LABORATORY OF APPLIED THERMODYNAMICS

Zissis Samaras
Professor

ARISTOTLE UNIVERSITY THESSALONIKI
SCHOOL OF ENGINEERING
DEPT. OF MECHANICAL ENGINEERING

Automotive Emissions Control: Challenges from real world performance regulatory requirements

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Acknowledgments

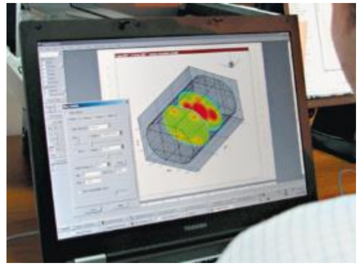
To the CLOVE consortium

Leonidas Ntziachristos, Christof Schernus, Jon Andersson, Norbert Ligterink, Willar Vonk, Stefan Hausberger, Paivi Aako and many others

Outline

- Short personal profile
- Need for continuing action to mitigate road transport emissions
- The next stage in the regulations
  - In use performance monitoring
  - CO_2/GHG and non regulated emissions
  - The institutional framework
- Concluding remarks

Scientific & research areas

Exhaust gas emissions & after-treatment technology

Vehicle fuel efficiency

Renewable fuels

Extensive know-how in combustion engines and emissions **measurement** technology combined with advanced CAE and **modeling** techniques

…**keeping the big picture on vehicle environmental performance!**

CERT
Quality Assurance ISO 9001
QMSCERT

The Lab of Applied Thermodynamics

Faculty

Pr. Z. Samaras

Pr. A. Tomboulides

Pr. G. Koltsakis

Pr. L.Ntziachristos

SECRETARIAT

Senior Researchers

Dr P. Pistikopoulos

Dr I. Vouitsis

Dr S. Geivanidis

Dr D. Katsaounis

Dr A. Dimaratos

Dr D. Mertzis

Dr P. Fragiadoulakis

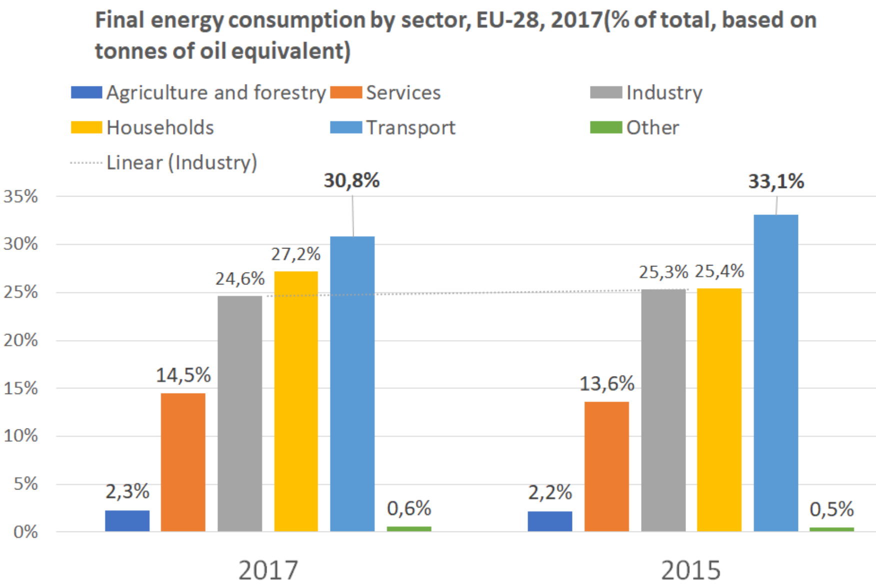
Phd Students

Technica l Staff

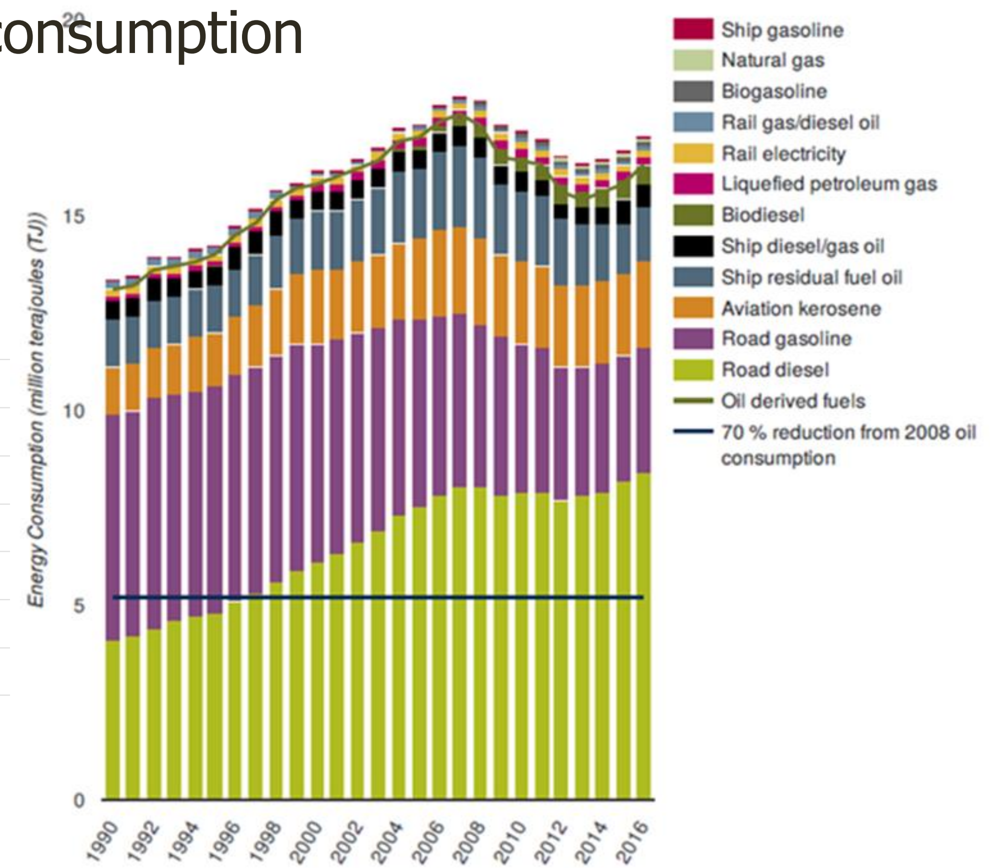
ROAD TRANSPORT EMISSIONS CONTINUE TO BE IMPORTANT

Energy consumption per mode in the EU

Road transport accounts for the largest share of final energy consumption



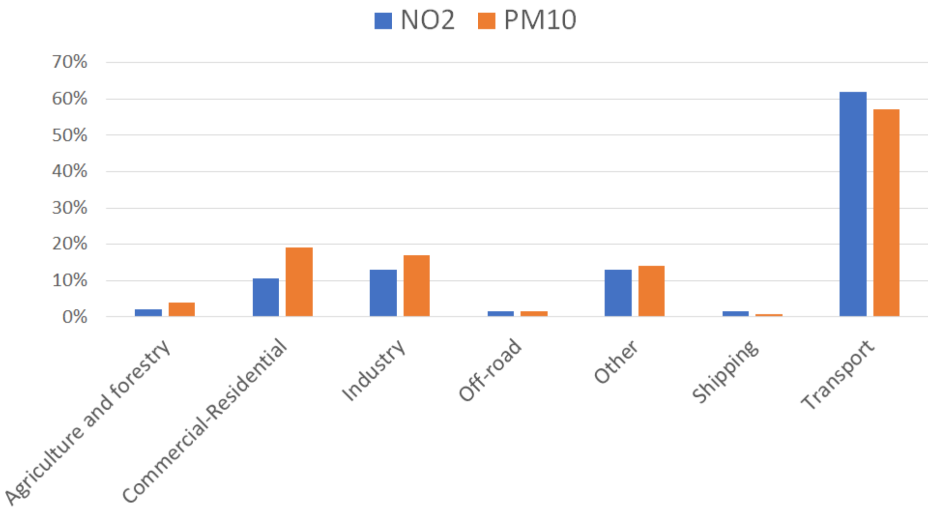
Source: EEA 2019, EEA 2017, Eurostat 2018



- Despite the drop, consumption in 2017 was still 20% higher than in 1990
- The fraction of diesel used in road transport continues to increase (74 % in 2016)
- NRMM: Aircraft have biggest share in consumption – but here only LTO emissions are counted
- Mobile machines, ships, rail make up the rest

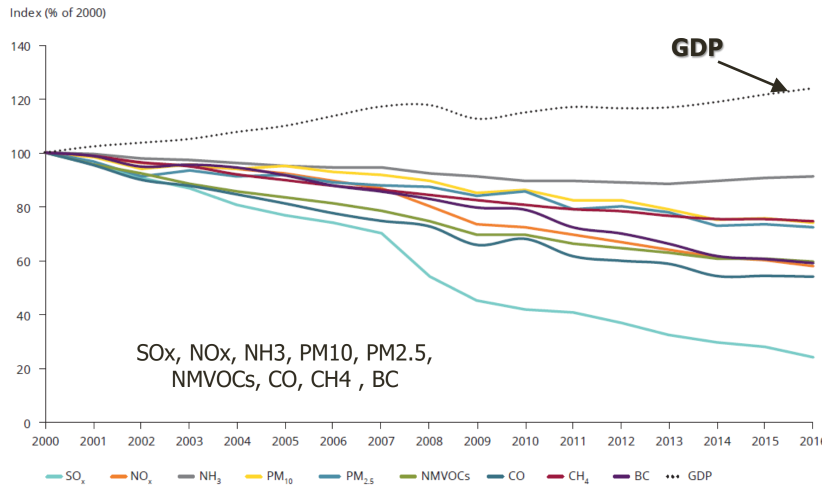
Regulations and Emissions

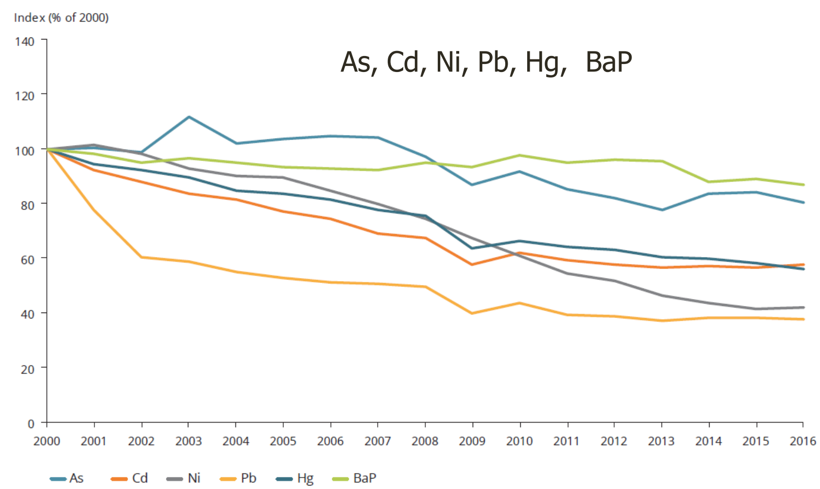
Sectors addressed by the measures reported by the EU-28 Member States for PM10 and NO2



Source: AVL 2018

Development in EU-28 emissions, 2000-2017 (% of 2000 levels).
Also shown for comparison is EU-28 GDP





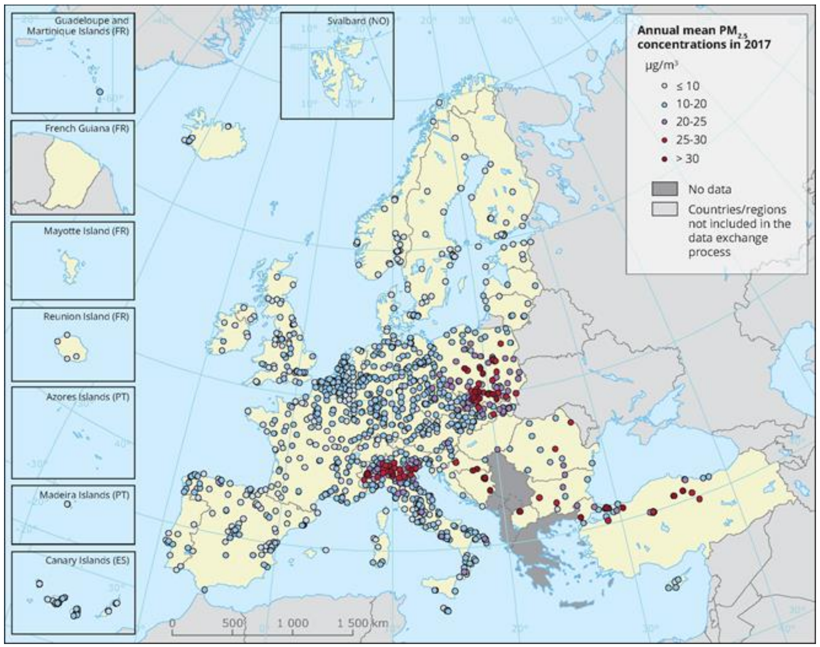
Source: EEA 2019

Annual Mean Air Quality in the EU (2017, PM and NO2)

PM2.5 conc.

- 10-20 μg/m³
- 20-25 μg/m³
- >25 μg/m³

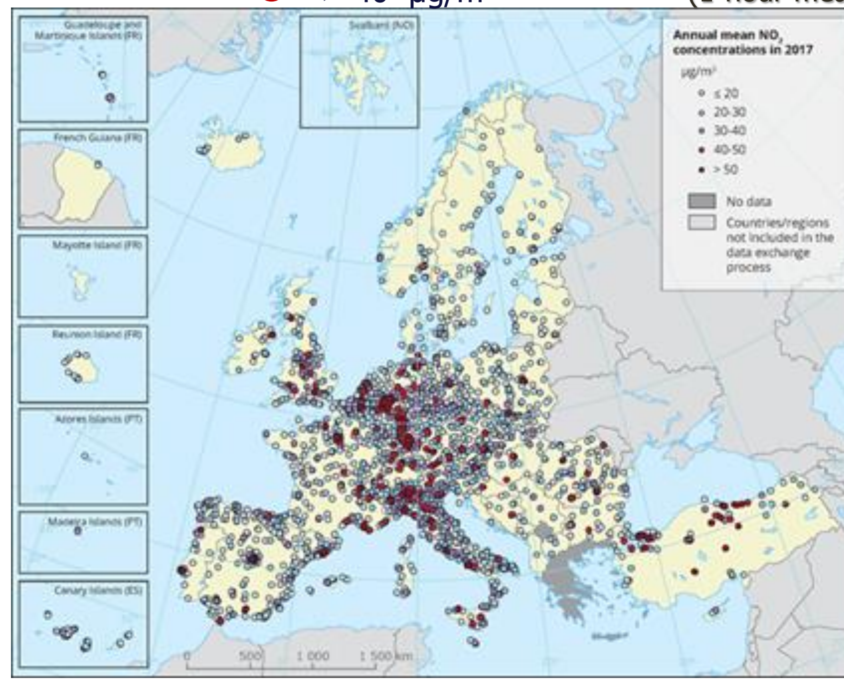
WHO limits: **10 μg/m³** (annual mean), **25 μg/m³** (24-hour mean)



NO2 conc.

- 20-30 μg/m³
- 30-40 μg/m³
- > 40 μg/m³

WHO limits: **40 μg/m³** (annual mean), **200 μg/m³** (1-hour mean)



PM10:
- Exceedances of annual limit value (40 μg/m³) in only 3 % of all the reporting stations
- The stricter value of the WHO (20 μg/m³) was exceeded at 54 % of the stations and in all the reporting countries

NO2:
- The highest concentrations (89 % of all values above the annual limit value=40 μg/m³) at traffic stations

The average contribution of local traffic to urban PM10, PM2.5 and NO_2 is estimated at 15%, 35% and 46%, respectively

Source: EEA 2017, 2019

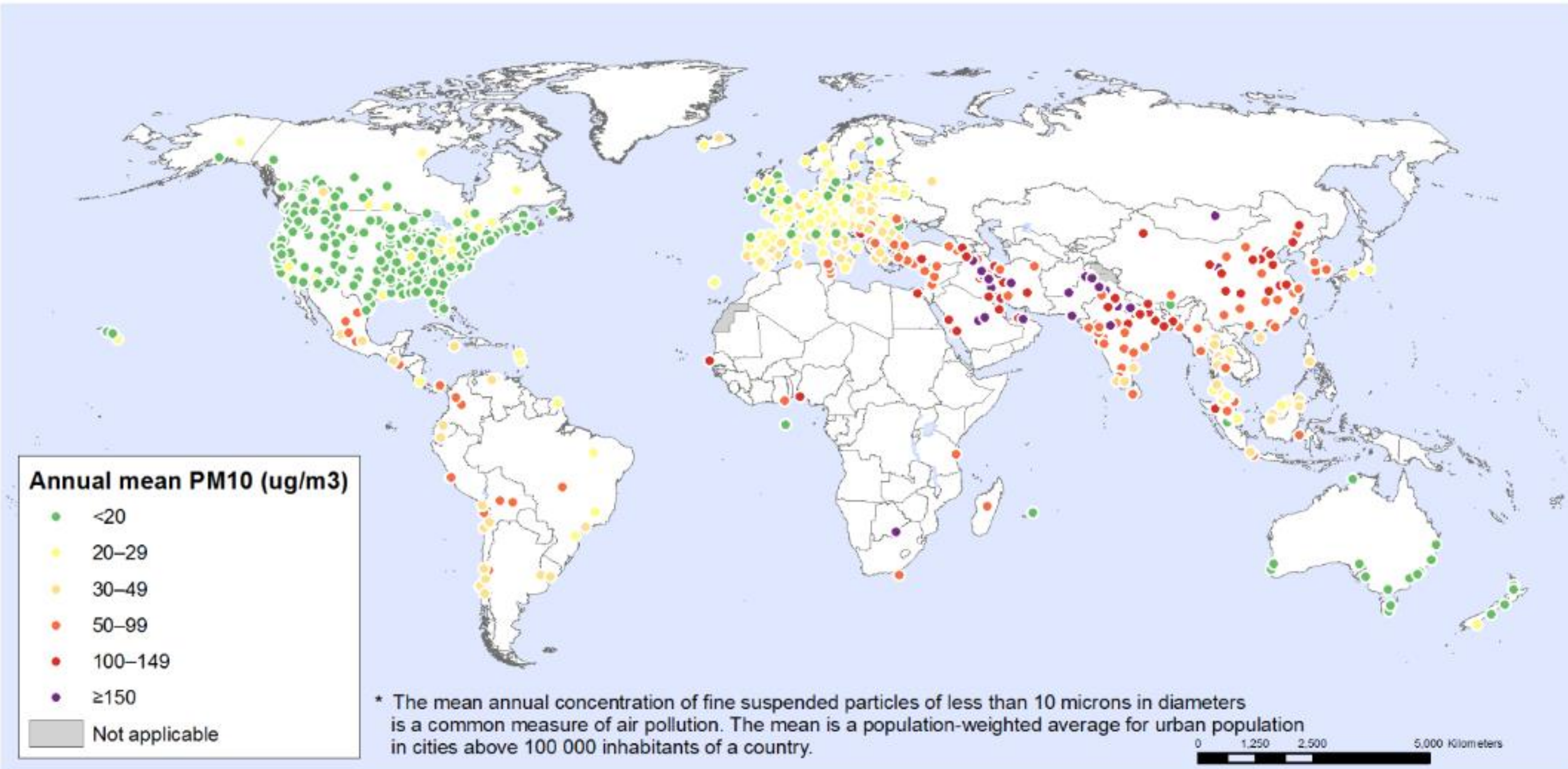
Exposure of the EU-28 population in urban areas in 2015 and 2017

Pollutant	EU reference value	Exposure estimate (%)	WHO AQG	Exposure estimate (%)
$PM_{2.5}$	Year (25)*	6-8	Year (10)	74-81
PM_{10}	Day (50)	13-19	Year (20)	42-52
O_3	8-hour (120)	12-30	8-hour (100)	95-98
NO_2	Year (40)	7-8	Year (40)	7-8
BaP	Year (1)	17-20	Year (0.12) RL	83-90
SO_2	Day (125)	< 1	Day (20)	21-31

*Values in parentheses denote limits in μg/m^3

Source: EEA 2019

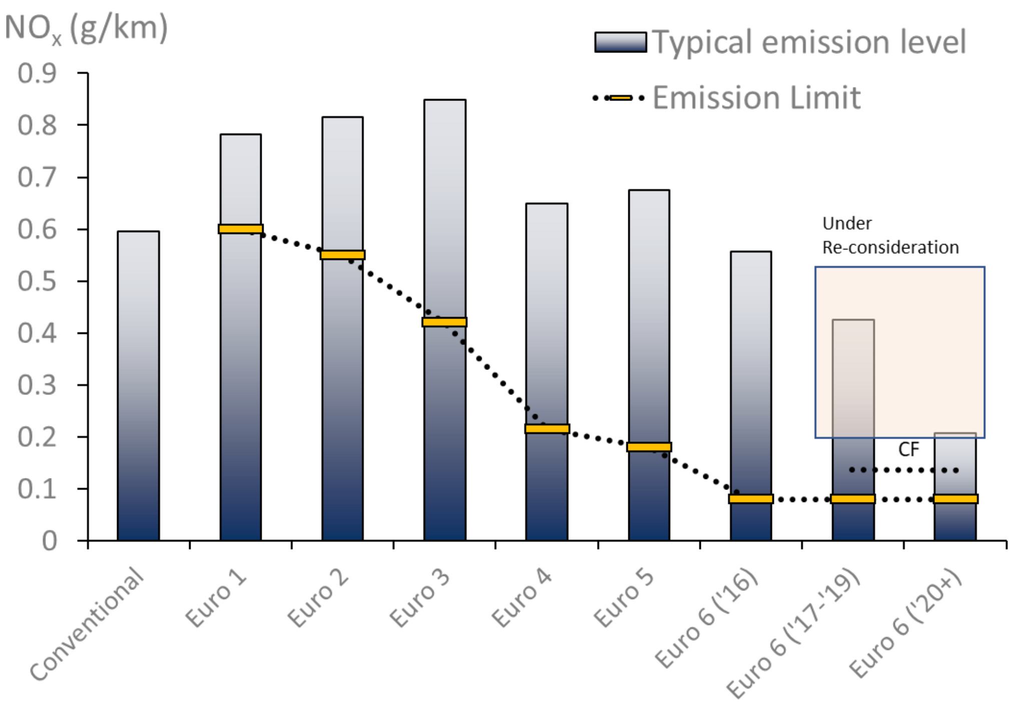
Exposure to PM_{10} in 1100 urban areas, 2003 – 2010



WHO Air Quality Guideline: Annual mean PM10 = 20 $\mu g/m^3$

Source: WHO, 2012

Emission levels: Light Duty Vehicles



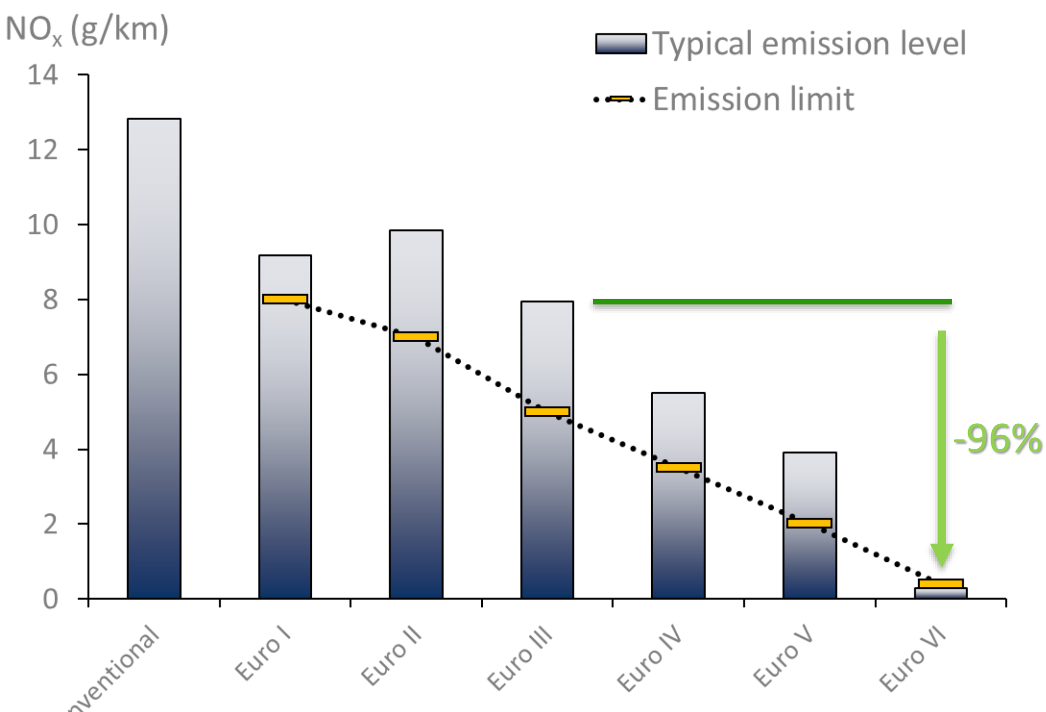
Medium diesel PCs - COPERT 5.0 V2017

Significant exceedances up to Euro 5

Expected reductions at Euro 6 step. Still limited evidence – models under revision

Light Duty Vehicles	M1 – Passenger Cars	Carriage of people and their luggage up to 8 seats	
	N1 – Light Commercial Vehicles	Carriage of goods and $M_{max} \leq 3{,}5$ t	

Emission levels: Heavy Duty Vehicles

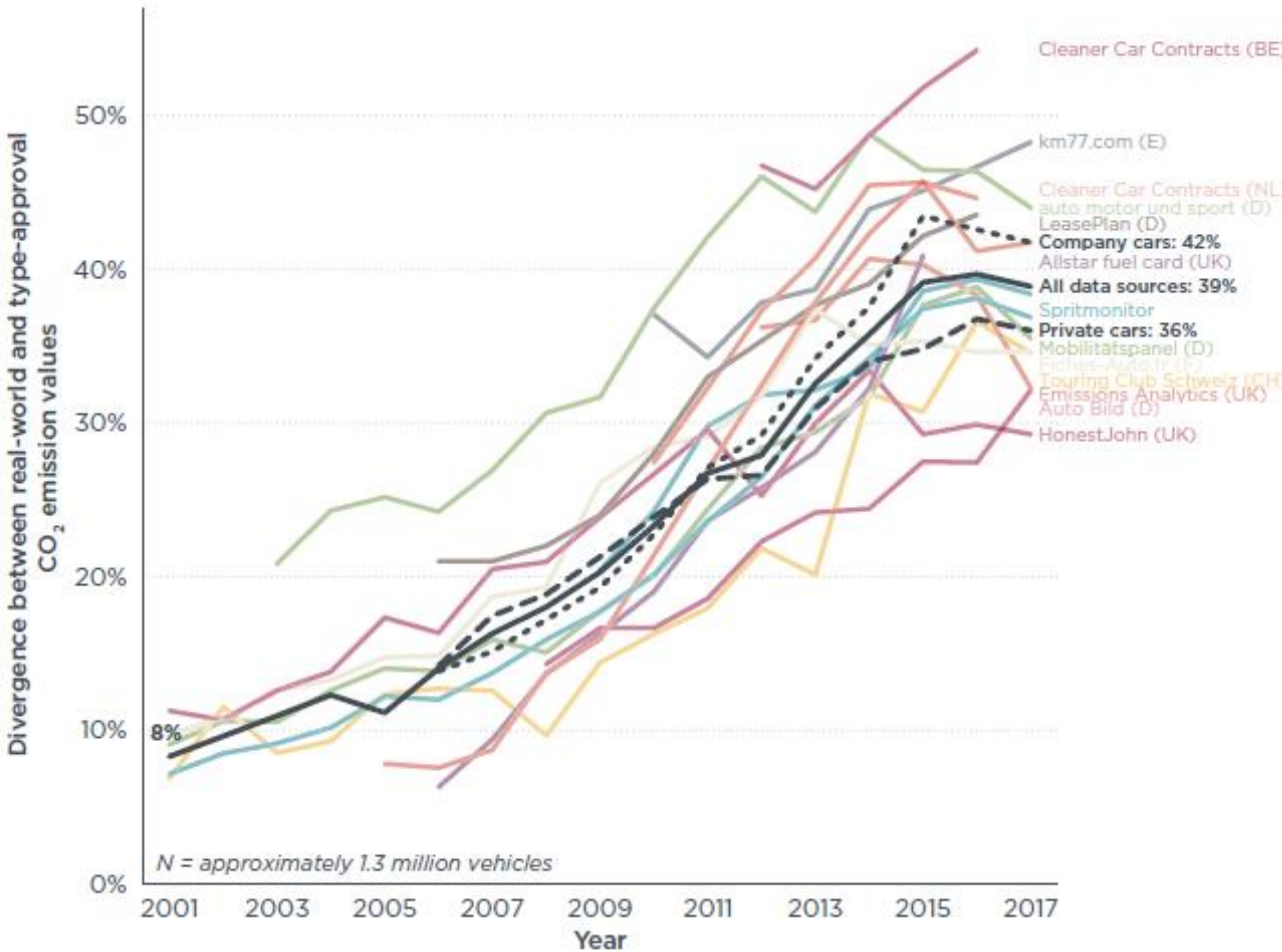


32t Rigid trucks - COPERT 5.0 V2017

Generally, consistent reductions between emission limits and emission factors

Heavy Duty Vehicles	N3 - Heavy Goods Vehicles	Carriage of goods and M_{max} > 12 t	
	M3 - Buses	Carriage of people and their luggage, more than 8 seats and M_{max}>5 t	
	N3S - Special purpose vehicles	Special arrangements and/or carrying equipment	

Divergence between real-world CO2 emissions and manufacturers' type-approval CO2 emissions



Source: ICCT. 2019

THE NEXT STAGE IN THE REGULATIONS: EURO FINAL OR EURO ULTIMATE?

Major lines of consensus for post Euro 6/VI emissions regulations

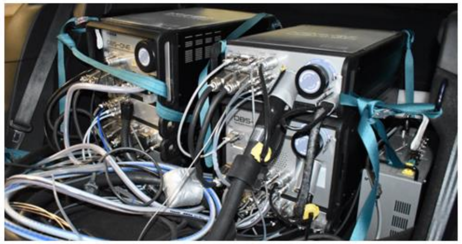
- In use performance monitoring for compliance and enforcement over the lifetime of the vehicle
- Pollutant emissions to be considered along with CO2/GHG emissions
- Non regulated emissions included in the regulations
- Need for simplification

IN USE PERFORMANCE MONITORING

Building on the achievements of Euro 6/VI

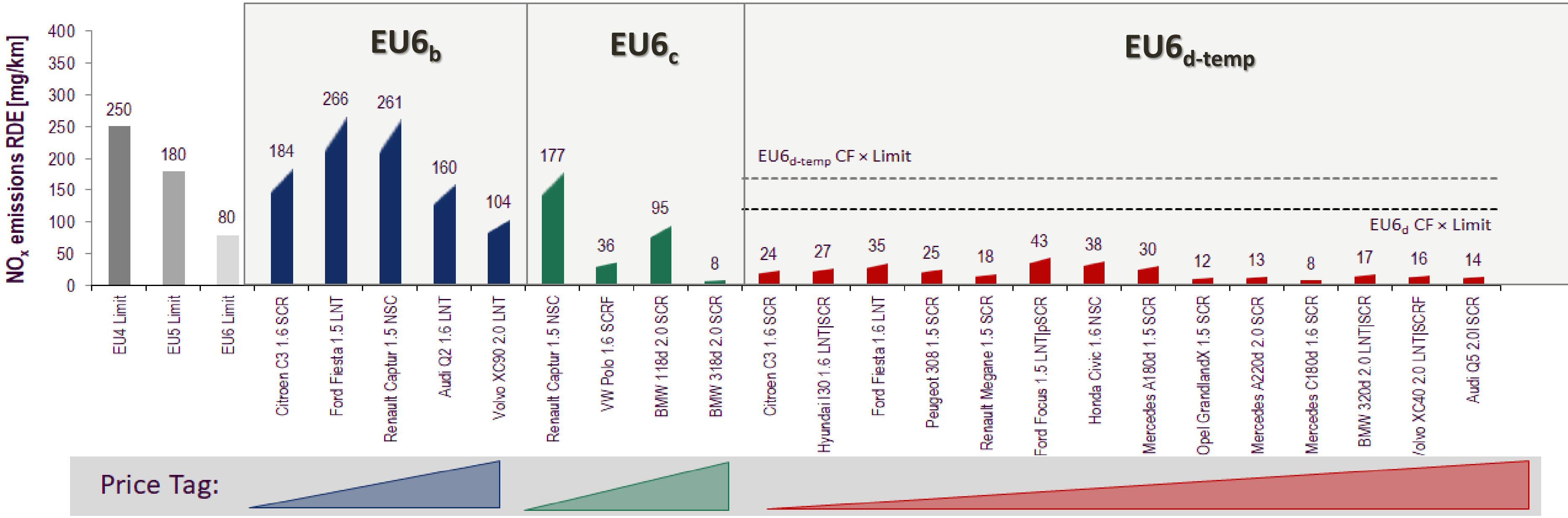
- The introduction of Real-Driving Emission requirements
  - In-Service Conformity testing requirements for HD vehicles
  - Real-Driving Emission requirements for LD vehicles

  is largely associated with



- Technology development, resulting in integrated powertrain and emission control and heat management
- Demonstration of technical capability of ultra-low-emission performance under real-world conditions
- And as a result, a decrease of vehicle pollutant emissions

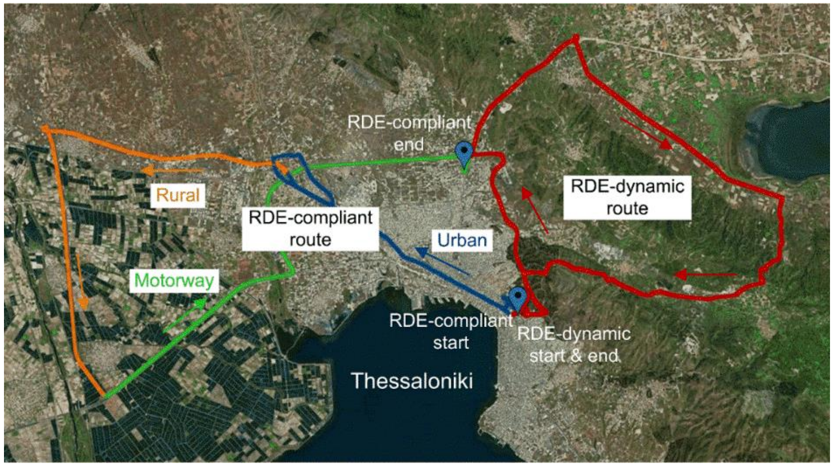
The impact of RDE on Diesel NOx



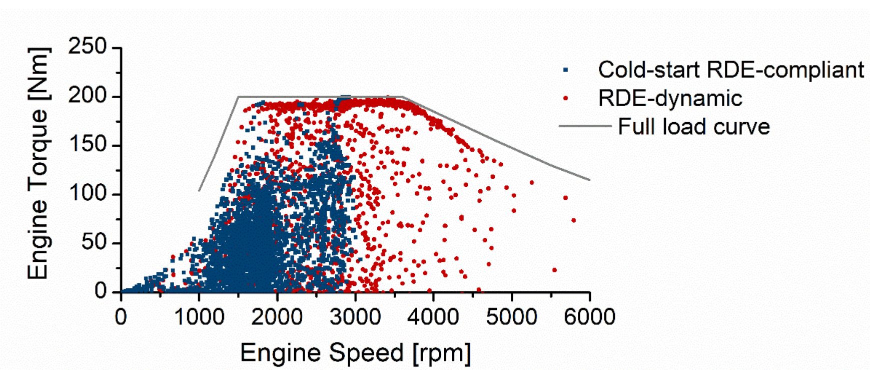
- **Official RDE results from public database:**
  - Euro 6 diesel before RDE continued to emit much higher than limit
  - Latest Euro 6d-temp already by far fulfil Euro 6d

source: //www.acea.be/publications/article/access-to-euro-6-rde-monitoring-data

RDE – Example Thessaloniki



RDE route respects regulatory requirements
DYN reflects a route of more demanding driving, incl. Uphill driving



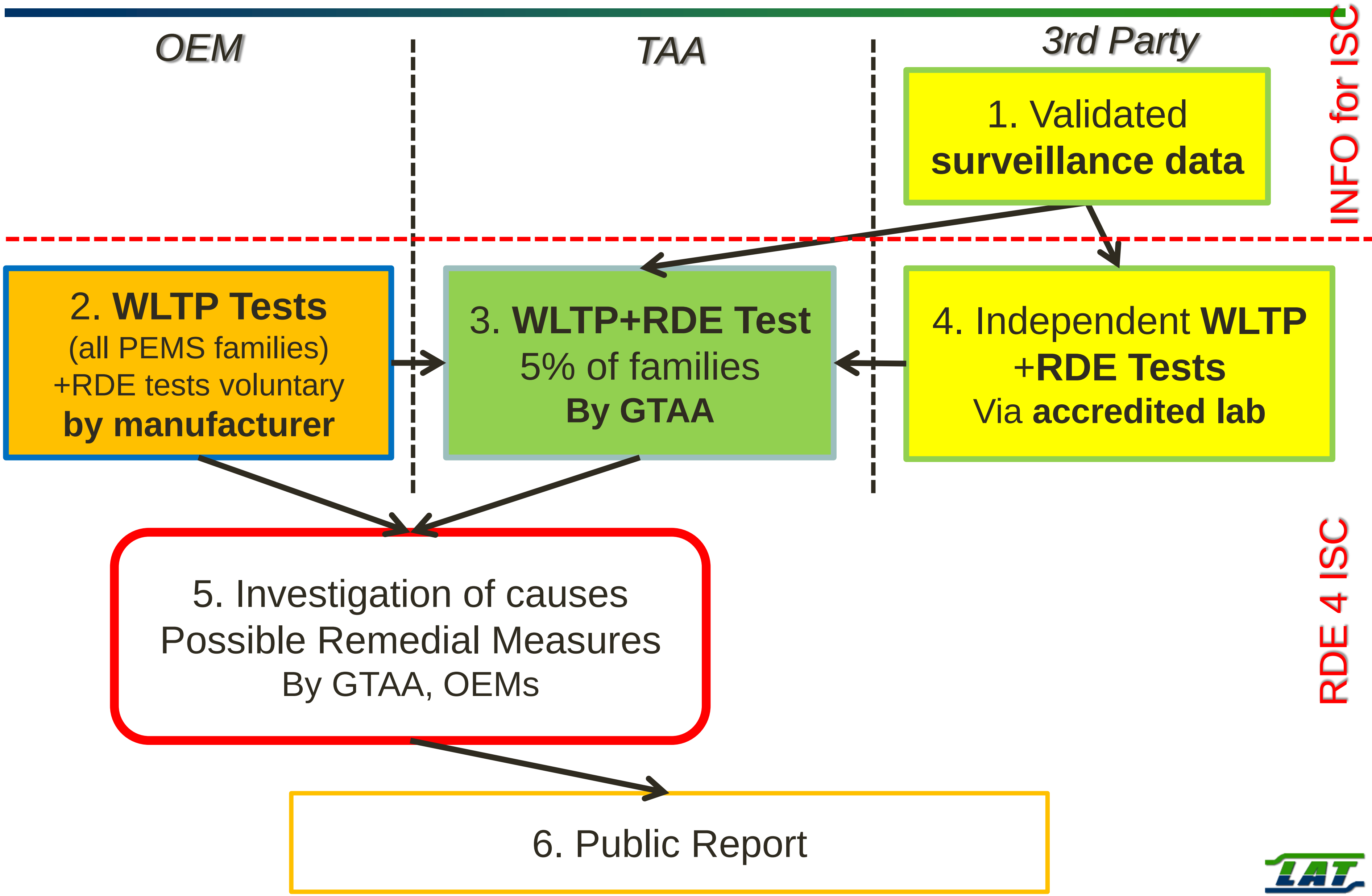
Trip characteristics	RDE	DYN	Regulation boundaries
Trip duration [min]	110	60	90 – 120
Stop duration [% of trip]	22	20	> 10
Trip distance [km]	77	77	> 46
Urban distance share [%]	37	30	29 – 44
Rural distance share [%]	29	36	23 – 43
Motorway distance share [%]	34	34	23 – 43
Urban av. speed [km/h]	21	30	15 – 30
Rural av. speed [km/h]	83	75	60 – 90
Motorway av. speed [km/h]	118	110	100 – 145
Max altitude [m]	115	530	< 700
Positive el. gain [m/100km]	507	1600	<1200
Total altitude gain [m]	-7	0	± 100

What do we need more from RDE?

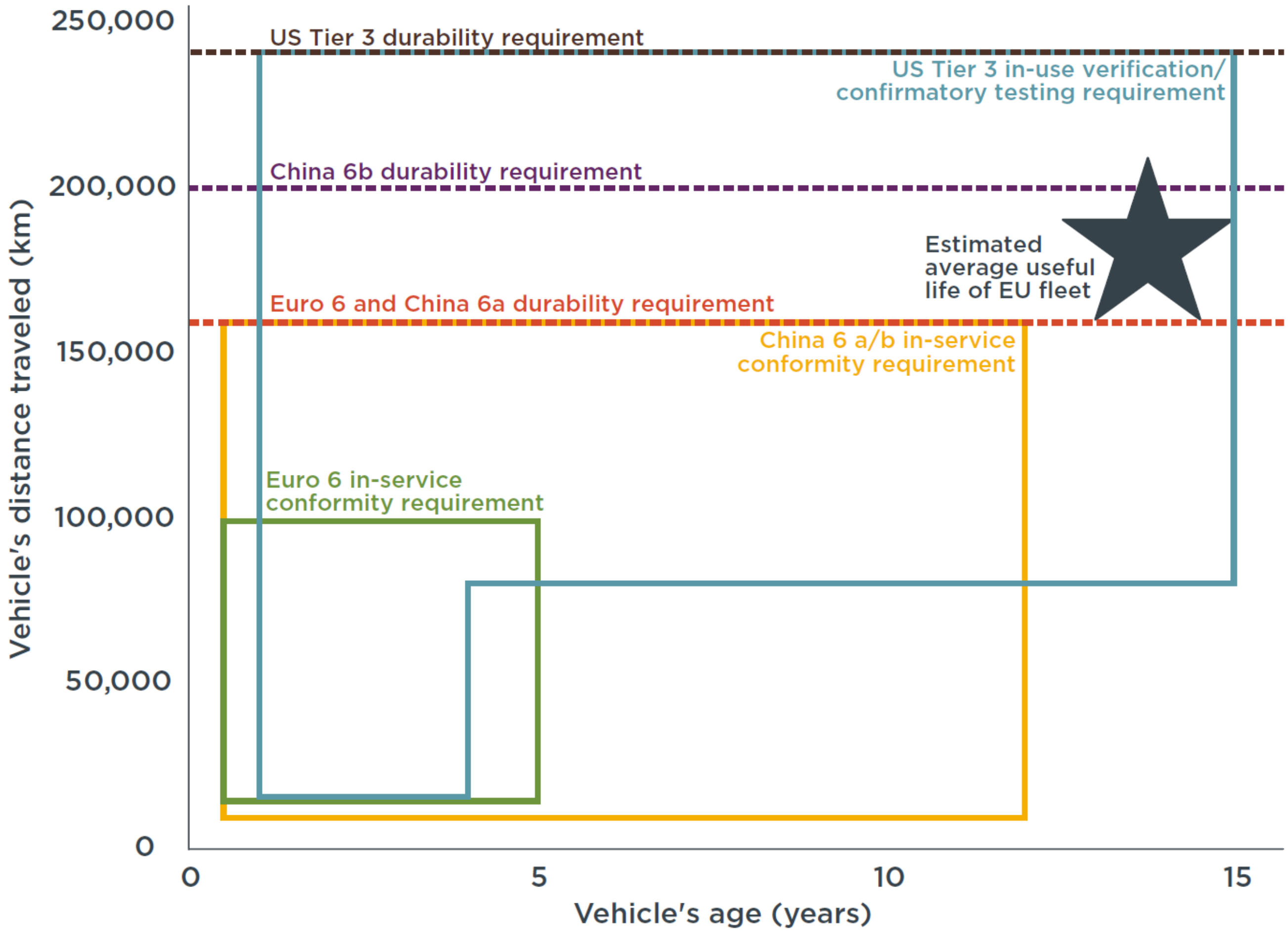
- Revisit and re-evaluate the test boundaries such as
  - Driving boundary conditions (upper and lower driving dynamics
  -
  - nd
- An
- Cle es

Source: AVL 2018

New ISC scheme from January 2019



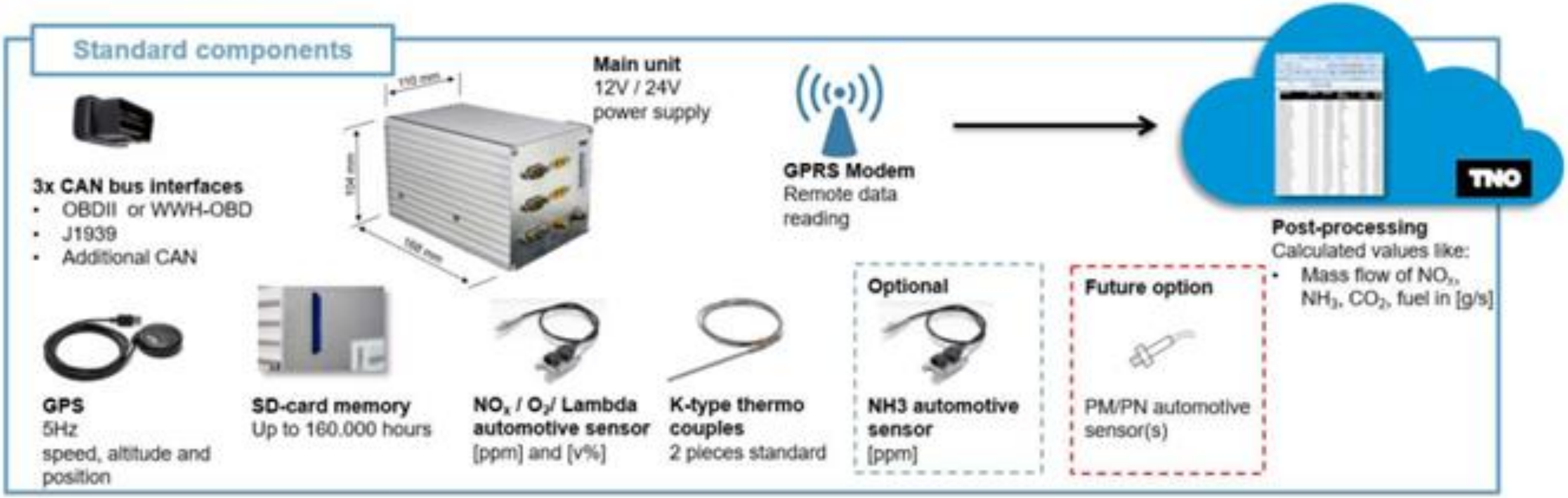
LDV Durability requirements

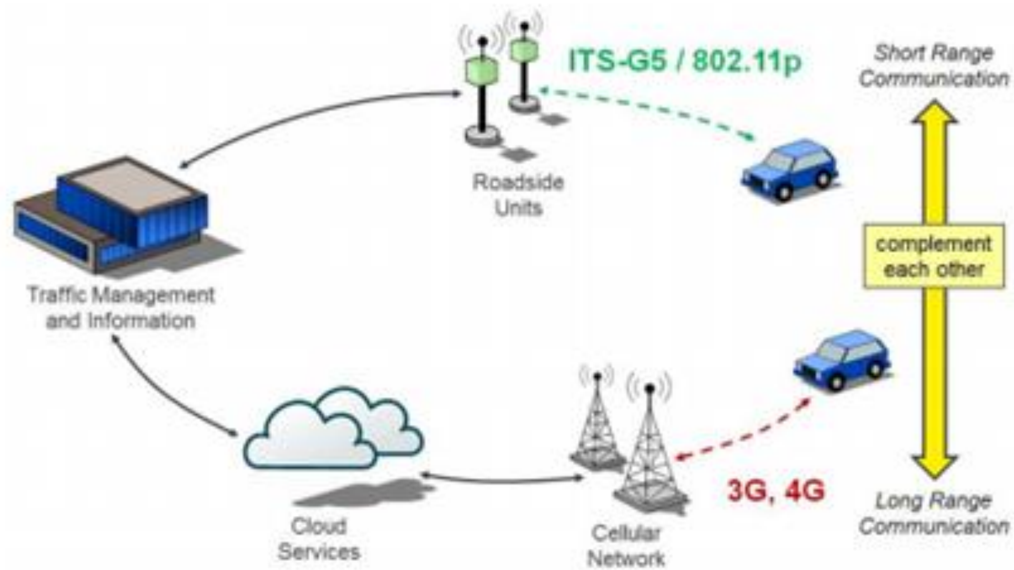


Aligning the **age** and mileage requirements for vehicle selection for ISC testing with the useful life.

Figure source: ICCT, 2019

Onboard emission monitoring – OBM
Future next step?



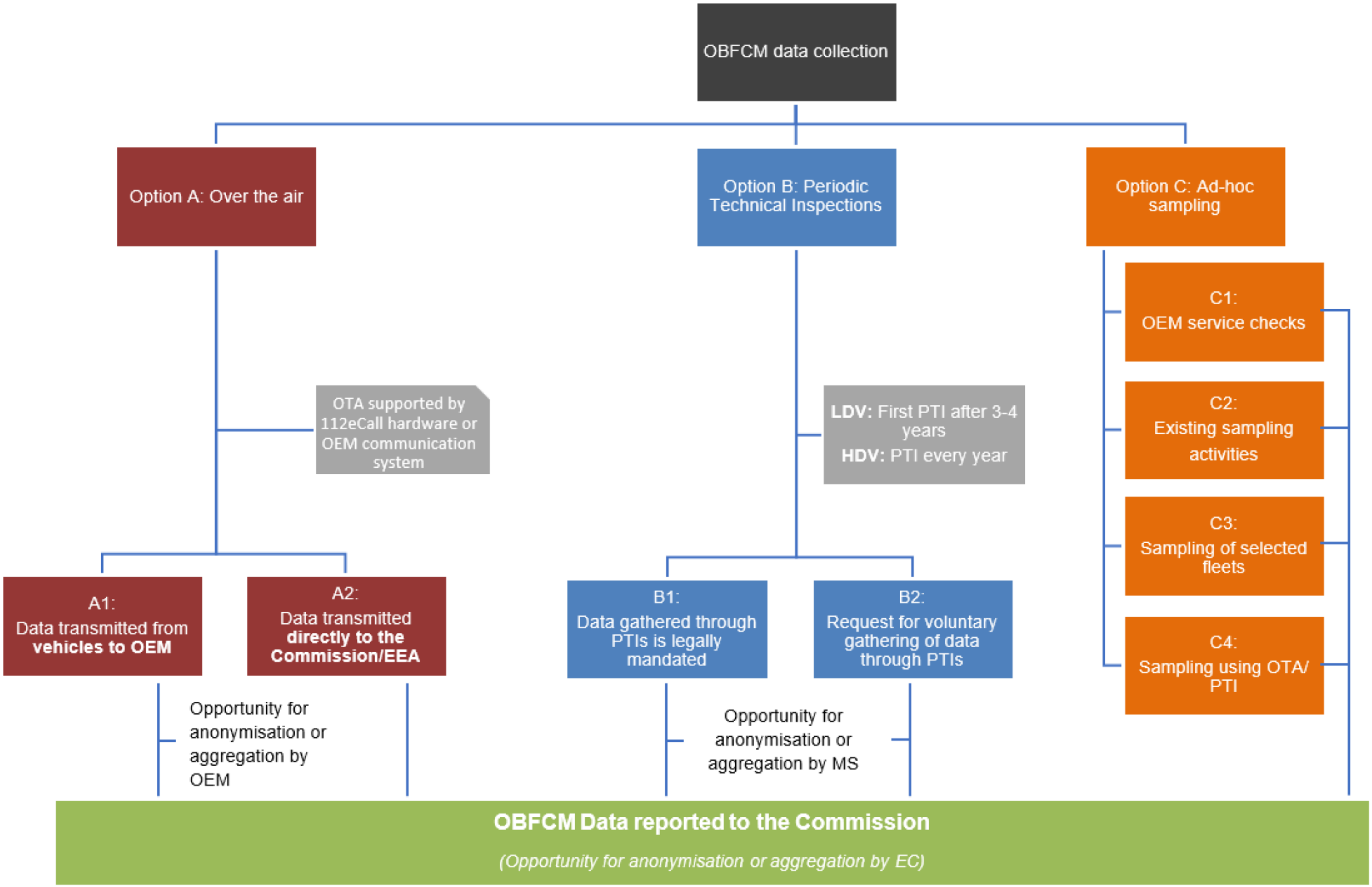


Source : C-ROADS, position paper on the usage of the 5,9 GHz band

OBM in China and the US

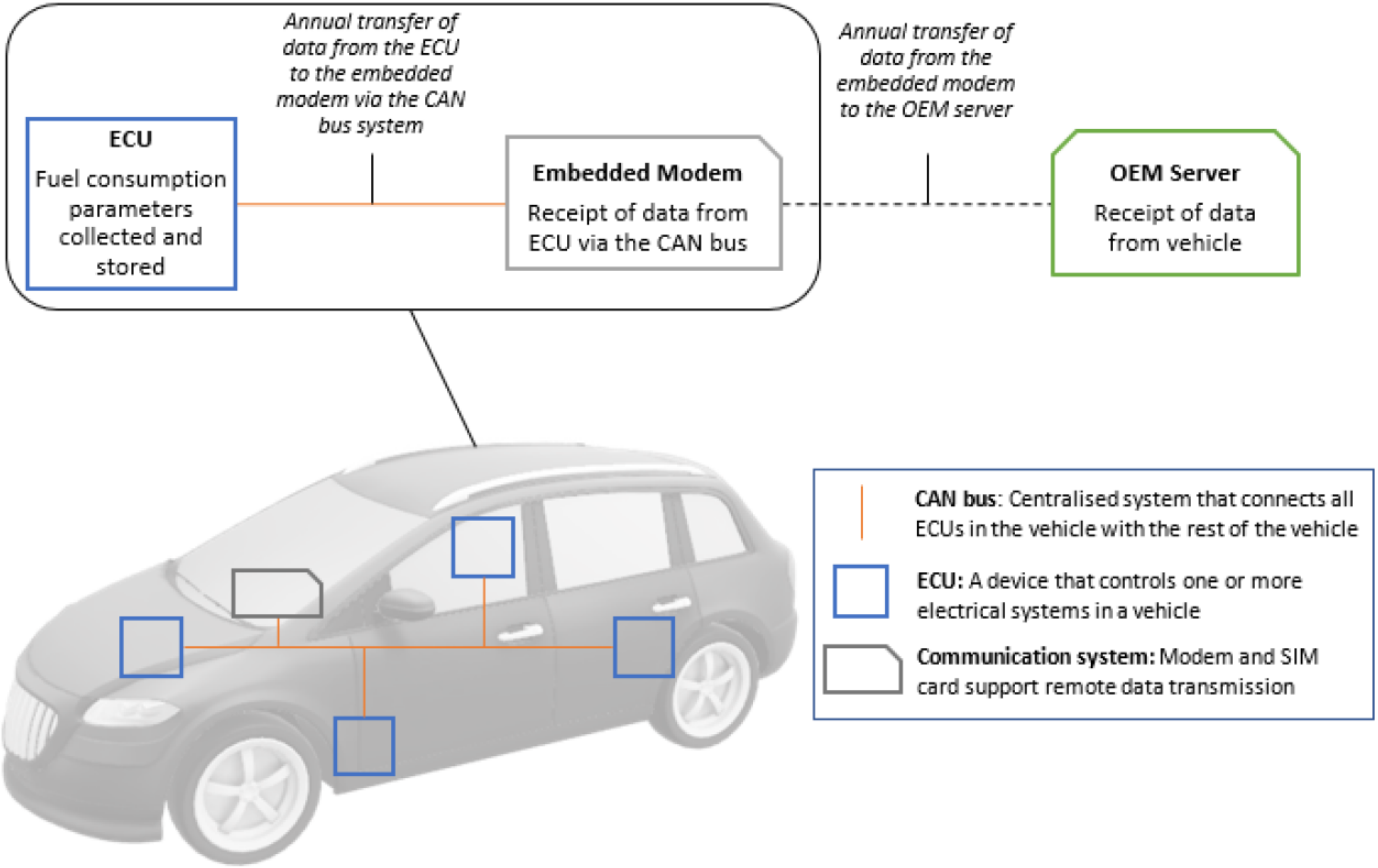
- China VI standard (2020) requires real-time data from ECU, NO_x sensor, DPF and other emission-related data to be reported remotely to regulator authorities
  - Establishment of telematics gateway
  - Communications protocol still unclear
  - Transmission at least every 10 s of various engine, aftertreatment, ambient and position info
- Beijing launched a pilot program to equip 5000 vehicles (mostly HDVs) with remote OBM systems to monitor real-time, on-road NO_x emissions.
- CARB: Real Emissions Assessment Logging (REAL)
- Phasing in 2019-2021: tracking/reporting of NO_x and GHG/CO_2 emissions data in real world use, special provisions for hybrids
- NOx tracking based on on-board sensors, together with engine operation parameters.
  - Storage in Active 100 Hour, Stored 100 Hour, and Lifetime Data Arrays (rate of 1 Hz)
- GHG tracking on FC measurement

A pilot programme in the EU: On-board Fuel Consumption Monitoring (OBFCM) for LDVs and HDVs

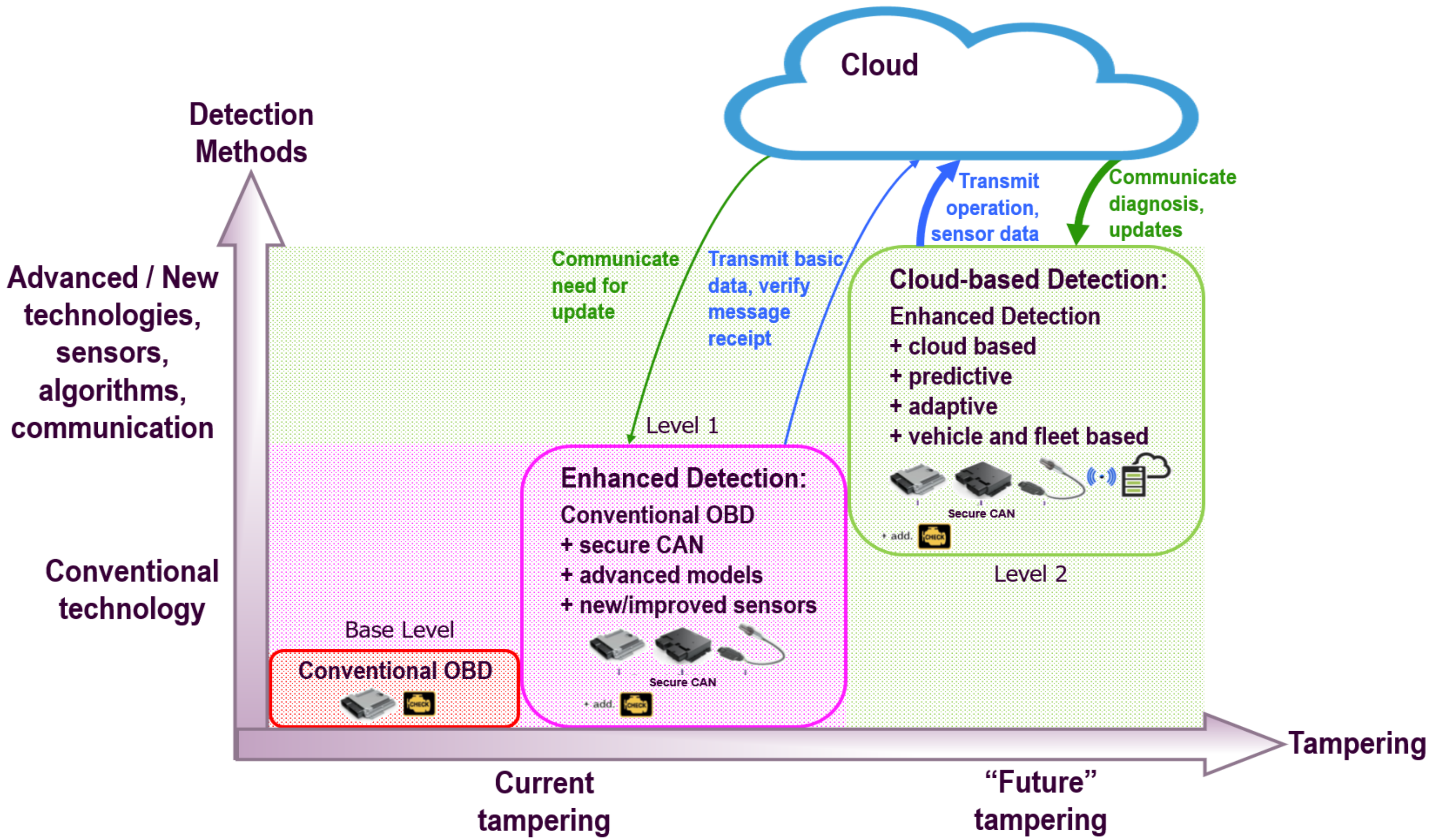


Source: Ricardo, 2019

An example: OEM Over-the-Air data transfer

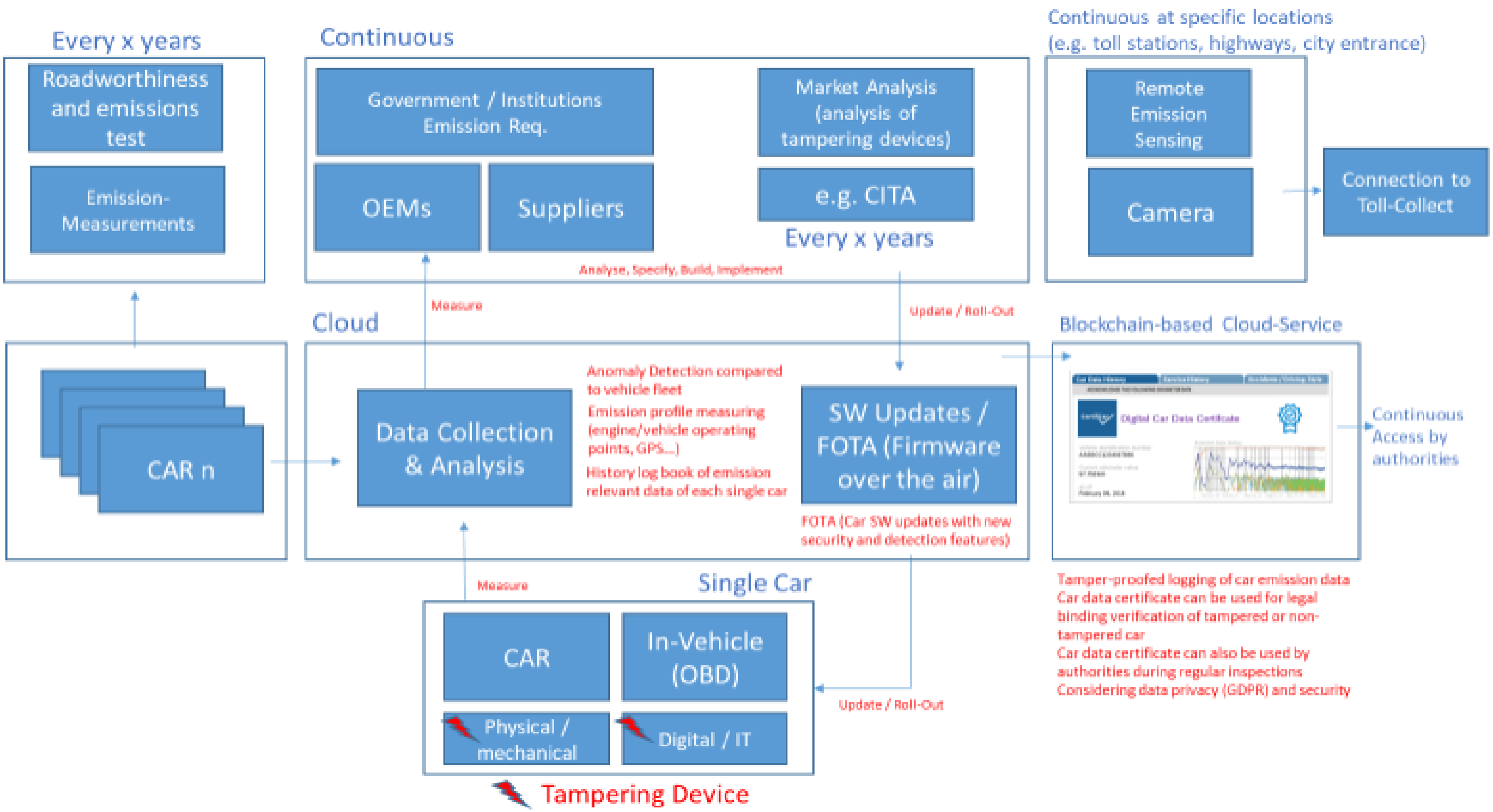


A vision for anti-tampering



Source: H2020 project DIAS, 2019

A cloud-based concept



Source: H2020 project DIAS, 2019

Sensors and on board measurement equipment

- Existing sensors
  - NOx sensor
  - PM or soot sensor

- Needed sensors
  - PN Sensor
  - Ammonia sensor
  - CO sensor
  - HC sensor
  - Other pollutants?

Portable FTIR

Atmospheric Environment 166 (2017) 488–497

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

On-road measurement of NH_3 emissions from gasoline and diesel passenger cars during real world driving conditions

Ricardo Suarez-Bertoa [a,*], Pablo Mendoza-Villafuerte [a,1], Francesco Riccobono [a,2], Michal Vojtisek [b], Martin Pechout [b], Adolfo Perujo [a], Covadonga Astorga [a,**]

Example: Current market solutions for PN/PM monitoring

Current OBD sensors

- Simple
- Low cost
- Compact
- …
- Accuracy
- Repeatability
- …

Advanced PN/PM sensor

- ➢ Optical
  - Absorption
  - Scattering
  - Extinction
- ➢ Electrical charge-based
  - Electrostatic
  - Diffusion charger

High-end PN and PM PEMS

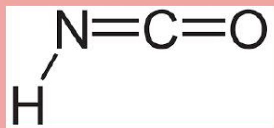
- High-end devices
- Robust
- Accurate
- Repeatable
- …
- Heavy
- Energy intensive
- Max. cont. operation<3-4h
- Calibration needs

CO2/GHG & NON REGULATED EMISSIONS

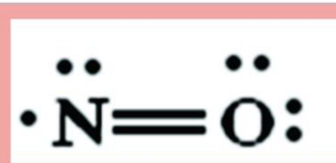
Pollutant emissions to be considered along with CO_2/GHG emissions

- Air and climate pollutants should not be dealt separately
- Help address the question: How much emission control needed and what expense on CO_2 acceptable?
- Address the non-CO_2 greenhouse gas emissions too
- Energy consumption and CO_2 emissions in normal use, including lights, auxiliaries, winter tires, options, deterioration, etc.

Non-regulated emissions in the regulations



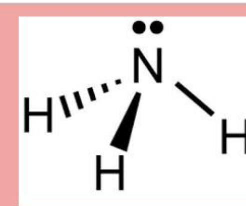
Isocyanic acid



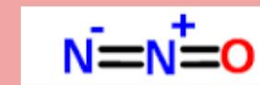
Nitric oxide

+

Nitrogen dioxide

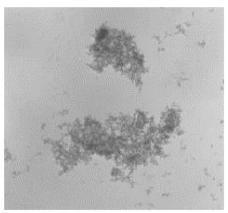


Ammonia



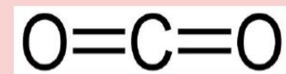
Nitrous oxide

Nitrogenous & “NOx”

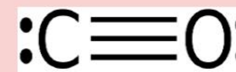


Particulate matter mass (PM), particle number (<23nm, >23nm; PN) & “soot”

H_2O!!!

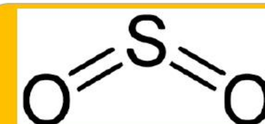


Carbon Dioxide

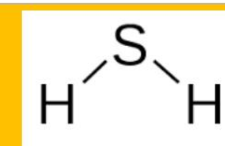


Carbon Monoxide

“COx?”

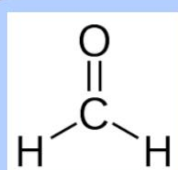


Sulphur dioxide

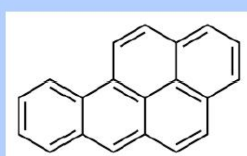


Hydrogen Sulphide

“SOx”



Formaldehyde

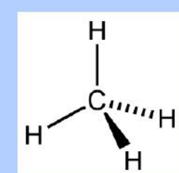


Benzo [a] pyrene; a PAH

“Hydrocarbons”

THC **NMHC**

NMOG

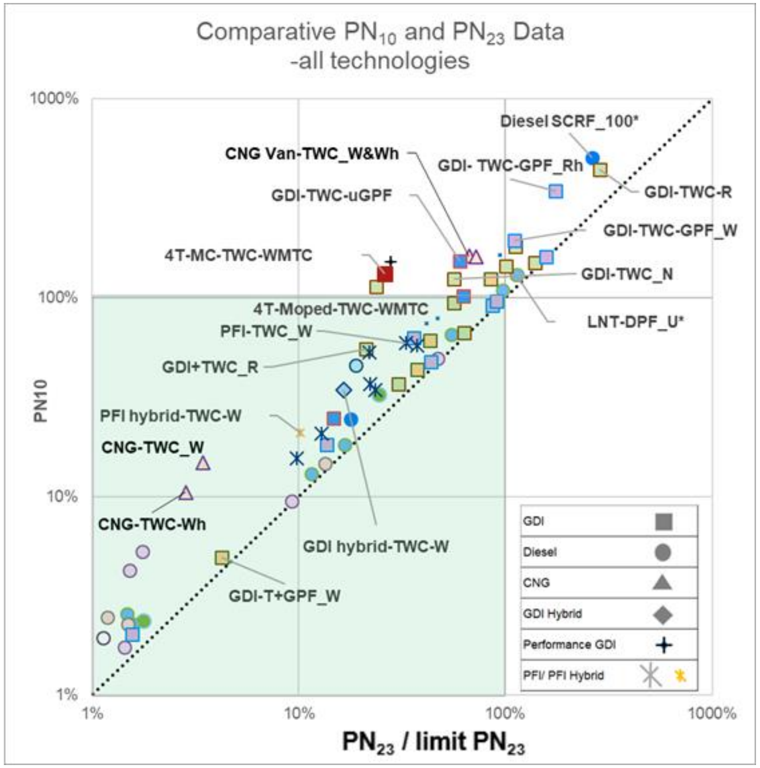


Methane

Source:Ricardo , 2019

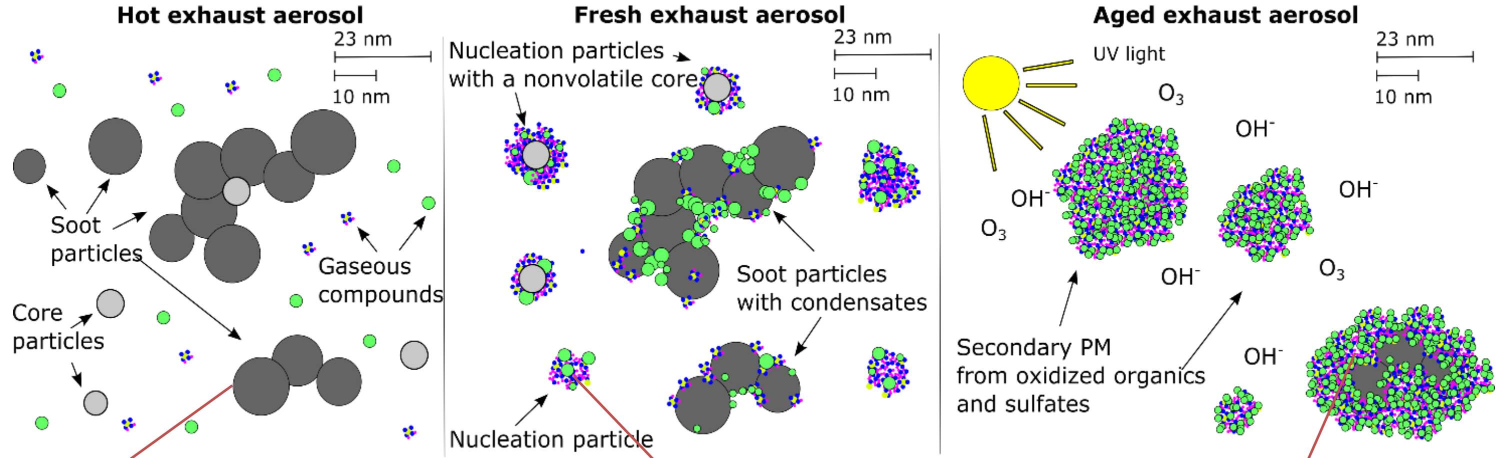
PN_{10} v PN_{23}: outside regulatory regime (no PCRF)

- Most technologies compliant with $6x10^{11}$#/km for both >23nm AND >10nm ranges
  - Some technologies may have PN emissions that are compliant with the current limit value (PN_{23} range), but would exceed the regulatory threshold if PN_{10} were measured instead
    - includes
      - a 4-stroke motorcycle with a three-way catalyst on the WMTC
      - a CNG van with a TWC on WLTCs
      - a GDI with an uncoated GPF



Exhaust aerosol is not only ‘solid’

Tailpipe (ms to s) … Roadside (s to min) … Urban Environment (h)



These are regulated

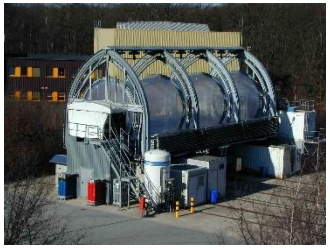
This mode tends to dominate roadside particle number

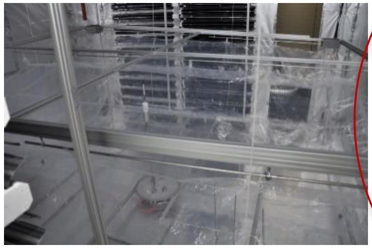
This part is not regulated, but affects AQ more than the PN limited

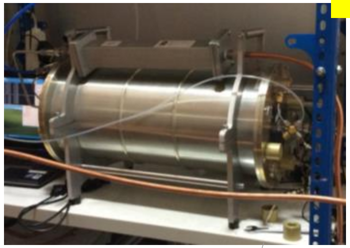
Different techniques to measure secondary particles and the one selected in the DTT project

Equiv. atmospheric age	days	hours		hours- days
Experimental throughput-time	hours -days	hours	<2min residence time	

Selected in DTT project







Concept of Potential Aerosol Mass: Kang et al. 2007

Continuous flow oxidation reactors enable vehicle technology development to reduce SA?

THE INSTITUTIONAL FRAMEWORK

Temptation towards higher complexity or Simplification needed?

Introduction of new pollutants leads to higher complexity

Lower limits do not always result in lower emissions

There is a business case for labs for type approval testing…

PEMS accuracy? (CEN PEMS working group)

Type I – Tailpipe emissions after cold start

Type II – CO emission test at idle

Type III – … ses

Typ…

Type … es

Type … gC]

Co…

In-Service Conformity testing

Market Surveillance

…?

Do we need all this? What is sufficient?

More and more requirements to close loopholes

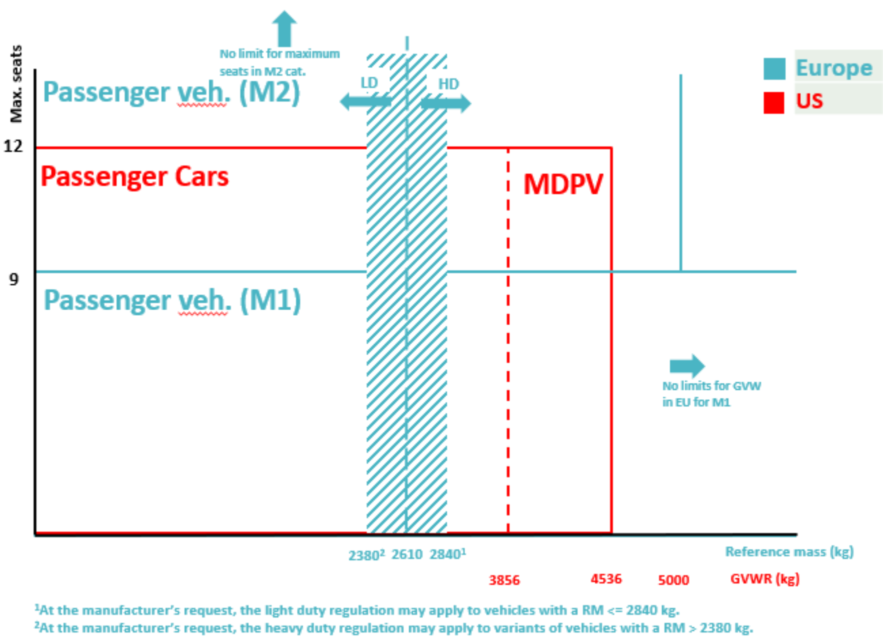
New equipment needed: lab or on road?

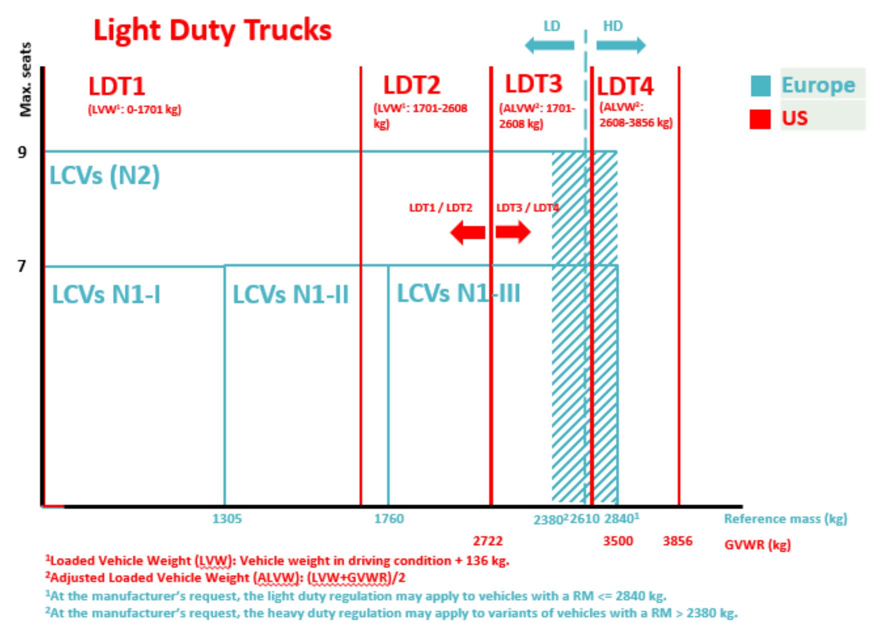
Do we take current equipment and tests as granted?

On-road testing or on-road monitoring?

Source: TNO, 2019

Passenger vehicle categories: EU & US





- Shaded area in EU provides flexibility for multi-stage vehicles and heavy passenger vehicles but creates regulatory difficulties, especially for CO_2 values reporting
- US: Medium duty passenger vehicles (MDPV) extend to larger sizes
  Light trucks extend to larger sizes, <6.35 t GVWR can opt for chassis certification

Additional topics

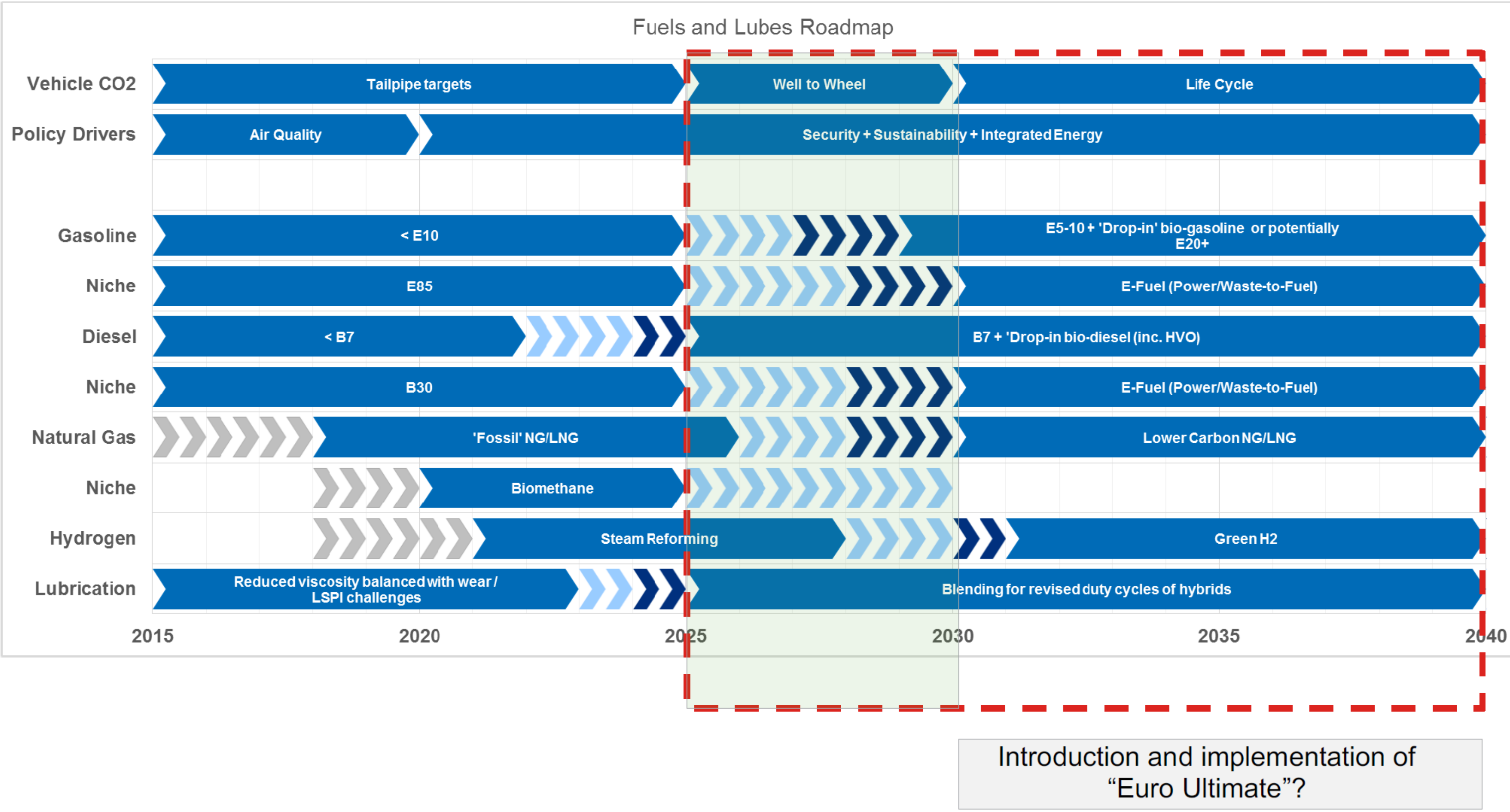
- **Fuel and technology neutral regulations and emission standards**
- A shift from g/km and g/kWh to other units?
- Evaporation losses: to further investigate for fuel neutrality and running losses
- Modelling (inverse air quality) and monitoring → link between concentration and emissions. Include Satellite observations
- Investigate if and how Remote Sensing can complement the existing regulatory arsenal

SOME CONCLUDING REMARKS

Future opportunities, Barriers and options

- New technologies should be taken into account:
  - Automated driving,
  - Self-learning technologies “anticipating the daily route”,
  - Geo-fence calibrations for environmental zones, multi-calibration or flex-calibration = currently defeat device but could be helpful in environmental zones
    → we need to secure lowest possible emissions when we really need them?
- Already for many years, low limits are not normative for proportional low real-driving emissions
  → Lowering limits only is no solution

The fuels: Could Low C Fuels be incentivised in a new fuels directive?



Source: Ricardo, 2019

Thank you for your attention

Zissis Samaras
zisis@auth.gr
☎ +30 2310 996014