vehicle, but we believe plans vary by OEM.

Lidar: We expect meaningful lidar adoption in the auto industry, especially beyond 2025 as the industry shifts toward higher levels of autonomy, at which point most OEMs consider lidar to be a key part of the sensor suite. We estimate the lidar TAM, inclusive of adjacent non-automotive markets such as industrial robotics and drones, could grow from about $1 bn in 2021 to about $6 bn by 2025 (a roughly 60% CAGR). In 2030, we see scenarios where the lidar market could range from roughly $15 bn to ~$55 bn. Our

2030 scenario analysis uses a range of assumptions about global vehicle production volumes (85 mn to 115 mn, or about +/- 15 mn from a baseline view of about 100 mn), L4/5 adoption (from 5% to 20%), and lidar sensors per vehicle (between 3 and 6 lidar sensors per car on average at L4/5, based on company commentary and our industry discussions; Exhibit 10).

Exhibit 10: We estimate the global lidar TAM is about $1 bn in 2021 and could reach $15 bn and potentially ~$55 bn by 2030
Lidar hardware opportunity in ADAS/AV and adjacent markets



Source: Goldman Sachs Global Investment Research

We believe the opportunity for lidar companies is significant even under our more conservative L4/L5 adoption scenarios. However, with well over 50 companies addressing the space, lidar players could face steep competition.

We believe the software TAM for ADAS/AV applications could be $15 bn+ in 2025 and potentially well over $100 bn by 2030

Several lidar companies plan to develop their own software to complement their hardware, and this ranges from helping interpret/better utilize lidar to full path planning and sensor fusion.

While autonomous driving software is an attractive opportunity (given the magnitude and complexity of the autonomous driving problem), the automotive software market is competitive with companies across the auto and tech industries looking to address this segment. We expect some larger OEMs to address software needs in-house (e.g., Tesla, GM, and VW have funneled significant R&D into software), but other OEMs may choose to use partnerships/auto tier 1 suppliers, including lidar companies.

We believe that the software opportunity could be several hundred dollars per vehicle for lower levels of automation (based on targets from the lidar companies and our conversations with tier 1 suppliers), and full autonomous software content per vehicle (CPV) could be several thousand dollars (e.g., Tesla sells its full self driving software, which is currently an L2/L2+ solution, for $10,000 USD as a license that would entitle the vehicle to receive future improvements that Tesla expects to deliver, including full autonomy). Importantly, several OEMs are seeking to develop full autonomy software on their own, and the CPV is debated by investors. Tesla points out that the utility of full autonomy would be several multiples higher than what it currently charges, and that the price could rise in the future. However, others argue that the technology will get to a point where the pace of innovation slows and there will be multiple providers, leading to lower CPVs (or that L4/5 autonomy is still many years away and/or likely to be limited in reach). These debates could take several years to resolve. We estimate though that the software addressable market could be $15 bn+ in 2025 and $100 bn plus (and potentially several multiples higher than this) in 2030.

Most lidar companies are focusing more on software for interpreting and utilizing lidar such as object detection, rather than on doing full sensor fusion or path planning. Innoviz has developed lidar-based perception software, which it expects will make up about 7% of its 2025 revenue. Velodyne is also developing proprietary perception software, Vella, with a focus on ADAS applications, and the company forecasts that over 20% of 2024 revenue will come from software. Velodyne has commented that it is focused on software for lower levels of autonomy, where it believes it can add more value, as the L4/L5 players (e.g., robotaxi companies) have already developed sophisticated software stacks.

Other ADAS features - driver monitoring, and voice control

We believe there are opportunities in ADAS beyond the sensor suite and software opportunities discussed above, such as driver monitoring and voice control/recognition.

Aptiv anticipates higher attach rates and enhanced use of driver monitoring technology to ensure drivers are alert if required for an L2 type of system, or to guard against drowsy driving. Aptiv's solution — which entered into production in 2018 — tracks behaviors such as driver fatigue, drowsiness, and distraction. **Magna** plans to launch its new driver monitoring system product in 2022 (per the company's 2021 analyst day). Magna's solution will be embedded into the interior mirror and will monitor — in addition to driver fatigue, drowsiness, and distraction — factors such as child presence, seat belt usage, and passenger identification to enable user preference (per Magna).

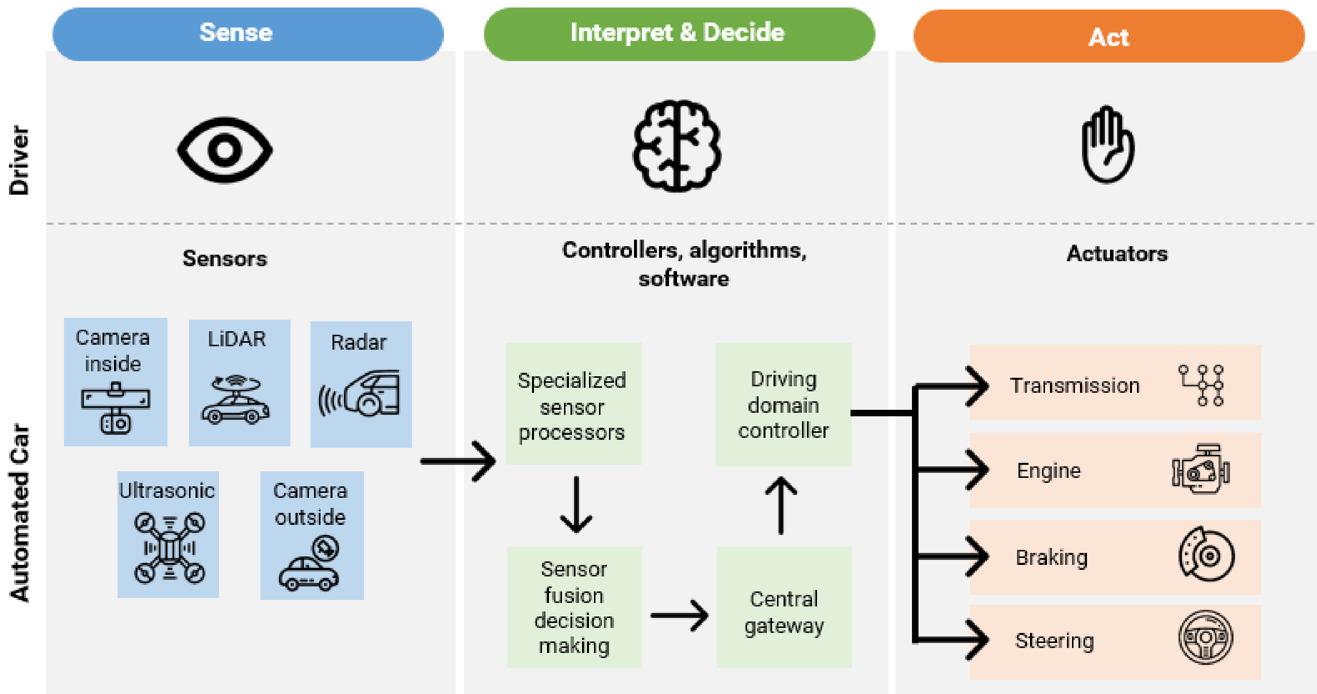
In voice control, we believe **Cerence** (CRNC; Buy) is a technology and market leader in natural language understanding voice technology for automotive applications (e.g., >50% of new vehicles sales have Cerence technology). Various research has shown voice assistants to be considerably safer than using a center console to complete tasks while driving. For example, eye gaze behavior while completing touch tasks on CarPlay and Android Auto do not meet NHTSA safety guidelines, whereas using voice controls meet these guidelines. We anticipate attach rates for AI voice technology to increase over time. See our 11/18/20 report for additional detail and analysis.

Finally, we believe that increased attach rates of ADAS/autonomous features, such as driver monitoring and voice control, will increase the in-vehicle computational load, which could lead to additional content opportunities for products such as Aptiv's Integrated Cockpit Controller.

Sensing systems overview

There are a variety of sensing systems that help to enable autonomous driving by gathering information about the environment surrounding the vehicle. These systems work together to feed different information to a software-defined compute platform in order to guide the vehicle along a planned path (Exhibit 11). The four primary types of sensors include: camera, radar, ultrasonic, and lidar.

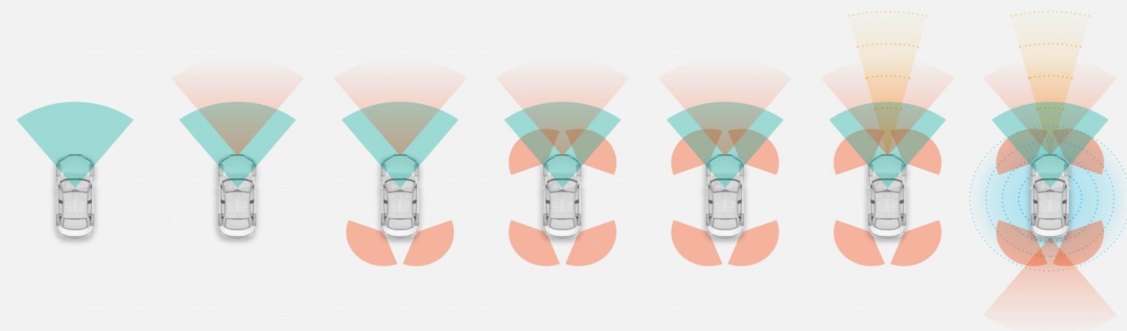
Exhibit 11: Sensors deliver information to drive the vehiclee



Source: Goldman Sachs Global Investment Research; Infineon

Each sensor type has its own advantages and limitations, and we provide an overview of each technology in this section. Importantly, we note there is no clear consensus around sensor configurations, and most automotive OEMs and suppliers believe that to achieve higher levels of autonomy, the vehicle will need to include a combination of different sensors, known as the **sensor suite**. We show an example of potential sensor placement at different levels of autonomy in Exhibit 12.

Exhibit 12: Automotive companies generally support the need for multiple sensor systems to meet different objectives
Sensor sample configurations per level



AUTOMATION LEVEL:	L0/L1	L1	L2	L2	L2+	L3 Traffic Jam	L3 Cruising/L4 Parking
NCAP:	1-3 Stars	1-4 Stars	4 Stars	4/5 Stars	4/5 Stars	5 Stars	5 Stars
SENSORS:	**Front Camera**	Front Camera **Front Radar**	Front Camera Front Radar **Rear Corner Radars (2)**	Front Camera Front Radar Rear Corner Radars (2) **Front Corner Radars (2)**	Front Camera Front Radar Rear Corner Radars (2) Front Corner Radars (2) **Mid Controller**	Front Camera Front Radar Rear Corner Radars (2) Front Corner Radars (2) **Lidar** **High Controller**	Front Camera Front Radar Rear Corner Radars (2) Front Corner Radars (2) Lidar High Controller **Rear Radar** **Camera Belt (7)**

Source: Aptiv

- **Cameras –** Cameras are one of the main sensors used in ADAS and AVs as they are less expensive on a relative basis than lidar, and operate well for high-resolution tasks such as object classification or functions that require color perception (e.g., interpreting traffic lights, driving lane lines, or street signs). However, cameras can encounter issues when operating in non-optimal lighting or weather conditions and in conveying three-dimensional data (as camera output is fundamentally 2D).That said, advancements in camera technology, such as **stereo vision systems**, use two adjacent lenses to detect objects with the added ability to calculate the distance to/between objects, which is ideally suited for ADAS/AV applications.
- **Radar –** Radar (radio detection and ranging) operates by emitting electromagnetic/radio waves into the surrounding area, and the waves are reflected back to the sensor. In general, radar is characterized as relatively inexpensive, operates well in non-optimal weather conditions, can help observe past obstructions, and is long-range capable (up to 300+ meters). However, radar generally lacks the detail/resolution needed for object classification. Advancements in semi chip and signal processing technology have enabled both **4G imaging radar** and also **digital radar** (which use digital code modulation and have improved range and resolution).
- **Ultrasonic –** Sonar (sound navigation and ranging) is used to detect surrounding objects by sending out sound (ultrasonic wave) impulses and processing the returning echo. Ultrasonic sensors are beneficial as they are relatively inexpensive and operate well in poor weather and lighting conditions. However, ultrasonic sensors have relatively low resolution, limited range (generally less than 10 meters), and cannot detect color. As a result, ultrasound is most commonly used for blind spot detection, parking assist, and other short range applications.
- **Lidar –** Lidar (light detection and ranging) emits laser pulses and measures the

reflection of these pulses from surrounding objects. Lidar collects millions of these measurements to create a **point cloud** and a high-resolution **3D map** of the area, which reflects the position of surrounding objects. The key advantages of lidar include its ability to detect long range objects and perform object classification, and lidar can operate better in certain light conditions than cameras. However, high system cost, limitations on what can be perceived (e.g. reading a sign), and durability of the systems have been some historical drawbacks of lidar. There are several methods of steering, receiving, and measuring the light, which we discuss later in this report.

- **High-definition mapping** - While not a sensor, high-definition mapping can also support autonomous driving capabilities. AVs that rely on maps meld the live data from sensors with an established understanding of particular roads/areas of operation. Industry views vary on whether maps are necessary for higher levels of autonomy. Some companies, such as Mobileye, are leveraging their installed base of camera-equipped vehicles to create high-definition maps that they expect will ultimately enable L3, L4, and L5 autonomy within the pre-mapped regions. Other players, such as Tesla, are not focused on AV map making and instead plan to use live vision technology to support autonomy in regions regardless of whether they have been previously driven/mapped.

Sensor fusion: silicon and software

Sensor fusion is the process of merging data from multiple sensors to achieve an outcome greater than each sensor individually.

AV/ADAS systems leverage **silicon and software** to merge the data inputs from the sensor suite and inform the vehicle's decision-making/movement. Perception and planning software is generally embedded in logic chips and supported by computer vision algorithms and machine learning. These systems require extensive data collection and training, particularly to address **edge cases**, such as deciding which vehicle has right of way when two arrive at an intersection simultaneously or knowing the difference between a heavy object that should be avoided and a lighter object, like a plastic bag, that would not require the vehicle to stop. As the system collects more real-world driving data, its responses improve. For this reason, total autonomous miles driven is an important metric for perception/planning software solutions, and we believe players with large fleets and/or with solutions installed across fleets would likely have an advantage. **Below we highlight some examples of sensor fusion platforms for autonomous driving:**

- **Mobileye (an Intel company) EyeQ** is a leader in vision chips/software for ADAS, and the company is developing capabilities that include sensor fusion with radar and lidar inputs. The EyeQ platform features a complete software development kit (SDK) to enable OEMs/Tier 1s/robotaxi companies to differentiate their solutions by deploying their own algorithms on the open platform. The SDK can also be used to train neural networks or access Mobileye's pre-trained networks. The company is developing an FMCW lidar sensor and a corresponding lidar SoC in-house (targeting deployment in 2025, per Intel). Finally, Mobileye is focused on AV map-making (called Road Experience Management, or REM), and has been using its installed base of vehicles to collect a high volume of real world driving data. These maps help Mobileye build out its planning software and can enable L2++ (Hypervision), a camera-based system supported by maps that is capable of highly autonomous features but lacks the redundancy of a lidar/radar sub-system and is therefore categorized as L2++ by the company. Mobileye is planning to use radar and lidar for redundancy with vision in order to implement L4/5.

- **Nvidia's DRIVE** platform is an L2+ solution, powered by Nvidia SoCs. The platform also includes a sensor suite (Nvidia Hyperion; including up to 8 cameras and up to 8 radars). In addition, lidar sensors can be integrated into the platform to enable higher levels of autonomy, and Velodyne and Innoviz are both compatible with Nvidia DRIVE. Nvidia offers a software stack for perception, localization, mapping, planning and control, that can enable partners to develop a complete platform (e.g., Baidu and Aurora have worked with Nvidia DRIVE as well as auto OEMs with their own software capabilities). DRIVE also includes a simulation platform (Nvidia Constellation) to test and validate AV algorithms and a training platform to train neural networks for AV perception and planning. The DRIVE platform can allow for improvements over time with OTA updates. Nvidia has partnered with several OEMs, including with Daimler on software (see the note from our GS European Autos analyst George Galliers 6/24/20 for details).
- **Tesla Full Self-Driving (FSD)** - Tesla switched to a proprietary chip in 2019 for its autonomous technology, and the company is developing its own software. Tesla vehicles are equipped with Tesla FSD chips (two, for redundancy) and can be upgraded over-the-air (OTA) to achieve higher levels of autonomy, as they become available. Tesla's fleet is able to operate in "shadow mode" (where the driver controls the vehicle, but the FSD system registers what action it would have taken in different scenarios, and Tesla is able to collect this data to refine its software). Tesla vehicles had driven over 3 bn miles in Autopilot as of April 2020, and the company's ability to collect data across its fleet (with well over 1 mn vehicles on the road today) is a competitive advantage in our view. While Tesla had been targeting to have 1 mn robo-taxis on the road and has historically said it is close to full autonomy, it has not yet met this objective. Importantly, Tesla's system does not use lidar sensors, which the company has described as expensive and unnecessary (and the company has commented recently that radar may be unnecessary at least for some applications, too).
- **Proprietary hardware/software solutions from mobility services companies**: Several autonomous/mobility services companies are working to commercialize self-driving "robo-taxi" fleets. Many have emerged from, or partnered with, big tech companies and/or automotive OEMs. For example, Waymo started as Google's self-driving car project, Zoox was acquired by Amazon, Apollo is owned by Baidu, Ford and VW are partial owners of Argo, and Motional is a JV between Aptiv and Hyundai. Some of these companies are developing not only their own software stacks but also have internally designed lidar sensors.

Examples of ADAS technology in the market presently

Passenger vehicles: L1/L2/L2+ systems are already available

There are already commercially available L1/L2/L2+ solutions on the market. Examples of ADAS technology include:

- **GM Super Cruise** is a driver-assist system that allows drivers to remove their hands from the steering wheel during extended periods of driving on certain highways. Super Cruise uses a combination of mapping, cameras, and radar to automatically steer and brake during highway driving. GM first launched Super Cruise in 2017 on the Cadillac CT6, and plans to include Super Cruise on 22 GM products by 2023. In addition, the company is working on an expansion of Super Cruise, which would offer hands-off driver assist technology for city driving. We view GM Super Cruise's technology as among the leading products on the market (and it has been well reviewed by Consumer Reports).
- **Tesla's Full Self Driving (FSD)** - Tesla's FSD system features navigation on autopilot, auto lane change, auto-park, smart summon, and traffic/stop sign control. All features currently require driver attention, and the system is categorized as "hands-on," though the company has a goal of updating this technology to L4/5. FSD is available as an optional $10,000 package, though a monthly subscription model is coming in 2021, per the company. The system is currently supported by external cameras, ultrasonic sensors, radar, and proprietary logic/software, but in April 2020 the company spoke to potentially reducing its use of radar and focusing on camera inputs.
- **Ford Co-Pilot 360** is an ADAS system first released on the 2019 Ford Edge, and features include pedestrian detection, automatic emergency braking, blind spot warning, lane keeping, and reverse cameras. The company is building towards lower levels of highway autonomy with its Active Drive Assist technology that also provides adaptive cruise control, park assist, and stop-and-go capabilities. In April 2021, Ford announced BlueCruise, which allows for hands-free driving on select highways and will be available later in 2021 as an OTA update for the new F-150 and Mustang Mach-E that are equipped with the Co-Pilot 360 Active 2.0 Prep Package. It will cost $600 for a three-year subscription per Automotive News.
- **Nissan ProPilot Assist** program is a hands-on driver assist system that offers adaptive cruise control and steering assist technologies, and the company plants to debut the ProPilot 2.0 software — with hands-off single lane driving and hands-on guided lane changing — on the Nissan Ariya SUV in 2021.
- On April 9, **Toyota** announced that two models (the Lexus LS and Mirai) would include a driver assist function for highways. On a standalone basis, the technology costs about $5,000 USD. See GS analyst Kota Yuzawa's 4/9/21 note for additional details.
- **Honda's Traffic Jam Pilot** offers level 3 autonomy under select conditions. Specifically, in highway situations, the vehicle is capable of lane changing and speed control without driver attention. This technology is currently included on the Honda

Legend Sedan, but is not yet available in the US.

- **Daimler (Drive Pilot)** builds on its current ADAS features (such as blind spot assist, steering assist, active lane keeping, and forward/rear collision warning) to achieve L3 autonomy under certain conditions. The company is targeting series production in 2H21 with the Mercedes S-Class, and is leveraging Nvidia's platform and has also worked with Tier 1s such as Bosch, Continental, and Veoneer.
- **BMW (Personal CoPilot)** offers L1 and L2 ADAS features such as forward-collision warning, low-speed automatic emergency braking, lane-departure warning, blind-spot warning, and rear cross-traffic warning. Its ADAS Pro version includes adaptive cruise control, stop-and-go capability, and the ability to steer at speeds below 40 mph. BMW works with Mobileye and plans to offer L3 capabilities by leveraging Magna and Innoviz.
- **VW** currently offers ADAS features such as forward collision warning, blind spot monitoring, rear traffic alert, lane assist, park assist, and adaptive cruise control. VW is leveraging Microsoft and Mobileye in addition to its in-house software efforts through Car.Software. VW is targeting L4 autonomous vans with Argo by 2025.
- **Li Auto** is leveraging Nvidia DRIVE to bring ADAS/AV features to its vehicles and plans to use lidar to deliver L4 capabilities for its next model launch in 2022.
- In addition, we note that certain tier-1 suppliers such as **Continental**, **Bosch**, **Valeo**, and **Magna** (in combination with **Fisker**) are working to commercialize advanced driver assist platforms and/or develop highway autonomy. We also note that Volvo, Rivian, and Lucid Motors have announced that they are developing L2+/L3 driving systems for upcoming models.

Commercial vehicles: unique business opportunity at higher levels of autonomy

We note significant potential for autonomy in the commercial vehicle segment, for several reasons. Fleet owners are highly focused on the total cost of ownership (TCO) and will gravitate toward the potential economic benefits from autonomous driving, which include (1) **more vehicle up-time and revenue** (if the human driver is responsible for overseeing the vehicle rather than operating it, the system would return time to drivers and enable them to be productive in other ways; the vehicle could likely travel further without stopping, as the mandatory resting breaks for long-haul drivers could be reconsidered for autonomous settings; finally, it is possible the human backup driver is removed completely in the future, which could generate wage savings for fleets), and (2) **potential insurance savings** from a safer vehicle.

Given fleets' focus on TCO, we believe adoption of autonomous technology could be more rapid in the commercial vehicle segment than in passenger vehicles. That said, there also could be more stringent safety standards for autonomous commercial vehicles, given their generally larger size (and higher likelihood of endangering other drivers).

Velodyne is collaborating with Beijing's Trunk Tech on autonomous heavy-duty trucks. IVECO has signed an MOU with Plus, a global autonomous trucking company with a full-stack solution for class 8 vehicles, featuring Ouster lidar. Lidar maker Aeva is targeting the trucking industry and has announced a plan to deploy its lidar on TuSimple's self-driving trucks. In addition, OEMs, such as Ford and GM, are bringing ADAS capabilities to their forthcoming electric commercial vehicles (the Ford E-Transit will have Co-Pilot 360, and GM's BrightDrop EV600 is outfitted with ADAS features). Tesla plans to offer FSD, eventually at L4/5, on its Class 8 Semi truck (recall that first units are expected to ship toward the end of this year).

Lidar deep dive: key components, classifications, and specifications

Lidar (also termed LiDAR; stands for light detection and ranging) is a sensor type that emits light and uses the return data in order to identify objects in the field of view. While autonomous driving has been one key focus area for the lidar industry, the technology has several other potential use cases, including for industrial robotics, logistics, drones, mining, security systems, medical devices, consumer devices (e.g., in the Apple iPhone), and smart cities (e.g., traffic systems, energy/grid management, and intelligent infrastructure).

We believe, per commentary from automotive OEMs, Tier 1s, and robotaxi companies, that lidar sensors could help to enable higher levels of autonomy (e.g., L3 through L5). Lidar solutions can help to augment other sensor types and provide redundancy. In addition, lidar can potentially add value at lower levels of autonomy (e.g., L2/L2+). While lidar can potentially be used in L2 applications, we believe that most OEMs prefer the less expensive radar/camera-based systems for lower levels of autonomy.

Key lidar components in an autonomous driving system

A lidar sensor typically consists of a laser source, laser detector, scanning system, and a logic chip that all work together to form a point cloud (Exhibit 13).

Exhibit 13: Sample of a lidar point cloud

Source: Velodyne

- **Laser source –** the laser source generates and emits light pulses, which are then reflected back from objects in the environment. The number of lasers can vary from 1 to over 100, depending on the product (and in turn have very different cost/performance criteria).
- **Laser detector or receiver –** the laser detector (or receiver) detects the light pulses that are reflected back.
- **Scanner – t**he scanning mechanism (which can be solid-state/MEMS or rotating) controls the speed and trajectory of the pulses emitted from the laser source (beam steering).
- **Logic silicon –** provides the intelligence to operate the components and interpret signals to form the point cloud. While many early lidars used programmable chips (FPGAs), which can be expensive, several companies, including Innoviz and Velodyne, are now adopting specific chips (ASICs or SoCs) that can reduce cost.
- Some companies are seeking to integrate multiple functions on a single chip, which is sometimes referred to as **lidar-on-a-chip.**

Different types of lidar systems

There are different methods of implementing lidar, and some common approaches include:

A) How signals are measured:

- **ToF** (time of flight) is the primary ranging method used today, which records the time interval between wave emission and wave return. Laser pulses are emitted from the lidar sensor one after another, reflected by objects in the environment, and recaptured by the receiver. The total elapsed time is used to calculate objects' distance and position.

- **FMCW** (frequency modulated continuous wave) is an alternative ranging method to ToF. FMCW lidar operates by continuously emitting waves of light at different frequencies (rather than sending discrete pulses at a fixed frequency). Under FMCW, the lidar can more easily measure velocity. However, FMCW technology has not been widely implemented in lidar, and key challenges to adoption include computing requirements and manufacturing yields, per our industry discussions.

B) How light is scanned:

- **Mechanical lidar** (also known as spinning lidar) uses a rotating laser and receiver assembly, which allows the system to collect data in an area of 360 degrees. Mechanical lidar systems have been popular in R&D efforts (e.g., in robo-taxi applications) and are still the most common type of lidar scanner in use today. However, the price and durability of a moving system (including vulnerability to shocks) are potential challenges for mechanical/rotating lidar.
- **Solid-state lidar** is built without motorized mechanical scanning. Solid-state lidar can be integrated more seamlessly into cars (as opposed to mechanical lidar, which typically sits on top of the roof). These systems are generally less vulnerable to shocks, more compact, and have potential to be less expensive than mechanical lidar. However, vehicles would require multiple solid-state sensors to capture a full 360 degree field of view (FOV). Solid-state lidar has various implementation methods:
  - **Flash lidar** operates similarly to a camera in that it uses a single, large laser pulse to illuminate the environment. An array of light sensors captures the distance and location of the surroundings.
  - **Optical phase array (OPA) lidar** splits the laser power into an array that can be individually steered in different directions. To separate and control the lasers, OPA lidar uses phase modulators.
  - **Micro-electro-mechanical systems (MEMS)** use mirrors to steer the laser beams and may be considered solid state or quasi solid state.

Key lidar specifications

There are several different metrics used to compare lidar system performance:

- **Detection range** refers to the farthest distance at which the lidar system can detect an object. The range of lidar is dependent on the power of the laser source (higher power has greater range), and the type of laser. Range is typically measured in meters. Leading solutions can reach 250+ meters.
- **Resolution** refers to the quality (detail, clarity, ability to detect small/dark objects) of the environmental data points that the lidar system can collect. Resolution is often measured in points per square degree.
- The lidar's ability to detect dark objects with low **reflectivity** (e.g., rubber tires), which are generally more difficult for systems to register, is an important aspect of

resolution.

- **Frame rate** refers to how quickly the system can detect objects in the environment and is generally measured as the time interval (in microseconds) between two laser emissions at the same point or set of points.
- **Field-of-View (FoV)** refers to area over which the lidar system can scan. Mechanical (i.e., spinning) lidar systems have 360-degree FoV, whereas solid-state lidar tends to have a FoV of 120 degrees or lower. FoV can also refer to a lidar system's vertical vision capabilities.
- **Weather performance -** snow, fog, rain, and unusual lighting conditions can impair lidar's range and resolution. Sensor fusion (e.g., co-existence with radar and ultrasonic sensors) may be necessary in certain environmental settings.
- **Automotive-grade** is an important designation for lidar systems that are targeting the automotive end market. Automotive-grade means that the lidar system meets the OEM spec requirements and has been verified for use through OEM testing (and able to withstand weather/temperature/vibration).
- **Wavelength: 905 nm vs. 1550 nm** - The two most common laser wavelengths used in lidar systems are 905 nm and 1550 nm. The wavelength of the lidar impacts the performance, cost, and power consumption of the system. While there are more 905 nm components (e.g., diodes and lasers) available off the shelf, some companies have found solutions for 1550 that they believe are cost competitive. 1550 nm systems can potentially be superior on range and eye safety, but may have drawbacks in certain weather, and we note that 905 nm solutions are also tested for eye safety.

We believe that the lidar industry is in its early stages and OEMs are pursuing various implementations for lidar. While we believe that there are a handful of lidar companies that lead in technical criteria (such as range, resolution, and durability), we believe that key factors to gauge which companies may have more long-term commercial success include the ability to have scalable solutions (e.g., manufacturing and cost), the ability to sell software (helping to create customer stickiness), and customer traction (including achieving automotive grade).

Regulatory landscape

As autonomous driving is an emerging technology, the regulatory environment is still developing and varies by country and state. We show key regulations in Exhibit 14 and discuss additional considerations below.

Exhibit 14: ADAS/AV Regulatory Landscape

Global ADAS/AV Regulatory Landscape		
	ADAS	**AV**
US	No current mandate on ADAS features, but 20 automakers are working voluntarily with the National Highway Traffic Safety Administration (NHTSA) to bring **automatic emergency braking and forward collision warning to their new passenger vehicles by August 2023.** The Biden administration's **American Jobs Plan**, introduced on 3/31/21, includes a **$20 bn investment in improving road safety** and reducing crashes and fatalities. While the details are unclear, we believe this investment could support the development of more sophisticated ADAS and autonomous driving technologies.	Autonomous vehicle companies need **permits from state DMVs** to conduct testing in specific geo-fenced areas and must comply with mandatory reporting requirements (e.g., share how many disengagements per autonomous miles driven on an annual basis). States with more advanced autonomous testing programs (offering driverless testing permits) include California, Arizona, and Texas.
Europe	In November 2019, the European Union voted to adopt regulations proposed by the European Parliament and **NCAP** (Europe's car safety performance assessment program) to **mandate advanced safety systems in passenger vehicles by mid-2022**, including lane-keeping assistance, advanced emergency braking, and technology to monitor driver drowsiness and distraction.	Regulatory focus in AVs on **data privacy and cybersecurity**; Europe aims to create a common European mobility data space to advance AV development and promote safety.
China	China's government aims for **80% of vehicles to be L1-L3 by 2025**	In February 2020, the Chinese government released its **AV strategy**, which outlined an ambitious plan to create a framework for technical innovation, infrastructure, regulations and standards, and network security in the AV market by 2025, and to fully establish an AV ecosystem from 2035 to 2050.
Global	A UN rule on **Automated Lane Keeping Systems (ALKS; Regulation 157)** entered into force in January 2021 and is considered to be one of the first **global L3 regulations**. The regulation currently applies in 60+ countries (not the United States). Reg 157 includes performance-based requirements for vehicles to be marketed/sold as L3 systems in designated regions and also sets restrictions on where vehicles can safely operate without driver intervention (e.g., under maximum speeds below 60 km/h, and on roads without pedestrian/cyclist lanes, among other requirements). In addition, L3 vehicles must be equipped with technology to monitor the driver's behavior in the vehicle (e.g., gaze monitoring technology to ensure the driver is avaialable to take over as needed) and with data storage systems to record when ALKS is activated/deactivated, which can be used to monitor the system's performance over time.	

Source: NHTSA, UN, Company data, Goldman Sachs Global Investment Research

Sensory technology: Autonomous vehicle testing does not currently mandate specific sensor technologies in the US. The Department of Transportation has pledged to remain "technology-neutral" as it develops more concrete autonomous driving regulations. Lidar companies are subject to the FDA's Electronic Product Radiation Control Provisions, which govern the manufacture and distribution of laser-emitting products to protect the public from hazardous exposure to laser radiation. Lidar companies must certify in reports and product labeling that their products comply with FDA standards.

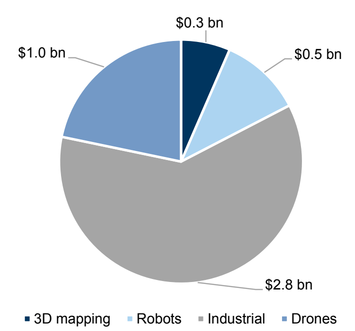
Cars without traditional features: NHTSA exemptions in the US are currently needed for concept vehicles without traditional car features, such as a pedals or a steering wheel.

Responsibility in case of an accident: If an accident were to occur involving autonomous driving technology, the responsibility depends on the degree of autonomy. For L2+ and below, the driver is responsible. At higher levels of autonomy (L3-L5) the responsibility could shift to the provider (which is one hurdle to higher levels of AV adoption and could be a factor why OEMs such as Tesla and GM are developing insurance offerings) and determining when the liability will be with the OEM or with one of the suppliers could be a part of negotiations when designing L3-L5 systems.

Other lidar markets - industrial, drones, mapping and robotics

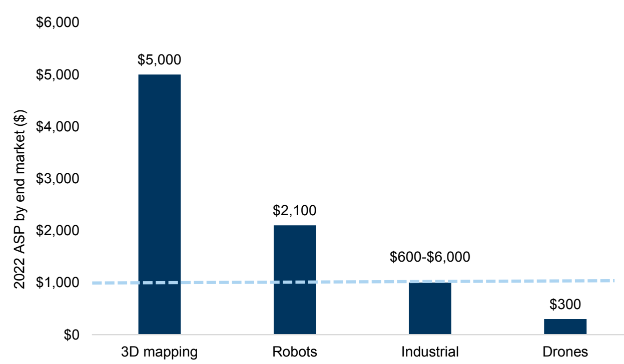
While ADAS and AV applications will be one of the key end markets for lidar in our view, we believe there is a material opportunity for lidar in non-automotive applications as well. Velodyne, which is more diversified across end markets than some of its lidar peers, estimates that non-automotive lidar market opportunity could be about $5 bn in 2022 (Exhibit 15), although we expect only a portion of this to be realized. Notably, these adjacent markets, which include **3D mapping**, **robotics**, **drones**, and **industrial** (e.g., off-road vehicles and construction equipment), carry different ASPs. For example, Velodyne estimates a weighted ASP across its products of ~$1,000 in CY22, and we note that drones fall generally below that threshold, while industrial, robotics, and 3D mapping may fall at or above it (Exhibit 16). ASPs in lidar can vary widely based on product type and performance. Similar to the automotive market, we would expect pricing to decline over time driven by cost reductions and competition.

Exhibit 15: Velodyne estimates ~40% of its 2022 market opportunity will come from non-automotive lidar applications, including industrial, robotics, mapping, and drones



Source: Velodyne

Exhibit 16: Velodyne estimates a wide range of ASPs by end market in 2022



Source: Company data

Valuation snapshot

We view valuation for VLDR and INVZ as reasonable but full (especially as our estimates are below the long-term company targets). The two stocks trade near the median of other lidar companies, at a premium to auto tier 1s, but at a discount to leading EV/auto tech companies that have a role in ADAS/AVs(Exhibit 17).

Exhibit 17: Valuation snapshot related to ADAS/AVs

		Valuation			
		EV/Sales		EV/EBITDA	
		2021	2022	2021	2022
Lidar companies					
^	Velodyne	8X	6X	49X	41X
^	Innoviz	6X	5X	41X	34X
*	Luminar	14X	11X	31X	26X
*	Aeva	4X	4X	11X	9X
**	AEye	8X	7X	15X	12X
*	Ouster	2X	1X	5X	4X
Auto Tier 1s					
+	Aptiv	3X	2X	16X	14X
+	Magna	1X	1X	7X	6X
++	Veoneer	1X	1X	--	--
Semis					
+	ON Semi	3X	3X	13X	11X
++	Ambarella	11X	10X	98X	63X
Auto tech					
+	Cerence	11X	10X	41X	36X
+	Tesla	17X	14X	84X	60X

* 2025 company guidance discounted at 20%
** 2026 company guidance discounted at 20%
^ 2025 GSe discounted at 20%
\+ GSe
++ Street (FactSet)

Note: company guidance from investor decks: Luminar deck from 11/10/20; Aeva from 11/1/20; AEye from 2/12/21, Ouster from 12/7/20

Source: FactSet, company data, Goldman Sachs Global Investment Research

Velodyne Lidar – Industry leader in lidar with a broad portfolio, although we expect lower long-term margins; Neutral

Velodyne Lidar designs and sells lidar technology for automated systems. The company was founded by David Hall who created the first 3D lidar solution for autonomous vehicles as an entrant in the 2005 DARPA Grand Challenges. Velodyne Lidar is headquartered in San Jose, CA and the company employs about 300 people, with Dr. Anand Gopalan as CEO. In July 2020, Velodyne announced that it would merge with special purpose acquisition company Graf Industrial Corp, and the transaction valued Velodyne at the time of announcement at an enterprise value of approximately $1.6 bn.

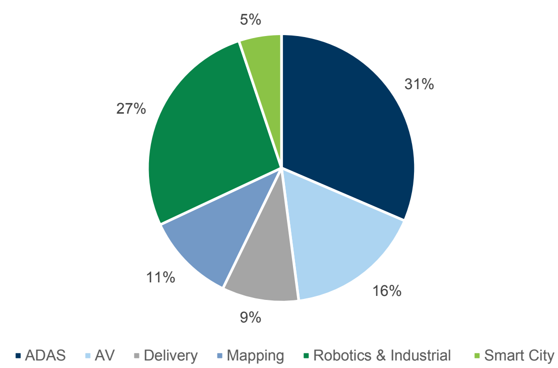
Velodyne is an early mover and the current market leader in lidar, with a broad product portfolio of rotational/hybrid solid-state lidar (the "Puck" and "Prime" sensors) and MEMs directional solid-state lidar ("Velarray," which is automotive grade, and the smaller form factor, shorter range, but cheaper "Velabit"). In addition, the company is developing a hemispherical lidar sensor, the "VelaDome," for high-resolution short-range sensing in ADAS applications. Velodyne's technology is supported by custom ASICs (Velodyne has 25 issued/allowed and 55 pending patents as of 4Q20 EPS call), a micro-lidar array (combining components like the laser and receiver), and the company is also developing a proprietary software platform, Vella. Management expects its ASICs and micro-lidar array, as well as the use of contract manufacturing partners, to help it to reduce cost.

Velodyne has shipped more than 50,000 lidar units since its inception (including 11.7K in

2020) to more than 300 customers, including automotive OEMs, Tier 1 suppliers, and autonomy players (e.g., GM, Ford, Toyota, VW, Aptiv, Argo, Zoox, ThorDrive, Motional, and Uber) as well as to customers in last-mile delivery, precision agriculture, industrial robotics, advanced security, and smart city initiatives. The company believes its long-standing customer relationships will be a competitive advantage over peers, given the high cost of switching sensors after spending money and time developing and validating solutions with Velodyne's technology.

Velodyne manufactures some of its sensors in-house at its San Jose facility (with a fully automated wafer-scale manufacturing process) but plans to increasingly work with contract manufacturing partners, such as Nikon, Veoneer, and Fabrinet in Europe and Asia to help drive scale and lower production costs. As of its 4Q20 earnings call, Velodyne has 26 active multi-year agreements and a total of 194 projects in its pipeline (including 8 with a software component), which could represent a revenue opportunity over $5 bn and up to 9mn units shipped by 2025, per the company (Exhibit 18). The company believes that roughly half of its revenue long-term could come from non-auto applications.

Exhibit 18: Velodyne's pipeline of 194 projects by end market



Source: Company data, Goldman Sachs Global Investment Research

Velodyne targets gross margins in the mid to high 50% range and EBITDA margins exceeding 20% by 2024. The company believes its software offering, Vella, will be a key driver of its margin expansion. The company forecasts that over 20% of 2024 revenue will from software and acquired Mapper.ai (a mapping software company) in 2019 to augment its offerings.

In CY20, Velodyne earned $95 mn in revenue, $68 mn of which came from its Product segment (revenue recognized when a lidar sensor is shipped or delivered to the customer, or in certain cases, using an output method over the duration of the contract or at the end of the acceptance period) and $27 mn of which came from License and services (e.g., product development, validation and repair, IP license and royalty revenue). As of summer 2020, Velodyne expected to earn revenue of $249/$412/$684 mn in 2022/2023/2024 and achieve a 58%/22% gross/EBITDA margin in 2024. However, due to COVID related challenges, the company has removed its guidance.

Exhibit 19: Velodyne Financial Targets as of July 2020

	2021E	2022E	2023E	2024E
Velodyne Financial Guidance				
Revenue (mn)	$152	$249	$412	$684
Gross Profit (mn)	$71	$126	$220	$395
Gross Margin	46%	50%	53%	58%
EBITDA (mn)	($8)	$16	$57	$149
EBITDA Margin	--	6%	14%	22%
Free Cash Flow (mn)	($4)	$7	$30	$104
FCF as % of Sales	--	3%	7%	15%

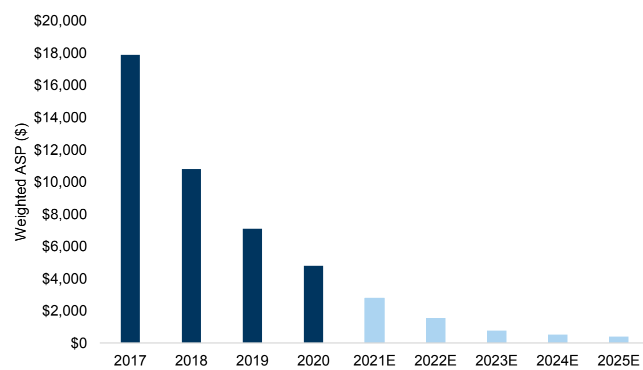
Source: Company data

We believe that lower units are the main delta in our forecast vs. the company's projections for 2021-2022, and lower margins are a key factor for 2023/2024.

While Velodyne's ASPs have been declining materially to a little under $5K in FY20, and the company expects about $600 by 2024, we believe pricing by 2024 may be lower than this (Exhibit 20).

Exhibit 20: We expect lidar ASPs for Velodyne to drop from $18k in 2017 to $400 in 2025

Velodyne Weighted ASP ($) and GS Estimates



Source: Company data, Goldman Sachs Global Investment Research

While our estimates are below the company's guidance, our estimates are relatively in line with the Street over the next couple years (FactSet; Exhibit 21).

Exhibit 21: Velodyne GS vs. Street Estimates

	2021			2022		
	GS	Street	% diff.	GS	Street	% diff.
Revenue ($mn)	$91	$91	0%	$180	$182	-1%
Gross margin (ex. SBC)	35.7%	32.8%	2.9%	42.6%	46.7%	-4.1%
EPS (ex. SBC)	($0.35)	($0.38)	--	($0.15)	($0.14)	--

Source: FactSet, Goldman Sachs Global Investment Research

Our 12-month price target of $13 is based on: 1) 90% weight of our base case valuation of $12 (using 7X EV/2024E revenue discounted back to be 12 months forward); 2) 5% weight of our bull case valuation of $43 (using a 16X multiple on the company's 2024 target and discounted back to be 12-months forward); and 3) 5% weight of our bear case valuation of $5 (using 4X a downside case 2024E revenue view of $195 mn, or half of our base case, discounted to be 12 months forward). Our bear/base case multiples are within the range of the peer group on average (Exhibit 17), and our bull case multiple is about in line with the high end of the auto tech peer group range.

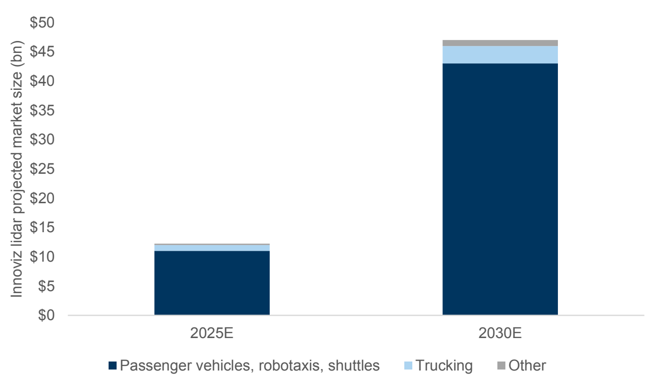
Key risks to our view relate to revenue growth (including faster/slower lidar adoption and ASPs, and this could depend on lidar and autonomous technology adoption in key verticals), margins (the company is targeting gross margins in the mid to high 50% range, and there could be upside to our expectations from lower costs/increased software mix/better ASPs), market share, and the balance sheet (while the company has a solid balance sheet, we are expecting negative cash flow over the next few years).

Innoviz – High performance MEMS lidar provider but operating in a competitive industry; Neutral

Innoviz Technologies designs and manufactures solid-state lidar sensors for consumer vehicles, robotaxis, and trucking (with additional opportunities in robotics, drones, security, and mapping). The company was founded in Israel in 2016 by alumni of the military technology unit (Unit 81 of the Israeli Defense Forces). Omer Keilaf serves as CEO, and Innoviz employs about 300 people. In December 2020, Innoviz announced that it would merge with special purpose acquisition company Collective Growth Corp, and the transaction valued Innoviz at the time of announcement at an enterprise value of about $1.0 bn per the company.

Innoviz's product offerings include the current InnovizOne (an automotive-grade 905 nm MEMS solid state lidar), the upcoming InnovizTwo (with a 70% lower cost than the InnovizOne per the company), and its proprietary perception software. The company plans to integrate its technology into vehicles with an initial focus on L2+ and L3. Innoviz's products, including its proprietary MEMS scanner, silicon detectors, and signal processing ASICs, are supported by 66 pending patents and 17 granted/allowed patents and are automotive-grade (validated by BMW and Magna). The Innoviz solutions can achieve up to 250 meters of range with good resolution.

Exhibit 22: Innoviz estimates a $12 bn market size in 2025 and $46+ bn market size in 2030 for high-performance lidar



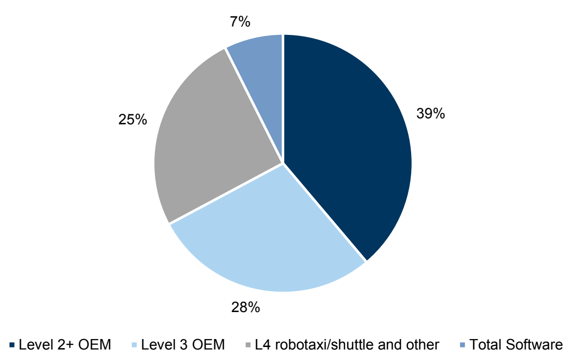
Source: Company data

Innoviz has partnered with Tier 1 suppliers, including Magna, Aptiv, Harman, and Hirain, as well as contract manufacturers, Flex and Jabil. Innoviz aims to sell its lidar sensors to Tier 1s that will then be integrated into the overall system supplied to OEMs. The company believes its Tier 1 partnership strategy will help it to reach more vehicle platforms across automakers. BMW selected Innoviz as its lidar supplier and plans to offer this as an add-on option for the iX platform in 2022 (and we believe then scale this to other models like the 7 Series and 5 Series based on comments from BMW on its ADAS plan). Innoviz believes this would make it the first lidar supplier designed into an L3-capable passenger vehicle. Innoviz estimates that its order book from BMW will generate $2 bn in revenue by the end of the decade.

In 2025, Innoviz projects over half a billion in revenue, largely from L2+ and L3 contracts (with some revenue from trucking, robotaxis, and about 7% from software; Exhibit 23). The company believes its lidar TAM could grow from $12 bn in 2025 to $46 bn in 2030 (Exhibit 22).

Innoviz expects to earn revenue of $79/$237/$581 mn in 2023/2024/2025 and achieve a 52%/31% gross/EBITDA margin in 2025 (Exhibit 24).

Exhibit 23: Innoviz targets $581 mn in revenue in 2025



Source: Company data

Exhibit 24: Innoviz financial targets

	2020E	2021E	2022E	2023E	2024E	2025E
Innoviz Financial Guidance						
Units (000s)	1	4	21	117	446	1,175
Revenue (mn)	$5	$9	$23	$79	$237	$581
Gross Profit (mn)	$0	$1	$6	$35	$118	$300
Gross Margin	4%	10%	26%	45%	50%	52%
EBITDA (mn)	($65)	($87)	($85)	($62)	$12	$179
EBITDA Margin	--	--	--	--	5%	31%
FCF	($69)	($90)	($93)	($82)	($38)	$75
FCF as % of Sales	--	--	--	--	--	13%

Source: Company data

While our 2021/2022 estimates are about in line with the company's guidance, we see the potential for lower revenue and margins in 2023-2025 as we believe that competition (both from non-lidar solutions and other lidar companies) could limit growth (Exhibit 25). According to IHS, BMW iX volumes could be about 30K per year and the 7-series could be about 50K units per year, implying that the company's 21K unit target for 2022 is achievable (as Innoviz's solution will be part of an optional add-on package). However, the ramp in units the company projects to 117K in 2023 and 446K in 2024 will require additional design wins, in our view.

Exhibit 25: We are in line with guidance on the 2021/2022 time horizon but below in 2023-2025

GS vs. Company Guidance

Innoviz GS vs. Company Guidance	2021E			2022E			2023E			2024E			2025E		
	GS	INVZ	% diff.	GS	INVZ	% diff.	GS	INVZ	% diff.	GS	INVZ	% diff.	GS	INVZ	% diff.
Units (000s)	4	4	0%	21	21	0%	53	117	(55%)	175	446	(61%)	750	1,175	(36%)
Revenue ($mn)	$9	$9	0%	$20	$23	(13%)	$50	$79	(37%)	$115	$237	(51%)	$365	$581	(37%)
Gross profit	$1	$1	(8%)	$4	$6	(31%)	$17	$35	(52%)	$49	$118	(58%)	$164	$300	(45%)
Gross margin	10%	10%	2%	21%	26%	(5%)	34%	45%	(11%)	43%	50%	(7%)	45%	52%	(7%)
EBITDA ($mn)	($89)	($87)	-	($93)	($85)	-	($77)	($62)	-	($49)	$12	-	$58	$179	(67%)
EBITDA margin	-	-	-		-	-		-	-	-	5%	-	16%	31%	(15%)

Source: Company data, Goldman Sachs Global Investment Research

Our 12-month price target of $11 is based on: 1) 90% weight of our base case valuation of $10 (using 5X EV/2025E revenue discounted back to be 12 months forward); 2) 5% weight of our bull case valuation of $40 (using a 16X multiple on the company's 2025 target and discounted back to be 12-months forward); and 3) 5% weight of our bear case valuation of $5 (using 4X a downside case 2025E revenue view of $183 mn, or half of our base case, discounted to be 12 months forward). Our base case multiple is about in line with the peer group on average (Exhibit 17), and our bull case multiple is near the high end of the peer group range. Our base case revenue multiple for Innoviz is lower than Velodyne given that Velodyne is already generating material revenue. That said, we believe that both stocks could trade in a wide range and since we consider Innoviz to be in the group of industry leaders technically, we believe that it has the potential to generate enough business momentum to trade materially higher in a bull case and thus merits a similar bull case multiple.

Key risks to our view relate to revenue growth (including faster/slower lidar adoption and ASPs), margins (management is targeting gross margins in the low 50% range, and there could be upside to our expectations from lower costs/increased software mix/better ASPs), market share, M&A, and the balance sheet (while the company has a solid balance sheet, we are expecting negative cash flow the next few years).

Valuation and price target methodology for additional companies

Aptiv: We are Buy rated on APTV shares. Our 12-month price target of $173 is based on 30X applied to our normalized EPS estimate of $5.75. Key risks to our view relate to Aptiv's ability to grow its content per vehicle ahead of industry production, the auto cycle, Aptiv's market share, margins, Aptiv's net debt position, component shortages in the auto supply chain, and the impact of COVID-19 on industry supply and demand.

Magna: We are Neutral rated on MGA shares. Our 12-month price target of $94 is based on 11X applied to our normalized EPS of $8.50. Our 12-month price target for MG.TO listed in Canada is 118 CAD and based on the exchange rate of 1.25X our MGA target price. Key risks to our view relate to the auto cycle (including impacts from COVID-19), market share, Magna's ability to outgrow industry unit production and capitalize on secular growth themes, capital allocation, FCF through the cycle, and the company's modest net debt position.

Tesla: We are Buy rated on TSLA shares. Our 12-month price target of $835 is based on 16X EV/Q5-Q8 revenue. Key downside risks to our thesis relate to the rate of EV adoption (and the ability for Tesla to meet this demand given supply chain constraints), Model Y demand, increased competition in EVs, the auto cycle, key person risk, the internal control environment, and operational risks associated with Tesla's high degree of vertical integration.

GM: We are Buy rated on GM shares. Our 12-month price target of $61 is based on an 11X multiple applied to our normalized EPS estimate of $5.50. Key risks to our view relate to the auto cycle, market share, margins, FCF, and GM's ability to profitably pivot to growth areas such as EVs and AVs.

Cerence: We are Buy rated on CRNC shares. Our 12-month price target of $129 is based on 14X applied to our Q5-Q8 revenue estimate. Key risks to our view include the industry and macro environment, competition, margins, natural ASP degradation, and its mature contract with Toyota.

Ford: We are Neutral rated on F shares. Our 12-month price target of $11 is based on 9X applied to our normalized EPS estimate of $1.20. Key risks to our view relate to Ford's ability to profitably pivot to growth areas such as EVs and AVs, the auto cycle, market share, and margins (both margin pressure in a downturn and margin expansion longer term from company specific initiatives).

Li Auto: We are Buy rated (CL) on Li shares. Our 12-month target price of US$60.0 is based on a DCF valuation. Risks: Market acceptance of extended-range EV, given it is new to the China market and requires consumer education; fast development of pure EVs in terms of battery cost reduction, battery range increase and charging infrastructure expansion could reduce the advantages of EREV products; product quality control risks given Li Auto has limited operating history in manufacturing, testing, delivering and servicing its vehicles.

Denso: We are Buy rated (CL) on Denso shares. Our 12-month target price of ¥8,400 is based on our FY3/22 estimates and theoretical value derived from P/B-ROE correlation, plus a premium of 20% (the average in past periods when ROE has been at 8%-10%). Key downside risks include yen appreciation, and quality costs (fuel pumps).

Toyota: We are Buy rated on Toyota shares. Our 12-month target price of ¥10,000 is based on P/B-ROE correlation and our FY3/22 estimates. Key risks include yen appreciation, a heavier upfront investment burden, battery sourcing issues amid rapid growth in the EV market, and disappointment in the company's shareholder return policy.

Daimler: We are Buy rated on Daimler shares. We value Daimler using a 50/50 blend of a P/E based methodology which implies a valuation of €92 share (8.2x target multiple applied to 2022E EPS) and our SoTP valuation which implies a valuation of €108 share to arrive at a 12-month price target of €100. Downside risks: cost savings do not materialize; inability to reduce capex; post COVID-19 return to normal sees opex and capex return to 2019 levels; cyclical nature of end markets; further lockdowns as a result of COVID-19.

Volkswagen: We are Buy rated on VW shares. We value VW taking a target multiple of 8.5x applied to our 2022 EPS of €33.43 to arrive at a 12-month price target of €284. Downside risks include software and BEV production issues; new products less well-received than recent products; semiconductor shortage has a more material impact on 2021/22 than anticipated; CO2 compliance in 2021; European lockdowns and Covid-19 related disruption; and China slowdown.

BMW: We are Neutral rated on BMW shares. We value BMW using a 12-month forward target P/E multiple of 8.2x applied to our 2022E EPS of €13.20 to derive our €108 12-month price target. Upside risks include overestimating costs required to meet CO2 compliance; BMW over-delivers on its efficiency program; and underestimating the positive impact on price and mix. Downside risks include the inability to reduce capex and control working capital; improvements in price/mix cannot be sustained through outer years; post Covid-19 return to normal sees opex and capex return to 2019 levels; cyclical nature of end markets; further lockdowns as a result of Covid-19; and policy changes that negatively impact flexible powertrain approach.

Disclosure Appendix

Reg AC

We, Mark Delaney, CFA, Alexander Duval, George Galliers, Kota Yuzawa, Fei Fang, Toshiya Hari, Bruno Dossena, Ryan Heeb and Eleanor Garland, 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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Growth is based on a stock's forward-looking sales growth, EBITDA growth and EPS growth (for financial stocks, only EPS and sales growth), with a higher percentile indicating a higher growth company. **Financial Returns** is based on a stock's forward-looking ROE, ROCE and CROCI (for financial stocks, only ROE), with a higher percentile indicating a company with higher financial returns. **Multiple** is based on a stock's forward-looking P/E, P/B, price/dividend (P/D), EV/EBITDA, EV/FCF and EV/Debt Adjusted Cash Flow (DACF) (for financial stocks, only P/E, P/B and P/D), with a higher percentile indicating a stock trading at a higher multiple. The **Integrated** percentile is calculated as the average of the Growth percentile, Financial Returns percentile and (100% - Multiple percentile).

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Disclosures

Rating and pricing information

Aptiv Plc (Buy, $141.84), BMW (Neutral, €87.47), Cerence Inc. (Buy, $98.36), Daimler AG (Buy, €75.36), Denso (Buy, ¥7,186), Ford Motor Co. (Neutral, $12.24), General Motors Co. (Buy, $58.61), Li Auto Inc. (Buy, $19.68), Magna International Inc. (Neutral, $95.75), Magna International Inc. (Neutral, C$119.82), Tesla Inc. (Buy, $738.85), Toyota Motor (Buy, ¥8,530) and Volkswagen (Buy, €238.25)

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BAIC Motor Co, BYD Co. (A), BYD Co. (H), Brilliance China Automotive, CATL, China Grand Auto, China Harmony New Energy Auto, Chongqing

Changan Auto, Dongfeng Motor, Fuyao Glass Industry Group (A), Fuyao Glass Industry Group (H), Geely Automobile Holdings, Great Wall Motor Co. (H), Great Wall Motor Co.(A), Guangzhou Automobile Group (A), Guangzhou Automobile Group (H), Huayu Automotive Systems, Li Auto Inc., MeiDong Auto, Minth Group, NIO Inc., SAIC Motor, Sinotruk (Hong Kong), Weichai Power (A), Weichai Power (H), Yongda Auto, Zhongsheng Group

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	Rating Distribution			Investment Banking Relationships		
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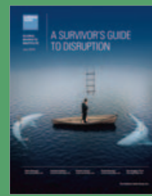

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