Advanced Capabilities for Future RDE Compliant Vehicles

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RDE as a development tool for future vehicles

Key objective is to develop RDE capabilities to support future vehicle development to comply with in-use emissions requirements

- Only the best of current vehicles have any value as “go-forward” benchmarks for future development
- Essential to develop capability to measure, correlate and differentiate very low NOx/emissions levels, over chassis & in-use routes
  - up to 2021- range of 50 to 100 mg/km
  - after 2021- range of 30 to 50 mg/km
  - after 2025- below 30 mg/km or even <12!

Future LDV Standards will require advanced PEMs capabilities

Region	Highway Emission Standards		
	Light-Duty SI & CI	RDE	NOx Level (g/km)
India	Bharat VI [2020]	Collection 2020 CF? Conformity 2023	60 - 82 SI 80 – 125 CI
China	China 6a [2019] China 6b [2023]	Collection 2019 CF2.1 Conformity 2023	60 - 82 35 - 50
EU	EU 6c EU 6d TEMP EU 6d	None CF2.1 Conformity 2017 CF1.5 Conformity 2020 CF1.0? / EU7?	60 – 82 SI 80 - 125 CI
US/Canada	LEVIII [2015] Tier 3 [2017] LEV IV (after 2025)	intent expressed under In-use compliance	<120 in 2017 12-45 by 2025 <12

CARB FTP NOx Certification Values[1] Reported at FUL (mg/km) for diesel vehicles	
2010 GMC Van- HD	~200
2017 Ford Transit T350 Van- MD	186
2016 GMC Sierra 2500 pick-up – MD	155
2016 GMC Canyon	58
2016 Chevrolet Cruze	<50
2013 BMW X5	29
2014 BMW X5	25
2016 BMW X5	18
2017 BMW X5	12
2017 BMW X3	6

[1] Source: https://www.arb.ca.gov/msprog/onroad/cert/cert.php

PEMS & PAMS & Test Cell Protocols

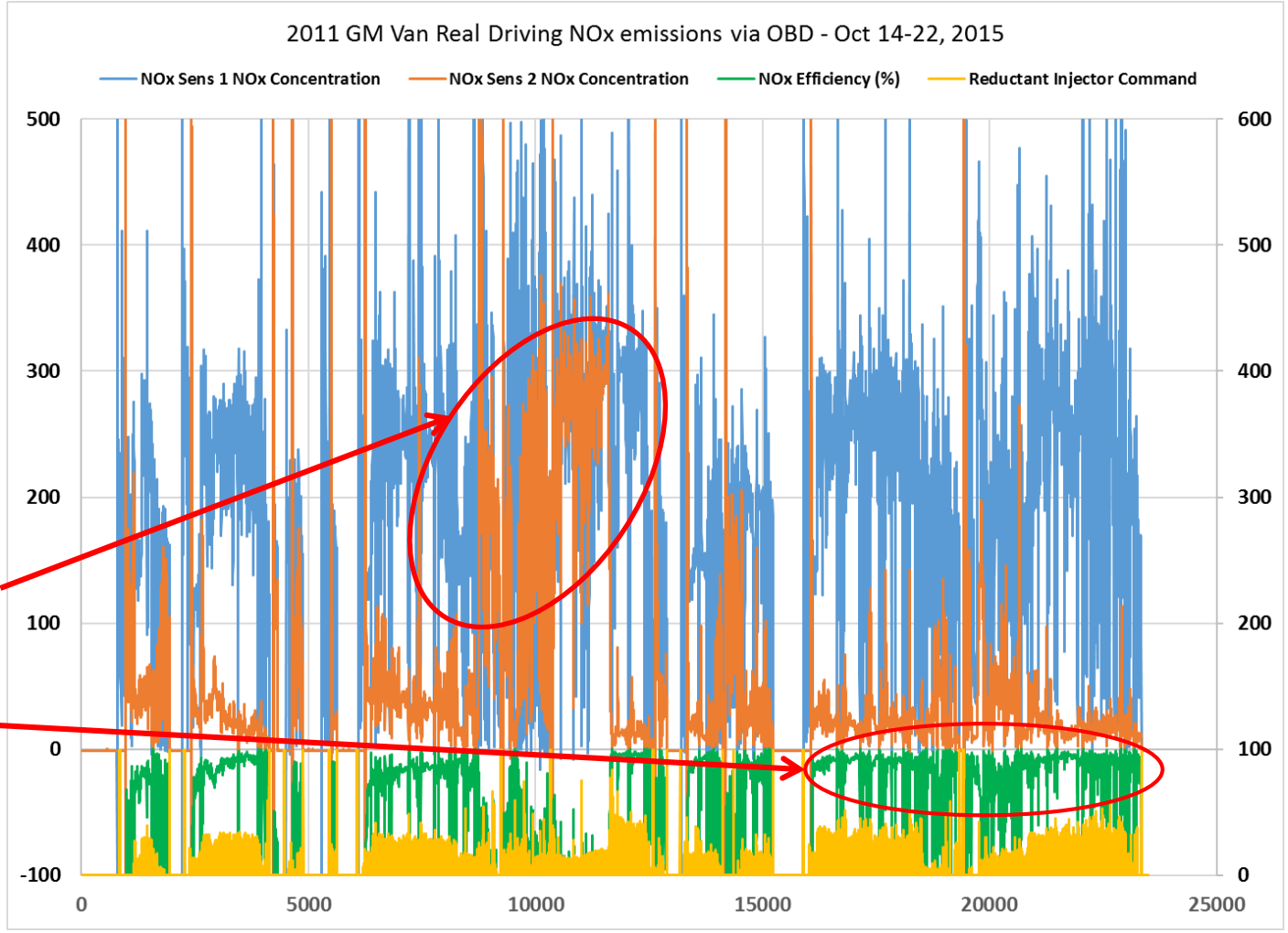
- **Portable Emission Measurement Systems (PEMS)**
  - Emissions profile at a point in time
  - Impacted by vehicle, engine controls, route, driver, driving style, load, season, weather, altitude, etc.
  - Confirms in-use emissions compliance profile via normalization protocol
- **Portable Activity Measurement Systems (PAMS)**
  - Additional information provided via OBD and other sensors including engine speed, vehicle speed, load, EGR rate, DPF regeneration, urea dosing rate, exhaust temperatures, etc.
  - For vehicles with NOx sensors, can be used to screen vehicles, cycles, over various driving conditions
    - To screen routes for PEMs compliance tests
    - Can be used to monitor for longer term deployment
- PEMS & PAMS can be used to recreate in-use driving conditions of interest in test cells to engineer solutions

Screening vehicles via PAMS with on-board NOx sensors

TENNECO

DPF regen leads to observed Low NOx efficiency

At 120 km/hr, >90% NOx reduction observed



Tenneco RDE PEMS Equipment

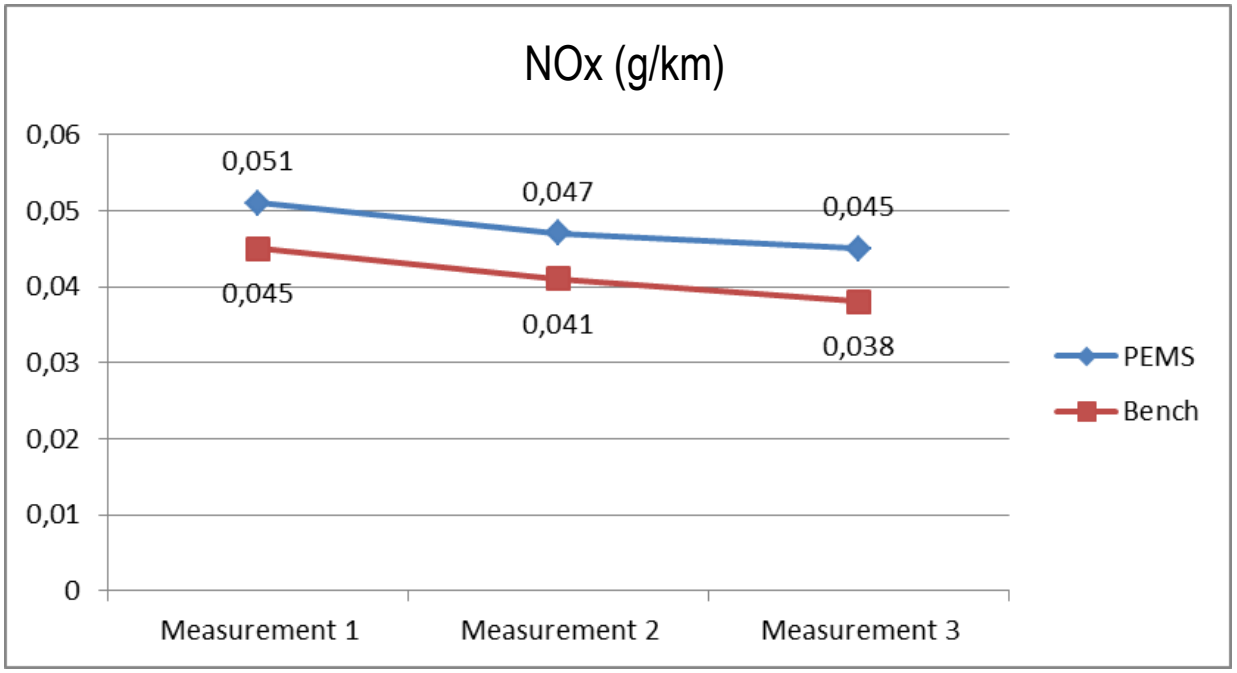
- AVL M.O.V.E - iS PEMS
  - NO/NO_2 measurement by using an ultra-violet (UV) analyzer
  - CO/CO_2 measurement with a non-dispersive infra-red (NDIR) analyzer
  - PN via advanced corona discharge principle
  - Exhaust Flow Meter (EFM) with exchangeable pipes for high accuracy of 2% of measured value
  - Wide operating range (-10°C to +45°C)
- Complete system with EFM arrange on bicycle carrier
- Ambient sensor and GPS mounted on the vehicle roof

Also have SEMTECH PEMS equipment

Emission Measurement Correlation

Full Chassis Emissions Lab vs. PEMS

- EU 5 CUV with 1.4L 90kW GDI engine with TWC
- WLTP test cycle on roller bench
- Emission measurement with CVS analyzer into bags parallel to PEMS

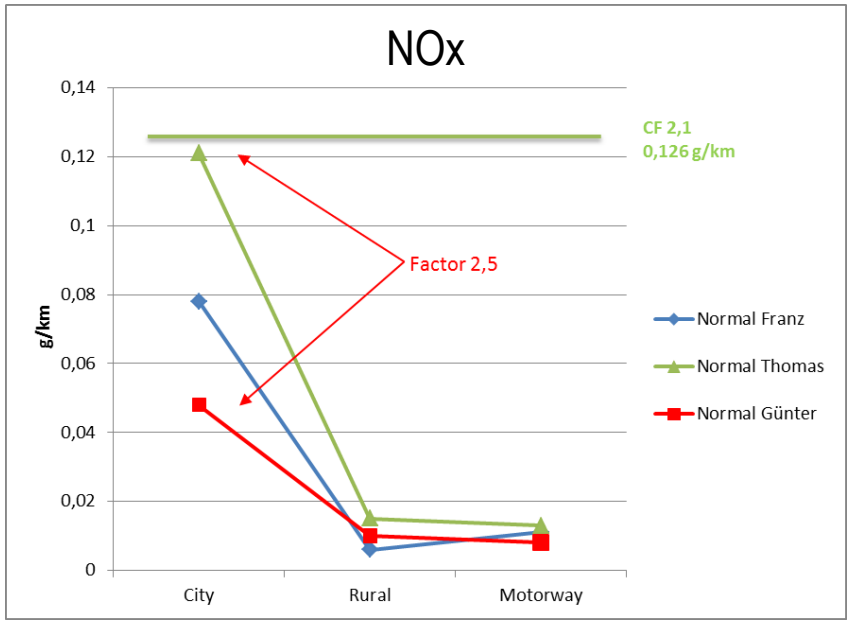


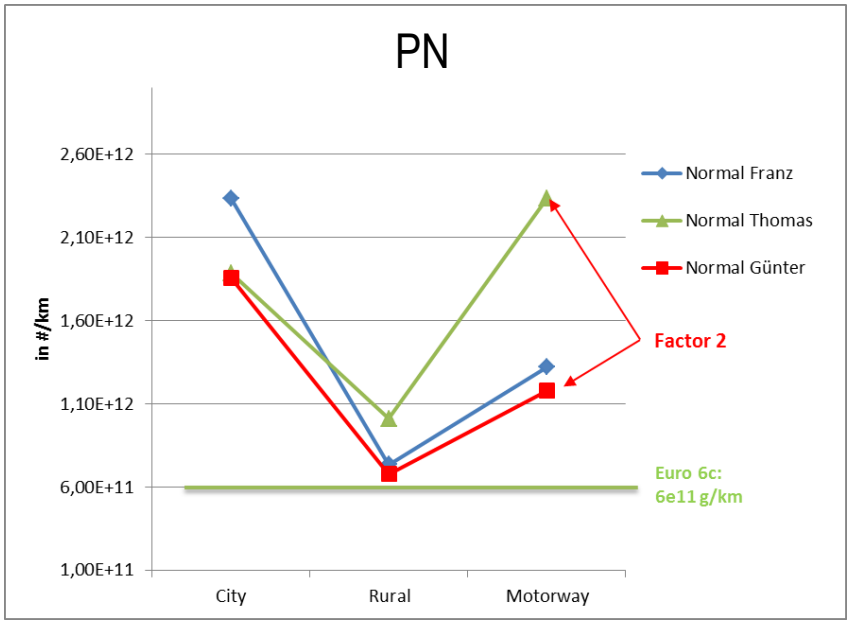
Result: PEMS measured NOx values 6-7 mg/km higher (15% - 20%)

Driver Influence on PEMs

Same route / Same vehicle / 3 Drivers / Normal driving

EU 5 CUV with 1.4L 90kW GDI engine with TWC





- **Results:**
  - NOx variation of factor 2.5 during city section; rural and motorway all drivers close together
  - PN variation of factor 2 on motorway

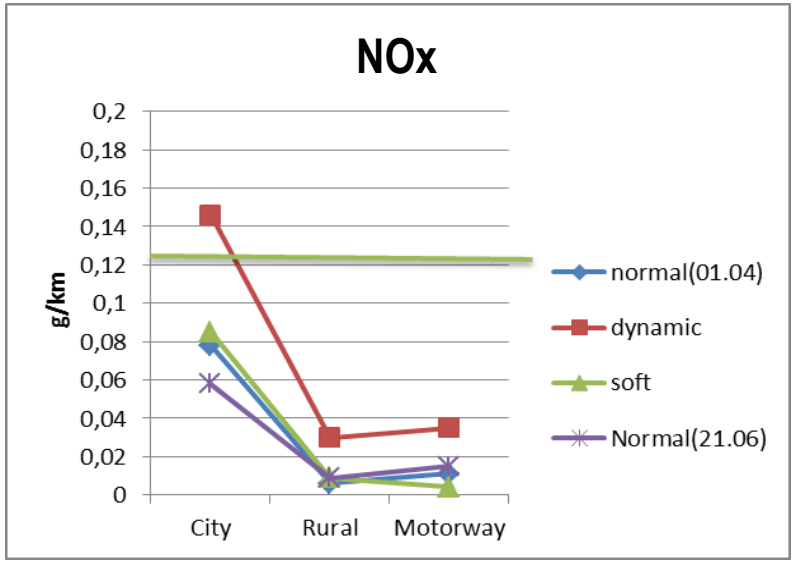
➔ **Driver influence up to factor 2.5**

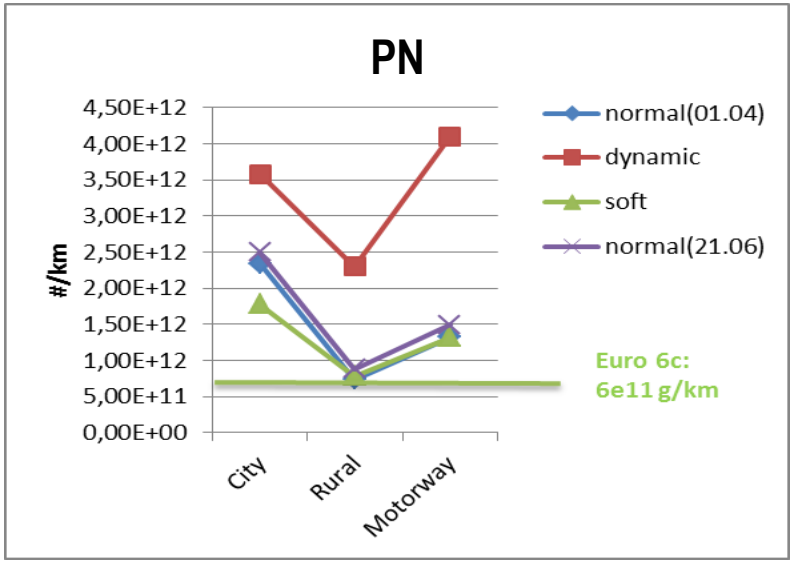
Influence of Driving Style

Same route / Same vehicle / Same Driver / Various Driving Styles

(soft – normal – dynamic/aggressive)

EU 5 CUV with 1.4L 90kW GDI engine with TWC





- **Results:**
  - Soft and normal driving emission yield similar values with NOx below CF2.1
  - Factor 3.5. difference between normal and dynamic driving
  - Highest NOx emission in the city

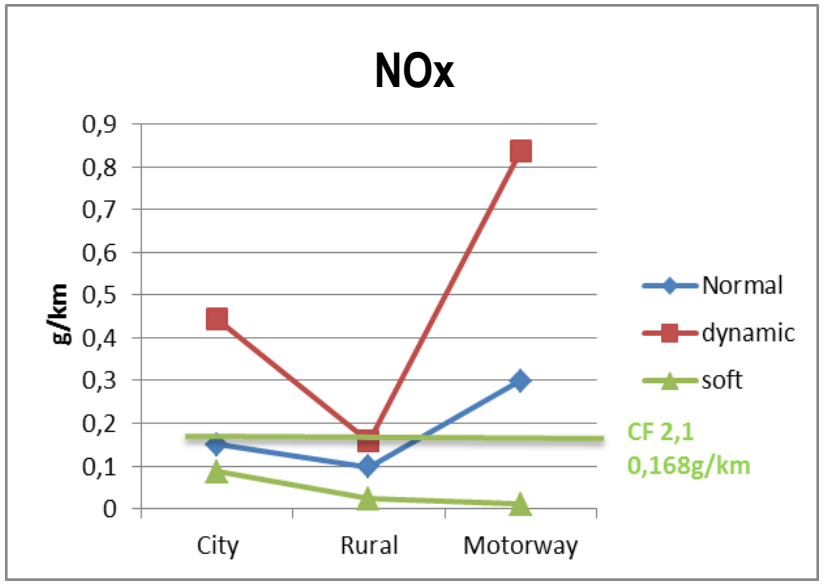
➔ **Driving style impacts PN up to a factor of 4**

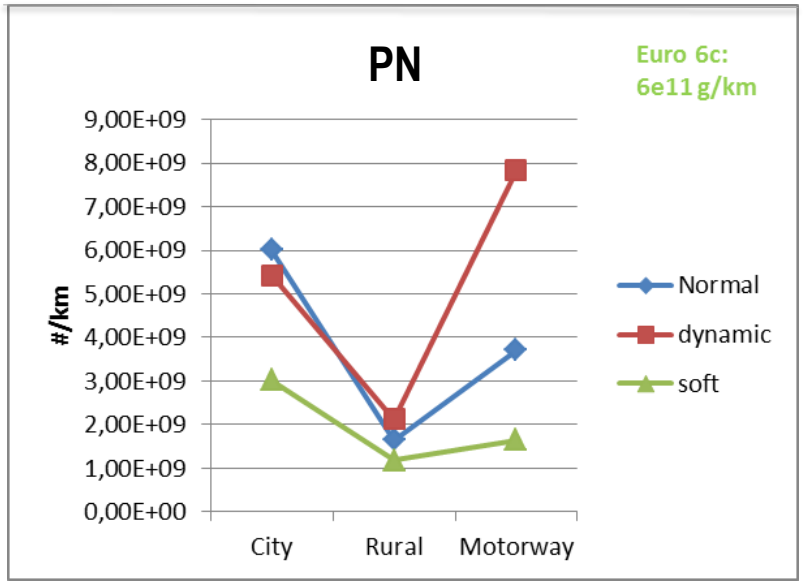
Influence of Driving Style

Same route / Same Vehicle / Same Driver / Various Driving Styles

(soft – normal – dynamic/aggressive)

EU 6 wagon 2.0L 140kW diesel with DPF & SCR





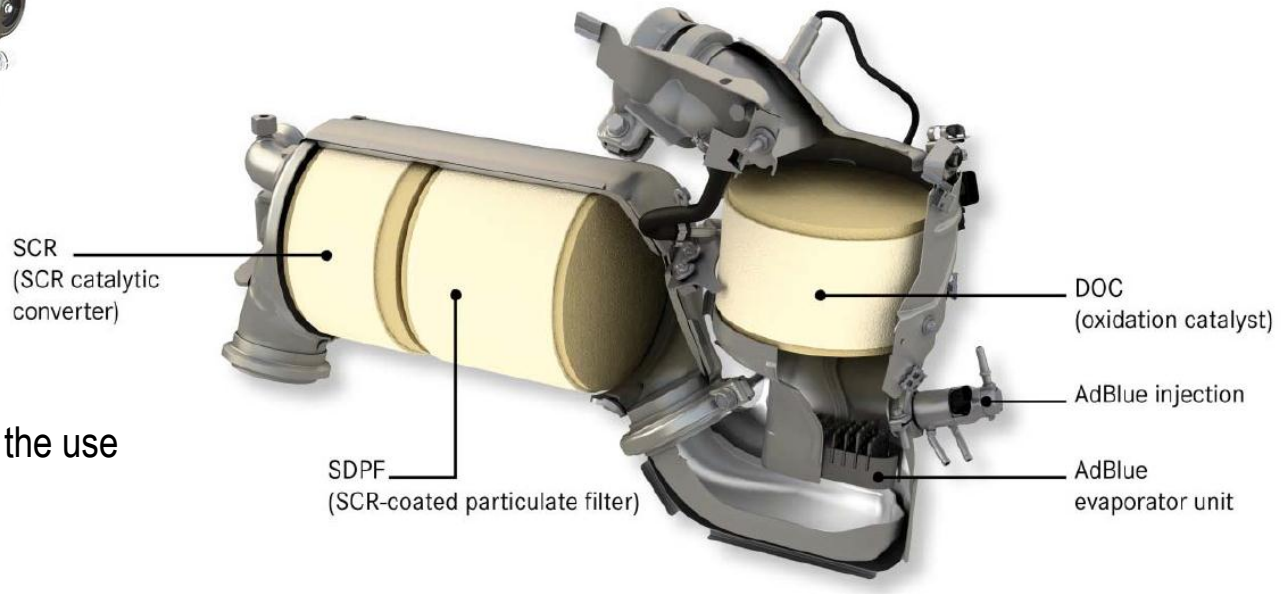
- Results:
  - Soft drive nearly below NOx limit (CF=1)
  - Moderate driving (city and rural) NOx below CF =2.1
  - Dynamic driving results in sizeable NOx increase
  - PN variation detected but with DPF about factor 100 below 2017 limit

➔ **NOx greatly impacted by Driving Style**

Example: RDE Diesel Solution

New Mercedes E Class EU6 Aftertreatment Module Supplied by Tenneco

- Mercedes E 220 is the first vehicle independently confirmed by DEKRA as 2017 RDE compliant (<80mg/km NOx) over all test routes
- RDE compliance via engine controls, packaging, insulation measures, urea mixing, SDPF and improved catalyst coatings.
- No need for engine temperature management during cold starting or at low load.



Note: Daimler has also announced the use of GPF's on all SI engines

Source: Daimler, http://500sec.com/thedieselfuturebeginsinthemercedesbenzeclass/ and https://www.dieselnet.com/news/2016/05daimler.php

Summary

- PEMS & PAMS testing of current in-use vehicles can identify best in class vehicles that can be used as benchmarks for development of future vehicles.
- Compliant vehicles will possess better vehicle/engine calibrations, controls, thermal management, and close coupled catalyst systems.
  - Diesel engines will need SDPF's and advanced urea injection & mixing
  - GPF's can resolve PN issues related to GDI engines
  - With RDE based in-use compliance, the key is to develop PAMS and PEMS capabilities that will be able to evaluate future vehicles for PN and very low NOx levels anticipated after 2025.