

Automotive LiDAR Report

Technology Deep-Dive, Trends, M&A, Future Predictions

March 2022



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A grayscale photograph of St Paul's Cathedral in London, viewed from a street level. The cathedral's large dome and classical facade are the central focus. It is flanked by modern multi-story buildings with many windows. The sky is overcast.

SCOPE OF THE REPORT

LiDAR systems no longer resemble clunky cylinders attached to the roof of a vehicle. The state-of-art automotive LiDAR now looks very different.

Automotive LiDAR today accounts for just a small part of all LiDAR applications. However, automotive LiDAR will soon become the dominant application.

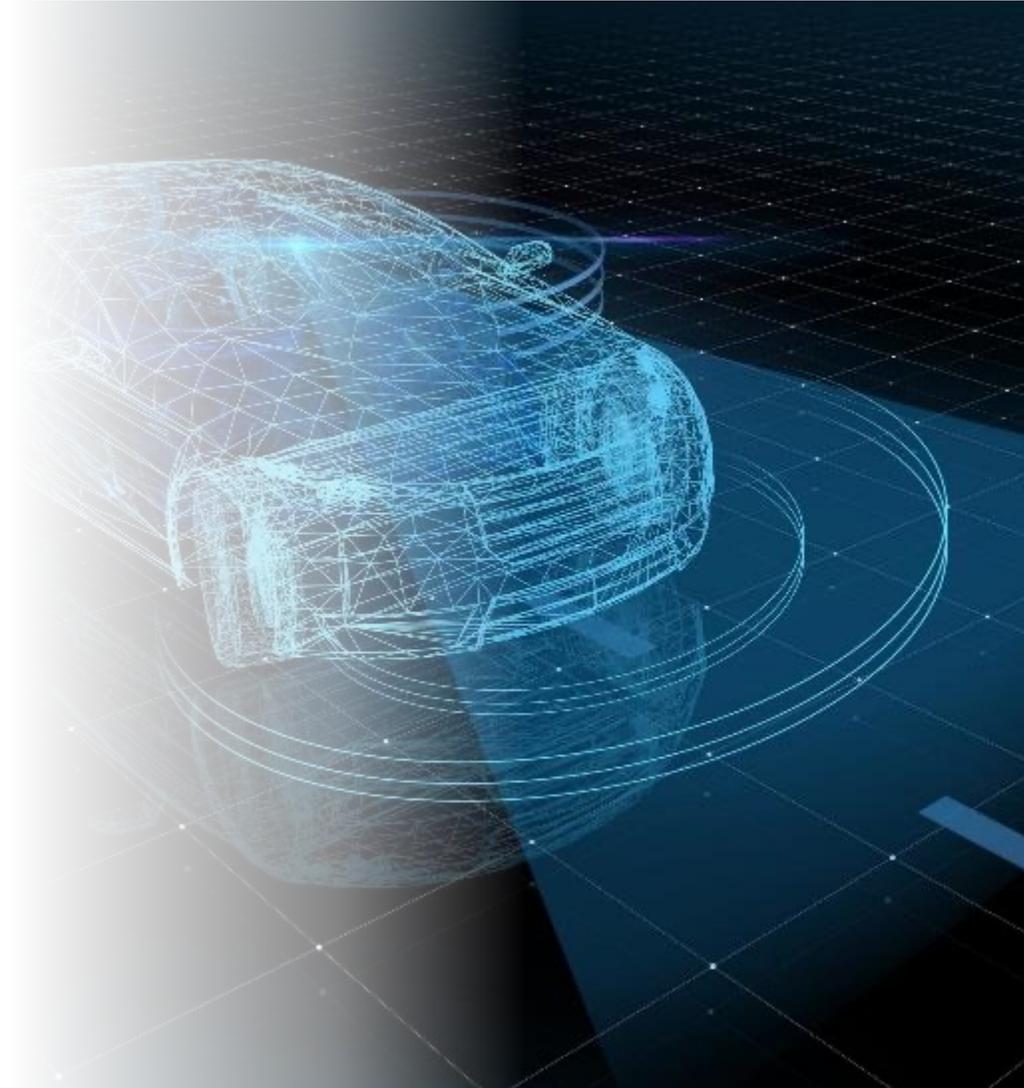
Multiple factors are triggering a rapidly growing industry curve:

- Automakers demand for L2 partially autonomous vehicles
- Improvements in Cost and Ease of Manufacture
- Wider market acceptance as leading players go public and target mergers

As such, this report is focused on automotive LiDAR, not generic LiDAR in all of its applications.

There are a number of autonomous driving companies with in-house LiDAR capability. These companies are mostly in the US and of a much bigger size compared to pure-play LiDAR companies. This report includes these companies in the overviews but excludes them in the case of financial statistics as their size distorts the analysis.

This report provides useful data and insight from technical, commercial and financial aspects for participants of LiDAR, optic, semiconductor, electronics industries and affiliate investors.

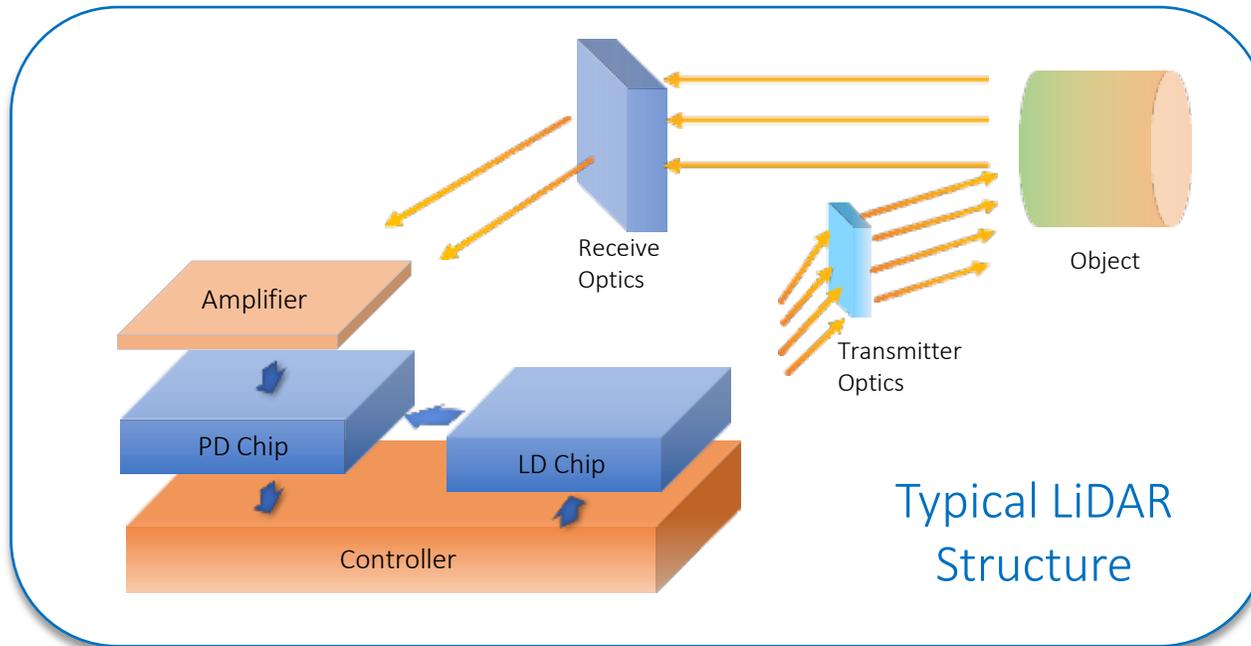




LIDAR TECHNOLOGY: DIFFERING PATHS

Automotive is the fastest growing LiDAR market

LiDAR is one of the most promising sensors for automotive autonomous vehicles. Automotive applications will become the dominant LiDAR market by value and unit shipments in the medium term.



Application areas for LiDAR

- Generation of high-resolution maps & GPS
- Wind Measurement
- Manufacturing
- Smart Infrastructure
- Logistics
- Autonomous Vehicles L1 – L5

Key Players:



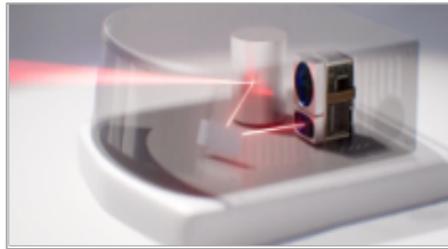
Current Technology Products Stack

While automotive LiDAR applications are set to dominate the LiDAR market, it is a competing solution for the automotive sensing market. Currently optical cameras or mmW radar paired with graphic processing ASICs are the incumbent solution.

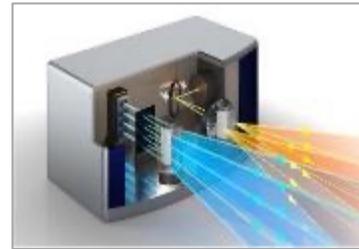
Rotating Cylinder



Spinning Mirror



MEMS



Flash

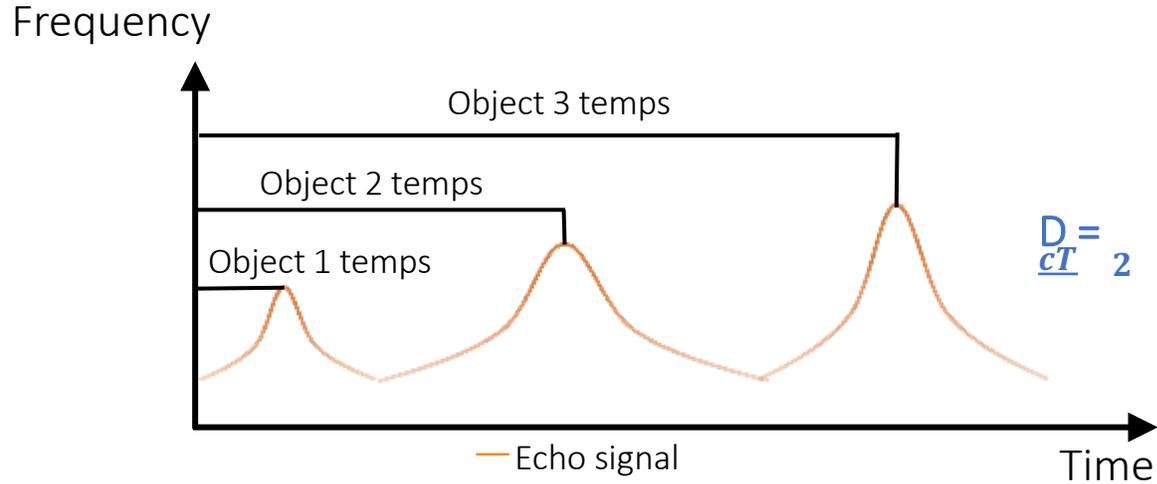


Automakers around the world are beginning to design-in LiDAR sensors into their vehicles with a large number of units ordered for 2022 and 2023



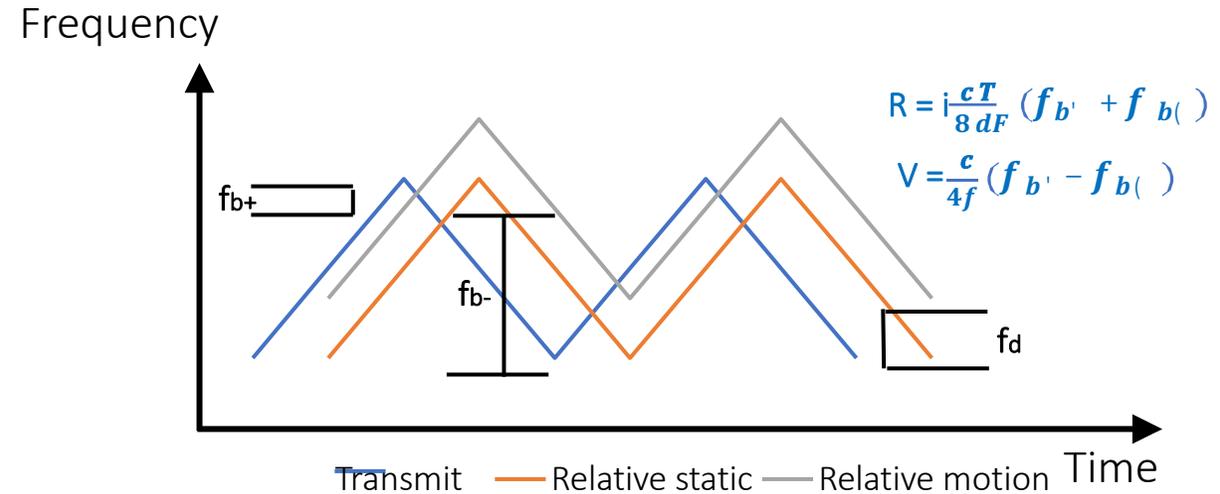
The LiDAR Industry is split between 2 Ranging Methods

Few players have mastered both Pulse & FMCW



Pulse (TOF)

The distance to the target is obtained by detecting the flight time (round trip) of the light by sending a continuous stream of light pulses to the target and receiving the light returned from the object with a sensor. Speed can be obtained by a relative frame by frame analysis using signal processing



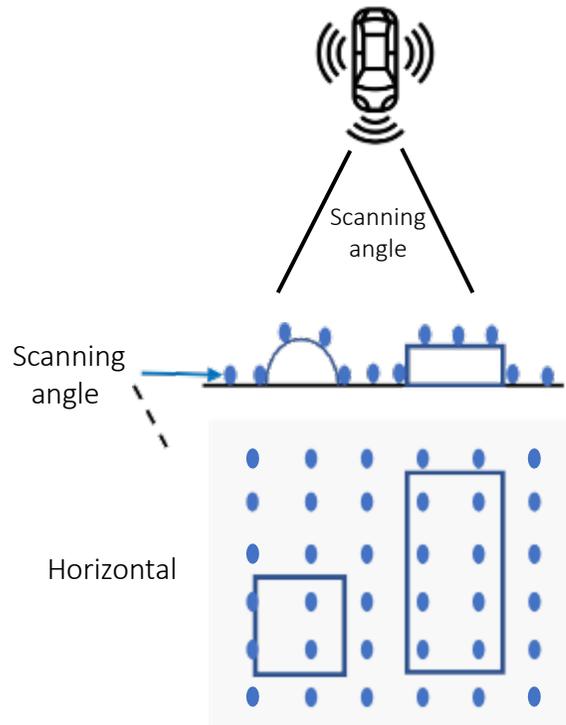
FMCW

A continuous beam of light is transmitted and a part of transmitted beam and the echo signal are coherently mixed to obtain the intermediate frequency signal which contains both the range and speed information of the target. Using signal processing it is possible to then extract the range and speed of multiple targets in the scanned field of view

Similarly, few players have mastered both Scanning and Flash methods

Scanning LiDAR

Scanning the environment by sending multiple laser beams at different angles horizontally and vertically



Mechanical

The transmitting and receiving systems physically rotate

MEMS

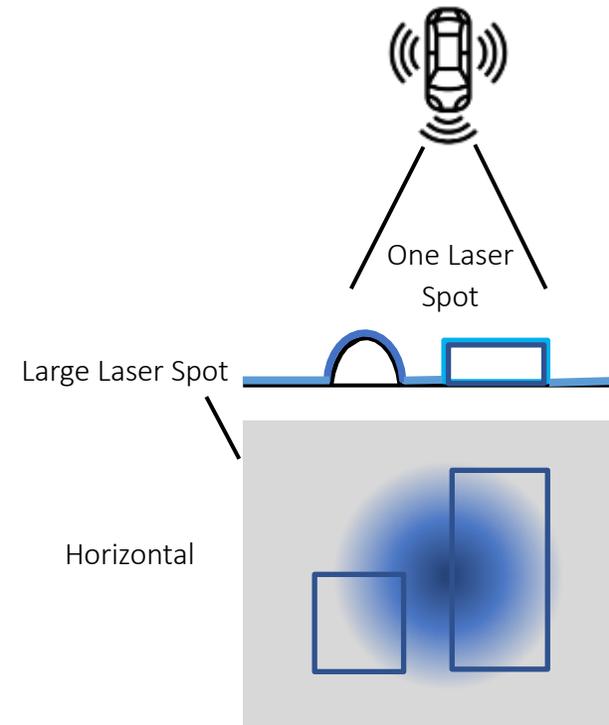
The transmitting and receiving mirrors still move, but the movement is by flexure of the mirrors

OPA (Optical-Phased Array)

Nothing moves, except the laser beam which reacts to programmable changes in refractive index. It is solid state

Flash LiDAR

Based on an array of lasers and detectors much like in a camera but different as each pixel can record the laser beam flight time



The Flash LiDAR light source is a set of laser beam array

A large array of laser beams covering the detection area is sent directly for a short period of time, and a highly sensitive receiver is used to view the laser painted environment



MARKET OBSERVATIONS

Technology Self-Reliance Incentive Policies Emerge Worldwide

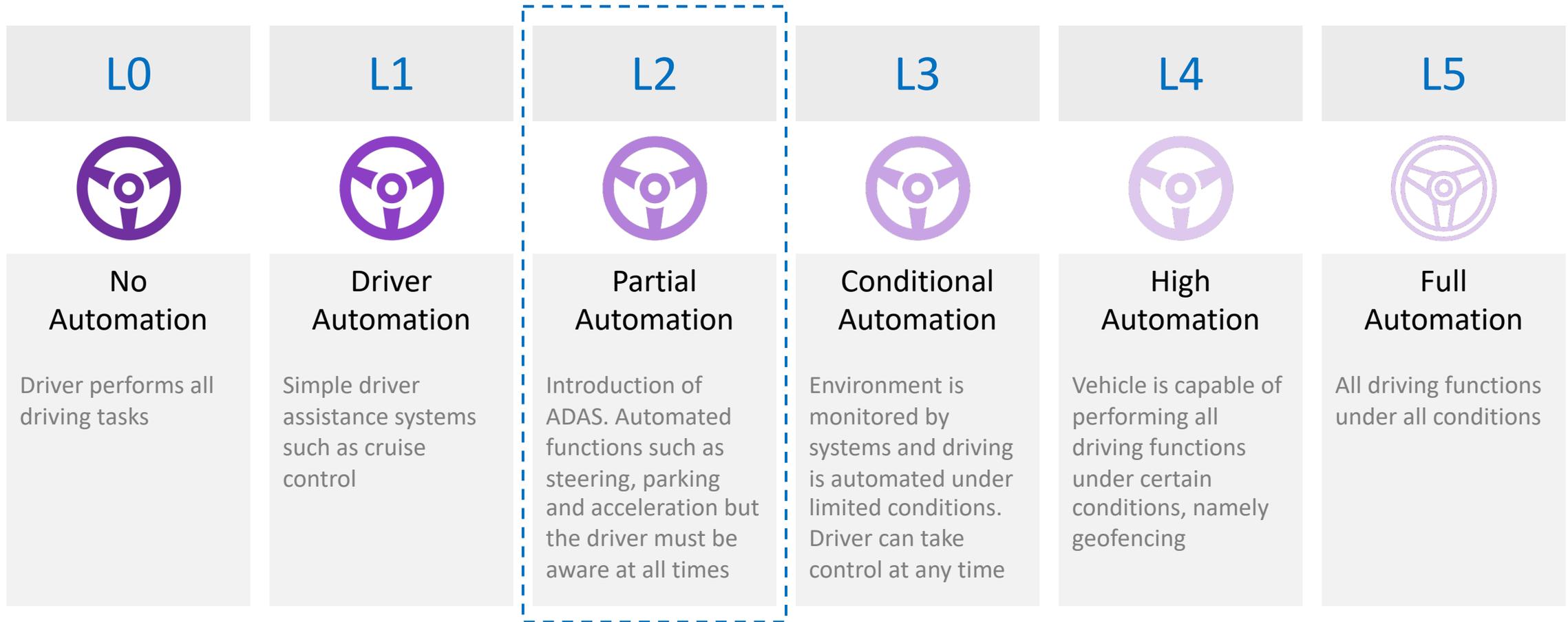
<p>Date: Jun-14 </p> <p>Following the publishing of the National IC Industry Development Outline, a significant number of municipal level supportive policies are debuted in China</p>	<p>Date: Oct-19 </p> <p>The Chinese government announces the second phase of its 50 billion USD National IC Fund, which aims to accelerate semiconductor equipment and materials manufacturing</p>	<p>Date: Apr-21 </p> <p>U.S. Innovation and Competition Act of 2021 (USICA) (S.1260), includes 52 billion USD in federal investments for the domestic semiconductor research, design, and manufacturing</p>	<p>Date: Feb-22 </p> <p>In Feb of 2022, US Congress passed the 'COMPETES Act of 2022', which will provide new subsidies for U.S. semiconductor manufacturing and among other measures</p>	<p>Date: Feb-22 </p> <p>The European Chips Act sets out measures to respond to future supply chain disruption, and to double EU's current market share of semiconductor production to 20% by 2030</p>
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<p>Date: Oct-15 </p> <p>'Made in China by 2025' is kickstarted with the goal of China's industries to be 70% reliant on Chinese supply chain by 2025, including microelectronics</p>	<p>Date: Mar-21 </p> <p>EU Commission sets digital transformation goals for 2030 with 'Digital Compass' initiative, including multi-country projects & legislation</p>	<p>Date: June-21 </p> <p>Senators put forward to congress the FABS Act [<i>not yet passed</i>]: a semiconductor investment tax credit, and could include expenditures to help strengthen the entire semiconductor ecosystem</p>	<p>Date: Jul-21 </p> <p>EU Commission launches the European Alliance on Processors and Semiconductor Technologies to design and produce microelectronics chips</p>	<p>Date: Feb-22 </p> <p>The EU announces potential for dedicated European Semiconductor Fund</p>
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Both the East and the West are taking steps to reduce its reliance on each other for microelectronics

Levels of Driving Automation

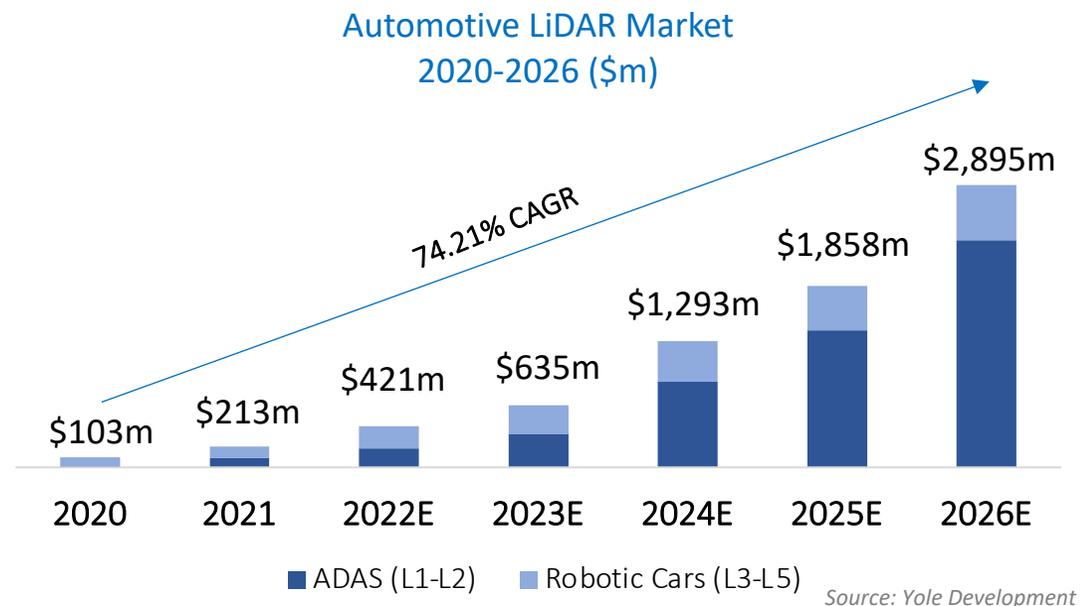


In reality **very limited number of vehicles have achieved L3** or above. The market is likely **many years away** from achieving significant autonomy in vehicles. However, a large number of automakers will **integrate L2 capability** in their vehicles in the **short-term**.

This step-change will **drive aggressive growth** in the LiDAR market over the next decade

Market Considerations: Automotive LiDAR

The market will experience explosive growth, fuelled predominantly by partially autonomous vehicle applications (L1-L2)



Key Drivers

- Commercialization of LiDAR sensors as price becomes more affordable
- Driven mainly by global mainstream automakers seeking partial autonomous driving through several Advanced Driver Assistance System (ADAS) sensors on their cars
- OEM Tier 1 suppliers purchasing and repackaging advanced systems
- Increased R&D spending in L3+ Autonomous Vehicle applications

Price of Mid-Range Automotive LiDAR sensors 2018-2021 (\$)

	2018	2019	2020	2021
Velodyne	\$4,000		\$500	
LUMINAR		\$500		
INNOVIZ TECHNOLOGIES			\$450	
Innovision		\$500		
AEVA				\$600
HUAWEI				\$200

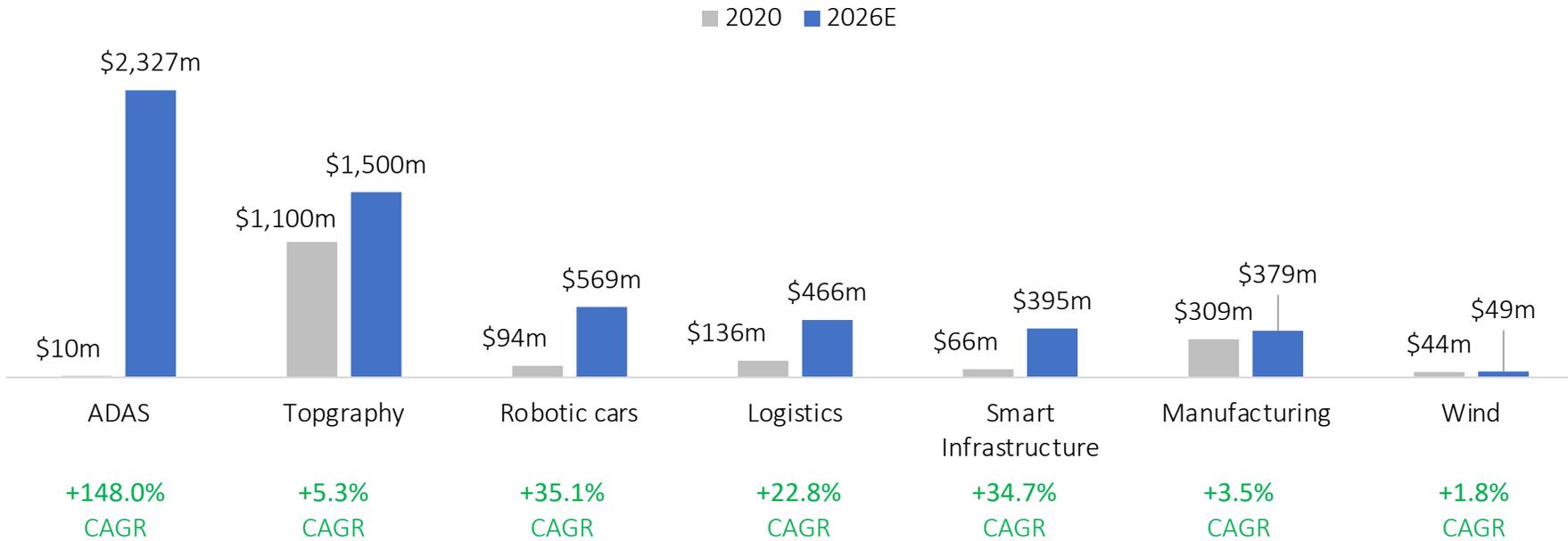
Source: Velodyne, Luminar, Innoviz, Innovision, AEVA, Huawei

Commentary

- The unit price of a mid-range Automotive LiDAR sensor is forecasted to drop below \$100 USD in 2026
- Typically 2 LiDAR sensors are equipped on an L2+ ADAS car, with many more LiDAR units (or other sensor types) needed on the higher L3-L5 applications
- As the automotive industry moves towards L3+, the number of LiDAR sensors on cars will rapidly grow. Sensor shipments will grow faster than the price will drop and the market in value and volume will expand substantially

Market Considerations: Total LiDAR Market

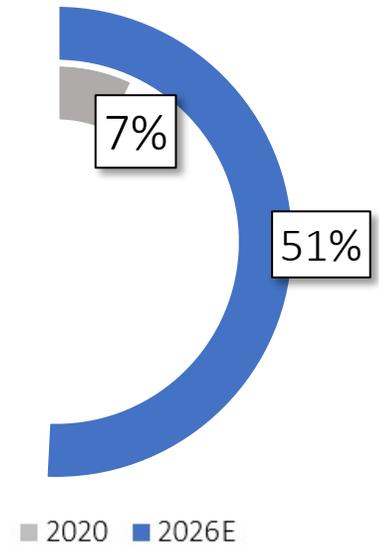
Global LiDAR Market by Application (\$m)

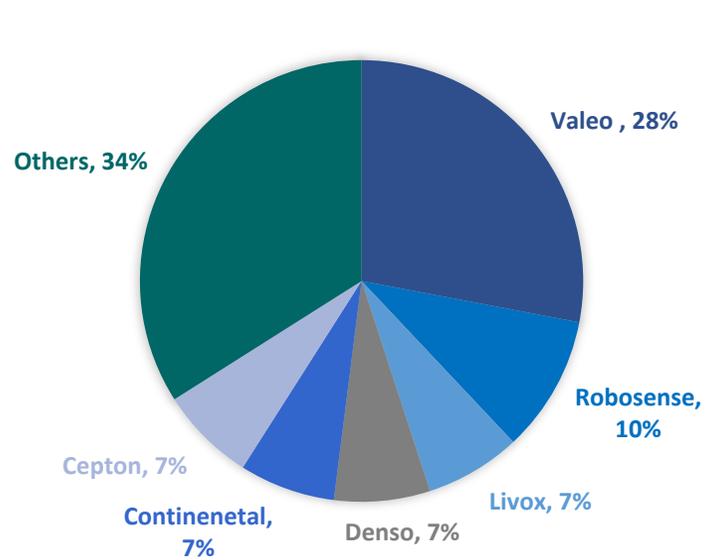


Comments:

- The Total LiDAR market is set to grow by 21.6% annually between now and 2026
- The market will be driven by demand for more units, while cheaper sensors & commercialization of the technology opens the doors to further applications
- Automotive LiDAR applications (ADAS & Robotic) are already benefitting from broader commercialization and are therefore the fastest growing subcategories
- Smart Infrastructure and Logistics will also experience significant growth as the industries will more readily adopt further LiDAR integration
- Topography is a mature market which will likely be surpassed by ADAS in size. While Manufacturing and Wind industries are unlikely to significantly increase their use of LiDAR technologies in the near future

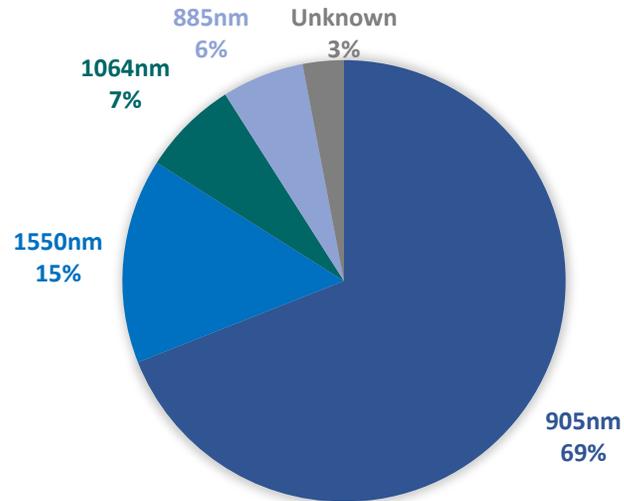
Automotive LiDAR Applications by Market Share (%)





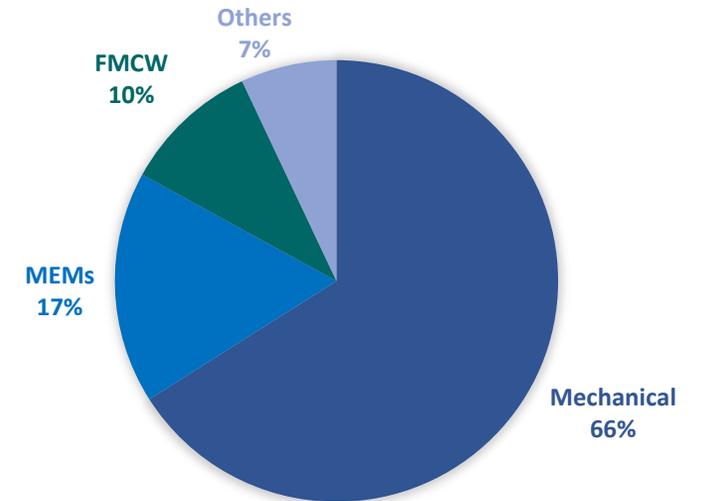
By Supplier

On the eve of commercialization, one leading player takes close to 30% market share, while the remainder of the market is spread fairly evenly over a well funded chasing group



By Wavelength

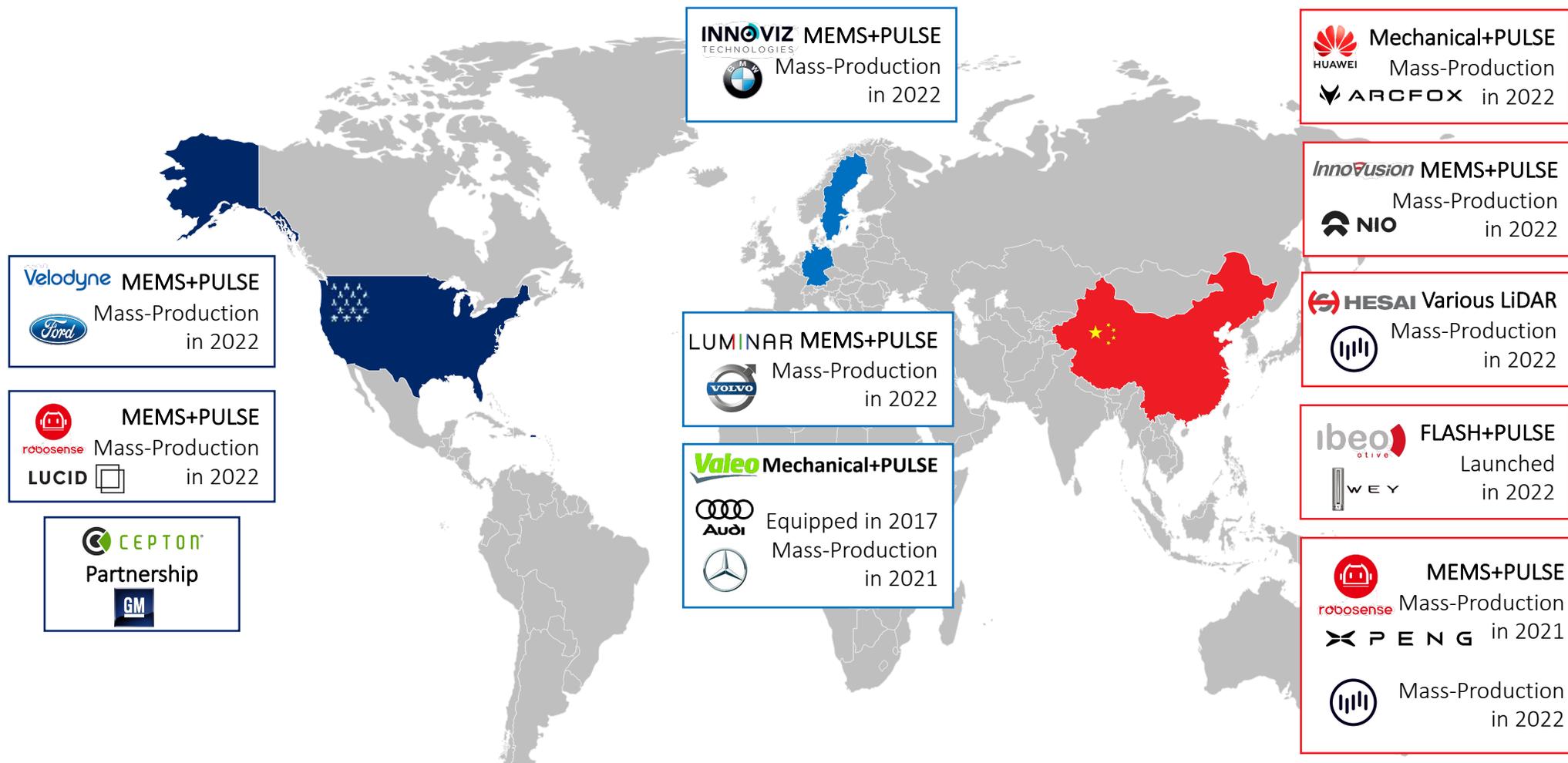
Automotive LiDAR products cover a wide range of wavelengths, each with various pros and cons. Also, once committed to a wavelength it is very difficult for LiDAR manufacturers to switch mid development. The most popular 905nm & 1550nm are also significant wavelengths in the adjacent transceiver markets



By Technology

Wavelength and technology are not completely separable as the choice of system often determines the wavelength, as compatible technologies for some light generation and detection schemes do not exist yet. Commercial considerations further complicate the identification of the optimum solution

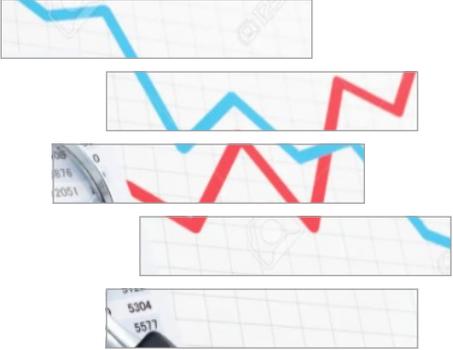
Final Stages of Commercialization



Automakers around the world are introducing LiDAR to premium models of their vehicles, with wider deployment across their models anticipated in the near future, as demand for partial autonomous driving increases



INVESTMENTS AND M&A TRENDS



1

From Private to Public via SPAC

Institutional Investors of LiDAR are shifting from private investments to more liquid publicly traded shares as several LiDAR companies have gone public via SPAC

2

Accelerated Consolidation

Largely fuelled by proceeds from SPACs, increased number of mergers within the LiDAR landscape & those adjacent in the industrial chain

3

Concentration as opposed to Diversification

M&A and investments are increasingly focussed on select key technologies, shifting from a diversified approach across multiple technologies

Growing Public Acceptance of LiDAR

Money Raised by LiDAR Companies, 2016-2021 (\$m)

Company	2016	2017	2018	2019	2020	2021
Velodyne	\$150m		\$25m		\$150m*	
Luminar		\$36m	\$114m	\$100m	\$170m, \$420m*	\$154m*
Ouster		\$30m		\$60m	\$42m	\$300m*
Aeva		\$4m	\$45m	Undisclosed		\$320m*
Aeye	\$3m	\$16m	\$40m	Undisclosed	\$30m	\$455m*
Innoviz	\$9m	\$73m		\$170m		\$350m*
Sense Photonics		\$5m	\$14m	\$26m	Undisclosed	
Robosense	Undisclosed		\$45m	\$38m		
Hesai	\$16m	\$40m			\$135m	\$370m
SiLC					\$12m	\$17m
Blackmore	\$4m		\$18m			
Innovusion			\$30m			\$130m
Quanergy	\$90m					
Ibeo						Undisclosed
Scantinel						\$8m

Source: Crunchbase

*Indicates Fundraise was through SPAC



Sep,2020
SPAC Valuation: 4B USD
SPAC Funding: 150M USD



Dec,2020
SPAC Valuation: 7B USD
SPAC Funding: 420M USD



Mar,2021
SPAC Valuation: 2.1B USD
SPAC Funding: 320M USD



Mar,2021
SPAC Valuation: 1.9B USD
SPAC Funding: 300M USD



Apr,2021
SPAC Valuation: 1.4B USD
SPAC Funding: 350M USD



Aug,2021
SPAC Valuation: 1.5B USD
SPAC Funding: 455M USD

Traditionally, the industry has been supported by occasional and small investments. The SPACs of 2020 & 2021 indicate a step change in the industry, signalling business validation and widespread acceptance of the technology

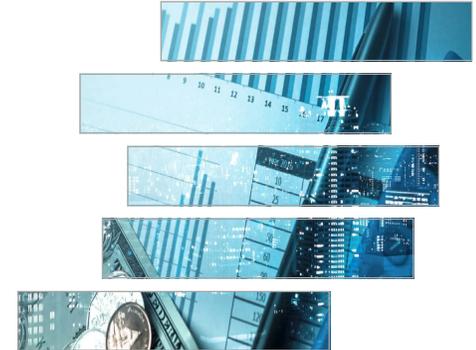
European Investors

In Europe, traditional automakers, Tier 1 and corporate investment arms constitute the majority of LiDAR investors



Chinese & U.S. Investors

VC, internet and semiconductor giants dominate; anticipate monetisation from the data collected from end-users



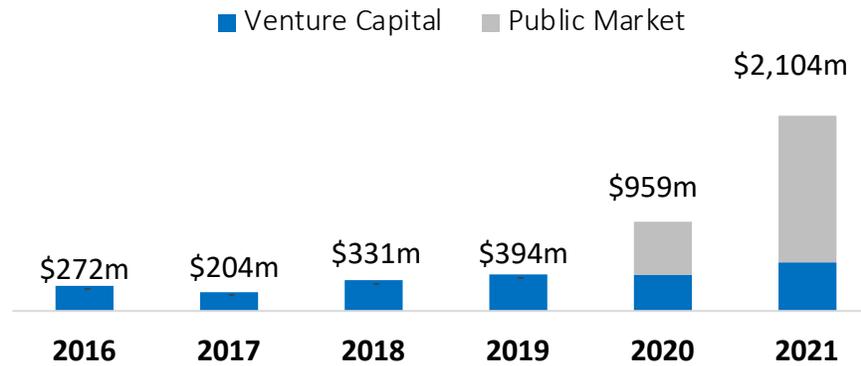
Global LiDAR Companies

Leading LiDAR companies have potential to evolve into full sensing solution
Tier 1 suppliers or even autonomous driving companies





LiDAR Industry Fundraises 2016-2021 (\$m)



2009-2013	2016	2016-2018	2017-2019	2020-2021
In the US, Waymo and Cruise pave the way for autonomous driving, benefitting from the deep pockets of the giant companies behind them: Google & General Motors respectively	Inflection point as autonomous driving begins to enter the pilot operational testing phase , triggering the attention of the financial world	Technology VC funds, from US & China accelerate their inflows into to the industry, investing into early stage R&D	Significant number of new entrants, with some making headway. Interest from PE funds sparks accelerated commercialization	Increased deployment into mass-produced vehicles . Investment from public markets becomes the dominant funding source

Europe



North America



APAC



1

Multiple Range Capability

An emerging trend driving horizontal integration is to expand products portfolio to cover multiple range capability



2

Future Consolidation Routes

Different technology stacks are likely to consolidate; FMCW and Flash would be symbolic consolidation event for the LiDAR industry

3

Performance, miniaturization and stability

As in the past, these will continue to be the underlying drivers for further investment and M&A, with Manufacturability and Price as key criteria

Notable M&A Transactions

Increasing M&A events driven by both **Autonomous Driving Company** and **Pure LiDAR company**

Pure LiDAR Company: more focus to commercialize its LiDAR and supply to automakers



Autonomous Driving Company: with in house LiDAR capability to support its autonomous driving solution

LUMINAR

➤ Well-Funded by VC

3 key investment rounds from 2017 - 2020 to accelerate R&D

\$420m raised in total before IPO

➤ Partner with Strategic investors

Autonomous vehicle production agreement and investment from Volvo

Business deal and investment from Daimler

➤ Successful Exit Round

\$5.4bn Market Cap today

\$574m funded from the reverse merger with the SPAC and combined financing round

Unique feature: 1550nm + MEMS

Using 1550nm laser as the source to deliver higher detecting performance, and select MEMS for ranging to reach low-cost purpose

Lower costs of laser and innovate ASIC through M&A

2016 acquired **Open Photonics**

2017 acquired **Black Forest**

2021 acquired **Opto Gration**

Mass-production in 2022

Iris
MEMS + PULSE



LUMINAR

Today, **Luminar Technologies** is a publicly traded company with a Market Cap of **\$5.4b**

The company operates in two segments: The Autonomy Solutions segment designs, manufactures, and sells lidar sensors, and related perception and autonomy software solutions, the other Component Sales segment engages in the designing, testing, and consulting of non-standard integrated circuits for government agencies and defence contractors

Despite a multi-billion dollar reverse merger with a SPAC, raising hundreds of millions of cash, the company is still not profitable and continues to seek out additional capital-raising initiatives with the latest being Mercedes purchasing \$20m of common shares. However, the company is seen favourably by the market, trading at 153x TEV/LTM Revenue

Luminar [LAZR]: Outside View					
Revenue	31.9	Market Capitalization	5,477.6	TEV/Total Revenue	153.4x
EBITDA	(210.4)	Enterprise Value	4900.0	TEV/EBITDA	NM
EBIT	(214.6)	Cash & ST Invst.	792.1	P/Diluted EPS (b.e.)	NM
Net Income	(238.0)	Total Debt	619.5	Price/Tang BV	26.2x
Capital Expenditure	(6.4)	Total Assets	883.5	Total Debt/EBITDA	NM

Source: Capital IQ

Currency in USD in mm, LTM as of Dec-31-2021 TEV where available and Market Cap are calculated using a close price as of Mar-02-2022

**S&P
Capital IQ**

Vertical Integration

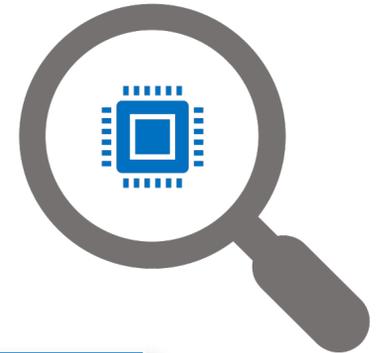
Innovative light source, detector, optical integration solution, ASIC, algorithm, mapping are the critical jigsaws to collect for vertical integrator

1

Deciding the mainstream model

Under debate, but IDM or fabless are likely to become the mainstream manufacture model

2



Divergence of Optics Business

Traditional Optics players may create spin offs or divest business units

3

THE TECHNOLOGY PREDICTIONS





Phase I

Large LiDAR systems for R&D

Historically, LiDAR has evoked images of test vehicles with a number of cylinders mounted on roofs

The technology is proven and validated but smaller more useful applications are sought out



Phase II

Integrated Systems in mass-produced vehicles

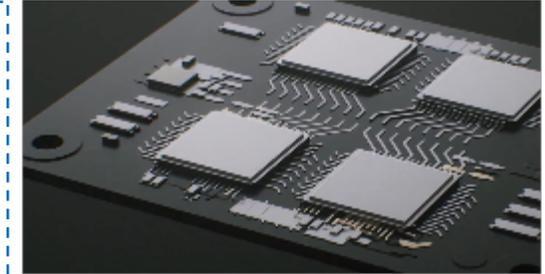
With the advances on performance and price, LiDAR players crossed the requirement threshold for automakers and end customers

LiDAR is now available in a wide-variety of top end mass-produced vehicles

Market Today

Further Development in:

- *Solidity*
- *Reliability*
- *Miniaturization at Wafer Level*



Phase III

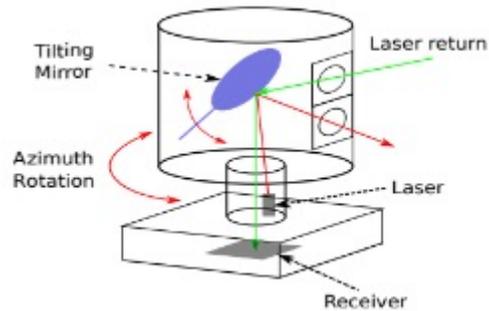
Photonic & Solid Integration

RCL believes the next breakthrough will be the integration of optical modules and digital process units

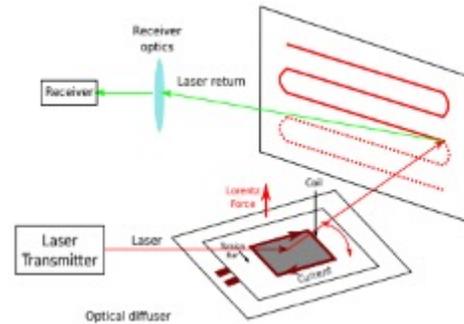
Conventional discrete device designs are too bulky and costly. Highly-integrated LiDAR chips may be the route to overcome these limitations

Mechanical Structure (MS)

Mechanical spinning LiDAR



MEMS LiDAR



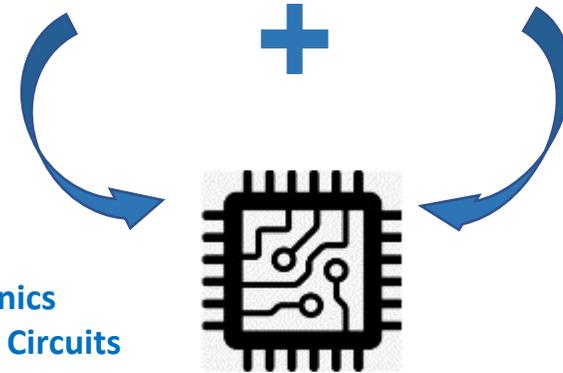
Traditional players have made major advances either; through the mechanical rotating systems feeding into the MEMS; or by increasing the number of miniaturized light sources and forming them into an array, with higher manufacturability and quality control

Wafer Level (WL)

Integrated light source

Solid state chip level scanner

Photonics Integrated Circuits



Newly emerging & disruptive LiDAR players have approached problems from a fundamentally novel approach by using unique integration architectures which incorporate different light sources and scanning systems at the chip level

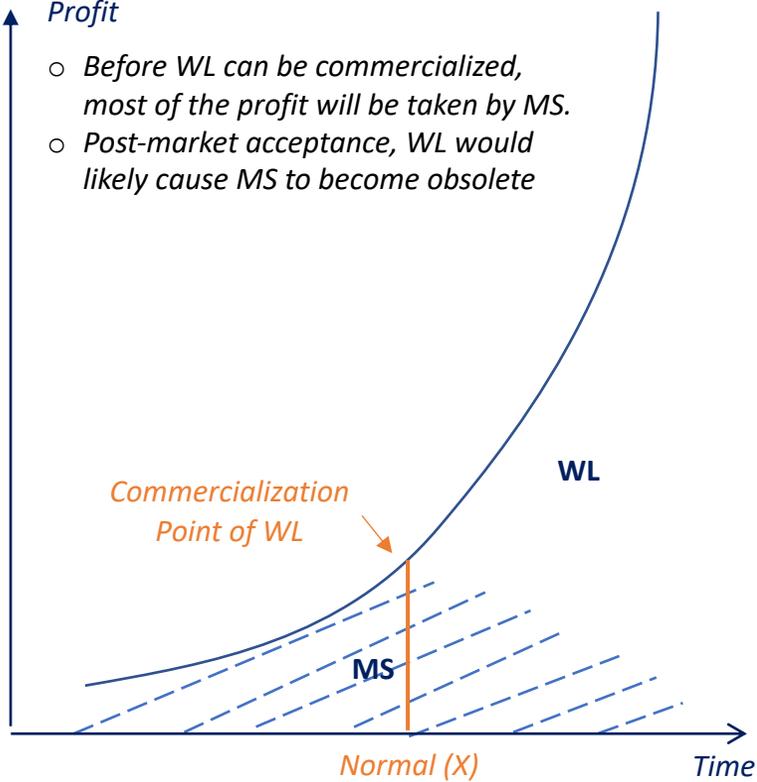
Wafer level manufacturing is the ideal high volume manufacturing techniques, as demonstrated by the ubiquity of CMOS electronics which is found in abundance in not only automobiles but also other daily-use smart devices

The Dominant Solution: What will be the decider?

Base

Profit

- Before WL can be commercialized, most of the profit will be taken by MS.
- Post-market acceptance, WL would likely cause MS to become obsolete

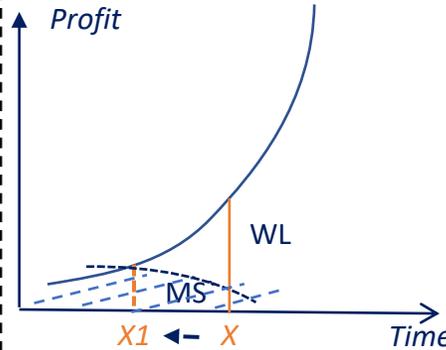


MS: Mechanical Structure WL: Wafer Level

Scenario 1

Profit

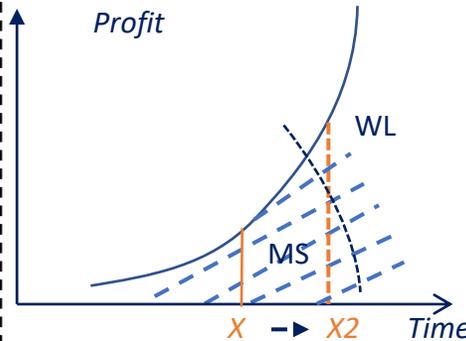
- If WL can be commercialized earlier, it can enjoy the ramping up of LiDAR demand and become the dominant solution



Scenario II

Profit

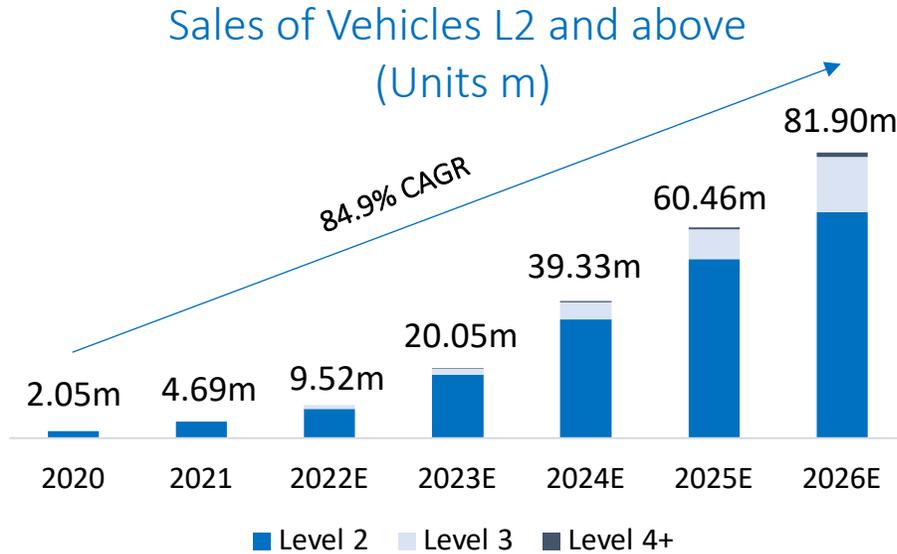
- If WL takes a longer time to commercialize, it leaves the market open for MS products to grow
- Constantly improving MS products would be difficult for WL to compete with



The deciding factor is not which approach is better technologically, but rather how long WL takes to achieve critical mass

MS players are growing rapidly and gaining market share in a this expanding market

As such, MS players have access to more resources: speeding up development and expanding capabilities in ASIC & software. Further leaps ahead may come from External Investments, Acquisitions or Internal Incubation



Commentary

- The automotive industry is accelerating to embrace ADAS and autonomous driving
- L2 vehicle sales will experience a 77.8% CAGR, while L3 vehicles will likely double every year from 2023-2026
- **Demand for sensing capabilities, LiDAR or otherwise is driven by L2**
- This will push the automotive sensors sales volumes to new heights

All Sensors Volume Up

Higher autonomy vehicles require more sensors of multiple types

LiDAR Market Maturing

Increased demand for automotive LiDAR along as market share grows in sensor market

Alternative Sensors compete with LiDAR on 3 levels

Camera & MMW Radar are stronger in:

- Solid state
- Performance
- Cost of Manufacture & Purchase

It is the RCL view that LiDAR needs to transition to wafer scale integration before it can become the dominant sensor solution for L3 deployment

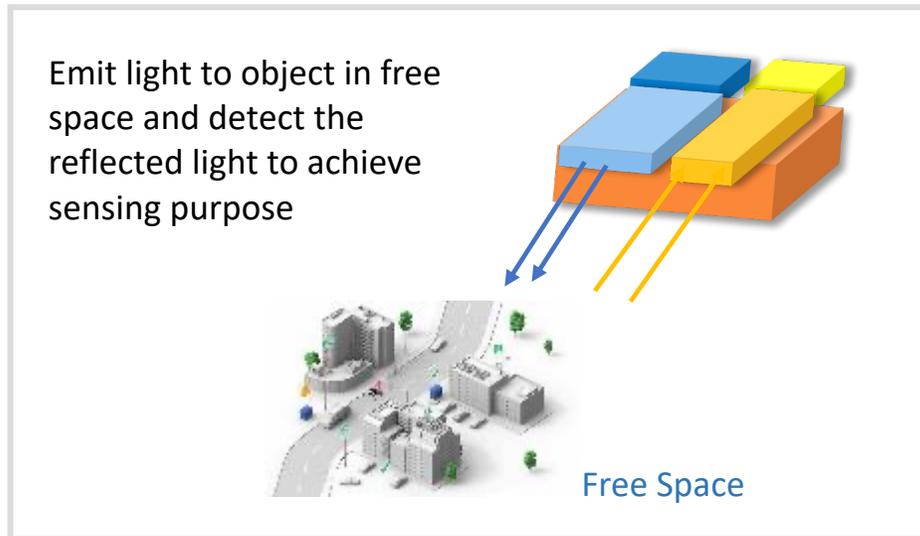


MARKET DYNAMICS PREDICTIONS

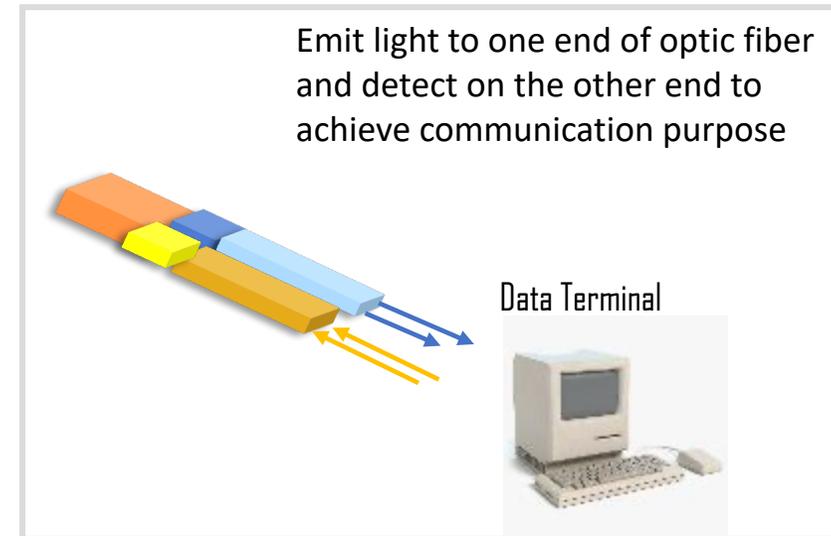
Transceivers: Will History Repeat itself for LiDAR?

Transceivers and LiDAR modules are similar in components and terminology, but they come together to achieve separate functions. These neighbours in the Optical Module Community might have answers for what the future holds

Automotive LiDAR



Optical Transceivers



Optical Modules

Active Transmit	EML,	DFB	VCSEL		
Passive Transmit	Collimator	Splitter	Diffuser		
Active Receive	PIN	APD	SPAD	SiPM	
Passive Receive	Lens	Isolator	Filter		
Digital Part	ADC	Driver	TIA	ASIC	FPGA

The 2000s were a defining decade for the optical transceiver industry, with innovative technology, product releases and stellar market growth. The LiDAR industry's 2020s may be very similar

2000s - Optical Transceivers

FINISAR

After listing in 1999, Finisar grew into a giant of the optical transceiver industry

Over **\$100M Market Size**

Booming Internet market at the beginning of the century pushed the market size crossed 100 million USD

Over **50**

Companies active in the market, from well established telecom giants to start-ups

1G

1G Ethernet speed is required, from M era to G era

2020s - Automotive LiDAR

Velodyne

2020, Velodyne is the first LiDAR company to go public

\$102M Market Size

After many years road test, LiDAR started to be implemented on mass-produced vehicle

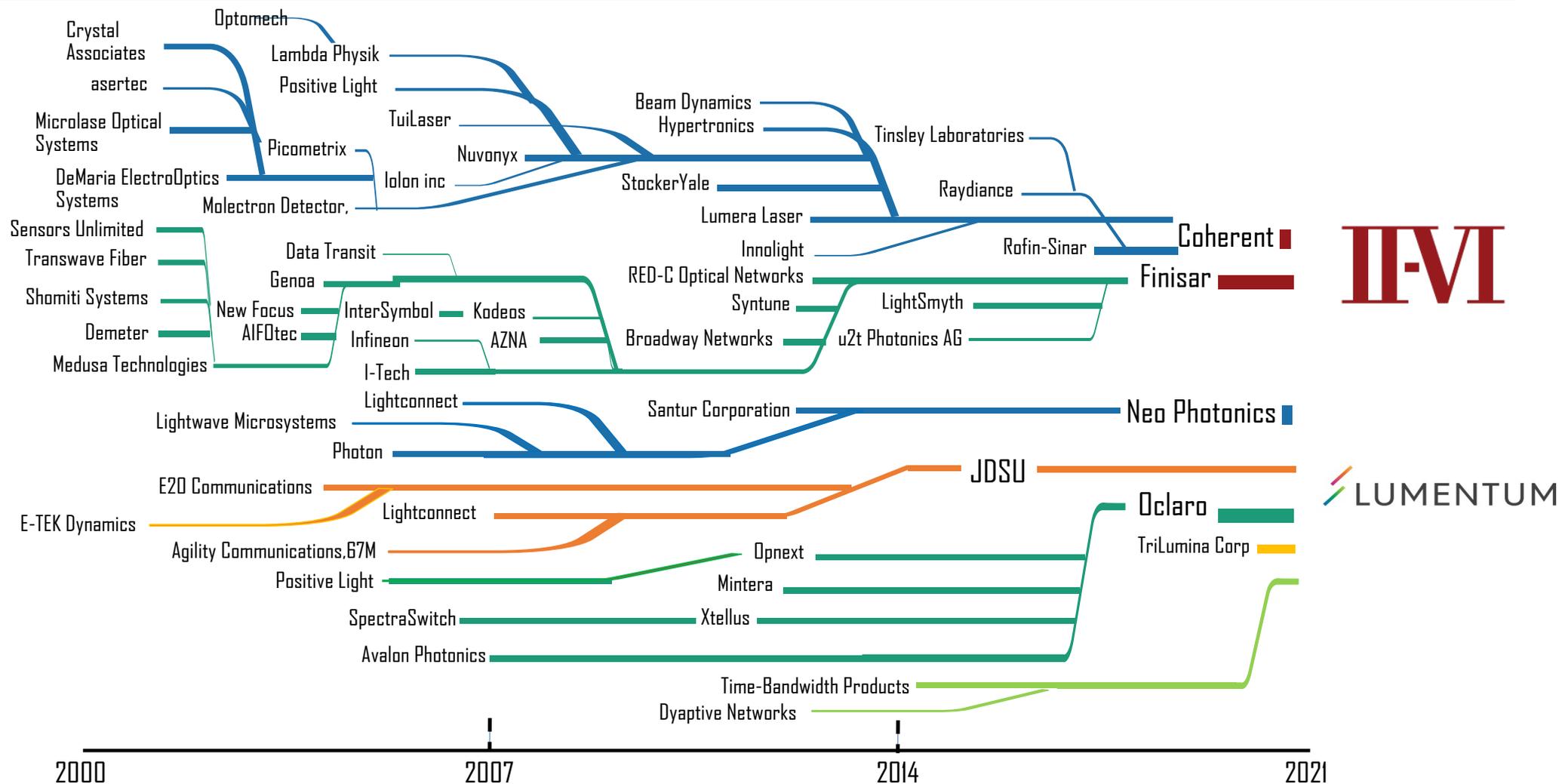
Over **85**

Start-ups with differentiated technology roadmaps shaping the future of the industry

Miniaturization

With the proven performance of automotive applications in LiDAR, miniaturization is on the way

Transceiver's Path to Consolidation



The industry's path to consolidation has occurred over **several stages**, and over **20 years**. Lidar might have a similar path. Today, there is no clear leader in **LiDAR**, there is **still room for new entrants, new consolidators and new winners**

RCL believe the development of the Automotive LiDAR Industry would likely follow a similar development path to that of the Optical Transceivers Industry, with potential for a faster pace

2020s - Optical Transceiver

II-VI
FINISAR

Finisar (now II-VI) has the top spot in this industry after multiple M&A, and being acquired by II-VI

\$9.6b Market Size

100X industry growth in 20 years despite several difficult industry cycles

10

Major Companies remain active in the market after a series of acquisitions

800G

Mega data center is planning to adopt 800G transceiver to meet the cloud's traffic requirement

2030s - Automotive LiDAR



\$10b Market Size

50m vehicles equipped with an average of 2 LiDAR units of LiDAR priced at 100 USD per unit

After going through an industry cycle, the winners would be those who have succeeded in acquiring exogenous growth through M&A activity

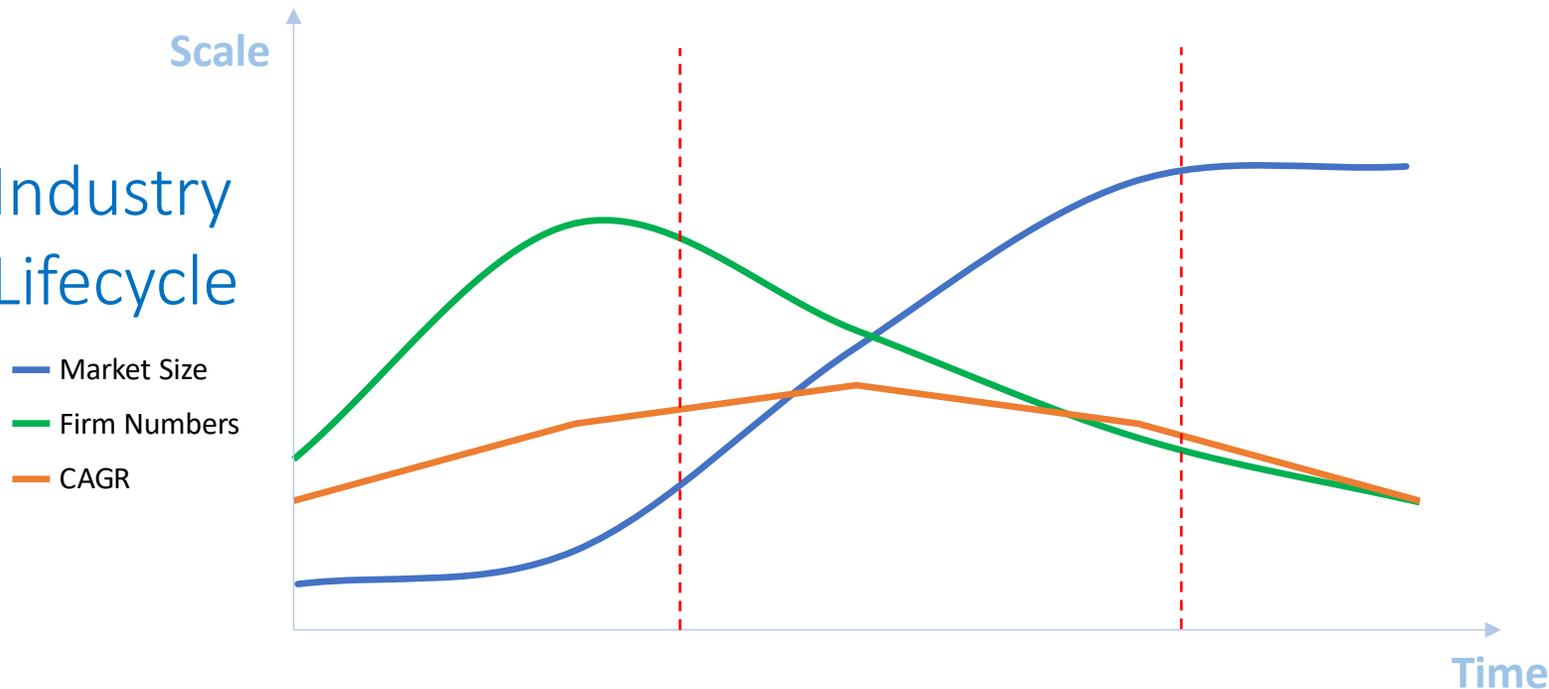
Fewer than **20**

LiDAR companies left standing post-cycle, similarly few left standing in the optical automotive industry

Solid-State

Pure solid-state LiDAR is the mainstream solution

Industry Lifecycle



Incubate

A large number of start-ups are incubated by inflow of capital. The market ramps but not enough for start-ups to be self-sustainable

Growth & Concentration

Growth continues, but the market becomes more concentrated, with a small number of key players emerging

Maturity

The market stabilizes with limited growth potential, further consolidation leads to fewer players

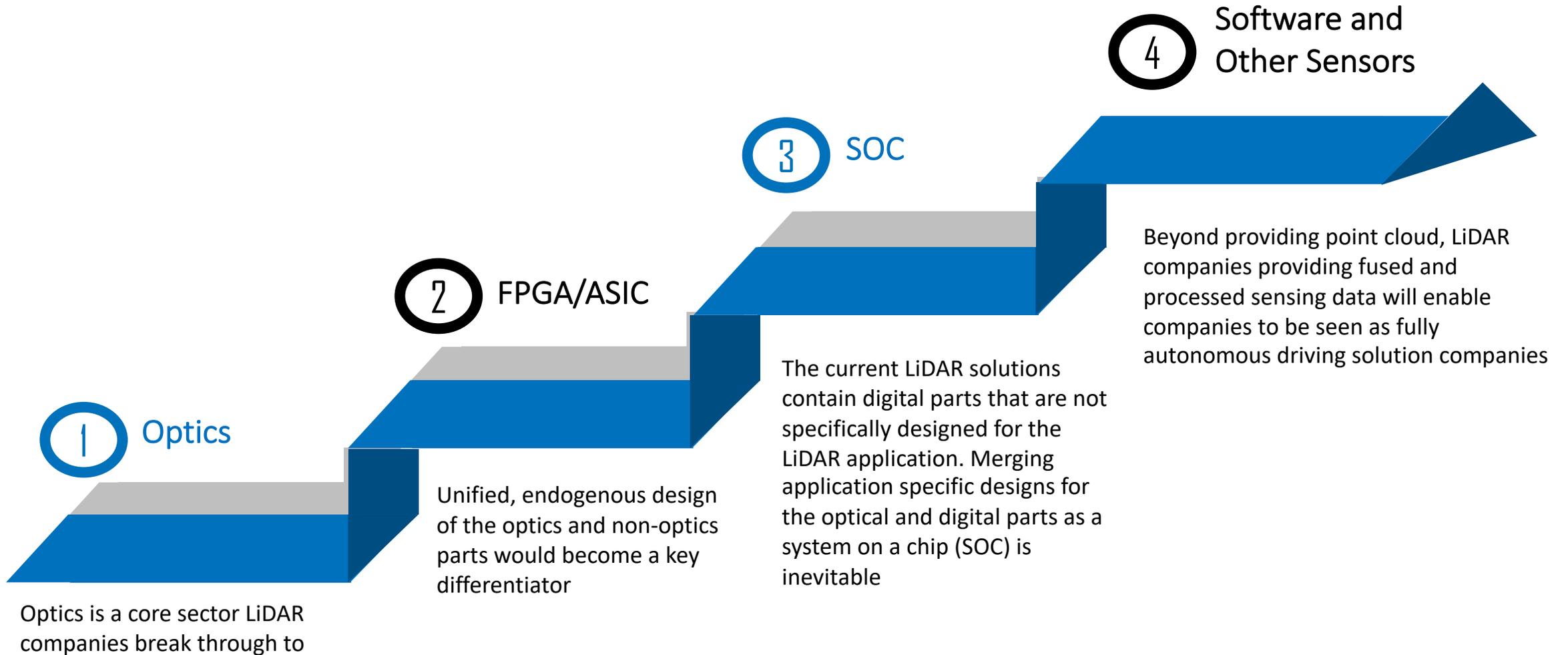
Usually, the path of profit-seeking capital is a good indicator of a change in dynamic

As the market expands, start-ups have a choice if they hope to survive:

- Play the role of an integrated or independent solution later expanding through M&A to achieve end-to-end.
- Be unique and focussed on solving the most difficult problems, with a view to being acquired once the solution is validated

Expanding the Boundaries of LiDAR M&A

RCL believes M&A will continue to be active among LiDAR and related optics companies in the short-term. With the maturing of the industry, cross discipline M&A would become increasingly common as leading LiDAR companies are likely to target an evolution into end-to-end autonomous solution companies





MARKET DYNAMICS PREDICTIONS

RCL's View to the Future

Merging of Technologies and Businesses

- The consensus is that multiple different sensors working in unison, including camera, mmW radar and LiDAR will be the universally adopted solution for ADAS and autonomous vehicles
- The challenge for LiDAR players is that cameras and graphic processing ASICs are a more well-established solution
- Moreover, graphic processing ASICs are following Moore's Law, meaning cameras are likely to become the ubiquitous automotive sensor solution
- This will limit LiDAR's market share growth into the market given its stage of maturity
- The longer LiDAR takes to improve, the stronger the competition LiDAR players would face from competing solutions; therefore, a fast commercialization of LiDAR is crucial if LiDAR is to become the dominant solution in the market

Business & Investment Strategy:

- LiDAR is unlikely to achieve Moore's Law, so players must focus on the manufacture, integration and packing approach; today wafer-level manufacturing and packing is the best route to faster scaling
- The fast-growth trend of LiDAR and its associated development of relevant supply chains will bring significant opportunities for investors in a More-than-Moore ecosystem



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