# LIDAR TECHNOLOGIES FOR THE AUTOMOTIVE INDUSTRY

## TECHNOLOGY BENCHMARK, CHALLENGES, MARKET FORECASTS

*Which LIDAR technology(ies) will win the race towards autonomous driving?*

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# TRENDS OF THE AUTOMOTIVE INDUSTRY – 1/5

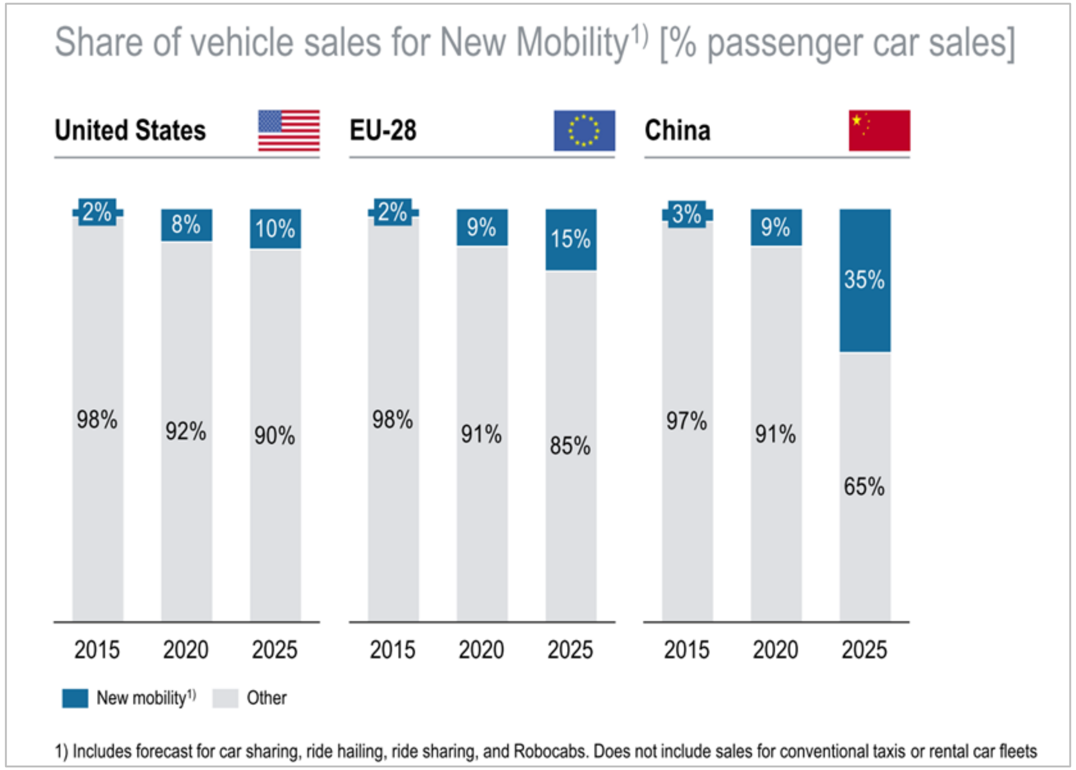
## Supplier and OEMs will need to build new business models to comply with new mobility schemes and the increasing connectivity of vehicles

### NEW MOBILITIES

- New mobility models emerge, especially pay-per-use models such as car/ride sharing, carpooling, “e-hailing” taxi alternatives, and peer-to-peer car rentals.
- Companies like Uber or Lyft are already developing these new transport models that meet the need for decongestion and environment protection, especially in urban areas.

### DIGITIZATION / CONNECTIVITY

- Communication between vehicles, between driver / passengers and vehicles will be more and more implemented in cars.
- Customers expectations are evolving, the car is now seen as a service provider adapted to each one: information, entertainment, etc.
- In this context, software and artificial intelligence companies will have a crucial role to play in future car developments.




Source: Global RB Mobility Revenue and Profit Pool Model, Lazard, Roland Berger

Source: Lazard / Roland Berger, Yole Developpement, IHS WardsAuto

Graph source: "Global Automotive Supplier Study 2018", Lazard / Roland Berger, December 2017

# TRENDS OF THE AUTOMOTIVE INDUSTRY – 2/5

## Regulations and technology readiness are pushing powertrain electrification and autonomous driving

### MORE SAFETY

- More driving safety is a demand both from customers and public authorities.
- It has led to the development of numerous robust ADAS (Advanced Driver Assistance Systems) features that are now implemented in series in cars.
- The demand for higher safety will continue to attract new players from the technology side.

### ELECTRIFICATION

- The growth of the electrical vehicles share will be driven by:
  - Developments of technologies for hybrid electrical vehicles and battery electrical vehicles are accelerating,
  - Increased regulations on $CO_2$ emissions, especially in Europe,
  - Potential oil prices rise,
  - Awareness of customers regarding ecological impact of cars.

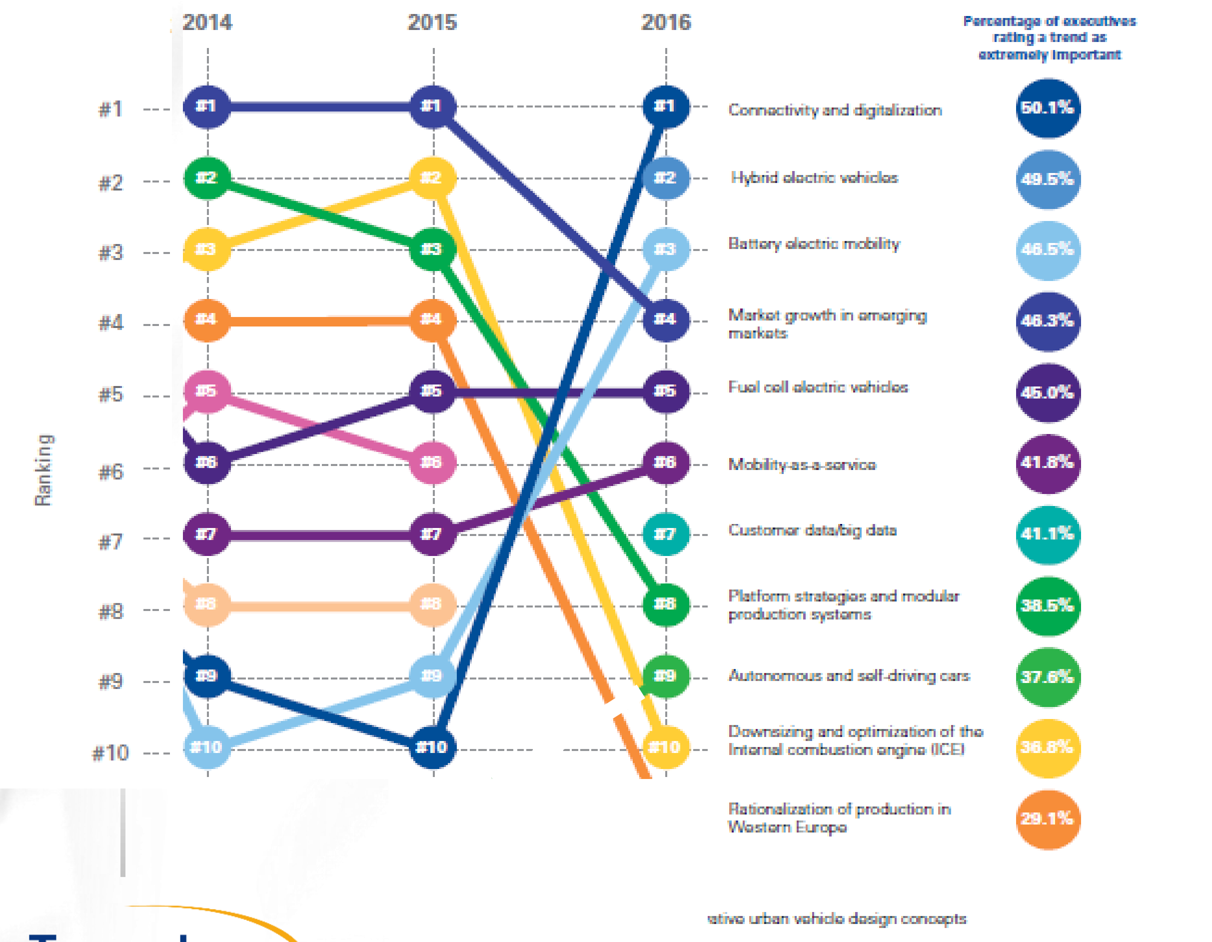
### AUTONOMOUS DRIVING

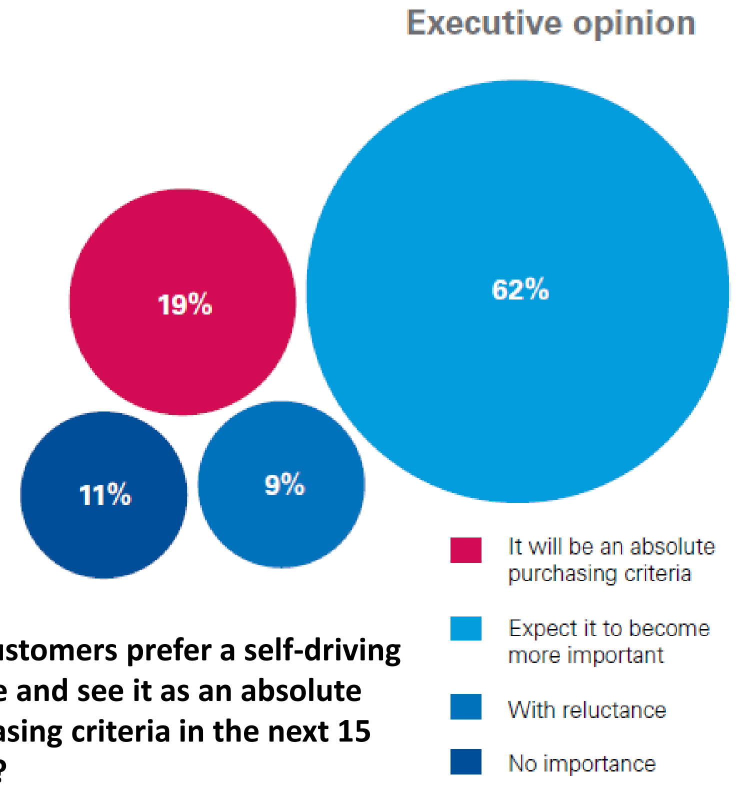
- One of the major trends of the industry for the next decade is the development of autonomous vehicles.
- Since 2007 and the first autonomous cars in DARPA challenges, the feasibility of automated driving has many time been demonstrated.
- The current challenge is to implement the production of such vehicles. The difficulty lies in the necessity to adapt technologies of the demonstration vehicles to automotive requirements: long-term operation, low maintenance, low cost, standardization, mass production, reliability, extreme temperature operation, etc.
- The development of autonomous vehicles will be highly related to the adoption of new mobilities. For example, autonomous "taxis"/shared vehicles are currently tested in cities around the world.

Source: Lazard / Roland Berger, Yole Developpement, IHS WardsAuto

# Autonomous vehicle became lately an issue for decision-maker

**What are the key trends until 2025 ? (Question to Executive in OEM and Tier )**

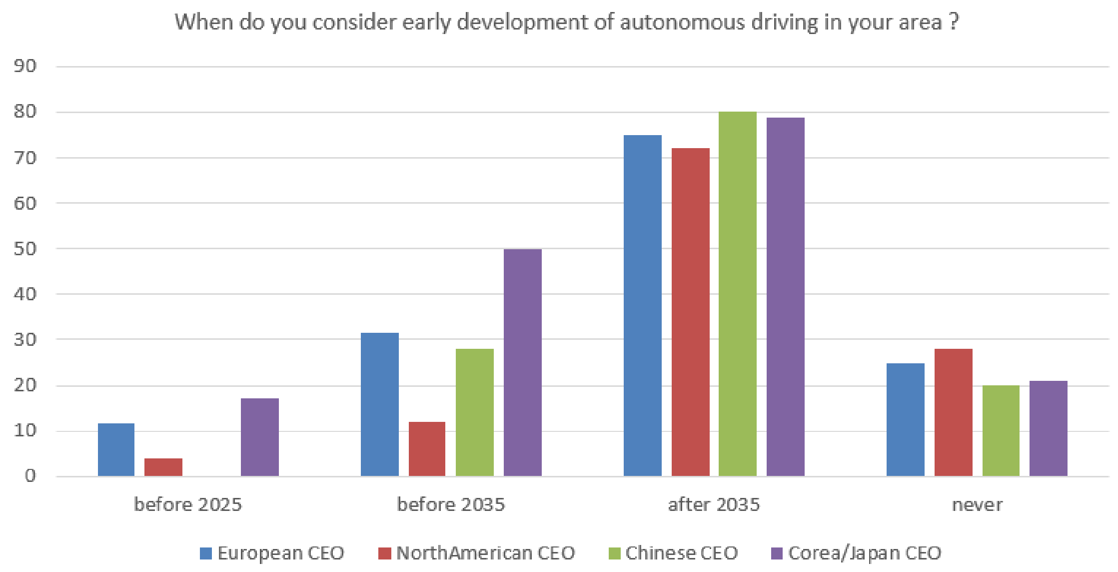


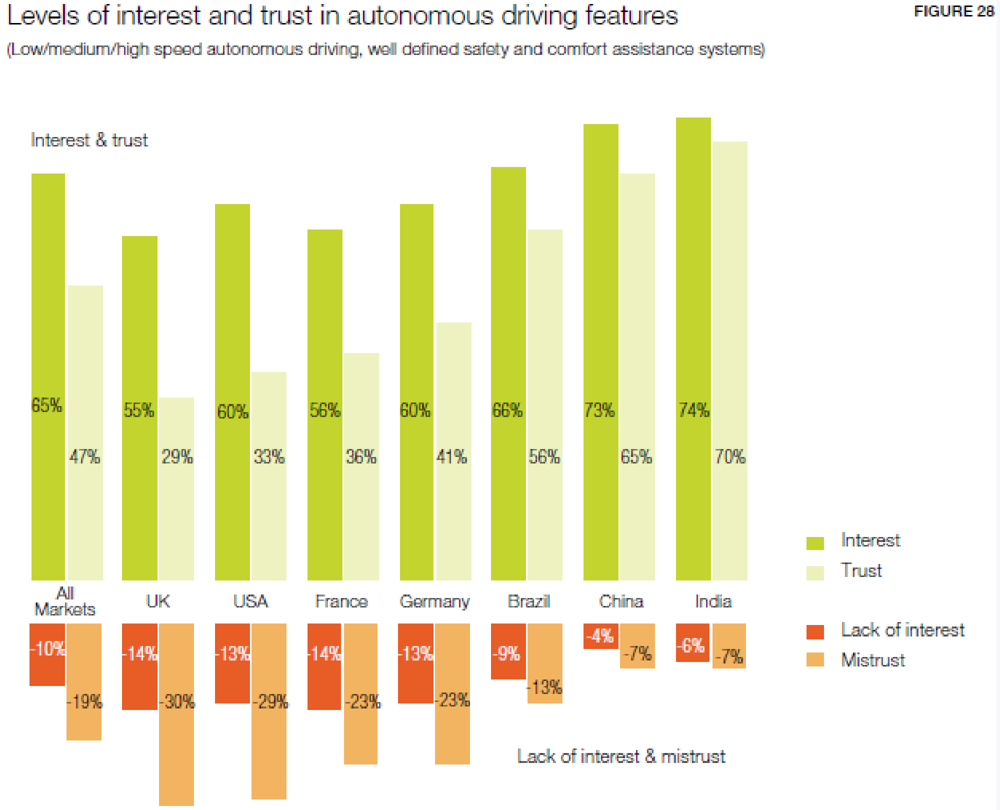



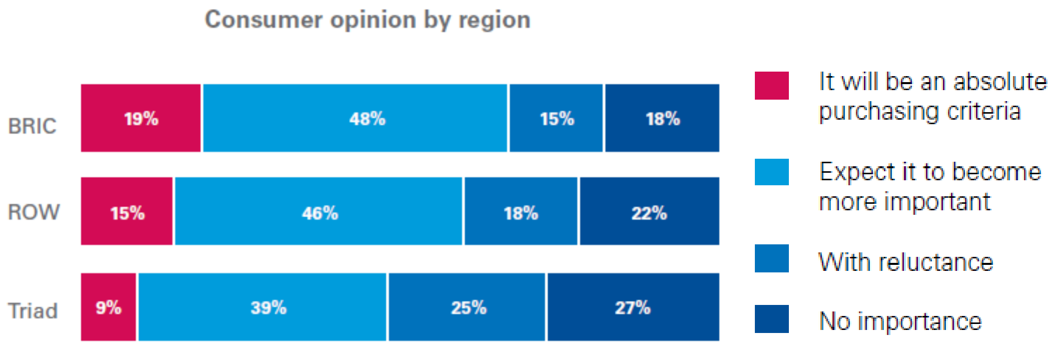

**Will customers prefer a self-driving vehicle and see it as an absolute purchasing criteria in the next 15 years ?**

Source : KPMG, GAES Study, 2016

# And in the meantime, consumers' reluctance still at high levels in triad countries




Source :Goldman Sachs, 2016, KPMG, GAES stduy 2016

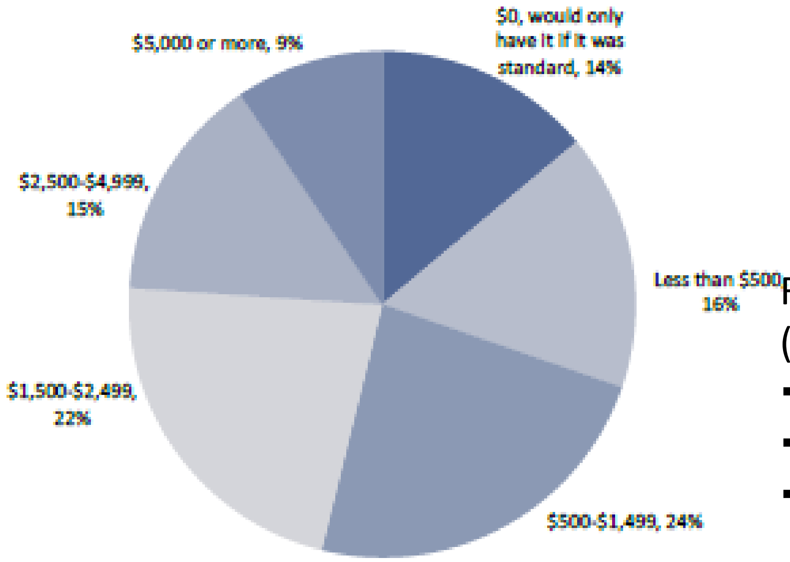
## But market education started 4 years ago and is now increasing consumer's willingness to pay

**When buying a car, how much extra would you be willing to pay for fully autonomous driving capabilities ?**

| Measure | US | UK | Australia | Total |
|---|---|---|---|---|
| 25th percentile | 0$ | 0$ | 0$ | 0$ |
| 50th percentile | 0$ | 0$ | 0$ | 0$ |
| 75th percentile | 2000 $ | 1710 $ | 2350 $ | 1880 $ |
| 90th percentile | 5800 $ | 5130 $ | 9400 $ | 8550 $ |
| Percent responding 0% | 54.5% | 59.8% | 55.2% | 56.6% |

55 to 60% of consumers didn't want to pay extra for autonomous driving functions in the survey 2014

Source : Michigan University, 2014,




Results of Survey 2015
(Goldman Sachs Study, 2000 Consumers interviexed)
- ➔ 14% for free
- ➔ 16% for less than $500
- ➔ 24% for less than $1500

Source : Market adoption, Michigan Univeristy, 2014, GoldmanScahs, 2015

# Trends in LIDAR : Investment of OEM manufacturers and Tier 1

## Almost all of major players in the automotive industry are investing in 2018 in the LIDAR technology as a key technology for automated driving

- The majority of Tier 1 suppliers and OEM manufacturers are investing in the development of LIDARs sensors for ADAS and autonomous vehicles.
- They all agree on the fact that LIDAR systems will be adopted among other sensors: RADAR, cameras, ultrasounds.
- Indeed, these sensors are complementary and multiple sensors will be necessary for redundancies and for back up in case one of them fails, especially in fully autonomous cars.
- Some OEM adopt a different strategy regarding LIDAR:
  - NO LIDAR
    - Tesla adopted a NO-LIDAR strategy for its autonomous car, stating that current LIDARs are too bulky and expensive with a low added-value compared to RADARs and cameras.
    - Mercedes-Benz is testing a sensor package with no LIDARs on its Mercedes-Benz F015.
  - Fully LIDAR: BMW is experimenting on the BMW i3 model integrating only LIDARs.
- Beside historic OEM targeting 8-10 years market deployment in a 100M units market, new operators (Waymo, Lyft, Baidu, Uber, Navya) develop robocars fleets to target 4-years market adoption with fleets growing from few hundreds vehicles (2018) to 100.000 vehicles (2022).

| Main partnerships of car manufacturers with LIDAR developers |
|---|
| Continental (ASC inc.) |
| Valeo (Ibeo, LeddarTech, Trilumina) |
| Ford (Velodyne, Princeton Lightwave) |
| Volvo (Velodyne) |
| Pioneer (Home-made) |
| Delphi (Quanergy, Innoviz) |
| Daimler (Quanergy) |
| ZF Friedrichshafen (Ibeo) |
| Toyota (Home-made) |
| Robert Bosch (Home-made, Tetravue) |
| Koito Manufacturing (Quanergy) |
| Denso (Trilumina) |
| Autoliv (Velodyne) |
| Magna (Innoviz) |
| General Motors (Strobe) |

# Trends in LIDAR : Global funding raised by LIDARs manufacturers

Although adoption of LIDARs will remain low until 2020, the high funds raised by manufacturers suggest a high growth potential in the following years.

**Velodyne**

**Total: $150M**
(2016, equity)
Ford, Baidu

**QUANERGY**

**Total: $134M**
2016: $90M (series B)
2015: $10M (equity)
2014: $31M (series A; equity)
2013: $3.5M (equity)

**oryx**

**Total: $67M**
2017: $50M (series B)
2016: $17M (series A)

**LUMINAR**

**Total: $72M**
2017 : $36M
2016 : $36M

**LeddarTech®**

**Total: $110M**
2017: $101M(equity)
2014: $7M (equity)
2013: $2.5M (unattributed)
2010: $6.5M (unattributed)

**HESAI**

**Total: $16M**
(2017, series A)

**blackmore**

**Total: $21.5M**
2018 : $18M (series B)
2016: $3.5M (series A)

**TETRAVUE** – SOLID STATE HD LIDAR

**Total: $10M**
(2017, series A)
Bosch

**OUSTER**

**Total: $27M**
(2017, series A)

**INNOVIZ TECHNOLOGIES**

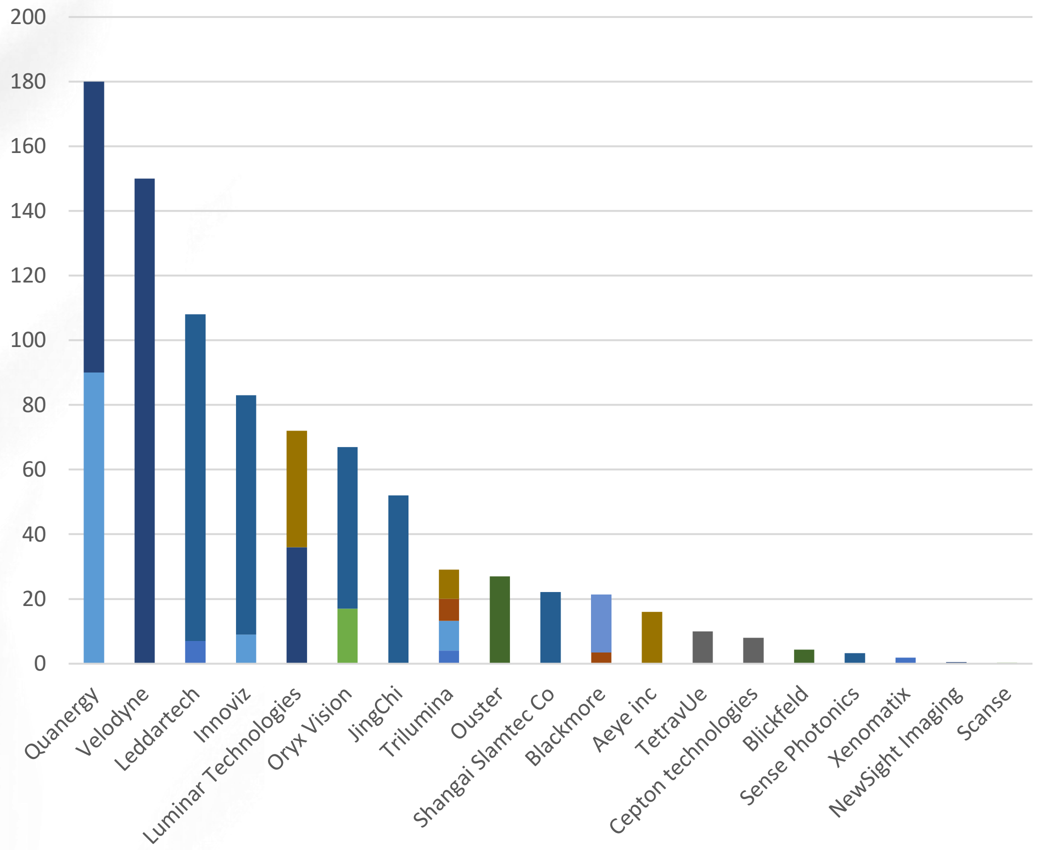
**Total: $83M**
2017 : $73,9M
2016: $9M

**XENOMATIX** – Automotive Vision Solutions

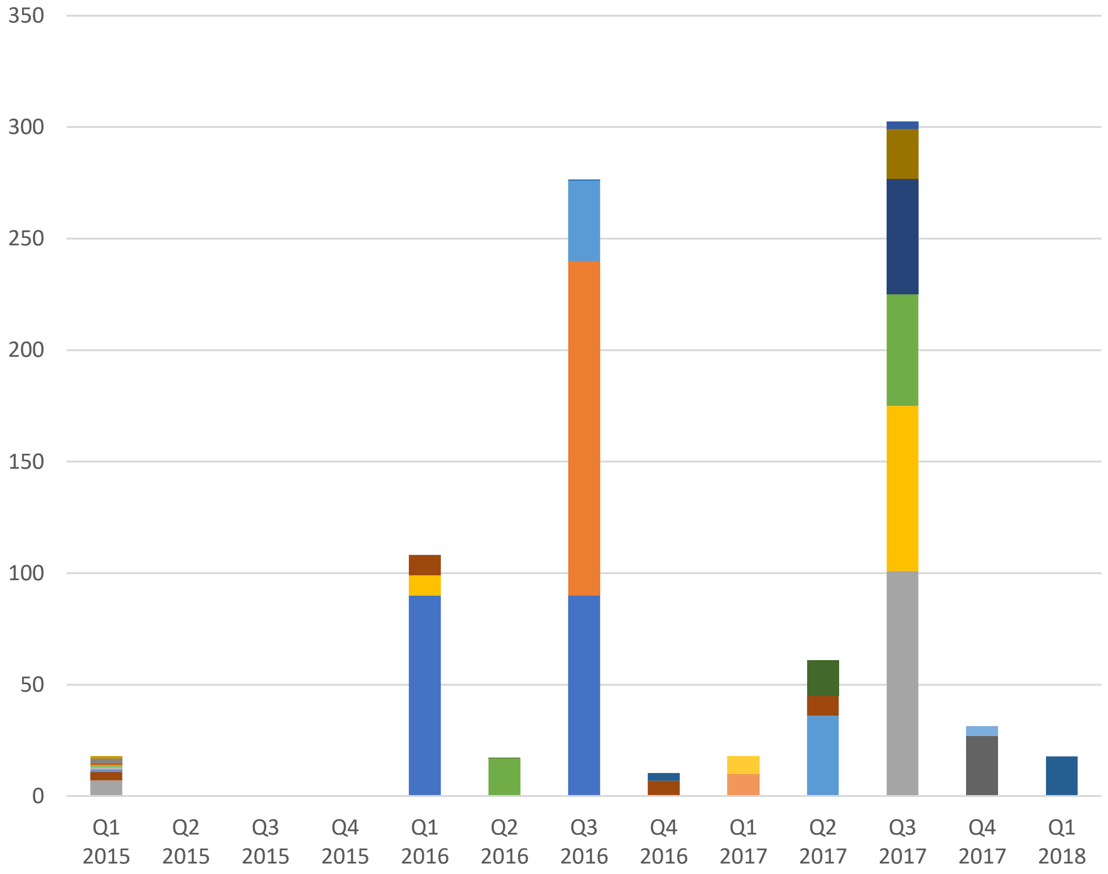
**Total: $1.8M**
(2015, series A)

# Trends in LIDAR technologies : Near 1B$ Investment in ventures in 3 years

Key VC-investments are made in most mature manufacturer (Velodyne), in Phase-based design (Quanergy, Oryx, Blackmore), in Shortwave-infrared wavelength (Luminar, Quanergy, Oryx) and in MEMS-based design (LeddarTech, Innoviz)




877 M$ Fundraised in LIDAR in last 13 quarters



## Strong investment still required in test with operating 24/7 robocars to validate the safety aspects of autonomous driving

Figure 1. Failure-Free Miles Needed to Demonstrate Maximum Failure Rates

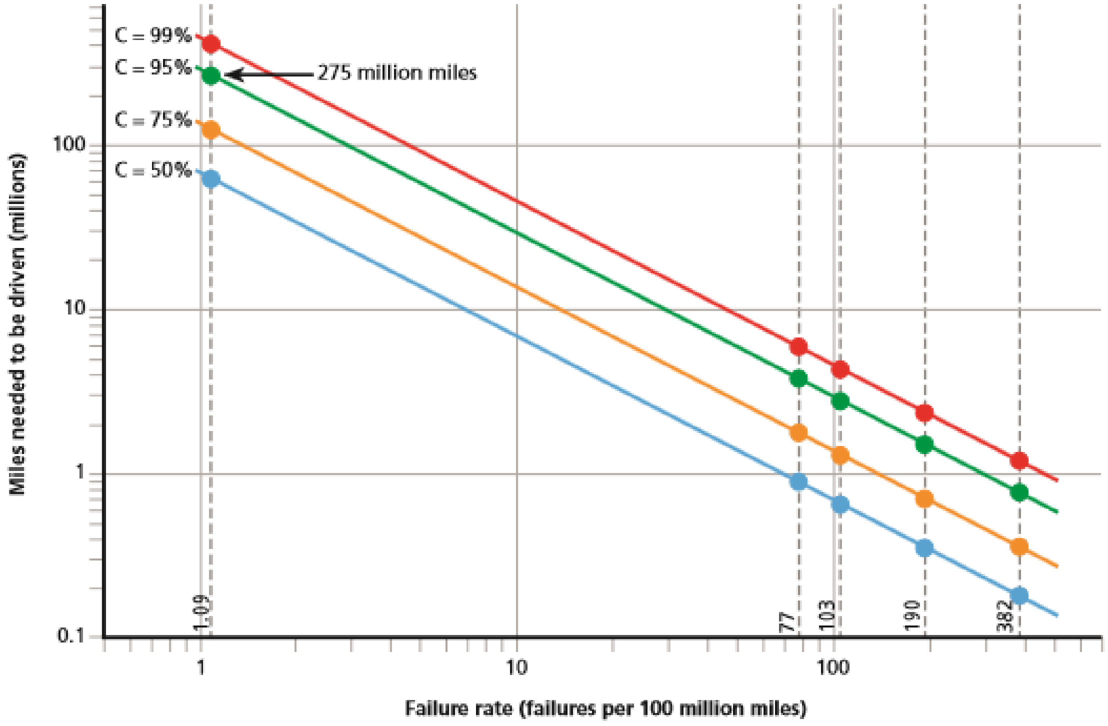
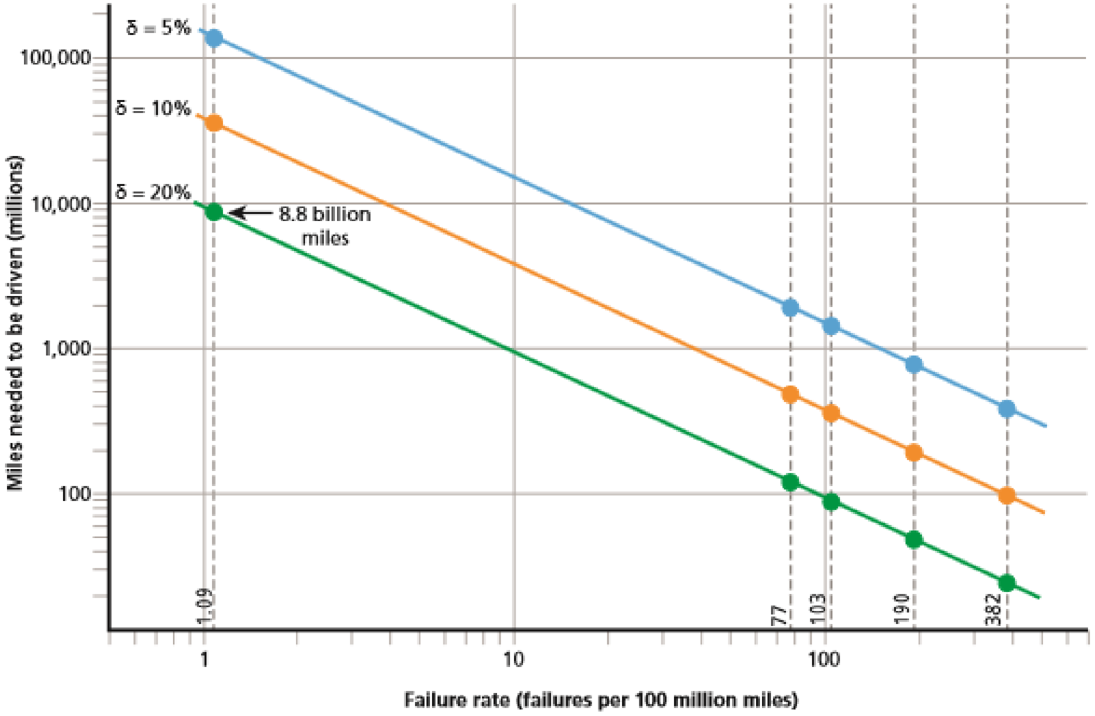



Figure 2. Miles Needed to Demonstrate Failure Rates to a Particular Degree of Precision




Rand Corporation « Driving to safety, 2016, Kalra & Paddock

# Strong investment in test with operating 24/7 robocars to validate the safety aspects of autonomous driving

**Figure 4. Miles Needed to Demonstrate with 95% Confidence and 80% Power that the Autonomous Vehicle Failure Rate Is Lower than the Human Driver Failure Rate**

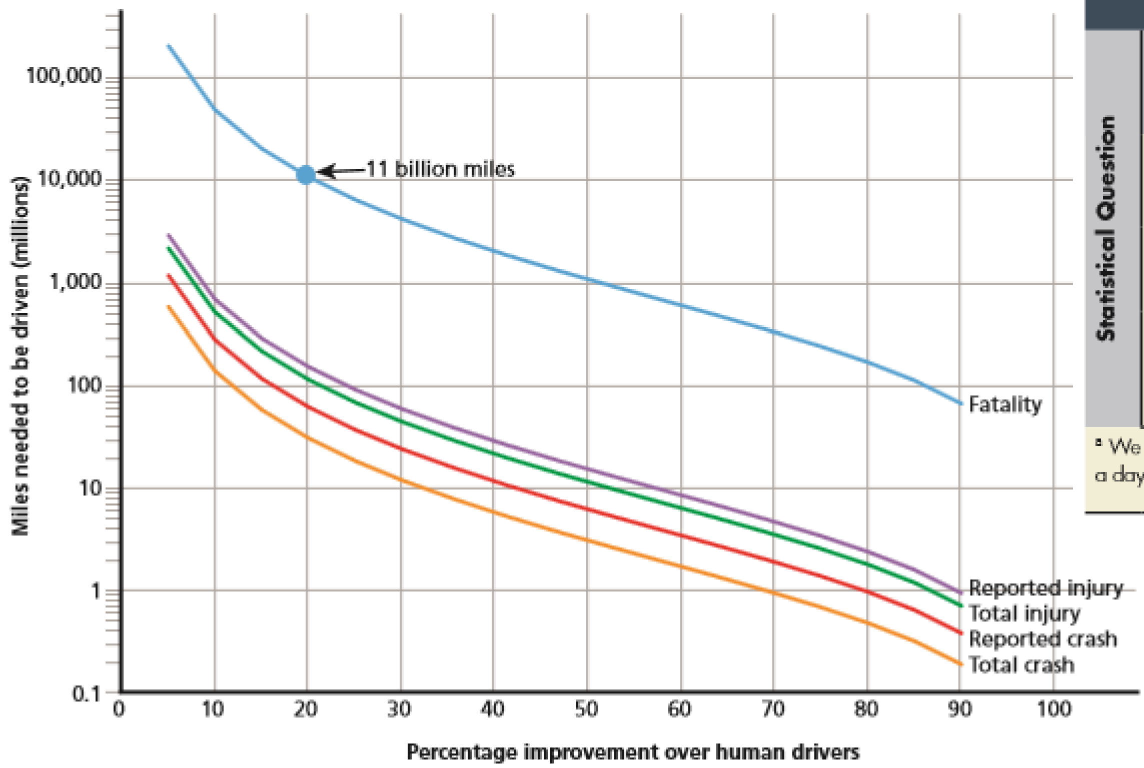



**Table 1. Examples of Miles and Years Needed to Demonstrate Autonomous Vehicle Reliability**

| | | Benchmark Failure Rate | | |
|---|---|---|---|---|
| **Statistical Question** | **How many miles (years[a]) would autonomous vehicles have to be driven…** | **(A) 1.09 fatalities per 100 million miles?** | **(B) 77 reported injuries per 100 million miles?** | **(C) 190 reported crashes per 100 million miles?** |
| | (1) without failure to demonstrate with 95% confidence that their failure rate is at most… | 275 million miles (12.5 years) | 3.9 million miles (2 months) | 1.6 million miles (1 month) |
| | (2) to demonstrate with 95% confidence their failure rate to within 20% of the true rate of… | 8.8 billion miles (400 years) | 125 million miles (5.7 years) | 51 million miles (2.3 years) |
| | (3) to demonstrate with 95% confidence and 80% power that their failure rate is 20% better than the human driver failure rate of… | 11 billion miles (500 years) | 161 million miles (7.3 years) | 65 million miles (3 years) |

[a] We assess the time it would take to compete the requisite miles with a fleet of 100 autonomous vehicles (larger than any known existing fleet) driving 24 hours a day, 365 days a year, at an average speed of 25 miles per hour.

12.000 hours lifetime for a laser ⇔ 500 days in 24/7 operation (1,25 years)
100 vehicles during 12,5 years or 1000 vehicles during 1,25 years to drive the miles ?

At 200 to 300k€ / vehicle, technology test will need 200 to 300M€ investment for low-level validation

Not speaking about security concern (jamming, hacking)

Rand Corporation « Driving to safety, 2016, Kalra & Paddock

# Contents



## 3 From ADAS to autonomous driving: the role of LIDARs

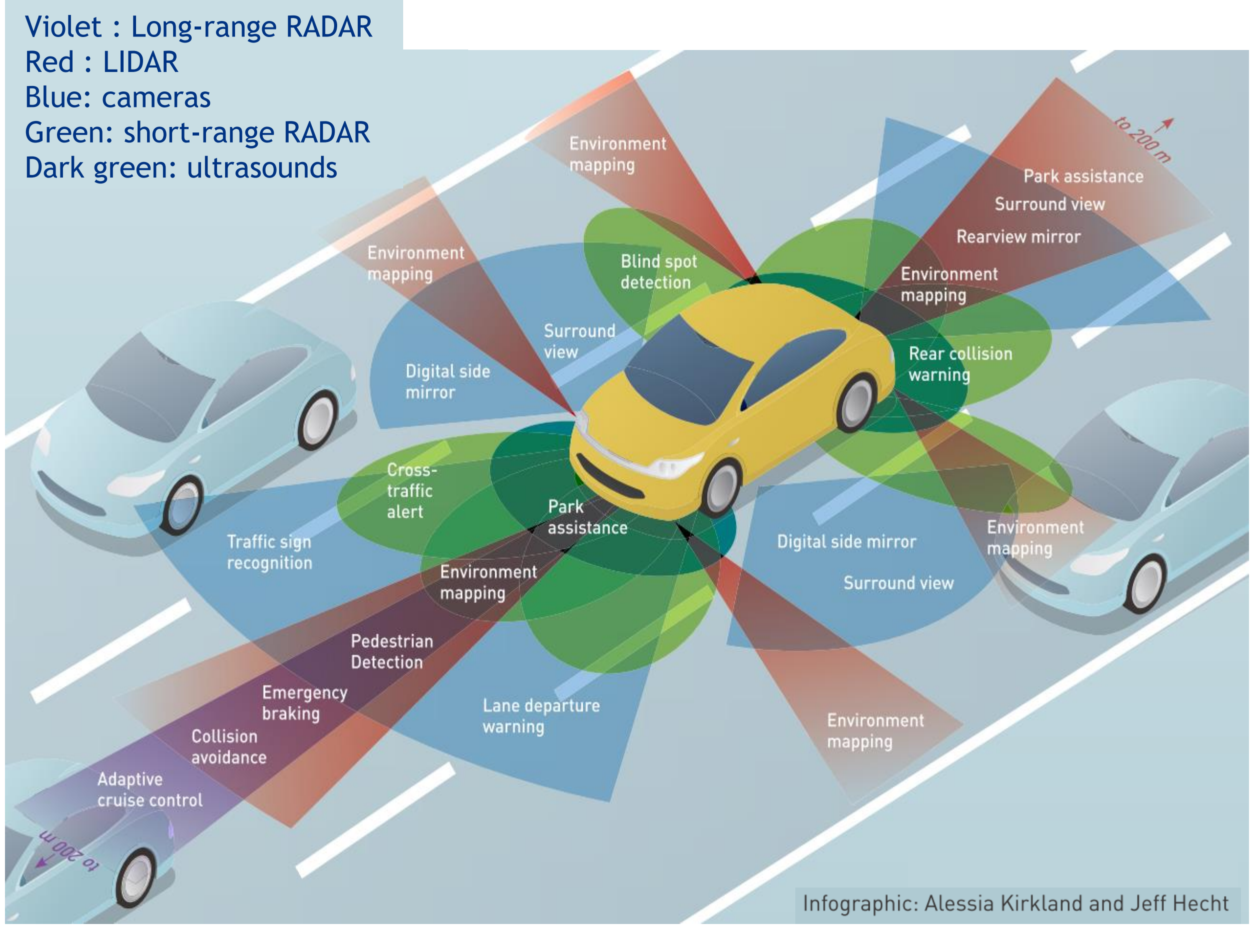
- Which technologies for which functions
- LIDAR, an enabler of autonomous driving

# SENSOR FUSION



## The combination of several sensing technologies seems necessary despite the resulting increase of the "sensing" budget ; Artificial Intelligence could be a solution to reduce the number of sensors

- The figure on the right highlights the complementarity of sensing technologies for ADAS and, in particular, autonomous cars.
- Sensor fusion is used to combine and analyze data from all sensors to make decisions and communicate them to the actuators (steering, brake, etc.).
- Sensor fusion requires complex data processing. Moreover, increasing the number of sensors, increases the total "cost of sensing" of the vehicle, which induces a high constraint on the individual sensor cost, and therefore a decrease of each sensor quality.
- One can wonder if one or two higher quality sensors could do the same (or a better) job than a set of 4 to 5 lower cost (i.e. lower quality) sensing systems.
- The introduction of artificial intelligence (that would be able to reconstruct the environment / the relevant information from less data points) is investigated to reduce the number of sensors and increase the robustness of automated tasks.



Infographic: Alessia Kirkland and Jeff Hecht

Source of the infographic: Jeff Hecht, "LIDAR for self-driving cars", Optics & Photonics News, January 2018, p 30

# Comparison of sensing technologies abilities in ADAS and automated driving situations

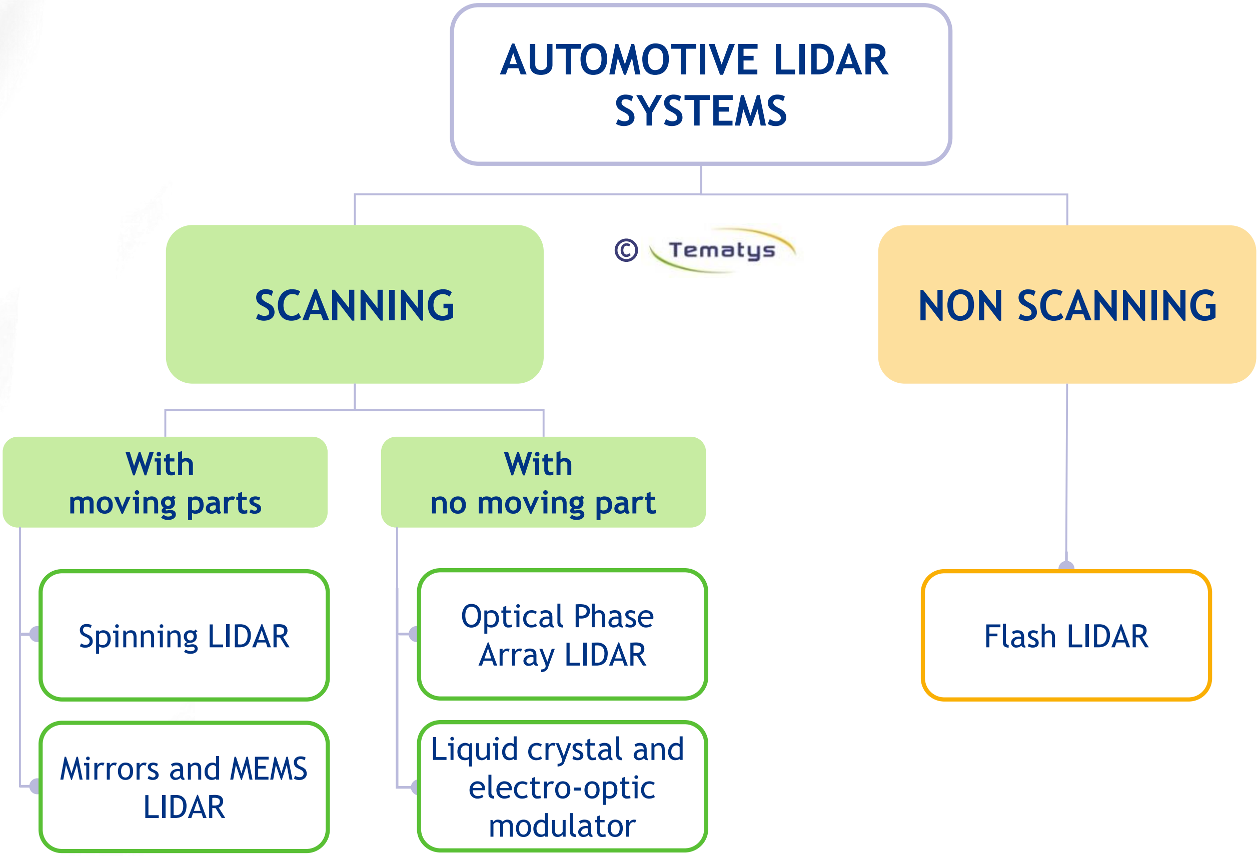
## Sensing technologies are complementary for ADAS tasks: sensor fusion is investigated, especially for autonomous driving

🟢 High ability
🟠 Ability with poor performance
🔴 Inability



| | Camera | Long Range RADAR (typically 77GHz) | Short & Mid Range RADAR (typically 24GHz) | Ultrasounds (48 kHz) | LIDAR CMOS <1µm | LIDAR SWIR > 1µm |
|---|---|---|---|---|---|---|
| Object detection | 🟠 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 |
| Object classification | 🟢 | 🔴 | 🔴 | 🔴 | 🟠 | 🟠 |
| Environment analysis | 🔴 | 🔴 | 🔴 | 🟠 (near) | 🟢 | 🟢 |
| Distance estimation | 🟠 | 🟢 | 🟢 | 🟢 (near) | 🟢 | 🟢 |
| Speed measurement | 🔴 | 🟢 | 🟢 | 🔴 | 🟠 | 🟠 |
| Object edge precision | 🟢 | 🔴 | 🔴 | 🟢 | 🟢 | 🟢 |
| Lane tracking | 🟢 | 🔴 | 🔴 | 🔴 | 🔴 | 🔴 |
| Range of visibility | 🟠 | 🟢 | 🟢 | 🔴 | 🟢 | 🟢 |
| Operation in bad weather | 🔴 | 🟢 | 🟢 | 🟢 | 🟠 | 🟢 |
| Operation in poor light conditions | 🟠 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 |
| Operation in dark | 🔴 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 |

# Main LIDAR technologies




- Although it is established among OEMs and suppliers that autonomous vehicles will integrate LIDAR systems, there are several available technologies of LIDARs.
- It is not clear yet which technology (or technologies) will meet automotive requirements in terms of :
  - performance (range, resolution, …),
  - operability (support temperatures from -40°C to 125°C, work under bad weather conditions, …),
  - reliability,
  - robustness,
  - cost,
  - manufacturing abilities (mass volume)
  - etc.

# Portfolio of available components for LIDAR systems in automotive

## Efforts are being made by components manufacturers to find the right compromise between cost and performance

### SOURCE

**NIR**
- Laser diode (GaAs)

**SWIR**
- Laser diode (InP)

**NIR / SWIR**
- FMCW laser
- VCSEL

**NIR:** Fiber Lasers (Nd)

**SWIR:** Fiber Lasers (Er)

### BEAM DELIVERY

**Scanning**
- Spinning
- Mirrors and MEMS
- Optical Phased array
- Liquid crystal and electro-optic modulator

**Flash**
- Nanosecond pulse laser

### DETECTOR

**NIR**
- SiPM/MPPC
- SPAD
- APD
- PIN Photodiode

**SWIR**
- SiPM/MPPC
- SPAD
- APD
- PIN Photodiode

MATERIAL
- NIR: Silicon
- SWIR: InGaAs
- NIR / SWIR: Colloidal Quantum Dots

Emerging / in development technology

FMCW: Frequency Modulated Continuous Wave
VCSEL: (Vertical-cavity surface-emitting laser)
MEMS: MicroElectro-Mechanical Mirrors
SiPM/MPPC: Silicon Photomultipliers/MultiPixel Photon Counters
SPAD: Single-Photon Avalanche Diode
APD: Avalanche PhotoDiode

Source: Melexis presentation, Autosens conference 2017

# General considerations on sources for LIDARs in automotive

## Laser diodes are the preferred choice for automotive LIDAR because of their low-cost, high compactness and high output power

**SOURCE**

| NIR | SWIR |
| --- | --- |
| Laser diode (GaAs) | Laser diode (InP) |
| FMCW laser | |
| VCSEL | |
| Fiber Lasers (Nd) | Fiber Lasers (Er) |

**Laser Diode**
Low cost and high compactness
Ability to provide high output power

**FMCW lasers**
Frequency-modulated laser sources are used for FMCW measurements allowing distance and speed measurement through Doppler effect

**VCSEL (Vertical-cavity surface-emitting laser)**
High beam quality, easy to manufacture
Low output power

**Fiber laser**
Very high output power
Bulky and expensive

Source: Jake Li, Slawomir Piatek, "Photonic Technologies for LiDAR in Autonomous/ADAS", Feb 2018

# GENERAL CONSIDERATIONS ON DETECTORS FOR LIDARS IN AUTOMOTIVE

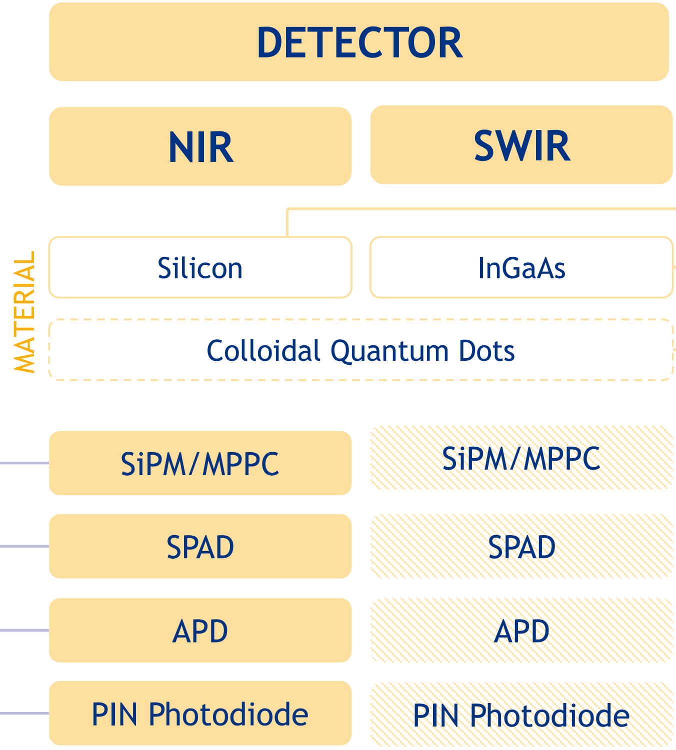
## High gain technology (SPAD, SiPM) are the most suitable to improve LIDAR performance at lower cost

**SiPM/MPPC - High Gain technology**
High gain simplifies the TIA electronics
High SNR at long range
Low cost

**SPAD - High Gain technology**
Can be fully integrated with readout electronics
High resolution for long range LiDAR
Small active area and limited dynamic range
Requires increase in Photon Detection Probability (PDP)

**APD - Low Gain technology**
High SNR for short to middle range LIDAR designs
In most cases, poor uniformity in arrays increases system size and complexity
Higher cost due to complexity in design and manufacturing

**PIN Photodiode - No Gain technology**
Limited eye-safe range in NIR range due to low system SNR
Poor ability to deal with low reflective targets at long distances
Low bandwidth due to high external amplification required




**Silicon**
Well-established technology
Low cost
Easily manufacturable at high volume

**InGaAs**
High cost
High sensitivity

**Colloidal Quantum Dots**
Emerging material technology
Lower Quantum Efficiency than InGaAs in the SWIR range
Low cost for large area

Source: Melexis presentation, Autosens conference 2017 ; Jake Li, Slawomir Piatek, "Photonic Technologies for LiDAR in Autonomous/ADAS", Feb 2018

# Comparison of LIDAR Technologies regarding automotive requirements

## Currently, there is no "perfect" LIDAR technology, developments must be undertaken ; a solution could be to combine technologies

| © Tematys | Spinning LIDAR | | Flash LIDAR | | MEMS LIDAR | | OPA |
|---|---|---|---|---|---|---|---|
| | NIR | SWIR | NIR | SWIR | NIR | SWIR | |
| Measurement speed | Medium | | Fast | | Medium to fast | | Fast |
| Measurement range | High | Very high | Low to medium | Very high | High | Very high | High to very high (expected) |
| Spatial resolution | High | | Low | | High | | Medium |
| Performance on low reflectivity target | Good | | Low | | Good | | Good |
| Performance in high ambient light level | Medium | Good | Medium | Good | Medium | Good | Good (in the SWIR range) |
| Compactness | Bulky | | Compact | Medium | Compact | | Very compact |
| Software complexity | Medium | | Low | | Medium | | Medium to high |
| Eye safety | Good (at low power) | Very good (at high power) | Good (at low power) | Very good (at high power) | Good (at low power) | Very good (at high power) | Very good (in the SWIR range) |
| Bad weather conditions performance (fog, rain, …) | Poor | Medium | Poor | Medium | Poor | Medium | Medium (in the SWIR range) |
| Maintenance | High | | Low | | Low | | Low to medium (calibration) |
| System cost | High | Very high | Low | Medium to high | Low (for high volume) | | Low (for high volume) |

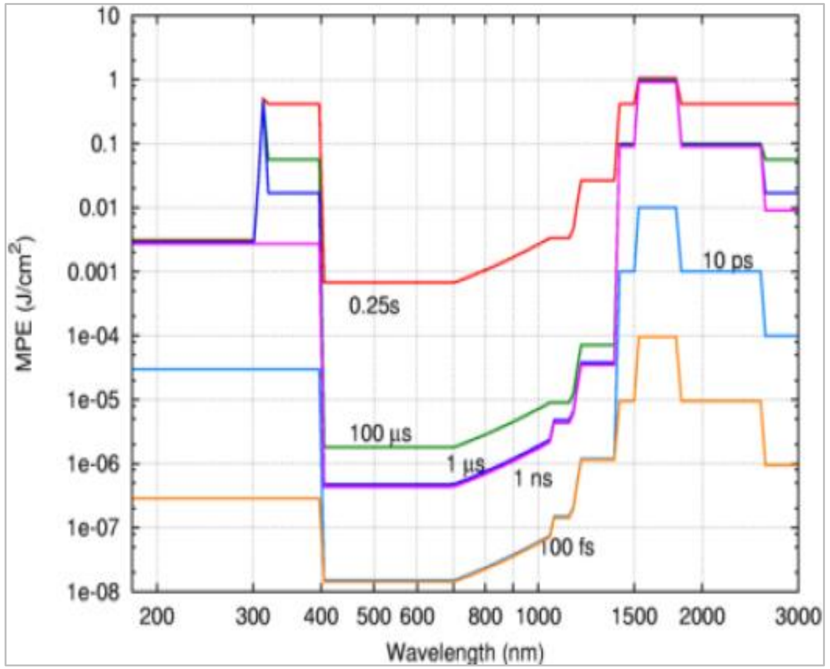
# LIDAR WAVELENGTH RANGE : NIR VS SWIR

## Opportunities for SWIR-based design in the long term

- Current status: the NIR range (typically 905 nm) is widely adopted
  - Main advantage of NIR: compatible with Si technologies → low cost and ability of high volume manufacturing
  - Limitations of NIR: sources are limited to relatively low power to obey eye-safety regulations which limits range
  - Current issues with SWIR :
    - InGaAs detectors are expensive
    - InP sources (laser diodes or VCSEL): issues at the material processing level for industrialization meeting automotive constraints: high volume, low cost
- In the future: the SWIR range (typically 1550 nm) is expected to replace NIR LIDAR, especially in Level 4 and 5 vehicles
  - Longer range: possibility to reach higher power than NIR while meeting eye-safety requirements
    - Maximum Permissible Exposure* (MPE) is gaining almost 6 orders of magnitude for a 1ns pulse when moving the wavelength from 900nm to 1550nm (see graph).
  - Better performance in adverse weather conditions
  - Less ambient noise at 1550 nm: less need of costly ambient light cut filters

*MPE is the highest power or energy density (in W/cm$^2$ or J/cm$^2$) of a light source that is considered safe.

**Maximum Permissible Exposure (MPE)**




MPE as energy density versus wavelength for various exposure times (pulse durations)

Graph source: Han-Kwang, based on the formulas from the international standard IEC 60825 (energy versus exposure time)

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## 5 LIDARS ADOPTION: TARGET COSTS AND MARKET FORECAST

- Market Definition
- Target Cost
- Market forecast
  - Figures and projection about technology maturity are available on demand.
  - jcochard@tematys.com

Tematys

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## 6 APPENDICES

- Methodology
- About Tematys

# TOOLS & RESOURCES

## The team can count on a network of experts on almost every major Photonic topic

### DATABASES and INFORMATION SEARCH KNOW-HOW

**Scientific and technical** databases: ScienceDirect, IEEE, SPIE, Wiley Online Library...
**Patent** databases: Google Patent, EspaceNet …
**Economic** databases: Kompass, Dun & Bradstreet ...
**Collaborative projects** databases: CORDIS, EUREKA, ANR ...
**Specialized press in Photonics and End-users markets:** LaserFocusWorld, BioPhotonics, Electro-Optics, Photonics Spectra, DevideMed, NewFoodMagazine, European Pharmaceutical Review, …

### NETWORK and INTERVIEW KNOW-HOW

Extensive **network in Photonics and its markets** : database of > 10 000 contacts (companies, research labs, public institutions, …).
Built on **over 20 years of field expertise**.
Know-how in conducting marketing **interviews on emerging technologies.**
Participation in **specialized conferences and exhibitions** to meet opinion leaders and key experts.

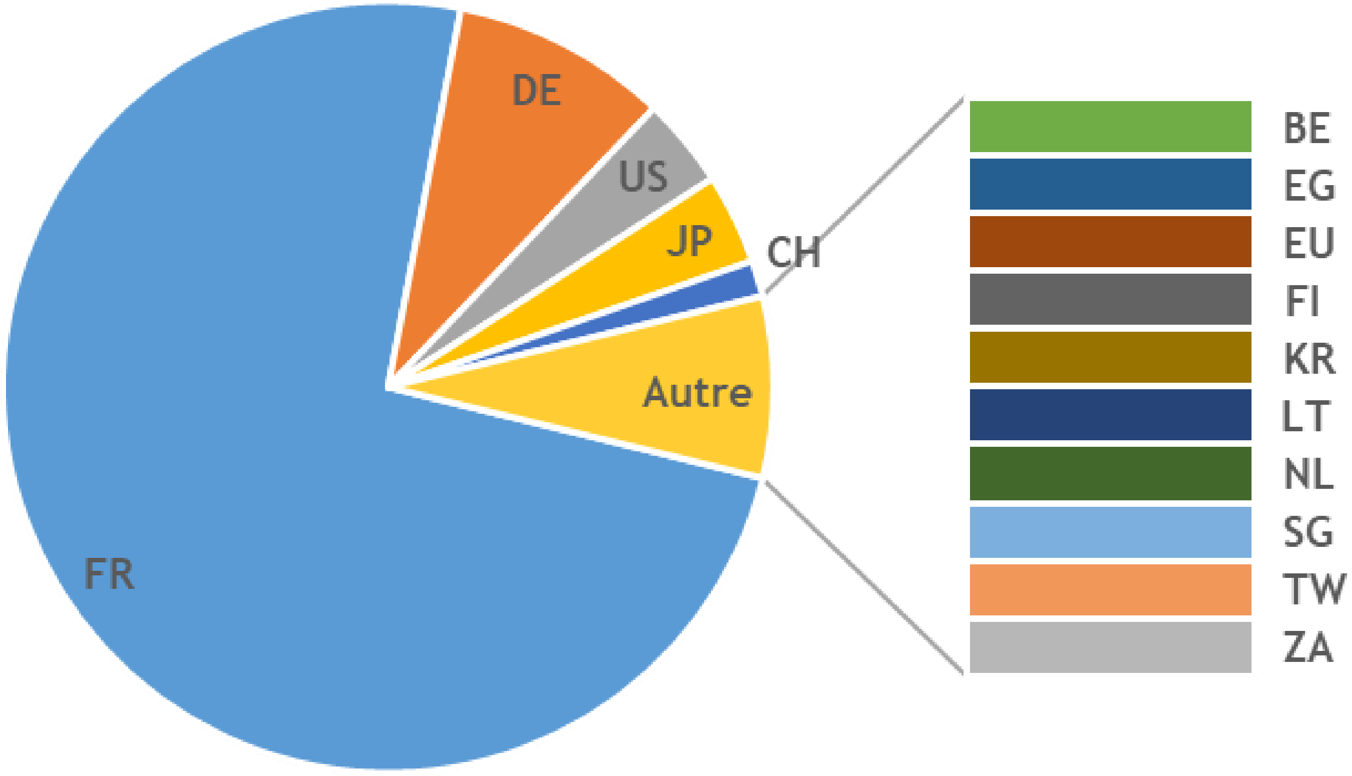
### ON-LINE SURVEYS

Expertise in building **on-line surveys on emerging technologies** to **evaluate the interest for a technology** and to help determining in which direction it should be developed.

### CARTOGRAPHY

**Geographic distribution of potential end-users / customers, of competitors, of market sales** to guide your geographic establishment.

# More than 120 clients in 15 Countries



# REFERENCES

## Research Organizations

Alphanov – C2N - CEA – CNES – CNRS – ECE – FIST – Fraunhofer IAF (DE) – Fraunhofer HHI (DE) – Gravit – Group Fraunhofer (DE) – Helmholtz Zentrum München GmbH – (DE) - IMEC (BE) - Institut Fresnel - Institut Langevin - Institut de la Vision – JST (JP) - LNCMI – LPN - LSCE – Observatoire de Paris – RTI (US) - SATT AXLR - SATT IdfInnov – SATT Aquitaine Science Transfert – SATT Conectus - SATT Grand Est – SATT Linksium - SATT Lutech – SATT Nord – SATT Ouest Valorisation – SATT Pulsalys - Supelec - Synerjinov – Télécom Paritech – Université de Bourgogne – Université Joseph Fourrier - Université Paris-Dauphine – Université Paris-Sud – Université Technologique de Troyes – Welience

## International Groups

AIR LIQUIDE – Amplitude systèmes – AZBIL Corp. (JP) - BERTIN Technologies – CANON (JP) - CASINO – COHERENT, Inc. (US) - DIEHL Group (DE) - Doro – ESSILOR – Groupe MAQUET – HORIBA Jobin Yvon - HUTCHINSON – INFINEON Technologies (DE) – LEICA Microsystems (DE) – NIKON Corp. (JP) - Ocktal-SE – ORANGE – OSRAM (DE) - Paramount Technologies (ZA) – PSA – QUANTEL – RÉSEAU FERRÉ DE FRANCE – REUNICA – Robert BOSCH (DE) - SAFRAN/Sagem – Sainte-Lizaigne/Groupe Claire – SCHOTT (DE) – SCREEN Holging (JP) - SIEMENS (DE) – Sofradir - SORIN Group – Sumitomo Electric Industries, Ltd. (JP) - TOPPAN Photomasks Inc. - THALES – Ymk Photonics (SK)

## SMEs and Start-ups

Act-Light (CH) – Adveotec – AIM Infrarot Module GmbH (DE) – AKA Optics - Altechna R&D (LT) - Apollo Medical Optics, Ltd. (TW) - Archimej – Armelio – Aurea – Bioaxial – BLOCK Engineering (US) - CAMBRIDGE Technologies (US) – Dreem - Elcarim Science (SG) - Eureva – GLOphotonics - Hublex - I2S – Imasonic - Indatech – Innoeco – Innov+ - ISP System - Ivea – Lake Shore Cryotronics (US) - Le Verre Fluoré – LightFab (DE) - LMDC – Lytid - Novoptim – Optopartner – Phasics – Phonoptics – Prestodiag – Probayes – Pyxalis - Seno Medical (US) - Sensup - Silltec – Si-Ware (EG) - SourceLab – Spectral Engine (FI) - Surfactis - Think & Go – T-Waves – Vactec – Lyonix Intl (NL) - Yole Développement

## Public Organizations & Clusters

Agoranov – Association ARMIR - BPI France - Bretagne Photonics – DGA - EPIC (EU) – EUREKA Secretariat - Incubateur Descartes – Ministère Industrie/DGE – Medicen – Normandie Aéroespace - Optics Valley – Optitec – SwissMem (CH) – VDI (Photonics21)

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| | Miniature and Micro spectrometers: End-users needs, Market and Trends | 2016 |
| | Terahertz Components & Systems, Technology and Market Trends (Update of the Report released in 2013) | 2016 |
| | Cascade Laser Components & Systems: Technology and Market trends | 2015 |
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# CONTACT

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