

Prospects for sensors in the new automotive economy



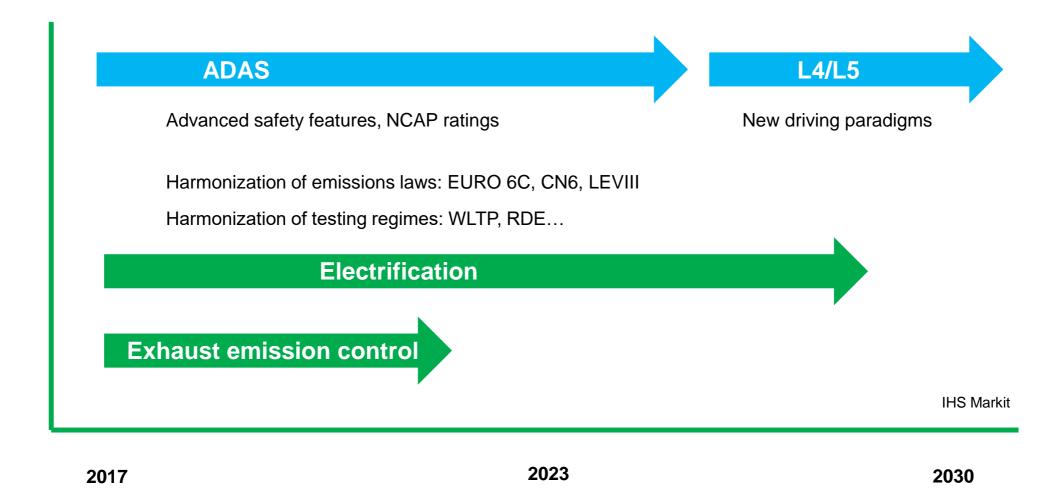
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- Market drivers
- Emissions aftertreatment and sensing
- Electrification and impact on powertrain
- Advanced safety and automated driving
- Sensor supply ecosystem

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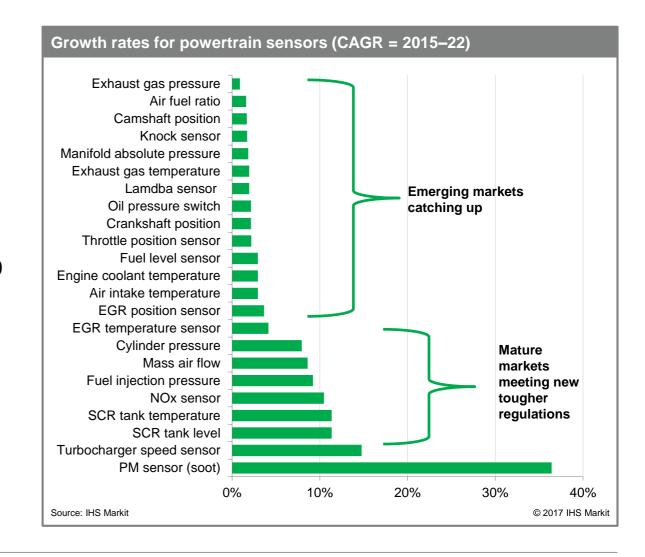
Four main drivers affect sensing going forward



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Near term opportunity for sensors - exhausts

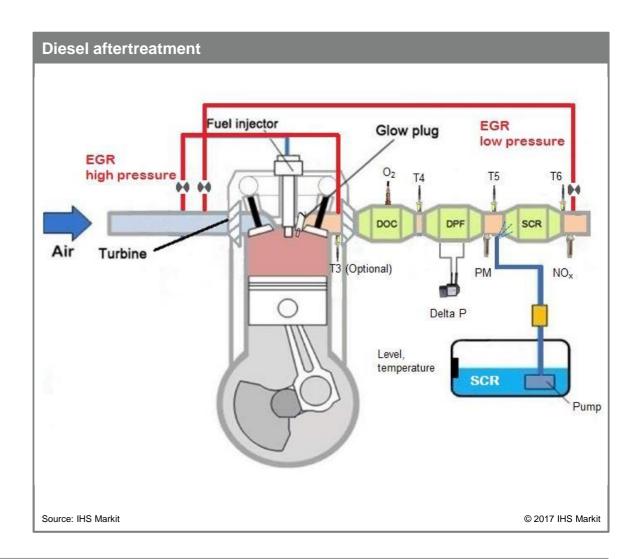
- Exhaust sensor modules market worth more than \$3.3 billion last year
 - Air-fuel ratio, lambda, exhaust gas temperature and pressure sensors are staple devices....
 - Mature markets need new sensors such as NOx, PM, and devices for SCR
 - Accelerate market past \$500 M in 2022, up from \$220 million in 2015
 - Gasoline engines fitted with particle filters
 - Emerging markets like China, India need basic exhaust monitors like pressure sensor



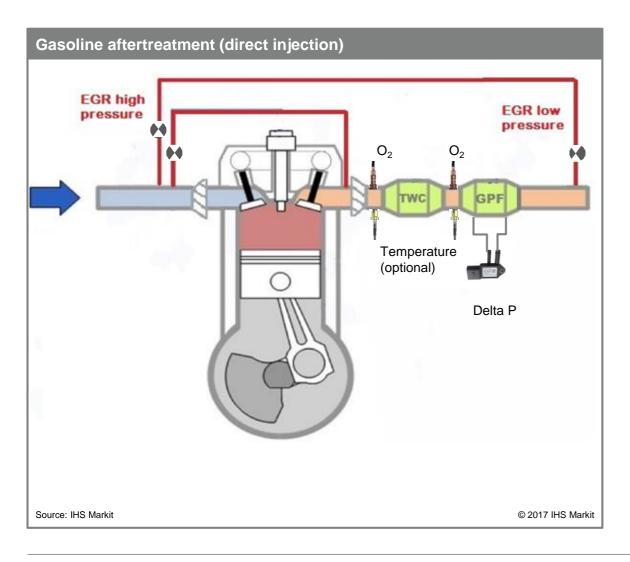
Source: Powertrain Sensor Report

What does a Euro 6c compliant diesel look like?

- Sensors are added for OBD of catalysts blocks
 - Diesel oxygen catayst oxygen sensor
 - Particle filter delta pressure + temperature
 - SCR filter NOx sensor + temperature, temperature + level + quality of AdBlue
- What's new
 - Particle mass sensors adopted in US market (LEVIII) since MY2014 to monitor DP filter
 - More PM sensors in European market (although legislation is focused on particle number)



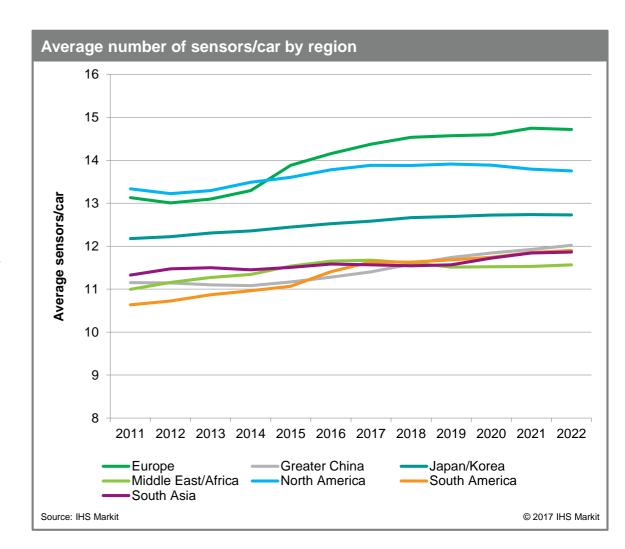
Gasoline direct injection engine treated like diesel under Euro 6c



- Gasoline multi-port injection (MPI) engines designed to combust with stoichiometric airfuel mixes
 - Temperature sensors not required for TWC, airfuel ratio and OBD oxygen sensors suffice
- GDI use non-stoichiometric air-fuel mixes
 - TWC + gasoline particle filter starting in 2017
 - GPF is (mostly) passively regenerating, but ΔP and temperature deployed for OBD monitoring and characterization
 - May also impact MPI engines
- Huge new market for pressure (+ temperature)

Regional variations in powertrain sensor adoption

- Harmonization of emission standards worldwide
 - Drives increasing sensor penetration in different regions
 - European GDI C-class car with Euro Standard 6 has 15+ sensors
 - By comparison Chinese C-class gasoline powered car with China 4 standard has 10 powertrain sensors, and Indian cars have fewer than 10
 - China and India adopt tighter standards, and sensor adoption also accelerates
 - India jumps Bharat 4 to Bharat 6, accelerating exhaust catalyst sensors



Aftertreatment sensors: who makes these devices?



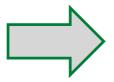
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From Internal Combustion Engine to Electric Car – threat to sensors?

All values first level package = sensor + ASIC + 1LP



Internal combustion engine: around \$50 for sensors



Electric motor: around \$8 to \$12 for sensors



BMW i3

MEMS: \$9 value / engine on average

- 4 pressure sensors
- 1 flow sensor

Silicon magnetic: \$5 / engine

6 position, speed devices

Non silicon sensors: \$35 / engine

Up to 7 gas sensors, temperature

Silicon magnetic: \$1 - 2 per traction motor

 3 – 6 position and current sensors for motor position control

Other sensor for battery: \$5-10

(temperature, voltage, current humidity)

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Safety sensors today... and tomorrow

Anti-blocking system Electronic stability control Tire pressure monitor Roll over detection Front airbag Side airbags Pedestrian occupation detection Passenger occupation detection **Automatic Emergency Braking Advanced Cruise Control** Accident sensor (Telematics) Black box sensor (insurance) Utrasonic distance Camera Radar

time



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Navigation (dead reckon)
Sensor fusion ECU
Intelligent tires (in tire sensor)
Advanced seat (heart rate)
Occupant drowsiness
CO₂ cabin monitor
Cabin particulate sensor
Active supsension
Adaptive lighting
Laser lighting

. . .

MEMS & Sensor technologies for autonomous driving

Automation level

System capability

Driving environment monitoring

Fallback responsibility of driving task

Fail-safe → Fail-operational Only driver **Partial** Conditional High Full **Automation Automation Automation** assistance Automation Some driving Some driving Some driving Some driving All driving modes modes modes modes modes **Human Driver Human Driver System System System Human Driver Human Driver Human Driver** System **System** L5 L4 L3 L2 L1

Evolution of established sensor technologies

Radar: from 1D to 2D detection

Camera: towards higher resolution (Up to 7MP); increasing frame rate (30 to 60 frames/sec)

Infrared Camera: essential for driver monitoring in L3

Ultrasonic: No big change

Emerging sensor technologies

Lidar: from macro-mechanical to solid-state

High-performance IMU: Dead reckoning sensors for L4 and L5

Adaptive Lighting: based on MEMS scanners and/or DLP

IHS Markit

Lidar: the technology fight

Mechanical Scanning LIDAR

- Valeo/Ibeo
- Ibeo
- Velodyne
- Quanergy



Non scanning Flash LIDAR

System Suppliers:

- Continental
- Continental (ASC)
- Valeo
- Invisage Technologies
- Strobe*

Solution suppliers:

- LeddarCore
- Phantom Intelligence



Phase array LIDAR

- Quanergy
- MIT + Darpa

Antenna clements IN Splitter Taser Source: Quanergy

MEMS based scanning LIDAR

- Microvision
- Innoluce (Infineon)
- Innoviz Technologies
- Lemoptix (Intel)
- Bosch
- STMicro
- .

Based on solid-state technology



Other

VCSEL based:

- Trilumina
- Xenomatix

Electro-optic scanner:

Princeton Lightwave

Optical Antenna:

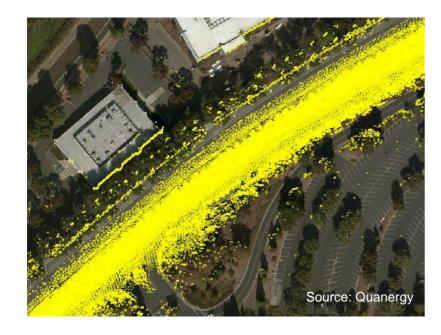
OryxVision

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Inertial navigation assumes 100x better performance than today

Autonomous driving requires high performance dead reckoning

Global positioning of point cloud images for high resolution maps with LIDAR

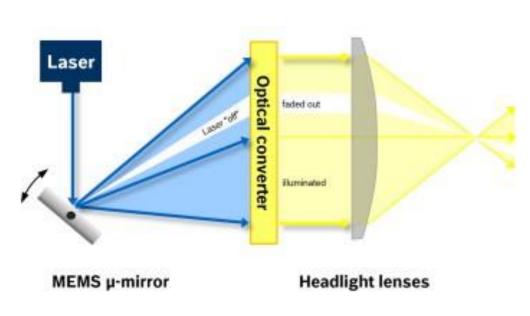


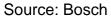
High-performance IMU can be inside LIDAR, e.g. Quanergy using ADI

Positioning for yaw rate sensor autonomous driving **Gyroscope** Bias drift °/h < 0.01 \ inertial grade 0.01 to 10 tactical grade 10 - 1000rate grade \$1 \$10 \$100-1000 **IHS Markit** Price per gyroscope axis

Adaptive lighting: full beam all the time

- Replaces night vision systems
- Competes with microbolometer (expensive) and sensitive CMOS sensors







Adaptive laser light based on MEMS

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Automotive supports many suppliers....

Safety modules

- Autoliv
- Bosch
- Continental
- CTS Automotive
- Delphi
- Denso
- EFI Automotive
- Hella
- Hitachi Automotive
- Kefico
- Mando
- Sensata (Schrader)
- TE Connectivity
- Valed



Consumer suppliers making inroads

STMicroelectronics,

Sensors suppliers (die and 1LP):

 ADI, Allegro, AKM, ALPS, Amphenol, ams, Bosch, Delphi, Denso, ELMOS, Epson, FLIR, Freescale, Fuji Elec., Infineon, Kavlico, Kionix, Melexis, Micronas, MEMSIC, Microstaq, Murata, NXP, Osram, Panasonic, Samyoung, Sensata, Sensirion, SGX, SMI, STMicroelectonics, TI, ULIS...

Powertrain modules

- Aisir
- Borg Warner
- Bosch
- Bourns
- Continental
- CTS Automotive
- Delphi
- Denso
- EFI Automotive
- Hella
- Hirschmann
- Hitachi Automotive
- Honeywell
- Kefico
- KSPG
- LEM
- Magneti Marelli
- Mando
- Melco
- NGK
- Sensata (Wabash)
- Stoneridge
- TE Connectivity
- TT-Electronics
- Valed
- Visteon..

Automotive MEMS & Sensors Ecosystem (simplified)

Tier 3 Tier 2 Tier 1 OEMs

MEMS & sensors foundries: Xfab, Teledyne, APM, SMI, TSMC... Vertically integrated Tier 1 (with own MEMS design and fabs)

Bosch, Denso, Sensata, (Delphi, Conti)

Merchant MEMS & Sensor chip suppliers: NXP/Freescale, ADI, On Semi, Infineon, Allegro, Melexis, ST...

Tier 1 Conti, Bosch, Delphi, Denso, ZF TRW, Autoliv, ... Traditional OEMs: Toyota, VW, GM, Ford...

Automotive MEMS & Sensors Ecosystem (simplified)

Historical suppliers of consumer MEMS devices make inroads into automotive applications like ESC, airbags...

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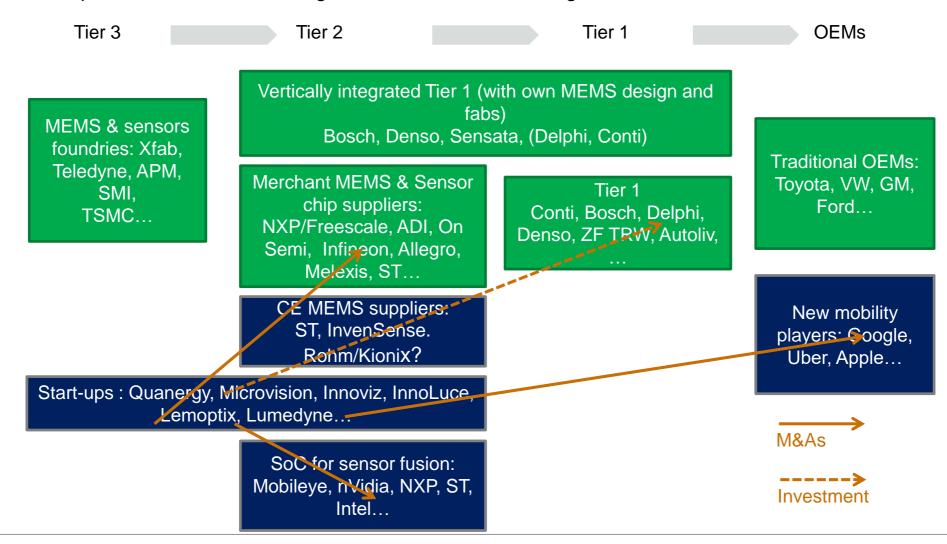
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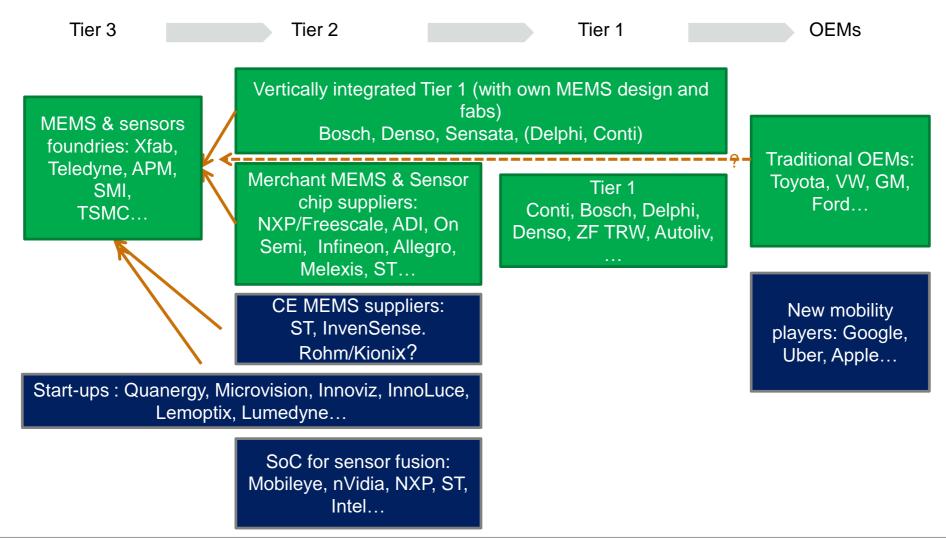
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CE MEMS suppliers: ST, InvenSense. Rohm/Kionix? Tier 1 Conti, Bosch, Delphi, Denso, ZF TRW, Autoliv, Traditional OEMs: Toyota, VW, GM, Ford...

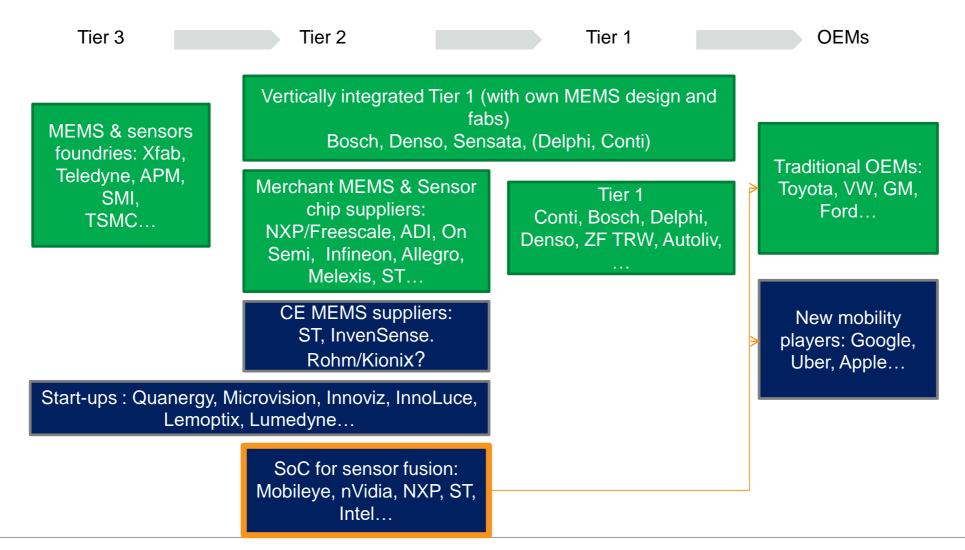
Tier 3 Tier 2 Tier 1 **OEMs** Vertically integrated Tier 1 (with own MEMS design and fabs) MEMS & sensors Bosch, Denso, Sensata, (Delphi, Conti) foundries: Xfab. **Traditional OEMs:** Teledyne, APM, Merchant MEMS & Sensor Toyota, VW, GM, Tier 1 SMI. chip suppliers: Ford... Conti, Bosch, Delphi, TSMC... NXP/Freescale, ADI, On Denso, ZF TRW, Autoliv, Semi, Infineon, Allegro, Melexis, ST... CE MEMS suppliers: New mobility ST, InvenSense. players: Google, Rohm/Kionix? Uber, Apple... Start-ups: Quanergy, Microvision, Innoviz, InnoLuce, Lemoptix, Lumedyne... SoC for sensor fusion: Mobileye, nVidia, NXP, ST, Intel...

Start-ups develop critical sensor technologies for autonomous driving





Shift of weight towards SoC to power Sensor Fusion ECU at expense of tier 1



Conclusions

- 2017 2022 dominated by need to make exhaust even cleaner
 - Aftertreatment no longer just an issue for diesels, also gasoline engines
 - General harmonization of emissions standards and testing regimes worldwide stimulates sensor backfilling in China, India....
- New European legislation targeting lower CO₂ levels force electrification strategies, i.e. hybrids
 - Aftertreatment depends on duty cycle of ICE, sensors needed for e-motor, sub-systems and batteries
- Autonmous driving will drive new sensing applications
 - Sensors enabling for new systems, e.g. LIDAR, adaptive lighting, performance navigation
 - Startups invigorate supply chain, e.g. for sensor fusion chips, working directly with OEMs
- Future looks great for sensors

Thank you for your attention!

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