The Future of Automotive Lidar

Laser technologies hold the key to self-driving vehicles

PitchBook is a Morningstar company. Comprehensive, accurate and hard-to-find data for professionals doing business in the private markets.

Credits & contact

Analysts
ASAD HUSSAIN Analyst, Emerging Technology
asad.hussain@pitchbook.com
VAN LE Senior Data Analyst

Contact PitchBook

RESEARCH
reports@pitchbook.com

Contents

Key takeaways

- Lidar will be critical to the adoption and expansion of autonomous mobility solutions, and we expect the emerging automotive lidar industry to reach $20 billion by 2030.
- Venture activity in lidar reached a record in 2019 with $1.3 billion invested.
- Inexpensive and effective automotive lidar solutions are likely to gain market share before camera-only self-driving is solved.
- Emerging lidar technologies, including solid-state and continuous wave, are helping solve critical adoption hurdles and will be key to growth and market penetration.
- While the current coronavirus pandemic may pause investment in the space and could lead to some shutdowns of earlier-stage startups, the long-term structural drivers are likely to stay intact.
- Amid consolidation and price compression, startups that have partnered with OEMs and Tier-1 suppliers or companies that focus on B2B use cases are well-positioned to succeed.
- Emerging Lidar-as-a-Service business models are likely to facilitate adoption among capital-constrained buyers.

Published on March 24, 2020

Overview

Lidar (which stands for light detection and ranging) is an emerging technology that has seen rapid growth and adoption within the automotive industry in recent years. Lidar uses light emitted from lasers to determine the shape and distance of an object. Previously utilized in aerospace and industrial applications, lidar technology has seen a significant increase in investment from the automotive industry due to its unique applicability to self-driving vehicles. By providing three-dimensional mapping of surroundings, lidar systems enable vehicles to sense their environments, laying the essential technological foundation for autonomous driving.

Lidar products continue to evolve, with emerging solid-state and continuous wave technologies helping drive adoption. We expect the lidar industry to expand to $20 billion by 2030. Several startups and OEMs are active in the space, which received $1.3 billion in VC investment in 2019, according to our proprietary analysis of the industry. Leading startups in the space include Luminar and Innoviz, which have achieved private market valuations of $900 million and $575 million, respectively. While fully autonomous vehicles may be many years away from widespread commercial use, we expect lidar to remain a key focal point for mobility tech investors.

The Tesla debate

Nearly every major OEM or technology company developing self-driving capabilities relies on lidar technology as a key component of its sensor suite. A notable exception is Tesla, which shuns lidar in favor of less expensive camera, radar and ultra-sonic based systems. The company's CEO, Elon Musk, has been a vocal critic of lidar due to its high cost and complexity. Tesla views lidar as a shortcut to autonomy; as Tesla's head of AI has noted, people do not rely on lasers to drive.[1]

Although these are important points, so far, Tesla has only succeeded in limited (Level 2 or 3) semi-autonomous applications.[2] Despite Tesla's major investment in self-driving technology, we regard the company as well behind key leaders in the space, such as Alphabet-owned Waymo and GM-owned Cruise Automation. For more detail on our relative ranking of self-driving companies, see our Q4 Emerging Tech Research: Mobility Tech report.

1: "Elon Musk Thinks Self-Driving Cars That Rely on Lasar Sensor are 'Lame,'" Mashable India, Sasha Lekach, May 2019.
2: "Tesla's Full Self-Driving Computer is Now in All New Cars and a Next-Gen Chip is Already 'Halfway Done,'" TechCrunch, Kirsten Korosec, April 22, 2019.

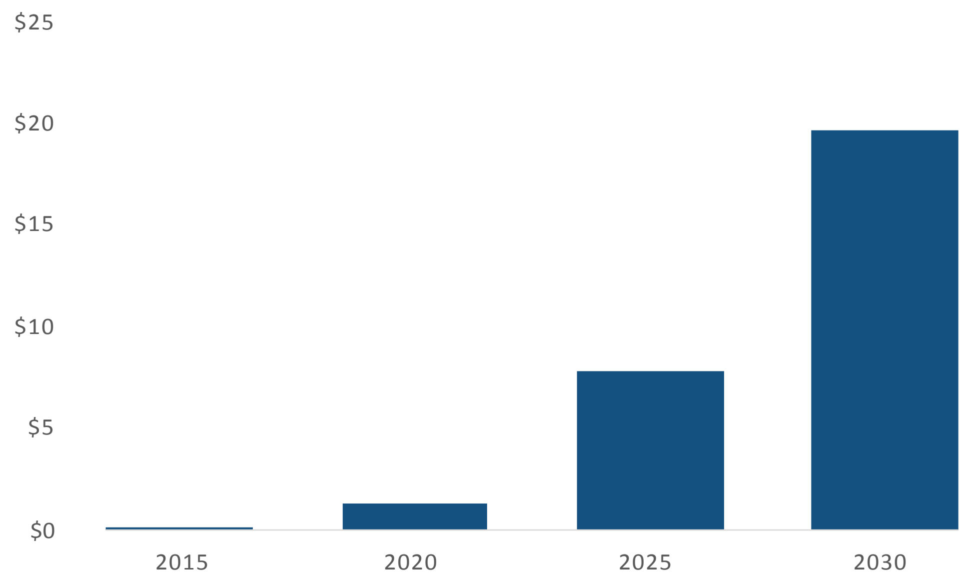
We believe lidar technology will be critical for automotive-grade, self-driving applications because it provides distance, speed and depth information in a computationally compact fashion. The utility of lidar is based on certain realities of how computers perceive the world. Autonomous driving depends on systems that can relay sensory inputs that computers understand. These inputs often do not correlate well with sensory inputs humans use. Although it may seem intuitive that cameras should be sufficient for self-driving capabilities (since cameras are the most similar sensor to the human eye), the amount of computational heavy lifting necessary to extract process information from a camera feed is currently out of reach for practical self-driving applications.

We believe cheap, effective lidar solutions are likely to hit the market before there is a viable solution for self-driving technology using only cameras. Lidar systems have already become significantly cheaper. Over the past few years, long-range lidar systems have decreased from over $75,000 per unit to the mid thousand-dollar range. We believe individual lidar units will need to price in the low-to-mid hundred-dollar range for mass-market deployment in automobile platforms.

Large potential market size

Fig. 1

Lidar market size ($B)

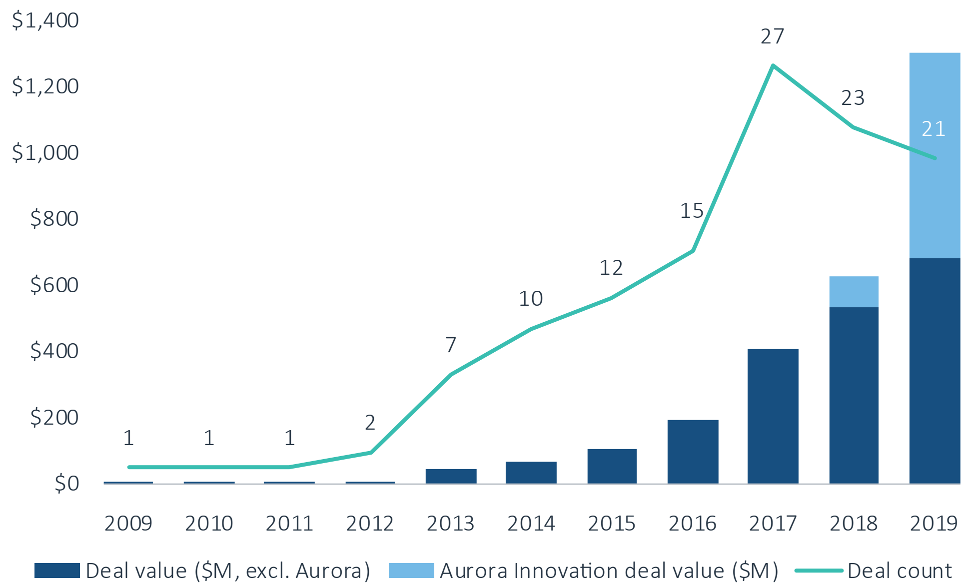


Source: PitchBook estimates | **Geography:** Global

Note: This represents global sales of third-party lidar systems and components

Automotive lidar has the potential to become a multibillion-dollar market as automakers add driver assistance and autonomous capabilities to vehicles. We estimate this industry can grow to a revenue opportunity of approximately $19.7 billion in 2030, implying a roughly 31% 10-year CAGR. This estimate is based on increasing unit sales as content per new vehicle sold increases, partially offset by significant price compression as manufacturing costs rapidly decline.

Fig. 2
Lidar VC deal activity



Source: PitchBook | **Geography:** Global
Note: We break out Aurora Innovation as investments at the time preceded its lidar acquisition.

Investors are flocking to lidar

Automotive lidar is a key driver of VC investment in the mobility and transportation industry. In 2019, investors deployed a record $1.3 billion in the space, up from $623 million the previous year. Standout deals in 2019 include the $170 million Series C round by Innoviz Technologies and the $230 million acquisition of Blackmore by Aurora Innovation. Though not included in this dataset, Hesai's $173 million Series C in January 2020 and Cepton Technologies' $50 million Series C in February 2020 are promising signs for the industry going forward.

Fig. 3

Key privately backed lidar companies

COMPANY	TOTAL CAPITAL RAISED ($M)*	LAST KNOWN VALUATION ($M)*
Innoviz Technologies	$264	$575
Luminar	$250	$900
Hesai	$231	$650
Velodyne Lidar	$225	$1,800
Surestar	$153	N/A
LeddarTech	$121	N/A
Aeva	$108	$460
Ouster	$100	$212
Trilumina	$74	$103
AEye	$62	$220

Source: PitchBook | **Geography:** Global
*As of February 15, 2020

Fig. 4

Key investors in lidar

INVESTOR	INVESTMENTS
Samsung	Innoviz, Quanergy, TetravVue, Sense Photonics
Aptiv	Innoviz, LeddarTech, Quanergy
Baidu	Hesai, Velodyne

Source: PitchBook | **Geography:** Global
*As of February 15, 2020

Fig. 5

Lidar KPIs

The following are nine of the most relevant KPIs for automobile lidar applications. Meeting these requirements simultaneously is challenging as many of them come at tradeoffs with one another.

KPI	DESCRIPTION
Range	Longer-range detection is favorable as it enables vehicles to see further distances. This is particularly important for high-speed uses. A range of 250 meters tends to be the standard for highway driving.
Resolution	Improved resolution is favorable as it enhances detection abilities. Whereas cameras describe resolution using megapixels, lidar resolution is based on the angular spacing between pixels. A resolution of 0.025°x0.025° tends to be the standard for highway driving.[3]
Sensitivity	Increased sensitivity is favorable as different materials vary in light reflectivity. 10% reflectivity for targets 200 meters away tends to be the standard for automotive-grade lidar.
Frame rate	Low latency is a key advantage as it allows information processing and decision making to occur more quickly. Most competitive systems typically scan at 10 hertz. Higher scan rates reduce latency and increase reactivity at the tradeoff of resolution.
Field of view	An increased field of view (up to 360 degrees horizontal) is generally favorable as it reduces the number of sensors required per vehicle. However, this typically comes at the tradeoff of other KPIs and is not always desirable for specific applications.
Unit cost	Reduced cost is favorable but typically comes at the cost of performance. We believe individual high-performance lidar units will need to price in the low-to-mid hundred-dollar range for mass-market deployment in automobile platforms. Systems on the market currently range from $100 to much higher ($75,000+).
Reliability	Increased reliability is favorable as it reduces downtime expense associated with routine maintenance, calibration and repairs. Resistance to shock and corrosion are key. In addition, effective heat dissipation is important, as lasers inherently produce heat and can adversely affect wavelength stability and system performance.
Power consumption	Low power consumption is favorable, especially for electric vehicle platforms. Power consumption of under 10 watts is generally seen as the standard for automobile applications.
Form factor	Smaller and lighter form factors are favorable as they better integrate with existing automobile design elements and enable wider use cases beyond passenger vehicles.

Source: Photonics Media, Phys.org, Phononic

3: "Market Trends in Automotive Lidar," Photonics Media, Greg Smolka, n.d.

Key trends in lidar technology

We have identified dozens of startups and companies developing technology in the space, all seeking to provide differentiated solutions. Although the market opportunity is large, assessing which technologies are likely to be successful can be a challenging prospect for investors. We expect the following two technological trends (i.e. solid-state lidar and the use of continuous wave technology) will be critical in driving development in the space.

Lidar is shifting to solid-state applications

We believe the lidar industry is shifting away from traditional spinning applications toward solid-state lidar technology. Spinning lidar units tend to be mounted on gimbals and rotate rapidly to create 360-degree views of driving environments. While this technology is well-tested and set the industry standard for performance—with producers including Velodyne, Ouster and Waymo—units are bulky and raise concerns about longevity. The macro-mechanical movement inherent to spinning lidar generates significant wear-and-tear that necessitates frequent servicing, replacement and recalibration. In addition, automobiles are constantly subject to fluctuations in temperature, vibration and weather conditions. In a future of autonomous vehicles operating in fleets, this could be a significant added expense.

Solid-state designs attempt to resolve these issues by incorporating fewer moving parts. Relative to legacy spinning and other macro-mechanical lidar applications, solid-state applications tend to be smaller and more easily integrated onto vehicle bodywork. Fewer moving parts could result in reduced costs associated with repair, replacement and maintenance for fleet operators. Another key advantage for solid-state systems is the ability to be "software-definable." This enables seamless integration into perception systems, neural networks and other sensors and makes them more responsive to changing conditions and use cases. Many technology companies testing self-driving vehicles utilize spinning solutions because solid-state lidar is more expensive and the technology has not yet been fine-tuned for mass adoption. However, this may be changing as VC investment in solid-state lidar has now eclipsed investment in spinning solutions.

Leading companies developing solid-state lidar technology generally take one of three approaches: micro-mechanical scanning, optical-phased array and flash. Each of these approaches has its own advantages and disadvantages relative to each other and to traditional spinning lidar (see Figure 6).

Fig. 6

Lidar scanning approaches

	BEAM STEERING TECHNOLOGY	DESCRIPTION	ADVANTAGES	DISADVANTAGES	KEY PROVIDERS (>$20M IN FUNDING)
Spinning lidar	**Macro-mechanical scanning**	Spins laser beams mounted on rotating gimbals	Full 360-degree coverage means fewer per-vehicle sensor requirements Maturity in software development makes it easy to integrate perception algorithms High performance (long range, resolution)	Highest priced systems on the market today Higher ongoing maintenance, repair and replacement costs Poor latency due to monostatic receiver design limiting scan rates High power requirements for spinning systems	Velodyne, Ouster, Waymo, RoboSense, Surestar, LeiShen, Valeo (non-spinning), Luminar (non-spinning)
Solid-state	**Micro-mechanical scanning**	Redirects laser beams with small oscillating mirrors, often using MEMS (micro-electro-mechanical systems)	High scan rates lead to low latency and allow for faster data interpretation Can be made software definable Low power consumption MEMS technology enables high precision mass production Increased reliability and lower maintenance, repair and replacement costs over lifespan of vehicle	High upfront cost due to complexity of system Lower field of view requires additional sensors per vehicle Small mirrors limit detection abilities to reflectivity in some applications Heat dissipation could be a concern for some applications	Innoviz Technologies, AEye, LeddarTech, Robosense, Cepton
Solid-state	**Optical phased array**	Steers laser beams without moving parts by adjusting phase of the array	Lower upfront cost Can be made software definable Increased reliability and lower maintenance, repair and replacement costs over lifespan of vehicle	Limited range not currently sufficient for automotive grade applications Beams more divergent than other approaches, forcing tradeoff between range, resolution and field of view Necessary complexity of system (using advanced nanotechnology) is expensive and can result in manufacturing hiccups and lower yields	Quanergy
Solid-state	**Flash**	Spreads laser beam across a wide swathe to illuminate up to 180 degrees	Produces images in a grid, ideal for perception algorithms. One-time flash reading saves on computing time, minimizing response delay and improving performance Can be made software definable Increased reliability and lower maintenance, repair, and replacement costs over lifespan of vehicle	Wide field of view and compactness of photodetector array limits power of laser, resolution and range 905 nanometer-based systems use a large amount of laser energy at a non-retina safe frequency. Gaining eye-safe automotive grade range could be difficult	Continental, LeddarTech, Oryx Vision, Sense Photonics, TetraVue,Argo AI/Princeton Lightwave

Source: PitchBook, ArsTechnica, TechCrunch, LaserFocusWorld, IEEE Spectrum, AutoSens
Note: Some industry participants do not classify MEMS lidar as solid-state because it contains small moving parts..

Hybridized and alternative approaches to lidar scanning also exist in the market. In conjunction with its main scanning method, Luminar utilizes a legacy technology known as polygonal mirrors, which is shared by laser printers and has been in use for over 30 years in non-automotive lidar applications such as sea mapping, collision avoidance and military target identification.[4] Another novel approach to one-dimensional scanning is being developed by secretive startup Baraja, and involves passing swept-wavelength tunable laser beams through prisms to scan the environment.

Future lidar systems could use continuous wave technology

We see opportunity for a shift in detection modality from time-of-flight pulsed lidar to coherent lidar, the most common application being frequency-modulated continuous wave (FMCW) lidar. The majority of lidar applications utilize time-of- flight (also known as direct detection) technology, which operates by sending out discrete pulses of light and measuring the time and intensity of their return. Although this technology works well in current applications, it faces many issues that could impede widespread adoption. Using a fixed scan system to sweep a laser across an environment takes time, and often multiple sweeps are required to gather velocity readings. In a high-speed environment such as a highway, the increased latency can hamper decision-making. Moreover, it can be difficult for some applications, such as 905 nanometer-based flash lidar, to put out enough power to reach automotive-grade range requirements while remaining safe for the human eye. Finally, time-of-flight lidar runs into interference upon contact with other lidar beams—such as those emitted from other autonomous vehicles—though interference mitigation techniques such as pulse-code modulation can help solve this issue.

FMCW technology addresses many of these deficiencies in time-of-flight pulsed lidar solutions. The technology works by transmitting continuous waves with varied frequencies, thereby enabling more signal processing and better performance. The FMCW solutions utilized by autonomous vehicles have long ranges (200+ meters) and are less likely to be impaired by sunlight or contact with other lidar sensors. The lower power requirements of continuous waves relative to laser pulses are also safer for human eyesight. Measuring the time delay of the return wave enables range measurements, which can be combined with frequency and the Doppler effect to deduce direction. This allows FMCW to transmit velocity information in every pixel without the need for the computationally intense process of tying together multiple frames

4: "MEMS Mirrors vs Polygon Scanners for Lidar in Autonomous Vehicles," Precision Laser Scanning, George Helser, December 31, 2017.

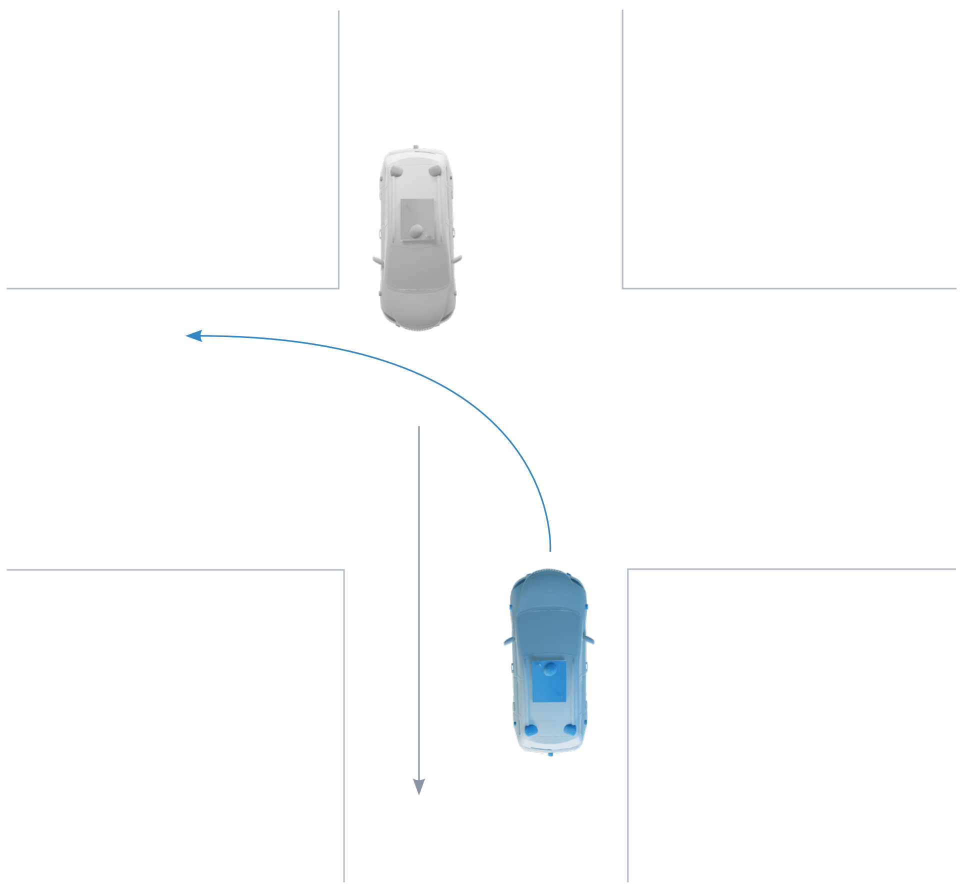
from a point cloud and calculating velocities. This reduces latency, allowing autonomous vehicles to receive velocity information instantaneously and make quick safety decisions.

FMCW technology is excellent at measuring instantaneous velocity readings from objects moving directly toward the sensor and could help solve the "unprotected left turn" obstacle faced by self-driving companies. Much of the criticism of Waymo's pilot programs has stemmed from the hesitancy of vehicles to make unprotected left turns, which frustrates passengers and other drivers waiting to turn. A key cause of this hesitancy is the reliance on time-of-flight lidar, which requires tying together multiple frames to compute velocity. This is a time-intensive process that often does not complete until it is no longer safe for the vehicle to turn. This is especially problematic on high-speed roads.

Fig. 7

The unprotected left turn

FMCW technology is very good at measuring instantaneous velocity readings from objects moving directly toward the sensor and could help solve the "unprotected left turn" obstacle faced by leading self-driving companies.



Although FMCW shows promise as an experimental technology, it has certain disadvantages relative to time-of-flight lidar and cannot provide sufficient velocity readings in all situations. For example, FMCW excels at measuring radial velocity (from the front) but not lateral velocity (from the side). Radial velocity is relatively less critical as head-on collisions represent just 10% of fatal vehicle collisions. FMCW applications also have greater power needs than time-of-flight applications, which could limit their use in low-power applications such as delivery bots. Finally, FMCW solutions are more complex and expensive than time-of-flight lidar.

We believe FMCW technology is a key beneficiary of the secular trend toward packing lidar on to single semiconductor chips to produce small lidar solutions. This approach eliminates the need for external amplifiers, modulators, fiber connections and other optical conditioning tools and could create a significant manufacturing cost advantage. According to a 2016 paper published in the Journal of Lightwave Technology, chip fabrication technology has finally advanced to the point where lidar systems can be packaged into single chips.[5] However, as the authors note, peak power demands of high-performance pulsed lidar systems are too much for conventional chip materials to handle, leaving FMCW solutions as a more promising technology given lower power demands.[6]

Several companies are taking this approach to developing integrated chip solutions. Insight Lidar, a subsidiary of medical imaging laser supplier Insight Photonic Solutions, has developed a long-range FMCW lidar sensor that is 10x-100x more sensitive than traditional lidar sensors. In April 2019, Voyant Photonics raised $4.3 million in VC funding for a high-performance FMCW-based solution that can balance on the head of a pin. Other companies leveraging FMCW technology include Aeva, whose “4D lidar” product gauges velocity readings for moving vehicles by sending out a unique signature laser from a cuboid sensor.[7] Another startup, Blackmore Sensors and Analytics, was acquired by Aurora Innovation for $230 million in May 2019 for its proprietary FMCW solution leveraging non-mechanical beam steering. Most recently, FMCW lidar company SiLC Technologies raised $12 million in seed funding in March 2020. We believe GM’s Cruise Automation, through its acquisition of Strobe, may also have access to this technology and could be one of the first to market.

5: “Photonic Integrated Circuits for Coherent Lidar,” Journal of Lightwave Technology (Volume 36, Issue 19), Paul J. M. Suni, John Bowers, Larry Coldren, S.J. Ben Yoo, May 28, 2018
6: “Photonic Integrated Circuits for Coherent Lidar,” 18th Coherent Laser Radar Conference, Paul J. M. Suni, et. al., June 2017
7: “Aeva Will Supply Lidar Sensors to Audi’s Autonomous Driving Division,” Venture Beat, Kyle Wiggers, April 17, 2019

Outlook for the lidar industry

We expect the following four trends to significantly affect the lidar industry going forward.

Pandemic-induced economic crisis to pressure industry in near term

We expect the current economic crisis to reduce near-term investment in the lidar industry from automakers and VCs. New car sales are likely to fall significantly in the near-term as consumers pull back on spending. Automakers will face pressure from the drop in demand and supply chain disruptions as they face sourcing and manufacturing delays. We have also heard anecdotally of VCs sharply pulling back on investing in capital expenditure-intensive businesses. Meanwhile, autonomous vehicle companies Waymo, Cruise, Argo.AI and Pony.AI have suspended testing due to coronavirus concerns. These factors are likely to manifest in reduced broad-based investment in autonomous technologies in the near-term. This pullback will primarily affect earlier stage lidar providers with lower market share, shorter cash runways and fewer established partnerships. We would not be surprised to see a significant shakeout of the tail-end of this fragmented industry. With that said, well-capitalized providers with established partnerships and proven technology, such as Luminar and Hesai, are better positioned to succeed in this environment. We believe lower oil prices could catalyze sales of luxury vehicles utilizing Level 2/3-focused sensors. However, lower gas prices reduce economic incentives to automate driving, and this could reduce investment in Level 4/5-focused applications. Longer term, we continue to view adoption of autonomous vehicle technology as a stable secular trend and maintain our favorable long-term outlook for the space.

Product commoditization to drive M&A and vertical integration

Downward pricing pressure is already occurring in the lidar industry. Waymo has reportedly lowered the cost of its in-house mid-range lidar units to $4,000, and lidar company Strobe announced that it has lowered the cost of its lidar technology by 99%, after which it was acquired by Cruise Automation. Luminar's Iris unit and Livox's Horizon unit each cost $1,000 per unit. In January 2020, Velodyne unveiled its latest lidar system, which costs $100 per unit. Over the long term, we believe price compression for lidar systems will have a negative impact on gross margins for suppliers and make it more difficult for smaller providers to compete, leading to increased industry consolidation and M&A activity.

We expect strategic acquisitions to escalate as technology companies, automakers and auto suppliers vertically integrate leading lidar startups. Examples of this include Aurora Innovation's acquisition of Blackmore, Ford/Argo AI's acquisition of Princeton Lightwave and GM/Cruise Automation's acquisition of Strobe. Vertical integration allows automakers and suppliers to reduce manufacturing costs and better integrate lidar systems within existing platforms. We view startups working on the latest proven technologies—such as solid-state and FMCW solutions—as likely acquisition targets. In addition, we rank Volkswagen, Toyota and Hyundai high on our list of buyers as they seek to gain a foothold in the self-driving space.

The need for partnerships opens the door for subscription services

Partnerships with automakers and Tier-1 auto suppliers could be positive differentiators for lidar startups. As product cycles for automobiles can extend well over 10 years, long-term partnerships with leading automakers and suppliers can provide significant competitive advantages. Additionally, as automakers have strict requirements for performance, reliability and longevity, partnerships can ensure R&D efforts meet the needs of potential customers. Companies including Luminar, AEye, Hesai and Velodyne have shown success at establishing partnerships with key OEMs and suppliers.

The need for partnerships may be sparking an industry shift to subscription-based business models. Lidar-as-a-Service offers many potential advantages to OEMs and providers of self-driving technology, including reducing capital expenditure, ensuring software is up to date and providing more vendor flexibility. Startup Luminar announced in January 2019 that it will begin selling its latest sensor as a subscription service to automakers targeting on-road deployments in the early 2020s. We expect an increasing number of lidar companies to pivot in this direction to secure additional partnerships with capital-constrained customers.

B2B end use cases could see earlier adoption and revenue generation

Although KPIs including range, sensitivity, framerate and resolution are key points of differentiation for automotive and robotaxi applications, cheaper and more durable solutions could thrive in less safety-critical applications such as B2B delivery and the “middle mile” of logistics. These environments have lower success thresholds relative to consumer applications, meaning alternative KPIs such as cost effectiveness, reliability, ease of integration, lower power consumption and weight could be prioritized over performance. Startups exposed to the B2B end market may see quicker growth compared to the longer adoption curve for B2C markets. For more details on this dynamic, see our Q4 2019 Emerging Tech Research: Mobility Tech report.