Prospects for sensors in the new automotive economy

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Agenda

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

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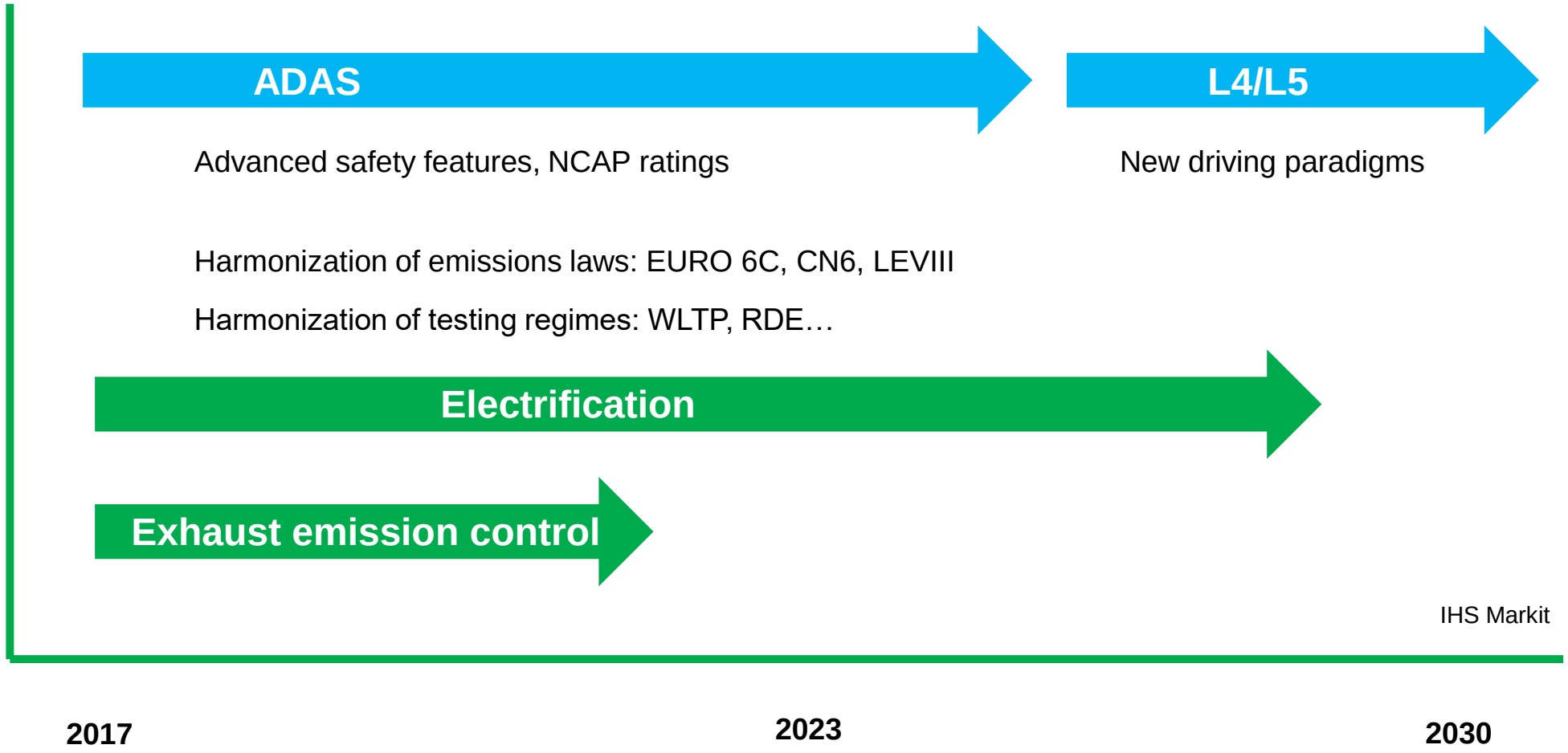
Four main drivers affect sensing going forward



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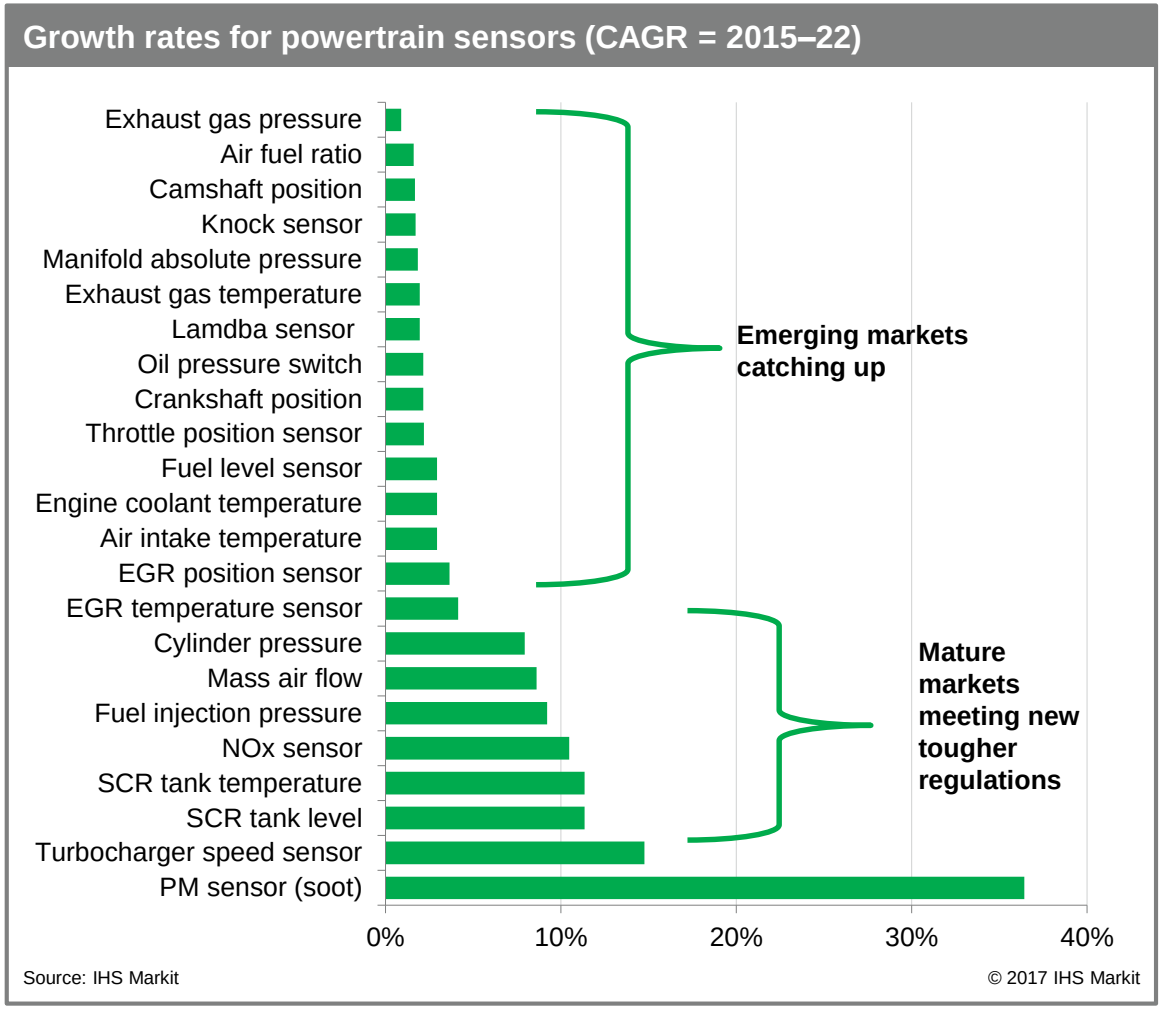
Near term opportunity for sensors - exhausts

- 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

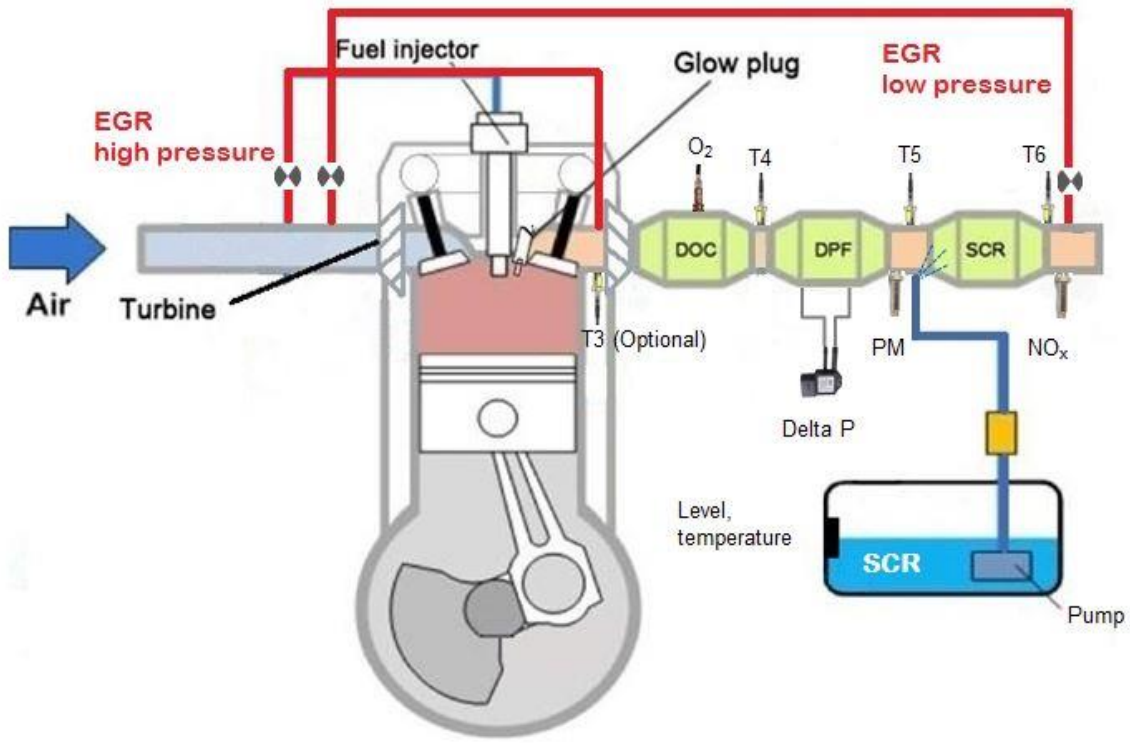


Source: Powertrain Sensor Report

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)

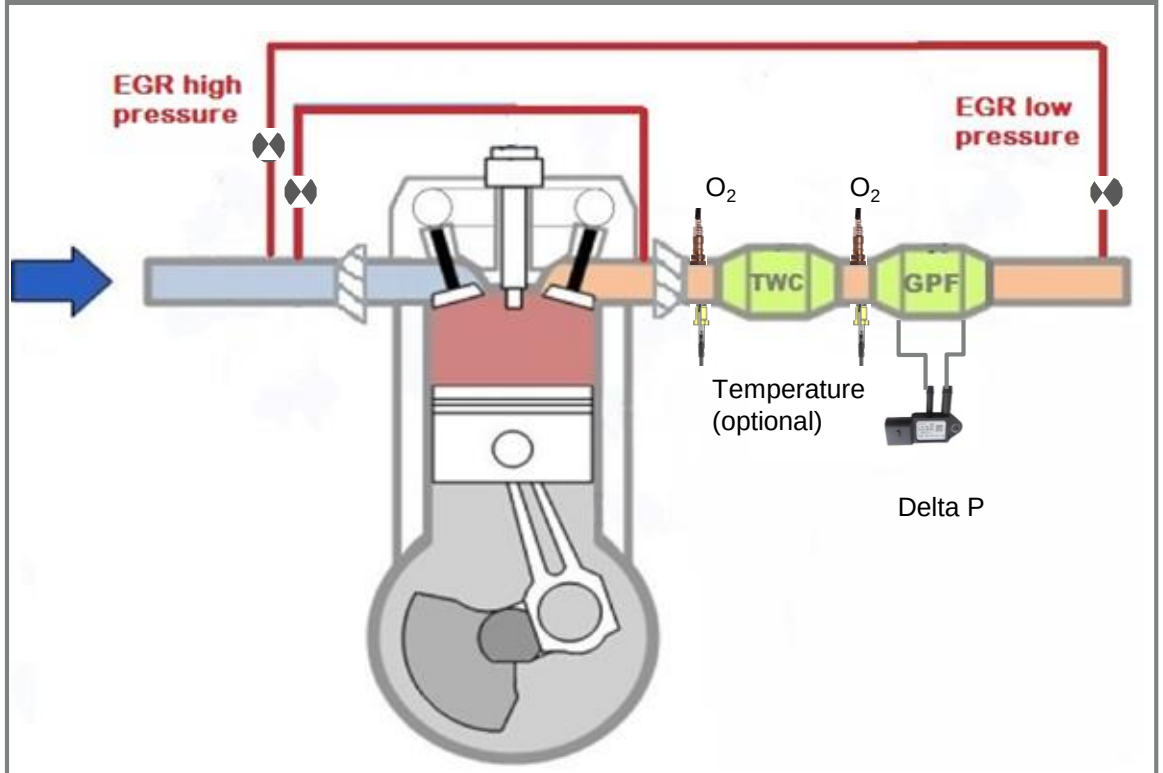
Diesel aftertreatment



Source: IHS Markit

Gasoline direct injection engine treated like diesel under Euro 6c

Gasoline aftertreatment (direct injection)



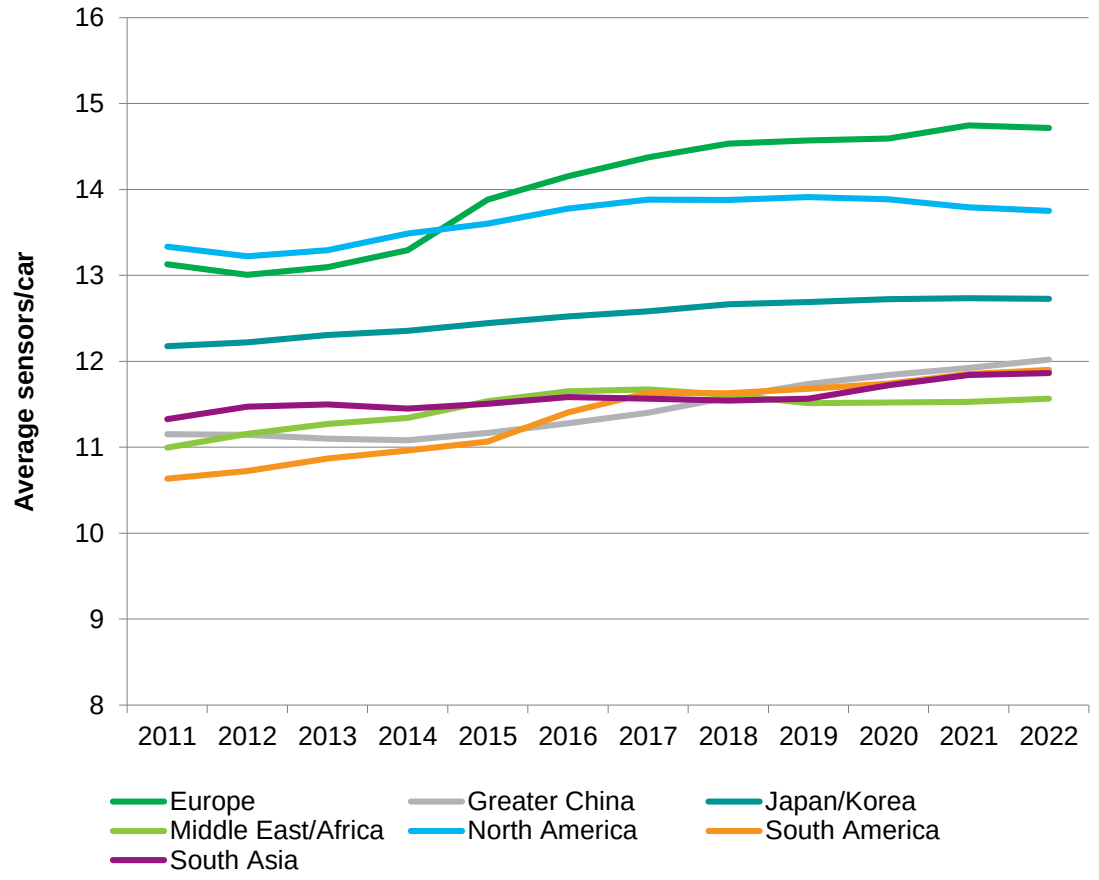
Source: IHS Markit

- Gasoline multi-port injection (MPI) engines designed to combust with stoichiometric air-fuel mixes
  - Temperature sensors not required for TWC, air-fuel 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

Average number of sensors/car by region



Source: IHS Markit

Aftertreatment sensors: who makes these devices?

Oxygen sensors: Bosch, Denso, NTK…

Bosch

IHS Markit

Continental

NOx: Continental – NTK, Bosch, Denso (prototype)

Bosch

PM: Bosch, Stoneridge, Continental (2017)

Bosch

Exhaust temperature: Sensata, NTK, Denso

Continental

SCR urea quality: SSI Technologies, AB Elektronik, Continental…

SCR temperature, level: SSI Technologies, Eltek, Elobau, Meder-Standex

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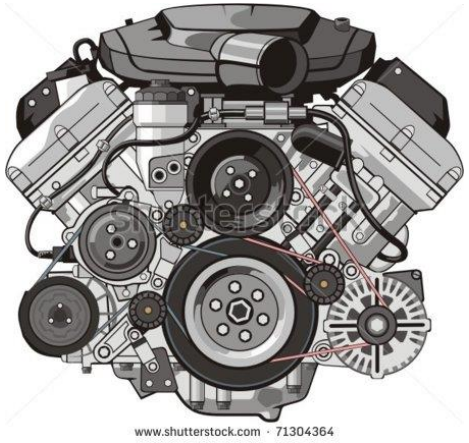
From Internal Combustion Engine to Electric Car – threat to sensors?

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

time

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

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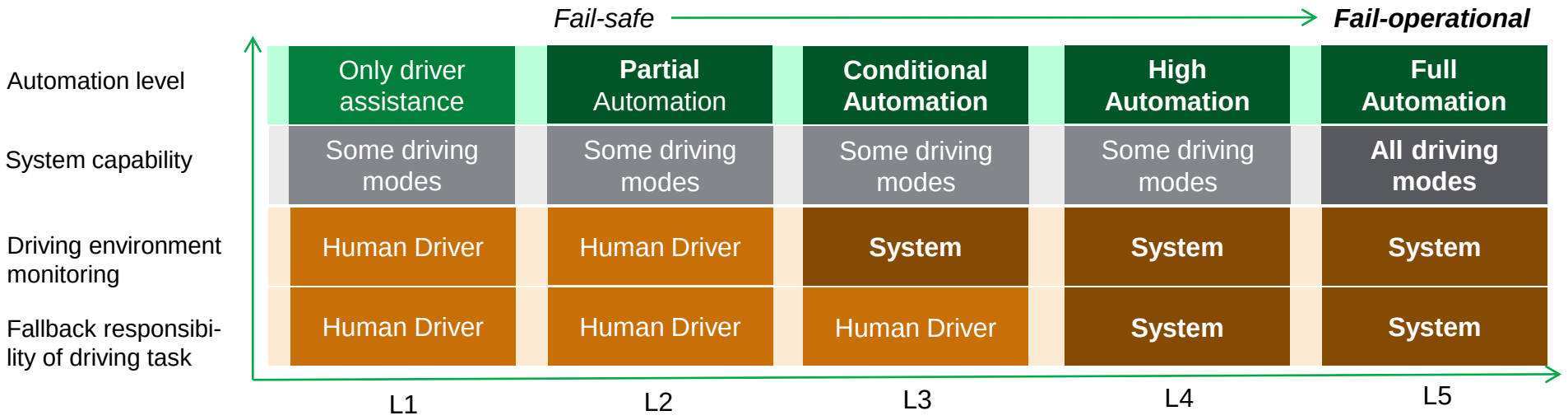
LIDAR
Navigation (dead reckon)
Sensor fusion ECU
Intelligent tires (in tire sensor)
Advanced seat (heart rate)
Occupant drowsiness
CO_2 cabin monitor
Cabin particulate sensor
Active supsension
Adaptive lighting
Laser lighting
…

MEMS & Sensor technologies for autonomous driving



Evolution of established sensor technologies	Radar: from 1D to **2D** detection
	Camera: towards higher resolution (Up to 7**MP**); 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**

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Lidar: the technology fight

Based on solid-state technology

Mechanical Scanning LIDAR

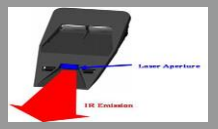
- Valeo/Ibeo
- Ibeo
- Velodyne
- Quanergy

Source: Valeo/Ibeo

Non scanning Flash LIDAR

System Suppliers:
- Continental
- Continental (ASC)
- Valeo
- Invisage Technologies
- Strobe*

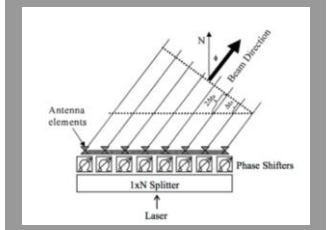
Solution suppliers:
- LeddarCore
- Phantom Intelligence



Source: Continental

Phase array LIDAR

- Quanergy
- MIT + Darpa



Source: Quanergy

MEMS based scanning LIDAR

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

Source: Innoluce

Other

VCSEL based:
- Trilumina
- Xenomatix

Electro-optic scanner:
- Princeton Lightwave

Optical Antenna:
- OryxVision

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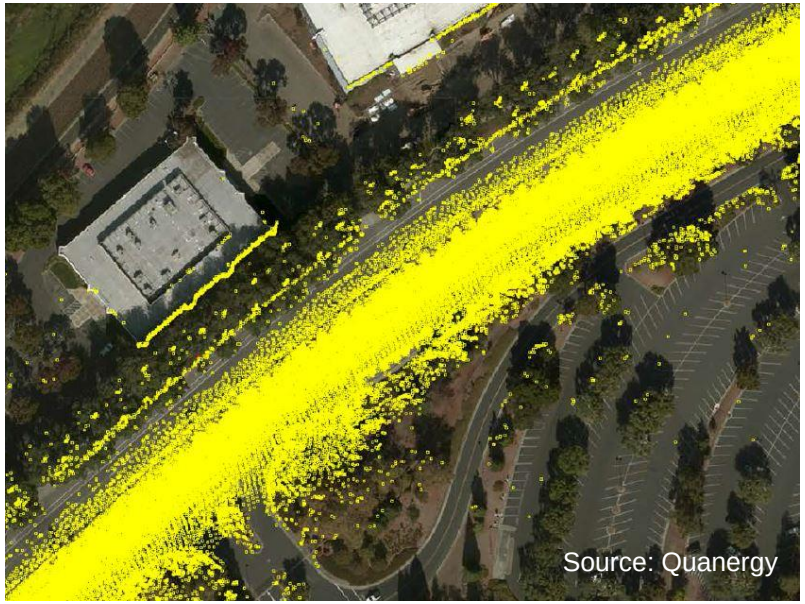
Inertial navigation assumes 100x better performance than today

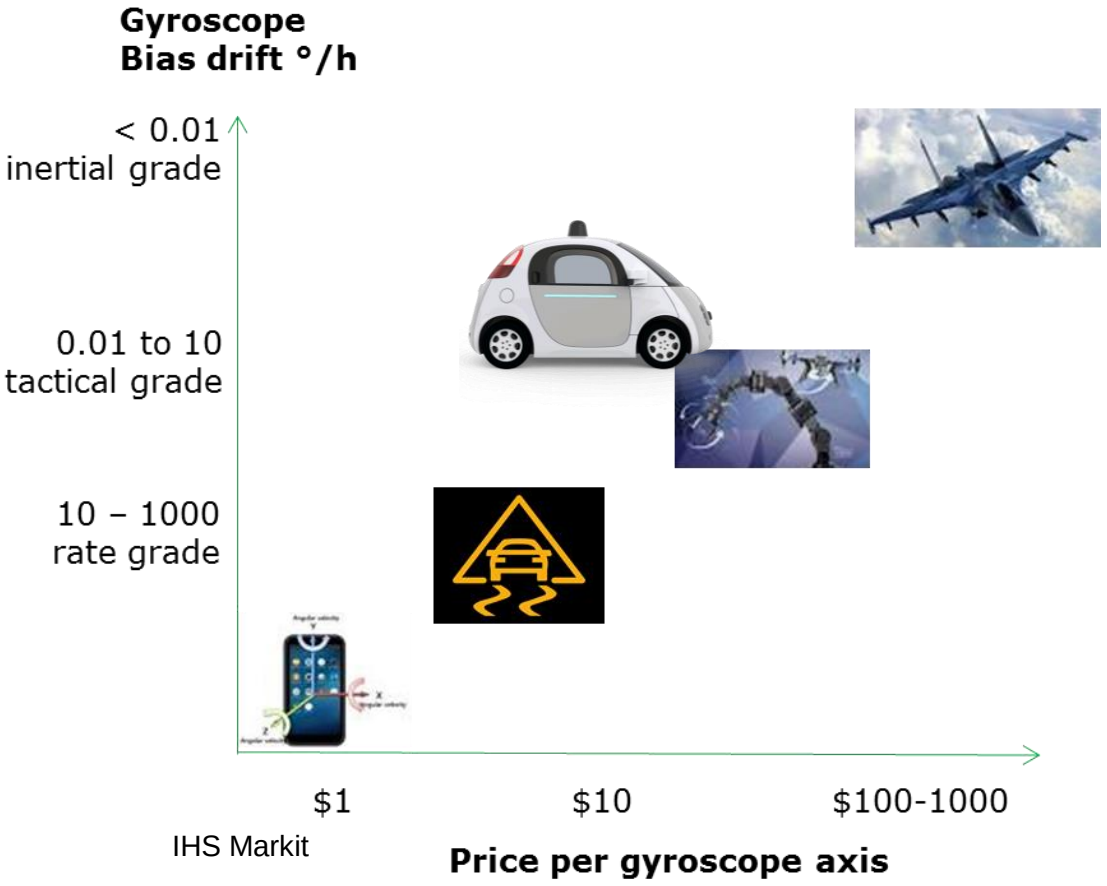
- Autonomous driving requires high performance dead reckoning

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



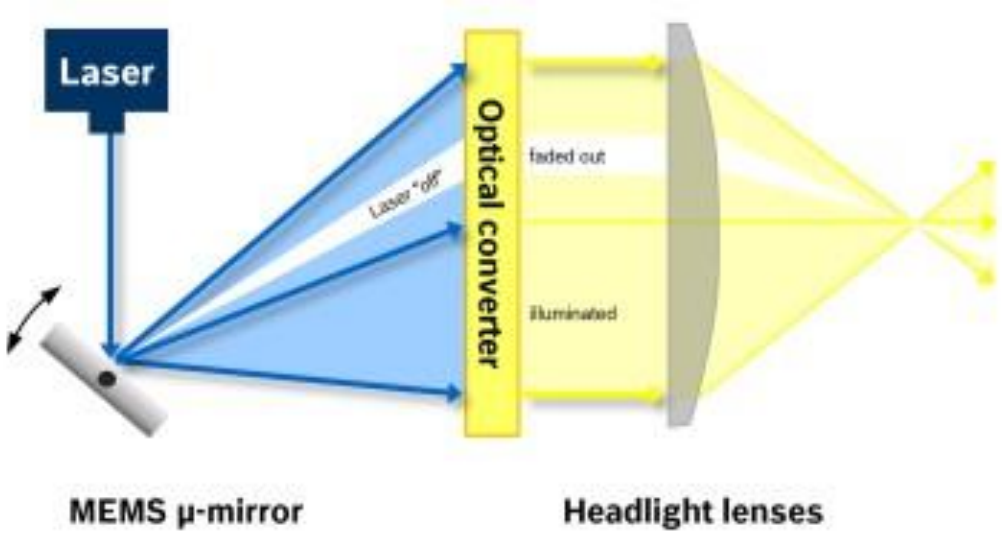
High-performance IMU can be inside LIDAR, e.g. Quanergy using ADI

Positioning for yaw rate sensor autonomous driving



Adaptive lighting: full beam all the time

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



Source: Bosch

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
- Valeo

Powertrain modules

- Aisin
- 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
- Valeo
- Visteon…

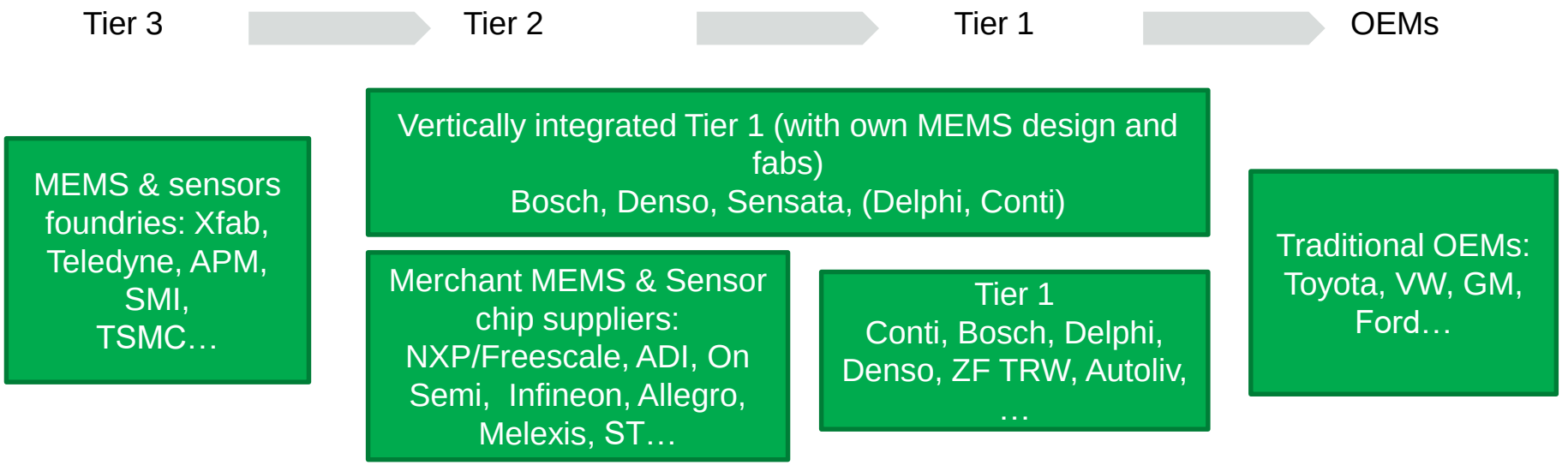
Consumer suppliers making inroads

- STMicroelectronics,

Sensors suppliers (die and 1LP):

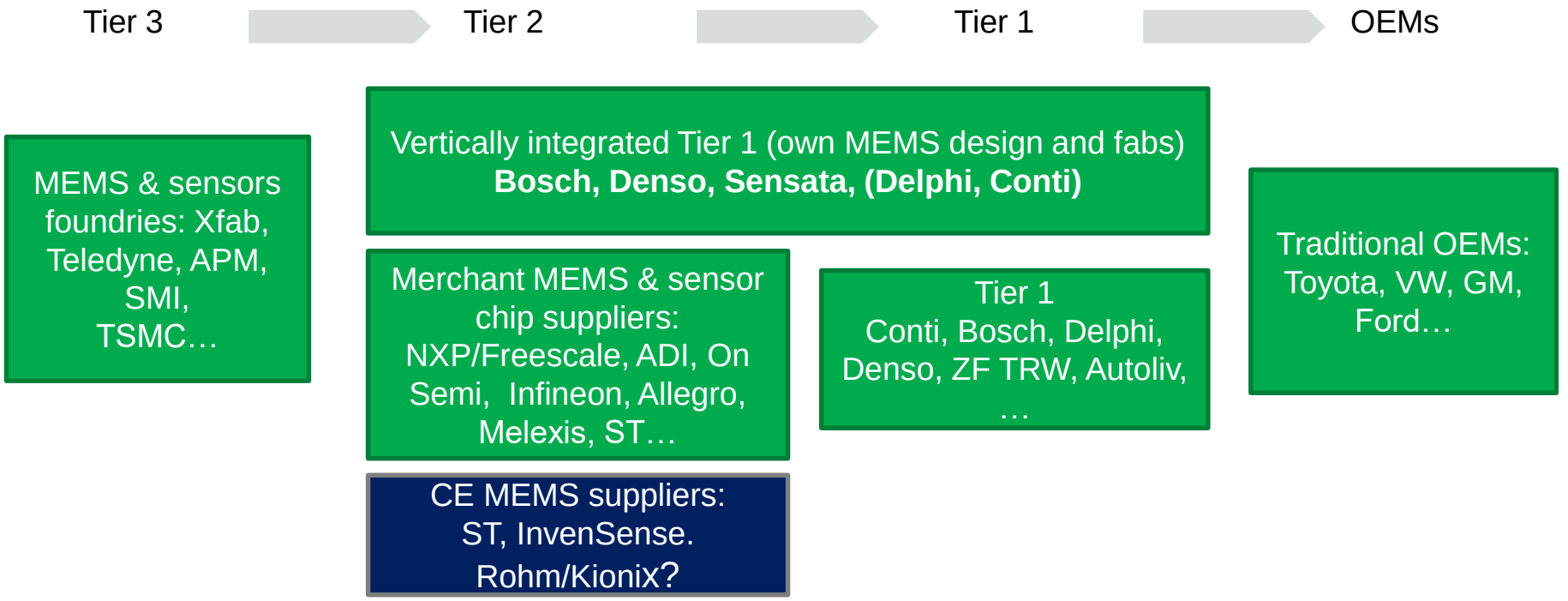
- ADI, Allegro, AKM, ALPS, Amphenol, ams, Bosch, Delphi, Denso, ELMOS, Epson, FLIR, Freescale, Fuji Elec., Infineon, Kavlico, Kionix, Melexis, Micronas, MEMSIC, Microstaq, Murata, NXP, Osram, Panasonic, Samyoung, Sensata, Sensirion, SGX, SMI, STMicroelectonics, TI, ULIS…

Automotive MEMS & Sensors Ecosystem (simplified)

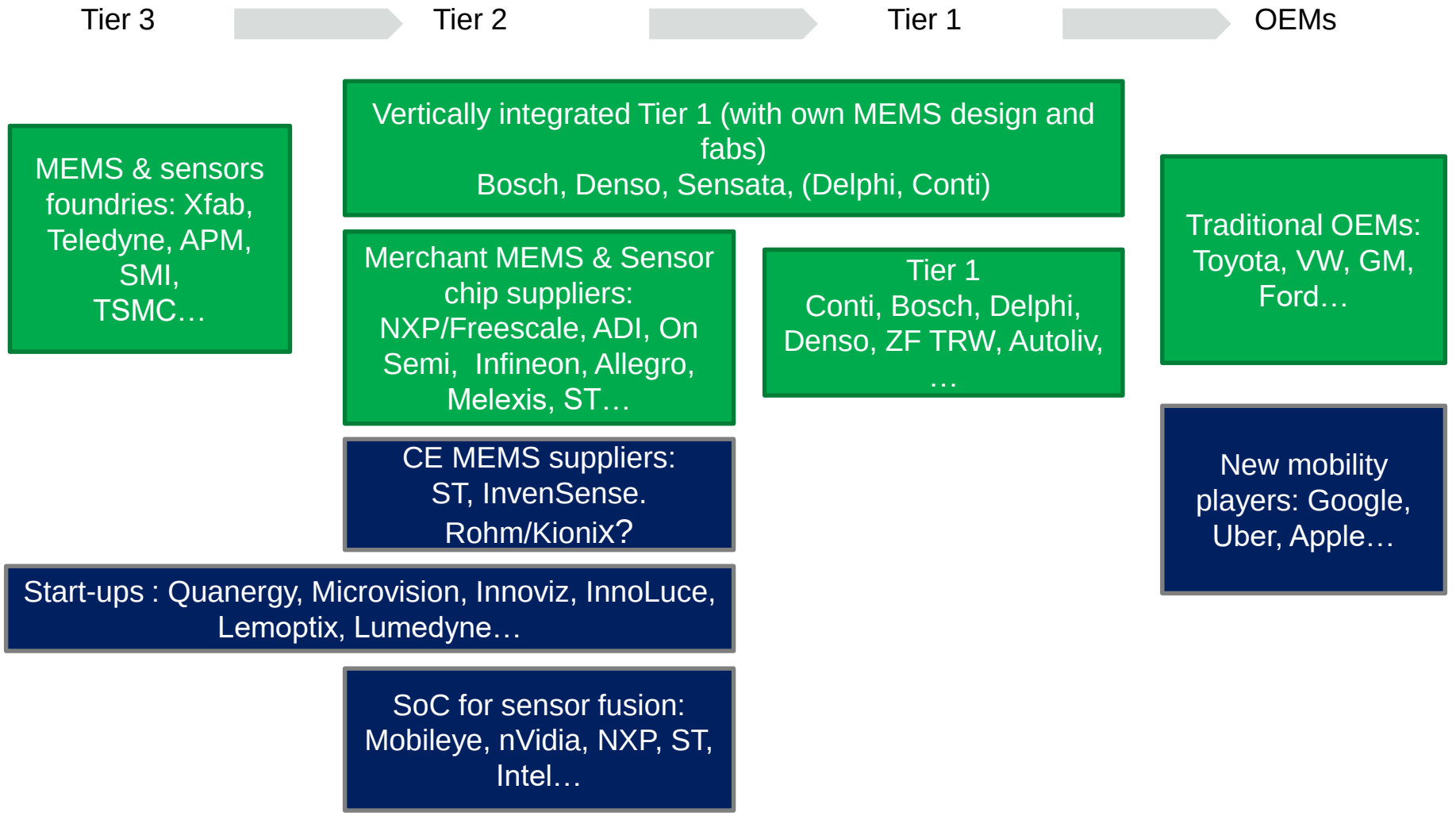


Automotive MEMS & Sensors Ecosystem (simplified)

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

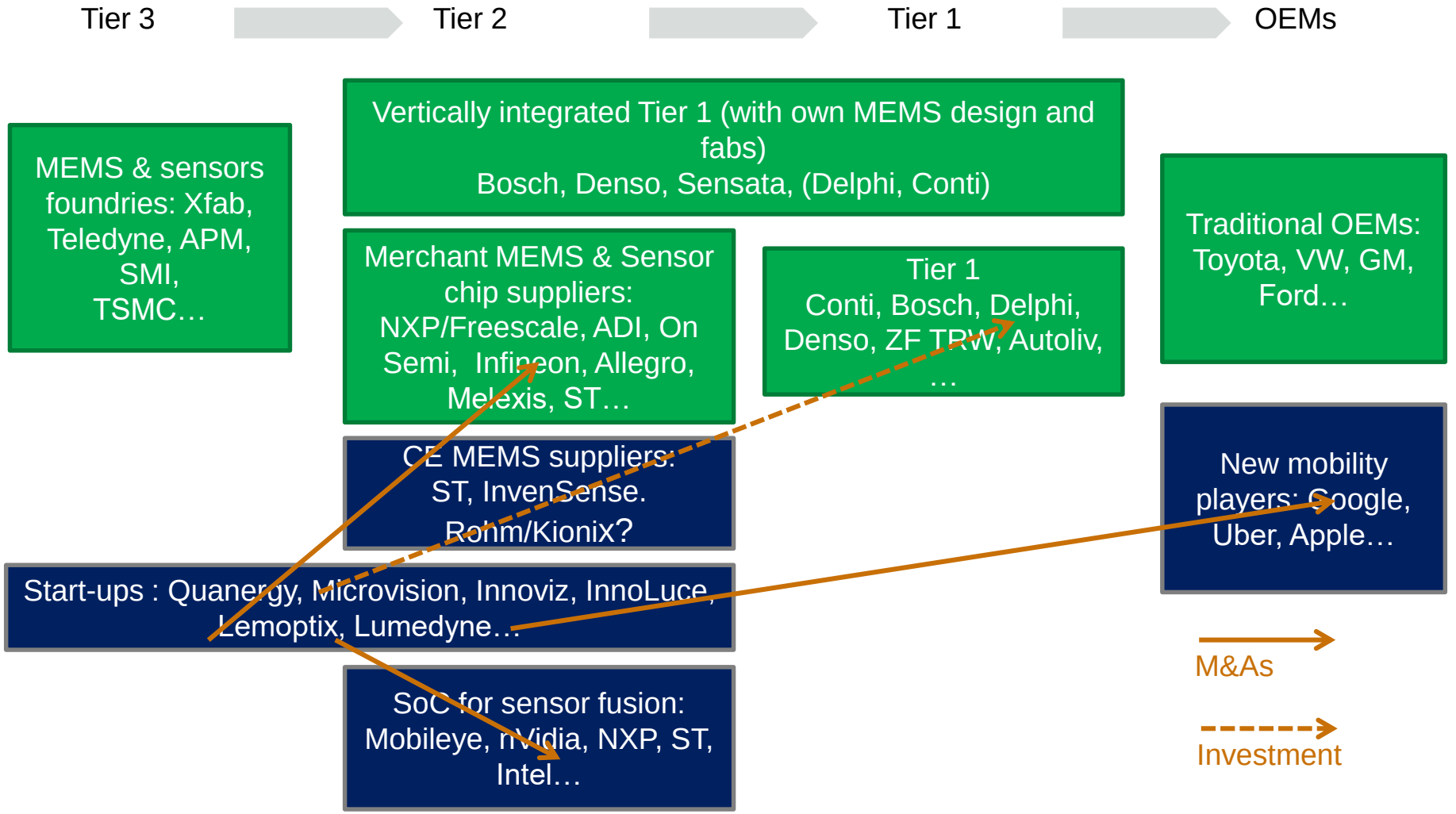


Autonomous driving impacts the ecosystem

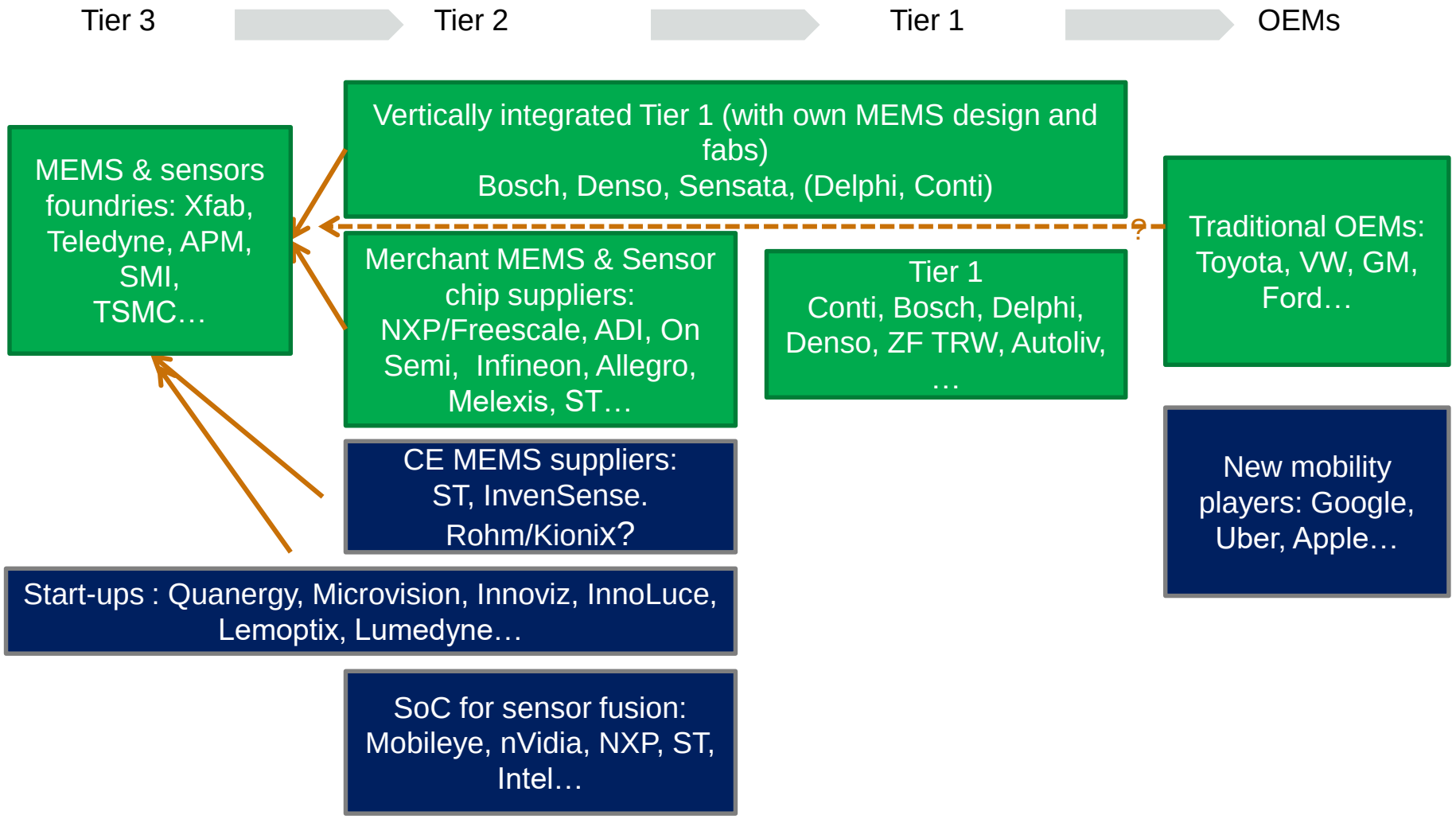


Autonomous driving impacts the ecosystem

Start-ups develop critical sensor technologies for autonomous driving

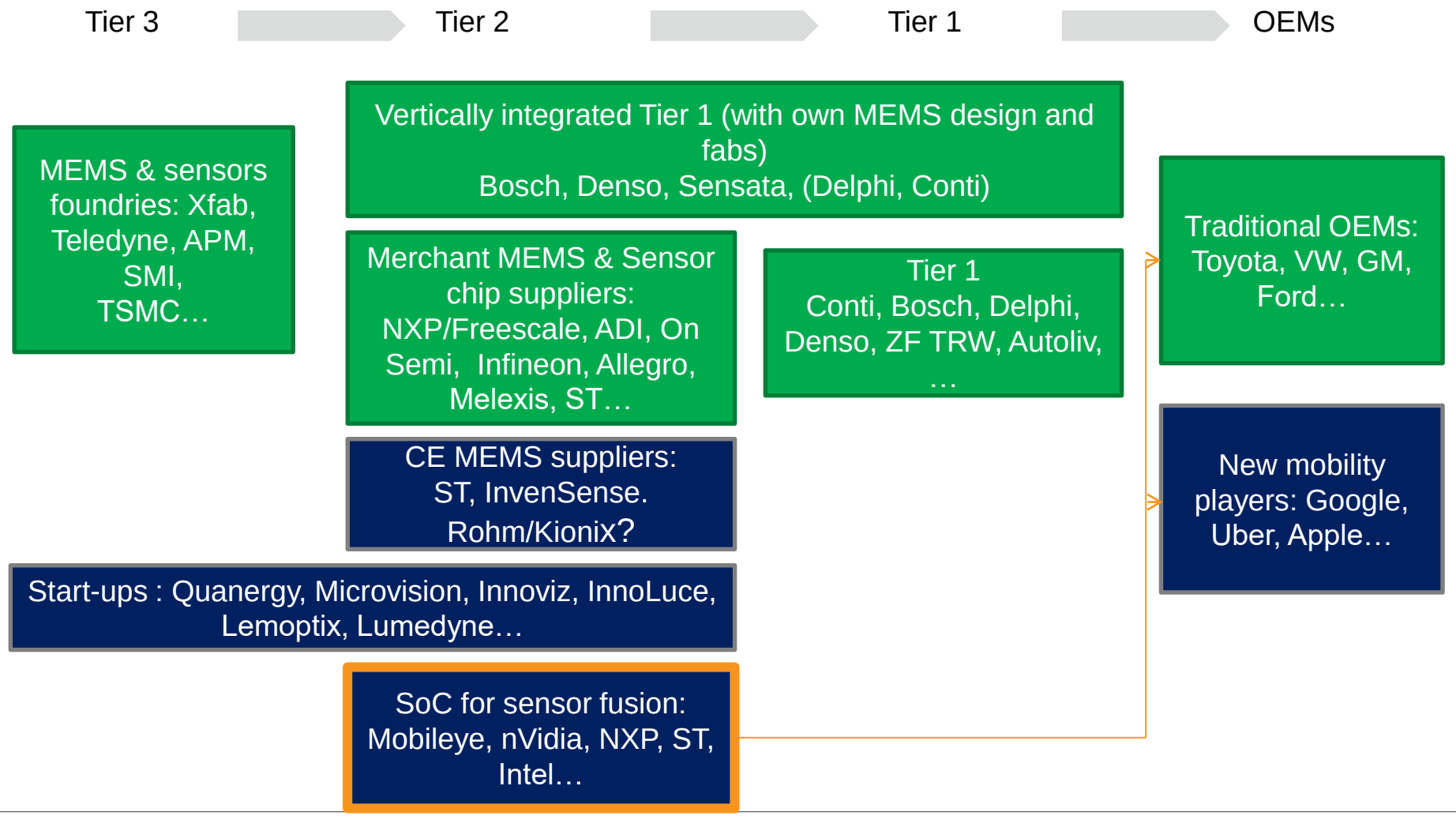


Autonomous driving impacts the ecosystem



Autonomous driving impacts the ecosystem

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 CO_2 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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