Preliminary findings on possible Euro 7 emission limits for LD and HD vehicles

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Agenda

- Objectives and approach
- Proposed Euro 7 test regime and pollutants
- Emissions database – background and preliminary findings on emissions
- Possible limits and technologies to meet them
- Evaporative losses
- Consultation

Objectives

- Propose limit values for each emissions species of interest
  - Need for more stringent emission limits in a more complex external environment with the required agility and flexibility to adapt to the most advanced clean technologies
- Emission species
  - Already regulated (tightening)
  - Not currently regulated in EU
  - Exhaust and non-exhaust
- Technology-based approach – assessing potential emissions performance and costs
  - Is culmination of work from “Part A” study
- Fuel agnostic limit values
- Feeds-in to impact assessment of Part B study
  (marginal costs and benefits compared to Euro 6/VI)

CLOVE approach

Methodology steps

- Emission performance analysis of latest technology vehicles (Euro 6d/d-temp and EU VI D)
- Identification of the best available technologies (BAT) as benchmark for the future emission standards
- Analysis of emissions reduction potential of future emission control technologies on BAT
- Proposal of technology scenarios for further analysis and the impact assessment

Comments

Emissions database under construction

Wide range of test conditions within and beyond the current test regime: urban short trips, Stop&Go, regeneration events, new pollutants etc.

Input from emissions database

BAT investigation both within and beyond the current test regime (focus on RDE)

Potential side effects (e.g. technology implications, CO_2 emissions, cost etc.) are identified and further discussed

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Proposed wide on-road testing vs current RDE for LDV

Parameter	Current RDE	Future wide on-road testing
Ambient temperature [°C]	Moderate: 0 – 30°C | Extended: -7 – 0°C & 30 – 35°C	**-10°C to +40°C** (all other trips covered by Defeat Devices and limited AES)
Average Speed [km/h]	Urban: 15-40 km/h (+ limitations for trip distance and duration, and speed range coverage)	-
v*a[95th] [W/kg]	Speed-based calculated limits	-
Max. altitude [m]	Moderate: 0 – 700m | Extended: 700 – 1300m	-
Positive elevation gain [m/100km]	Total: <1200 [m/100km] Urban: <1200 [m/100km]	-
Durability [km]	ISC 100k | MaS 160k	**Up to 240k km** (and then higher emission limits until end of life)
Trip distance [km]	U/R/M >16 km each	**5 km min** (all lower trips covered by Defeat Devices and limited AES)

Proposed wide on-road testing vs current ISC for HDV

Parameter	Current ISC	Future wide on-road testing
Ambient temperature [°C]	-7°C to 35°C	**-10°C to +40°C** (as for cars)
Cold start	Test evaluation from $t_{coolant}$ > 30°C on; cold start weighted with 14%%	Test evaluation from engine start on; no weighting of cold start
Trip duration [kWh]	> 4 x WHTC work	> 0.11 * P_{rated} (i.e. > 0.5 x WHTC work*)
Engine load [kW/kW_{rated}]	Only work windows > 10% valid	Test average > …% (**)
Max. altitude [m]	1600 m	-
Positive elevation gain [m/100km]	-	-
Durability [km]	N2, N3<7.5t, M3: 300k km M3, N2, N3 <16t: 300k km N3 > 16t: 700k km	**

* WHTC work can be approximated with 0.5 hours at average 22% P rated

** Analysis ongoing

Emission testing – Light Duty Vehicles (cars/vans)

Main Regulation 715/2007	Type	Name	Implementing Regulation	Current status	Euro 7 approach
Art. 5, par. 3(a)	1A	Emissions – RDE	EU 2017/1151 EU 2018/1832	On-road testing with boundaries + CF on limits (which refer to WLTC)	**Wide on-road testing** Limits (per km) refer to on-road testing Run-replicate on-road testing on dyno for pollutants not measured with PEMS
Art. 5, par. 3(a)	1	Emissions – WLTP	EU 2017/1151	WLTP vehicle lab testing, limits (per km) refer to WLTP	Vehicle lab testing maintained because of CO_2 and pollutants not measured with PEMS (to be confirmed, pending analysis of portable systems)
Art. 5, par. 3(a)	6	Low T	UNECE R83 EU 2017/1151	WLTP Lab testing at -7 °C	Covered by wide on-road testing Possibility to run-replicate on-road testing on climatic dyno
Art. 5, par. 3(a)		ATCT	EU 2017/1151	WLTP test at 14 °C	Repeal ATCT possibly, pending analysis on differences between ATCT and Type 1

Emission testing – Light Duty Vehicles (cars/vans)

Main Reg. 715/2007	Type	Name	Implementing Regulation	Current status	Euro 7 approach
Art. 5, par. 3(a)	2	Idle CO emissions & smoke opacity	UNECE R83 EU 2017/1151	CO at normal & high idle Smoke emissions at free acceleration	Covered by wide on-road testing (which can include idle and free acceleration) Separate tests will be needed in PTI.
Art. 5, par. 3(b)	4	EVAP emissions	EU 2017/1151	Diurnal emissions in SHED	Extended diurnal emissions (SHED), and include running and refuelling emissions as well as OBD leak check
Art. 5, par. 3(b)	3	Crankcase emissions	UNECE R83 EU 2017/1151	PI engines. Crankcase emissions directly into the atmosphere not allowed.	Declaration by OEM and checked at MaS
Art. 5, par. 3(c)		OBD (emissions)	UNECE R83 EU 2017/1151	OBD Threshold Limits (OTL)	OBD not checked at TA. OBD functionality kept for diagnostics/service. Introduction of Testing Conformity indicator (**TCI**). Emissions checked during ISC/MaS and OBM. OBM accuracy requirements at TA (similarly to OBFCM)
Art. 5, par. 3(d)	5	Durability	UNECE R83 EU 2017/1151	Three options: 1. Whole vehicle durability 2. Component testing in lab 3. Deterioration factors	Whole vehicle durability only (240k/15yrs) Declaration at TA and covered by ISC/MaS

Emission testing – Light Duty Vehicles (cars/vans)

Main Reg. 715/2007	Type	Name	Implementing Regulation	Current status	Euro 7 approach
Art. 5, par. 3(d)	-	Replacement pollution control devices	EU 2017/1151 (Annex XIII) UNECE 103	Type 1 test	Approach to be defined (possibly a separate implementing regulation)
Art. 5, par. 3(f)	-	Electric range (PHEV)	EU 2017/1151 EU 2018/1832	Type 1 test (WLTP)	Maintained. Also covered by CO_2 In-Service Verification during lifetime *Battery durability from UN GTR discussions*
Art. 5, par. 3(j)	-	Engine power	UNECE R85 EU 2017/1151	ICE power at full load as function of engine speed	Maintained for WLTP gear shifting, vehicle classification, maybe for competitiveness/consumer information
-	-	Non-exhaust PM	–	–	Adopt brake emissions testing developed at PMP
Art. 5, par. 3(d)	*-*	*ISC/MaS*	*EU 2017/1151 EU 2018/858*	*Type 1, 1A test ISC 15,000-100,000km MaS up to 160,000km*	*Covered by wide on-road testing in ISC/MaS. Mileage coverage: from 0 to lifetime*
Art. 5, par. 3(d)	*-*	*COP*	*EU 2017/1151 EU 2018/858*	*Type 1, 3, 4 and OBD tests*	*Declaration by OEM and covered by wide on-road testing in ISC/MaS [Different approach for CO_2 – pending discussions for In-Service Verification]*

Emission testing – Heavy Duty Vehicles (lorries/buses)

Main Reg. 595/2009	Name	Implementing Regulation	Current status	Euro 7 approach
Art. 5, par. 4(a)	Emissions – PEMS	EU 582/2011 EU 2019/1939	ISC on-road testing with boundaries + CF, MAW for emission calculation	**Wide on-road** testing for TA, ISC, MaS, Limits (per kWh) refer to on-road testing
Art. 5, par. 4(a)	Emissions – WHTC, WHSC	EU 582/2011 2017/2400 (CO2)	WHTC, WHSC engine lab testing, limits (*per kWh*) refer to WHTC, FCMC for CO2	WHTC, WHSC, FCMC maintained because of CO_2 and pollutants not measured with PEMS (to be confirmed, pending analysis of portable systems)
Art. 5, par. 4(a)	Off-cycle emissions	EU 582/2011 UNECE R49	Lab testing + TA PEMS demo WNTE limits CO, HC, NOx, PM	Covered by wide on-road testing
Art. 5, par. 4(a)	Idle CO emissions	EU 582/2011 UNECE R83	CO emissions at low/high idle	Covered by wide on-road testing Separate tests will be needed in PTI.
Art. 5, par. 4(b)	Crankcase emissions	EU 582/2011 UNECE R49	PI engines. Crankcase emissions directly into the ambient atmosphere not allowed (closed system or routed in exhaust).	Declaration by OEM and checked at MaS

Emission testing – Heavy Duty Vehicles (lorries/buses)

Main Reg. 595/2009	Name	Implementing Regulation	Current status	Euro 7 approach
Art. 5, par. 4(c)	OBD (emissions)	EU 582/2011 UNECE R49	OBD Threshold Limits (OTL)	OBD not checked at TA. OBD functionality can be kept by the OEM for diagnostics/service. Introduction of Testing Conformity indicator (**TCI**). Emissions checked during ISC/MaS and OBM. OBM accuracy requirements at TA (similarly to OBFCM)
Art. 5, par. 4(d)	Durability	EU 582/2011	Test for useful life deterioration factors	Whole vehicle test for durability Increased lifetime (mileage/years) Declaration at TA and covered by ISC/MaS
Art. 5, par. 4(d)	Replacement pollution control devices	EU 582/2011	Provisions for replacement devices, part efficiency and durability	Approach to be defined (possibly a separate implementing regulation)
Art. 5, par. 4(d)	*ISC/MaS*	*EU 582/2011* *EU 2019/1939* *EU 2018/858*	*In-Service-Conformity*	*ISC/MaS on wide on-road testing,* *Mileage coverage: from 0 to lifetime*

Emission testing – Heavy Duty Vehicles (lorries/buses)

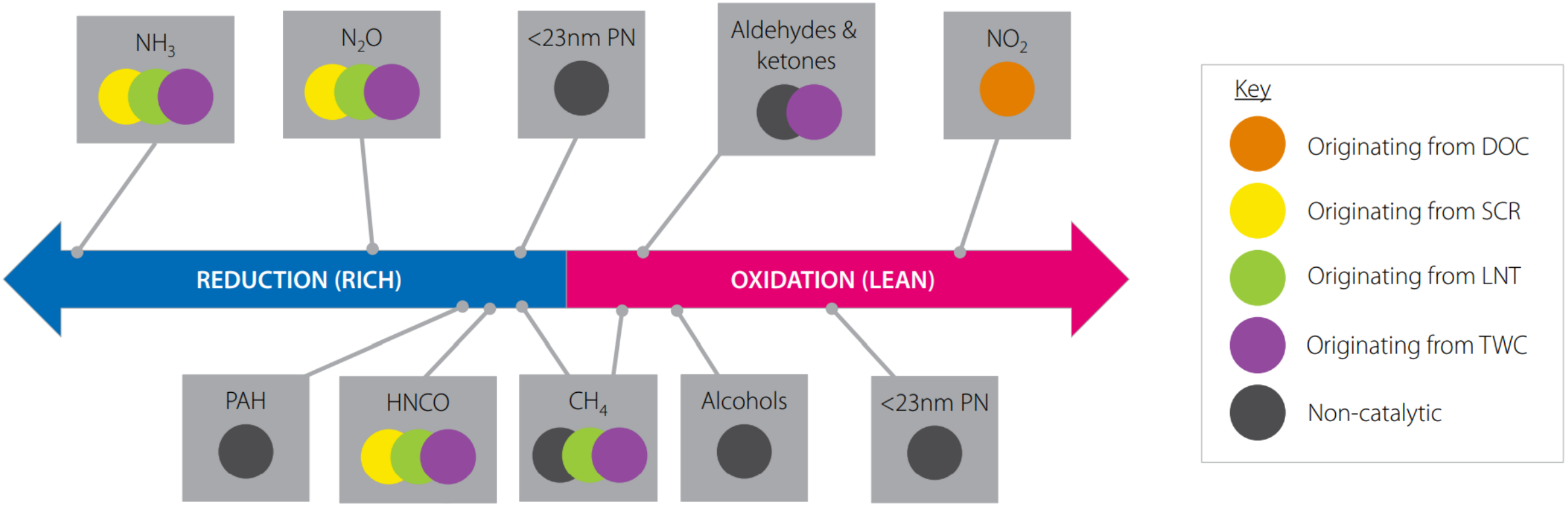
Main Reg. 595/2009	Name	Implementing Regulation	Current status	Euro 7 approach
Art. 5, par. 4(d)	*COP*	*EU 582/2011 2007/46/EC*	*Engine tests in WHTC*	*Emissions declaration by OEM and covered by ISC/MaS Different approach for CO2*
Art. 5, par. 4(i)	Engine power	EU 582/2011 UNECE R49	ICE power at full load as function of engine speed	Kept in EU 2017/2400 acc. to R49 for CO2 determination and for consumer information
Art. 5, par. 4(k)	NOx control operation, reagent freeze protection	EU 582/2011 UNECE R49	Demonstration that dosing works latest 70' idling after start @ -7°C with frozen reagents.	Covered by the wide on-road testing
	CO_2 Verification test procedure (VTP)	2017/2400	On-Road Verification Test Procedure	Extend with in-service verification by 3rd parties and allow parallel pollutant monitoring.

Emissions species investigated for LDVs and HDVs

	Emissions species	Regulated in Euro 6/VI		Regulated if not in EU
Regulated	**NOx**	Yes		
	THC	Yes		
	NMHC	Yes		
	CO	Yes		
	PM	Yes		
	PN >10nm	PN >23nm		
	NH_3	Yes-HDV	No-LDV	South Korea
	CH_4	Yes-HDV	No-LDV	US
Unregulated	NO_2	Indirectly through NOx		US
	Non-methane organic gases (NMOG)	Indirectly through THC		US (NMOG +NOx), South Korea (NMOG +NOx)
	N_2O	No		US, China
	Formaldehyde (CH_2O)	No		US, South Korea

In bold: Proposals in this presentation

New species and their origins



Almost all (new) pollutant species are associated with some kind of enrichment; mostly catalytic

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Emissions database of Euro 6 vehicles test data

- Target: Emission performance analysis of latest technology vehicles (Euro 6d/6d-temp)
  - To determine best available technology (BAT) and emissions reduction potential of each technology
  - To identify and quantify Euro 6 improvement and extension needs
- Database currently includes 49 LDVs with results from >500 tests (as of 20 October 2020)
- Test data sourced from 9 sources (CLOVE, JRC, H2020 projects, stakeholders)
- **Parallel work is being performed for HDV**

Vehicles included in LDV emission database

→ 49 vehicles* (7 Euro 6d | 42 Euro 6d-temp) with the following technologies:

Vehicle technology	Number of Euro 6d vehicles	Number of Euro 6d-temp vehicles	Total number of vehicles in database
GDI	0	14	14
mHEV-GDI	2	2	4
PHEV-GDI	1	3	4
PFI	1	4	5
HEV-PFI	1	1	2
PHEV-PFI	0	1	1
Diesel	2	10	12
mHEV-Diesel	0	2 (+1 demo)	3
CNG	0	3	3
LPG	0	1	1
TOTAL	**7**	**42**	**49**

→ Additional data expected:

- JRC (~20 vehicles)
- RDE ISC (incl. LCV, ~30 until end 2020)
- GreenNCAP/GVI project

→ For each test, data for:

- Total test and
- Urban/Rural/Motorway

* Bi-fuel vehicles (CNG-Gasoline, LPG-Gasoline) tested with both fuels are counted as separate vehicles.

Vehicle and test data included in emissions database

Fuel	Vehicle data			Emission test available data	
	Engine/Powertrain	EU std	ATS (Number of vehicles)	Current RDE/Non-compliant RDE	Non-reg. pollutants
Gasoline	GDI	6d-temp	TWC+GPF (13) TWC* (1)	✓/✓	✓
	mHEV-GDI	6d/6d-temp	TWC+GPF (4)	✓/✓	
	PHEV-GDI	6d/d-temp	TWC+GPF (4)	✓/✓	✓
	PFI	6d/d-temp	TWC (5)	✓/✓	✓
	HEV-PFI	6d/d-temp	TWC (2)	✓/✓	✓
	PHEV-PFI	6d-temp	TWC (1)	✓/✓	✓
Diesel	DI	6d/d-temp	DOC+DPF+SCR (4) DOC+sDPF+ASC (1) DOC+sDPF+SCR (1) DOC+sDPF+SCR+ASC (1) LNT+DPF+SCR (3) LNT+DPF (1) DOC+DPF+2xLNT (1)	✓/✓	✓
	mHEV-DI	6d-temp	LNT+SCR+sDPF+SCR+ASC (1) DOC+SCR+SCRF (1) DOC+DPF+SCR (1)	✓/✓	✓
CNG	PFI	6d-temp	TWC (3)	✓/✓	✓
LPG	PFI	6d-temp	TWC (1)	✓/✓	

*CNG-Gasoline vehicle, type-approved as monofuel → Not included in further analysis

Tests conditions covered by emissions database

→ On-road tests, evaluated in two groups:

- **Current RDE:** RDE-compliant routes, moderate driving conditions in most cases, PHEVs tested with low and high SoC → 12 km urban with ICE not fulfilled in all cases
- **Non-compliant (beyond) RDE:** routes with high v*a, hilly routes with high positive elevation gain, urban short trips (and Stop&Go) and tests with DPF regeneration are included in this case

	Current RDE tests in database	Non-compliant* tests in database	Current RDE regulation limits
Ambient temperature [°C]	0 – 34 (10-25 avg. temp in most cases)	-6 – 39	Moderate: 0 – 30 | Extended: -7 – 0 & 30 – 35
Average Speed [km/h]	43 – 58	9 – 102	Urban: 15-40 (+ limitations for trip distance and duration, and speed range coverage)
v*a[95th] [W/kg]	10.1 – 23	1.6 – 55.6	Speed-based calculated limits
Max. altitude [m]	590	2050	Moderate: 0 – 700 | Extended: 700 – 1300
Positive elevation gain [m/100km]	Total: 368 – 750 Urban: 324 – 970	Total: 264 – 1.964 Urban: 331 – 2700	Total: <1200 [m/100km] Urban: <1200 [m/100km]
Durability / Max mileage [km]	~41k	~41k	ISC 100k | MaS 160k
Trip distance	76 - 103	4.5 – 188	U/R/M >16 km each

* Values refer to all non-compliant tests, not only to each non-compliance case

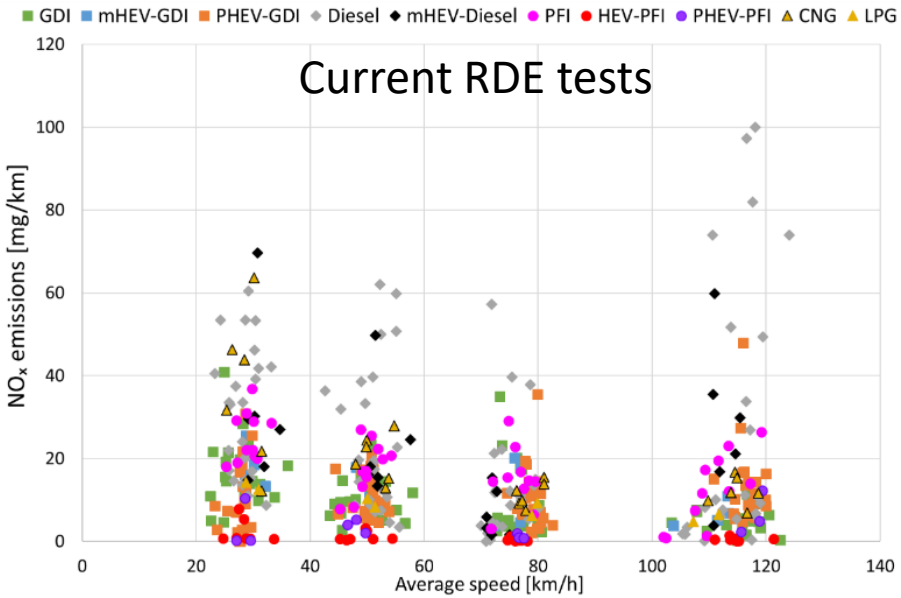
Tests conditions covered by emissions database

→ Chassis dyno tests for the determination of currently non-regulated emissions.

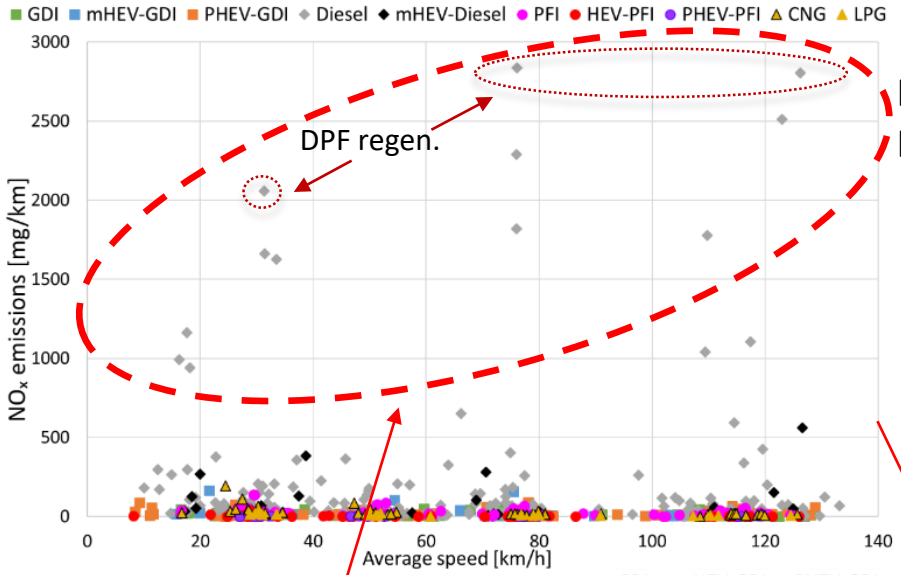
→ Correlations with regulated emissions (NOx vs NH_3 and NOx vs N_2O) assessed separately

Species	Test cycles	Instrument/Measurement method
CH_4	WLTC, NEDC, US06, ERMES, BAB130, TfL, Urban RDE, RDE	FTIR
NH_3		FTIR
NO_2		FTIR
N_2O		FTIR
NMOG/NMHC		FTIR + FID
HCHO		FTIR
$SPN_{>10nm}$		Modified PMP system – DownToTen sampling system in most cases
$SPN_{>2.5nm}$		

Vehicles excluded from further analysis

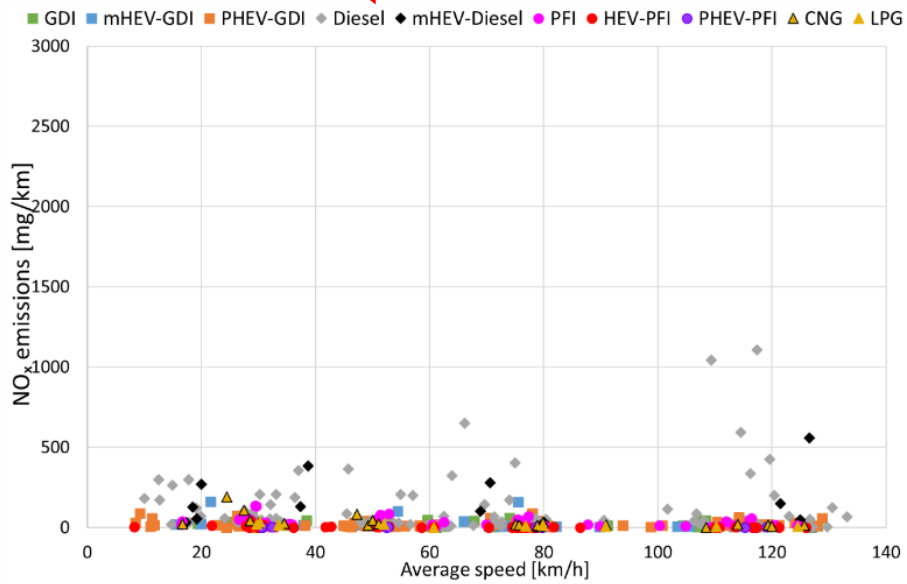


Non-Compliant RDE tests



Euro 6d-temp vehicle
DOC + LNT + DPF

Removing the LNT-equipped vehicle



- LNT-only equipped vehicles (one or double LNT) excluded from the analysis.
- Other vehicles excluded: 1 Euro 6d-temp GDI with un-ashed GPF (mileage <1000km), 1 Euro 6d-temp GDI without GPF (CNG-gasoline vehicle type-approved as monofuel CNG)

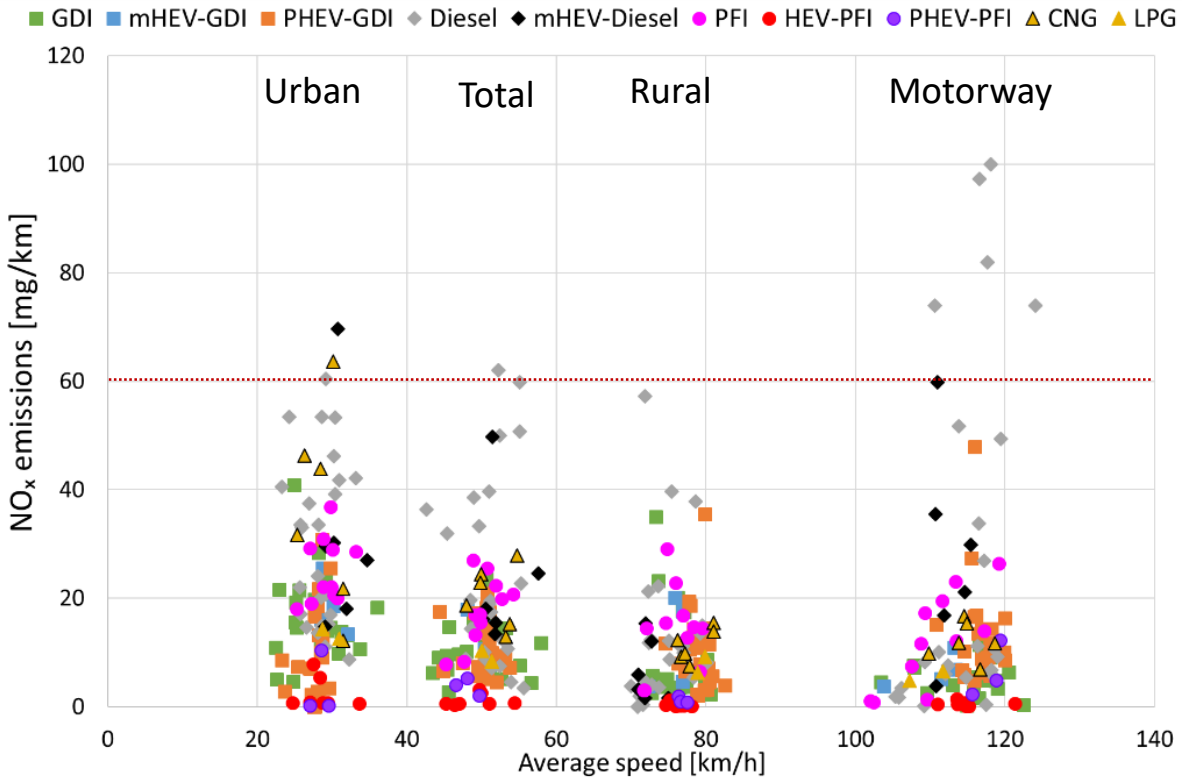
Measurement campaign and data collection HDVs

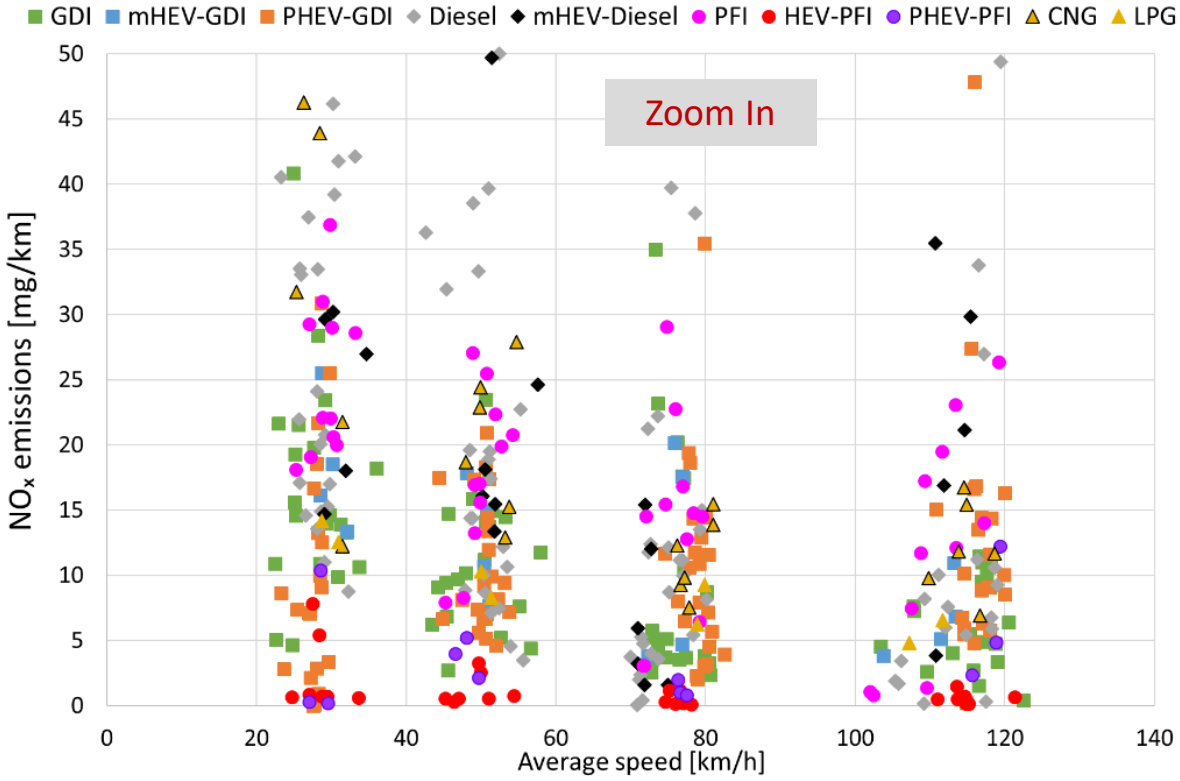
4 HDVs measured in CLOVE, further vehicle tests collected from TUG (project from Umweltbundesamt Germany) and from TNO (sponsored by the Dutch Government). In total 8 HDVs with more than 120 tests collected.
Tests cover WHVC, ISC and several alternative tests (stop&go up to full loaded uphill).

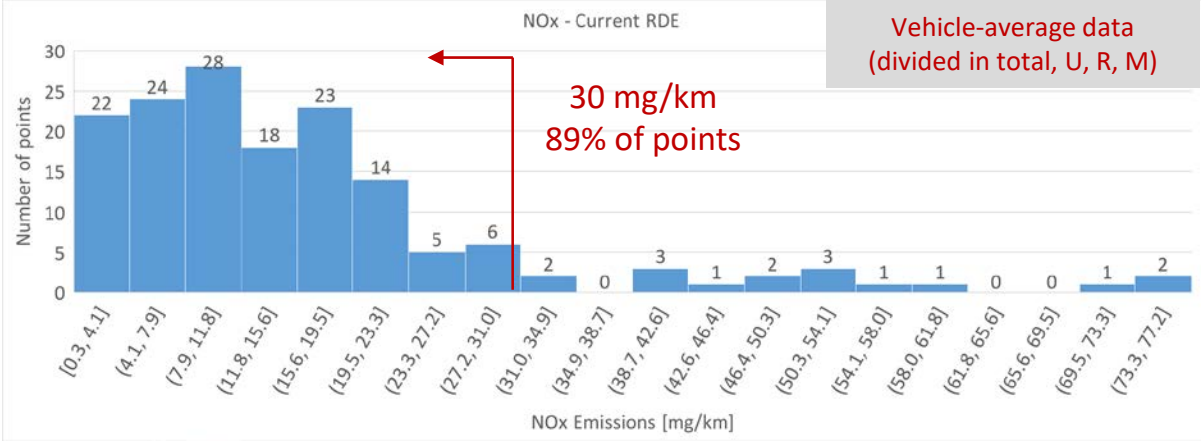
Vehicle type	EURO Class	Engine	Lab
Rigid truck	VI D	Diesel	TUG
Tractor	VI C	Diesel	TUG
Tractor	VI D	Diesel	TUG
City Bus	VI C	Diesel hybrid	Ricardo
City bus	VI D	Diesel	VTT
City Bus	VI D	CNG	VTT
Tractor	VI D	Diesel	TNO
Tractor	VI D	Diesel	TNO

Due to time restrictions, test data is shown together with limit proposals.

Emissions database preliminary results for NOx emissions - Current RDE, Euro 6d-temp and 6d





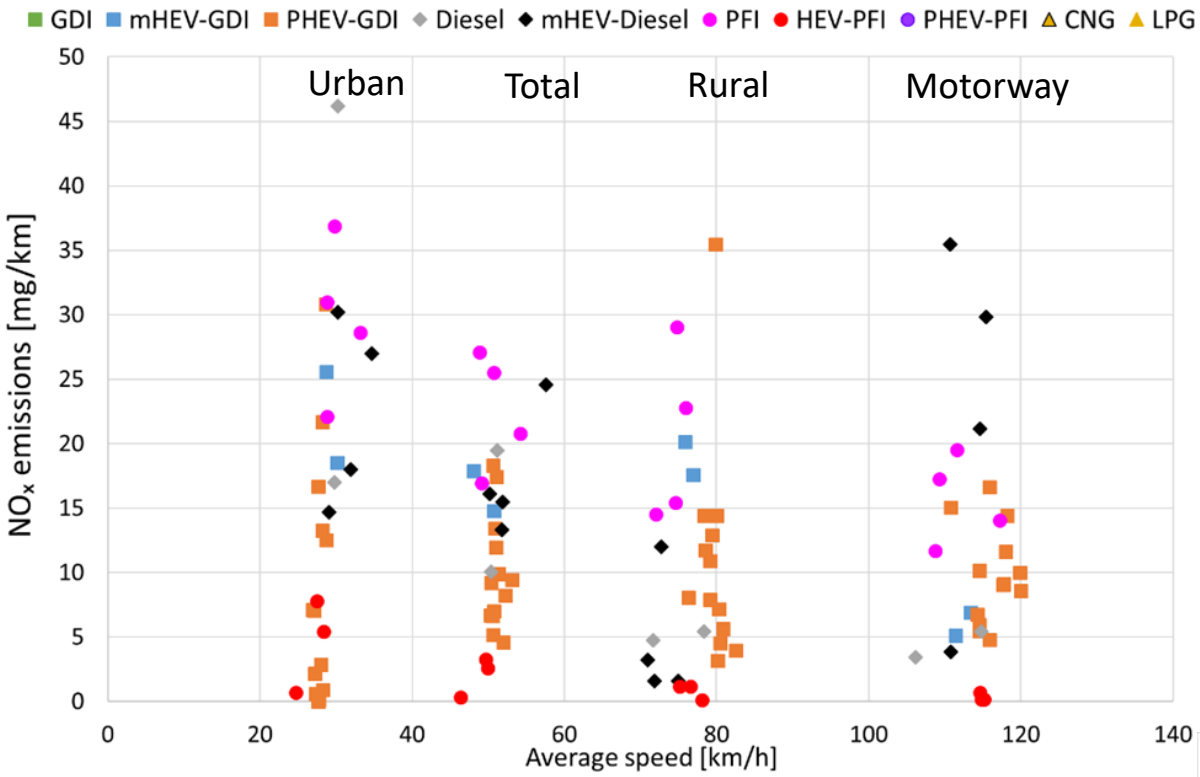


→ Most vehicles already at low levels, well below 60 mg/km.

→ High variations in some technologies, e.g. diesel

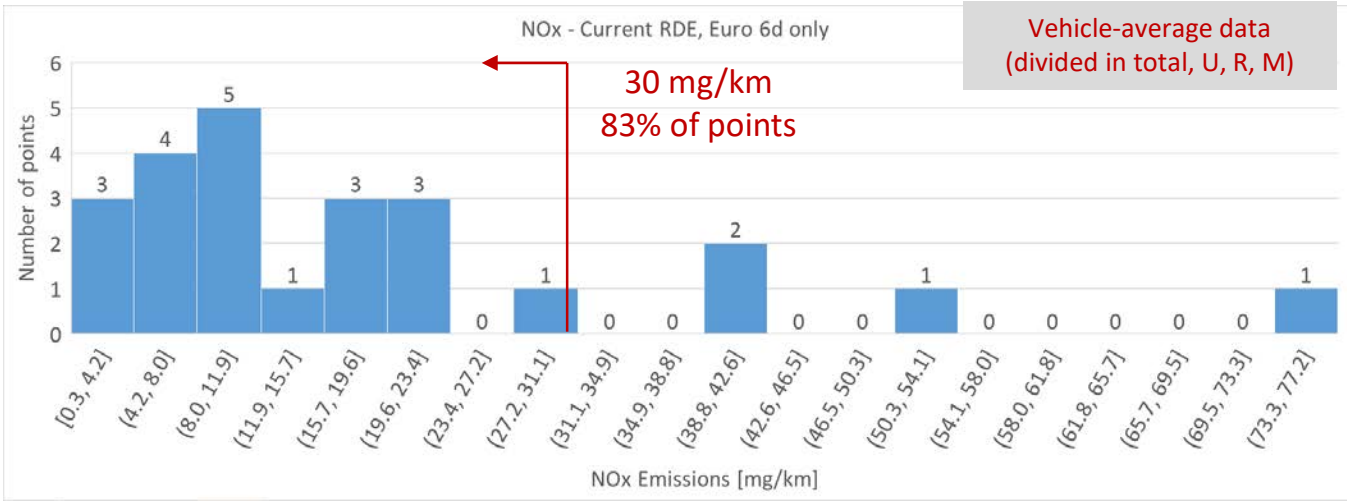
*The lowest Euro 6 limit (60 mg/km) without conformity factor is presented in this analysis and the following slides as a reference.

Emissions database preliminary results for NOx emissions
Current RDE, Euro 6d only + demo vehicle

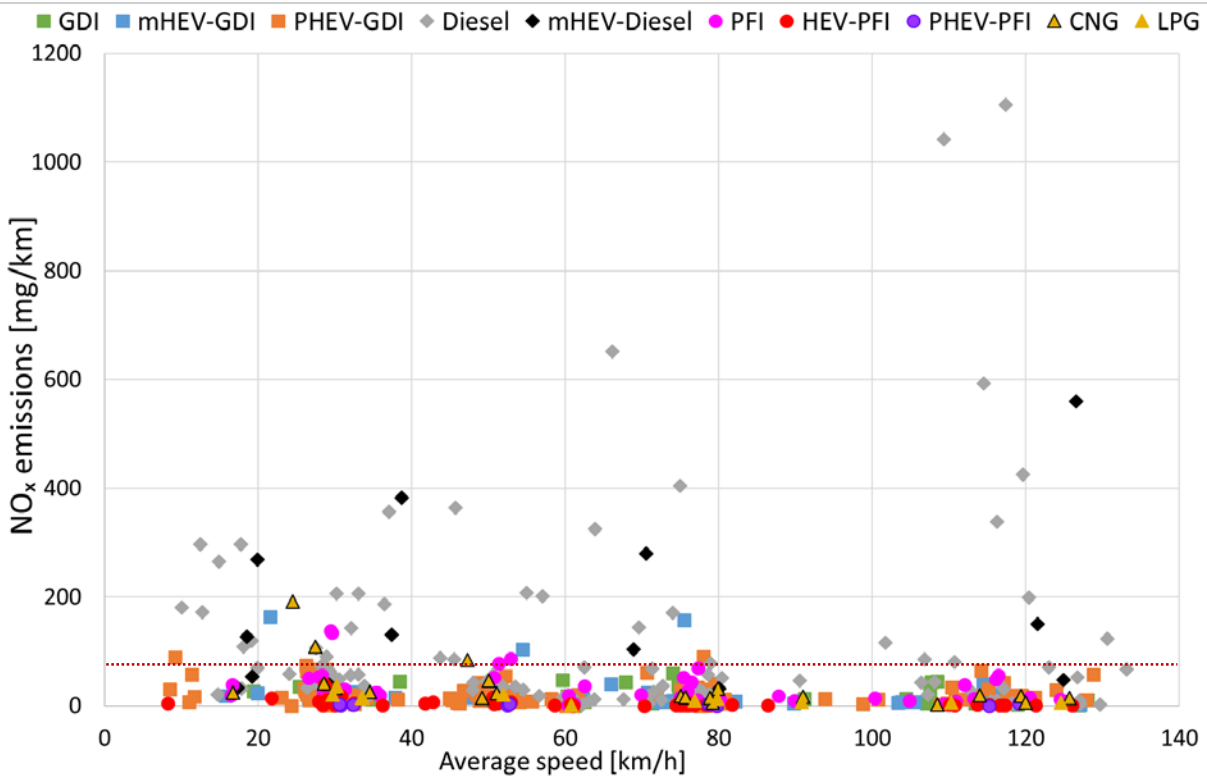


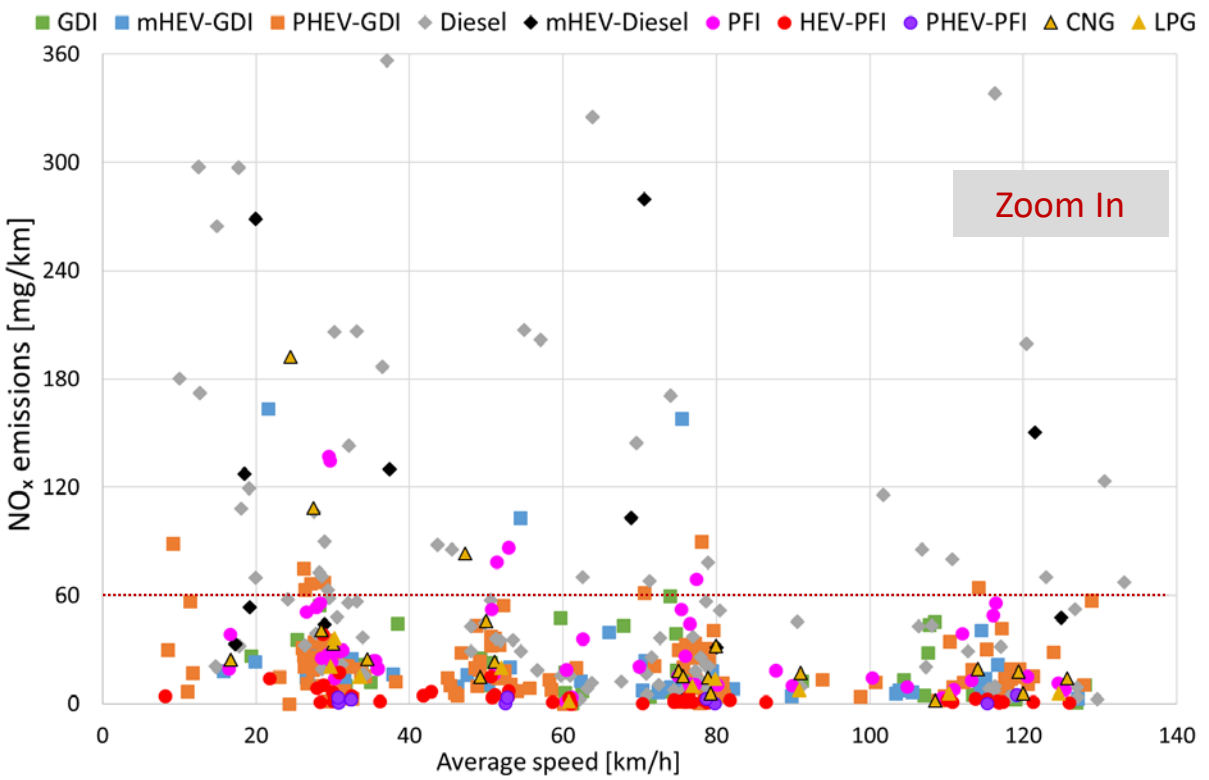
→ No significant change compared to all Euro 6 vehicles

Note: black markers refer to demo (originally a Euro 6b vehicle)

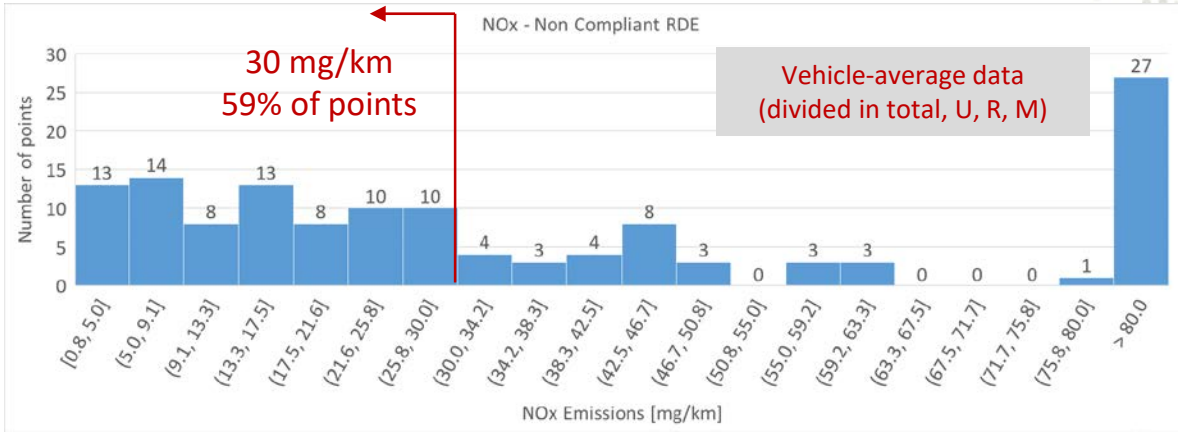


Emissions database preliminary results for NOx emissions – Non-compliant RDE, Euro 6d-temp and 6d



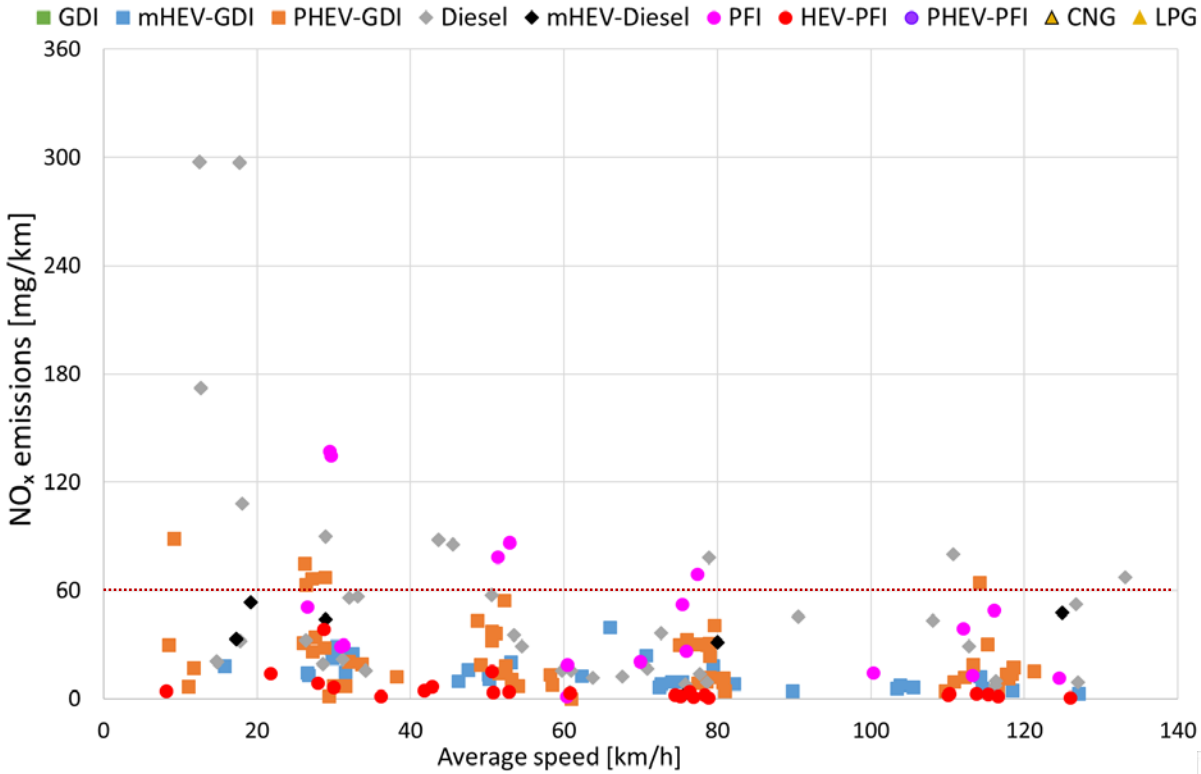


→ Higher emission levels outside the current RDE, especially in diesel.



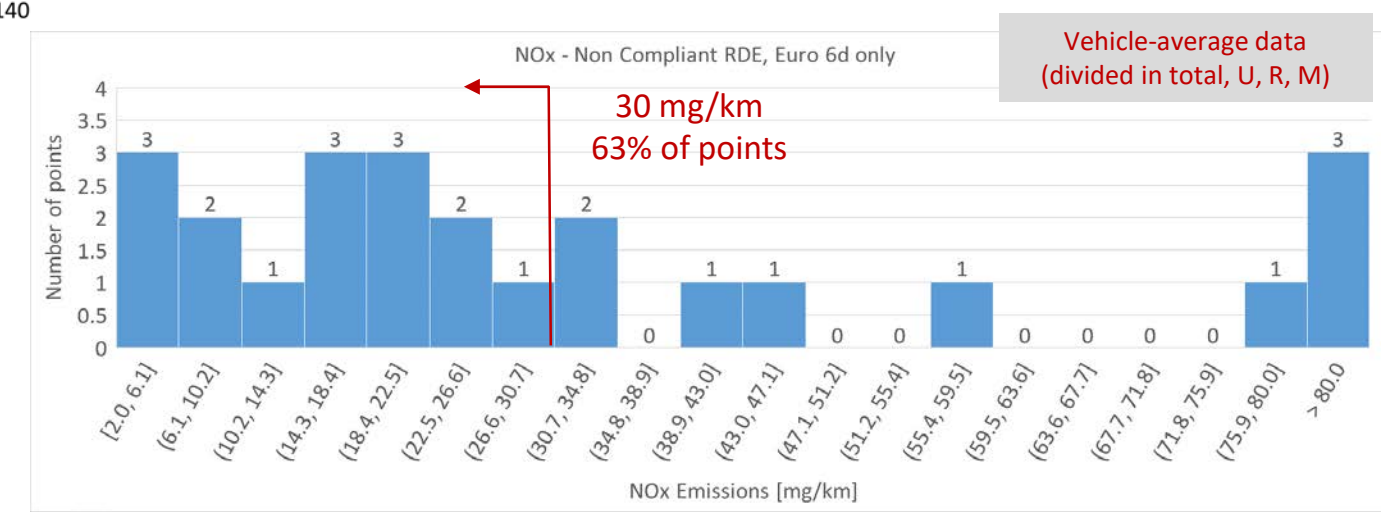
*See non-compliance criteria and parameters range above

Emissions database preliminary results for NOx emissions – Non-compliant RDE, Euro 6d only + demo vehicle

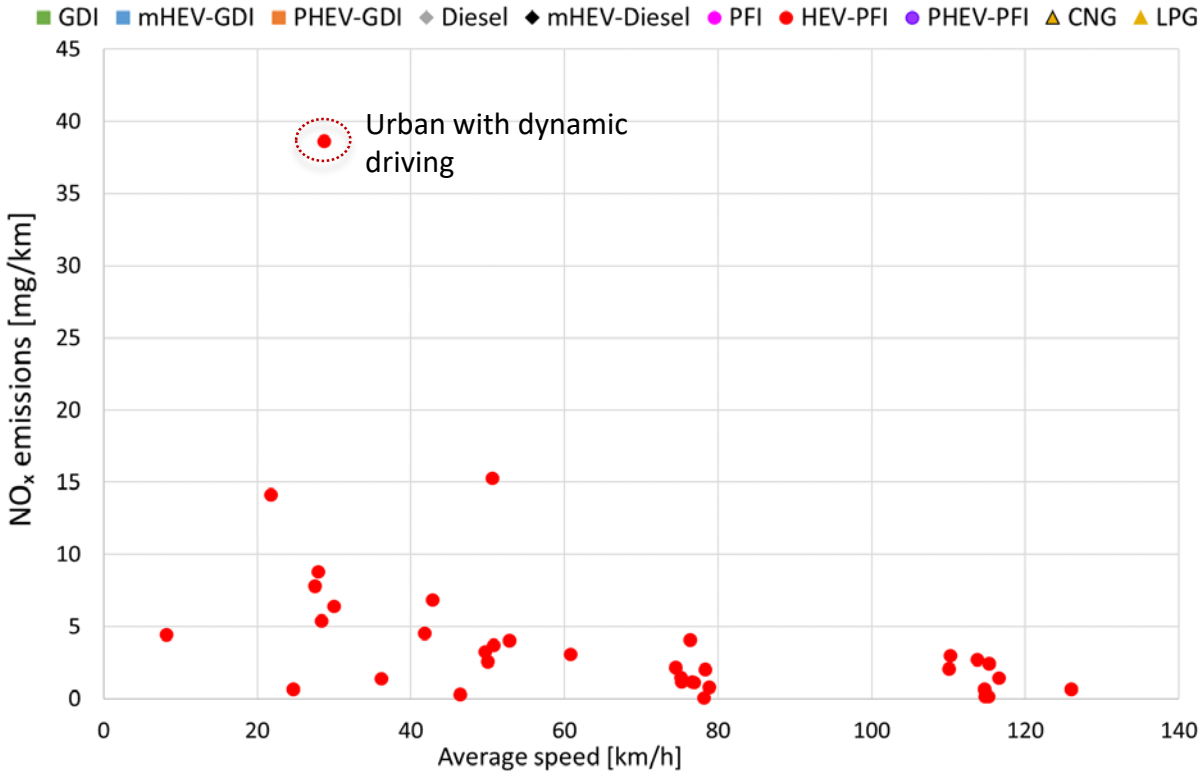


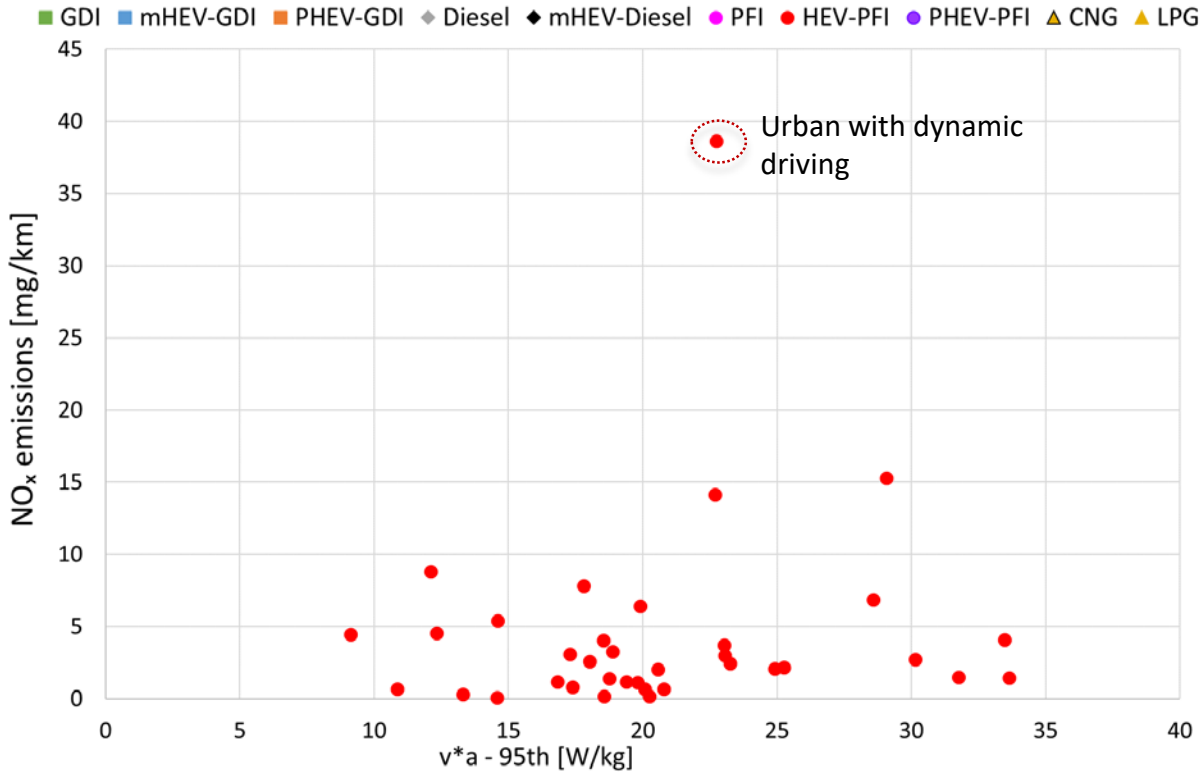
→ No significant change compared to all Euro 6 vehicles

Note: black markers refer to AECC demo (originally a Euro 6b vehicle)



Euro 6d gasoline HEV-PFI (TWC), NOx
All RDE tests (compliant and non-compliant)

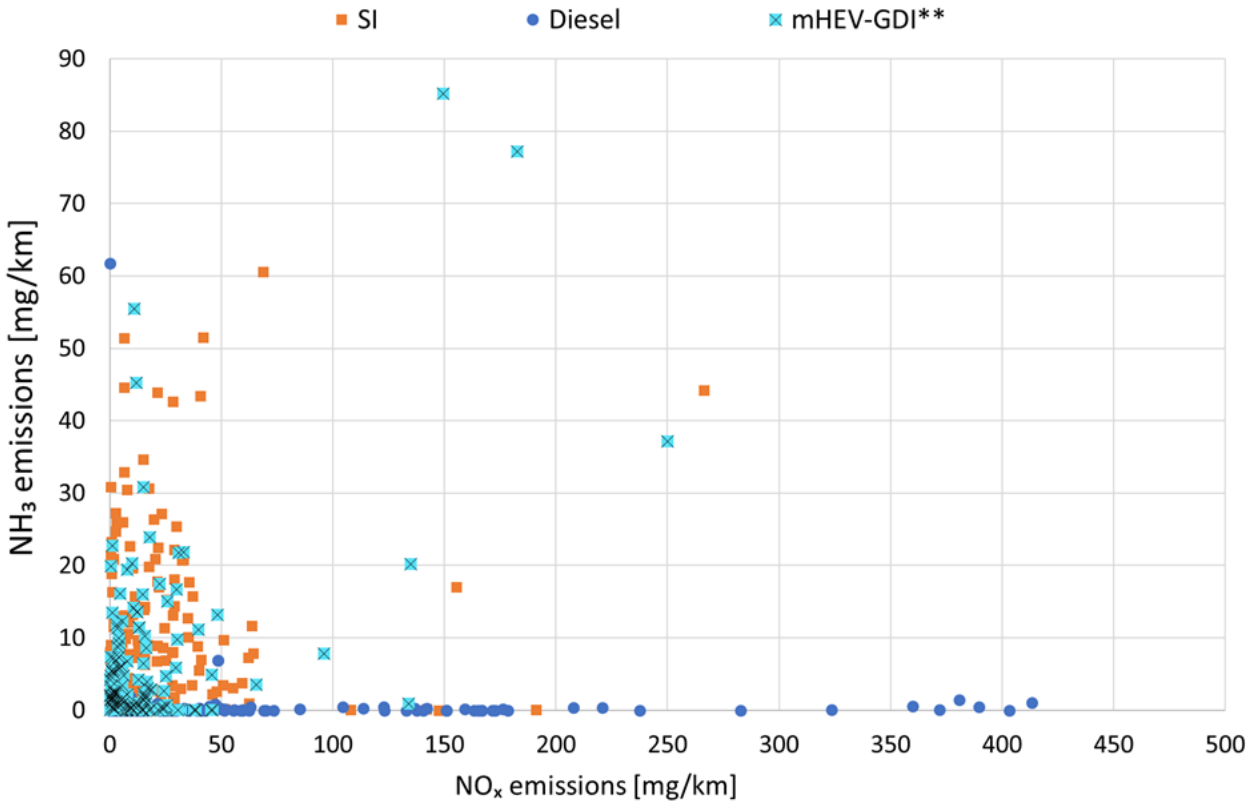


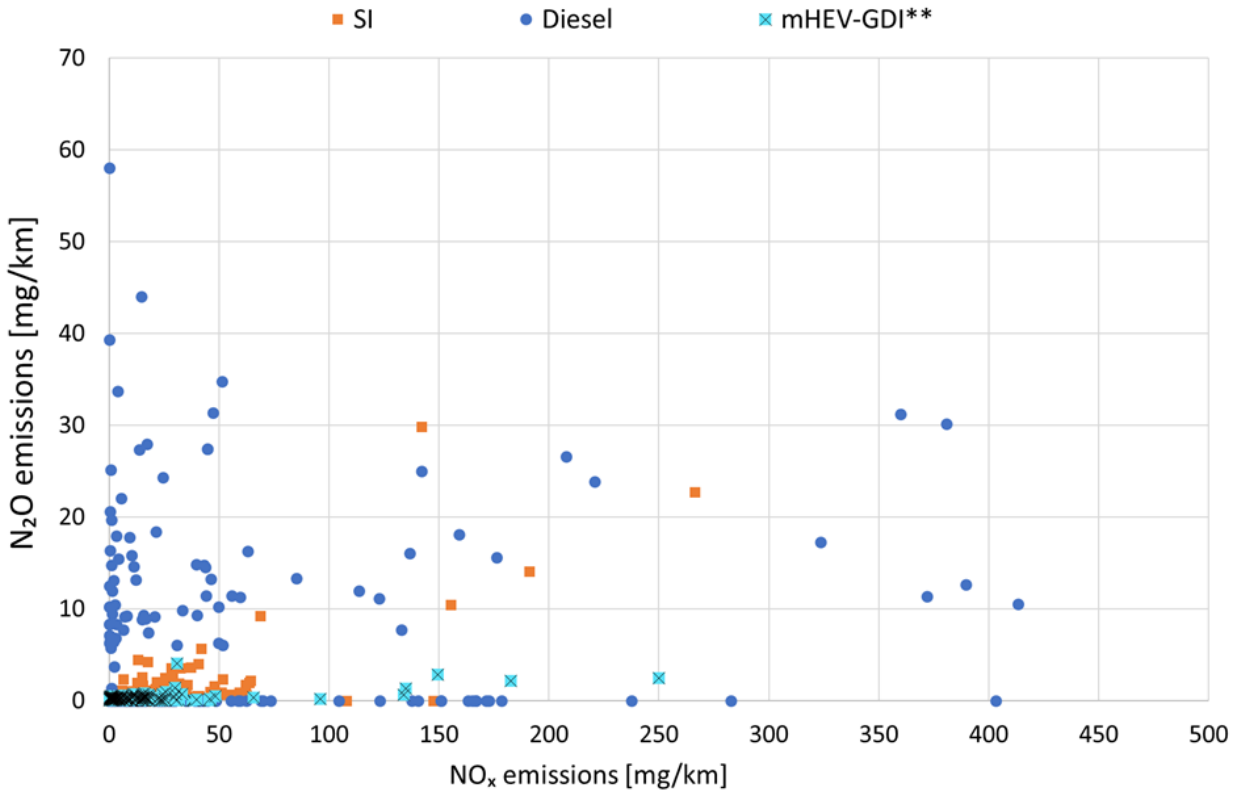


→ Low NOx emissions under a wide range of testing conditions, even in non-compliant RDE tests.

→ Higher emissions in urban marked parts could be solved with pre-heated catalyst and better engine calibration.

Emissions database preliminary results for NH_3 – NOx and N_2O – NOx, All chassis dyno tests, Euro 6d-temp and 6d





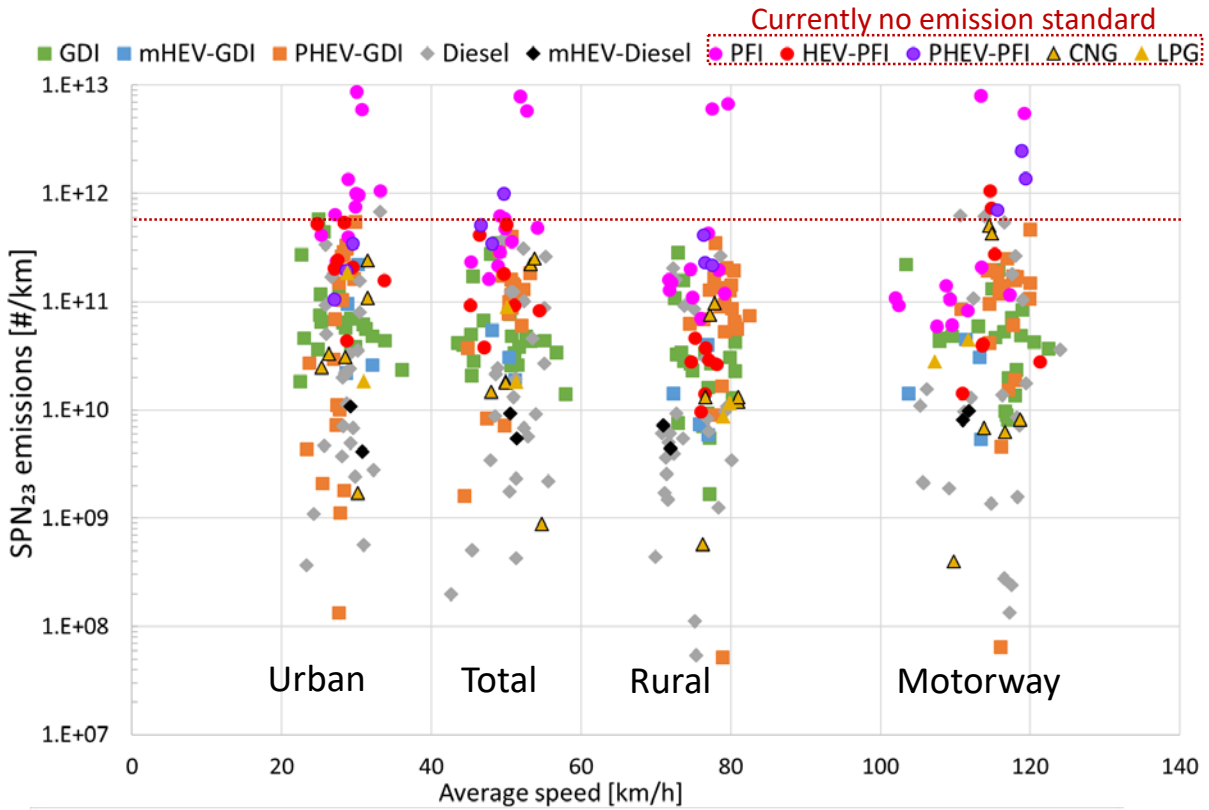
For comparison, NH_3 limits:

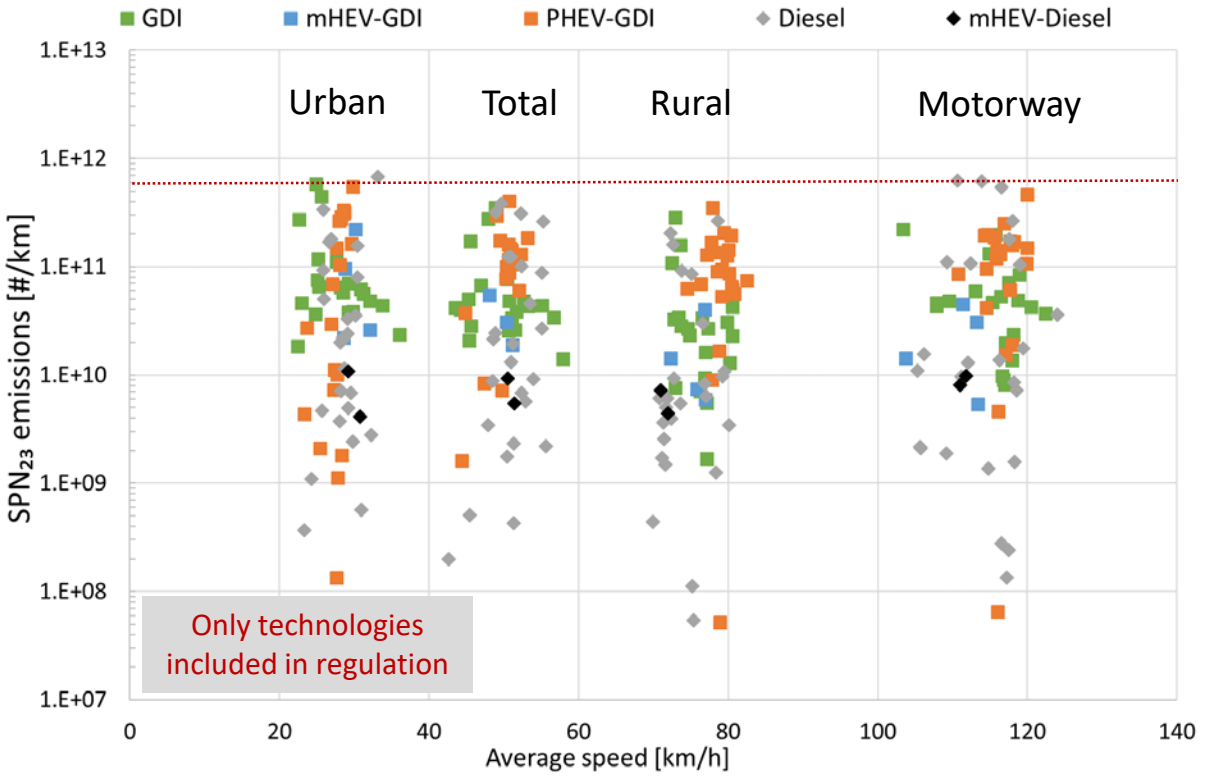
- EU and China HDV: max 10 ppm
  → **max ~17 mg/km** for LDV during RDE
- US HDV: max 25 ppm
  → **max ~41 mg/km** for LDV during RDE

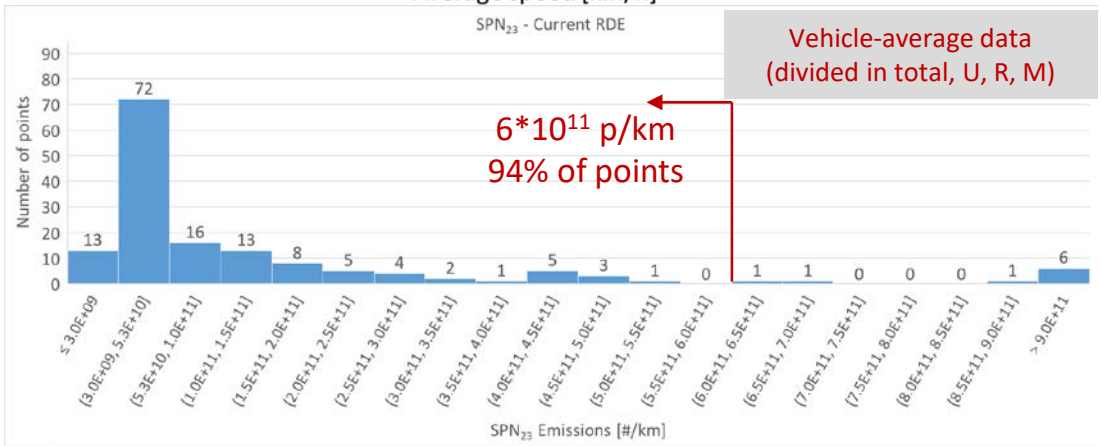
For comparison, N_2O limits in other countries:

- China LDV: **20-30 mg/km**
- US LDV: **6 mg/km**

Emissions database preliminary results for SPN_{23} emissions – Current RDE, Euro 6d-temp and 6d

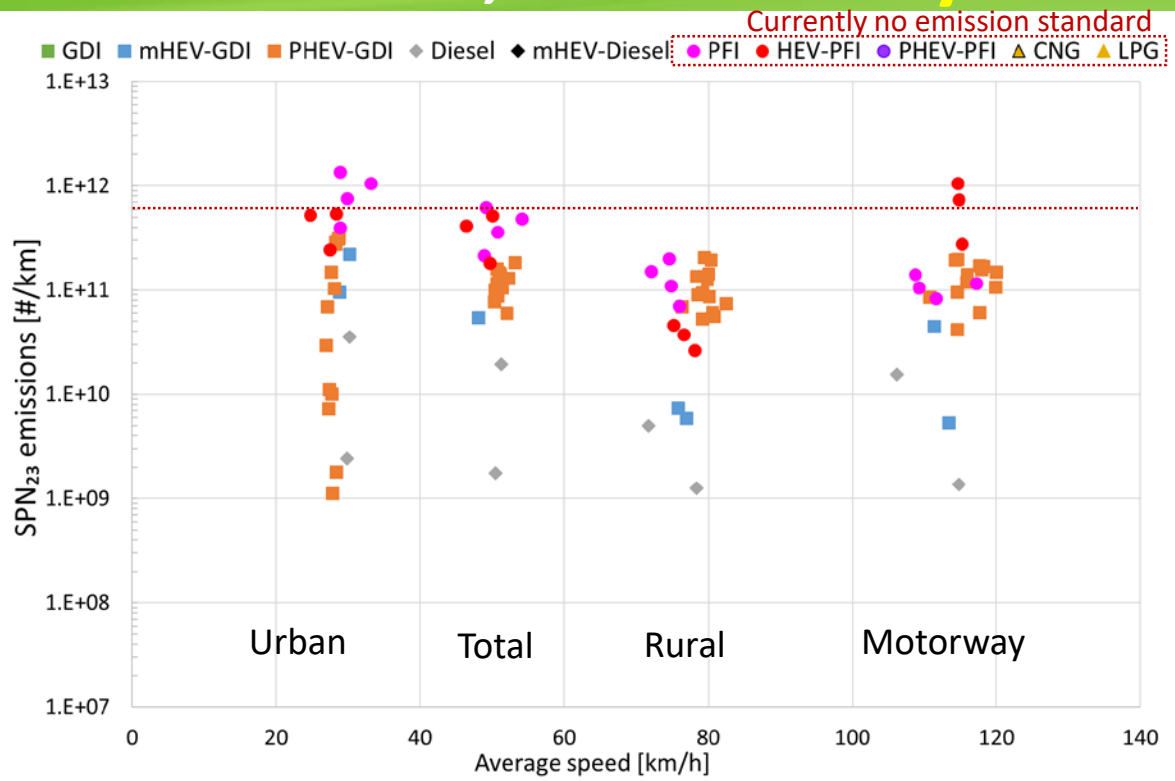


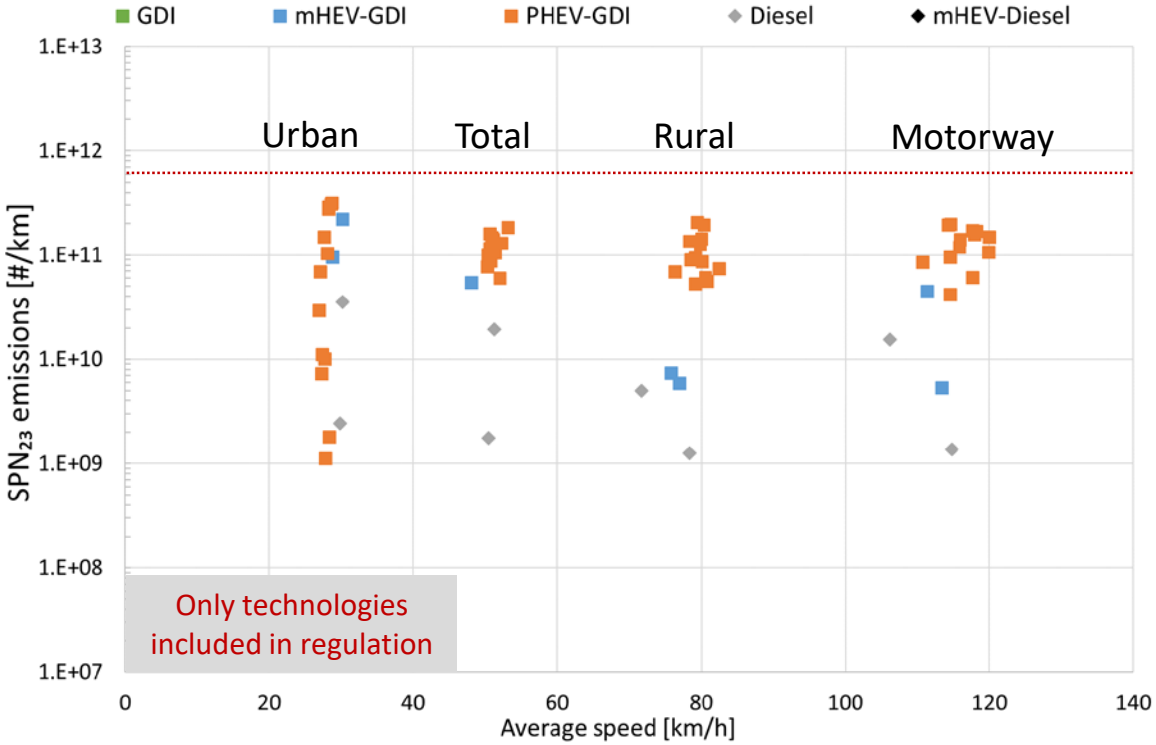


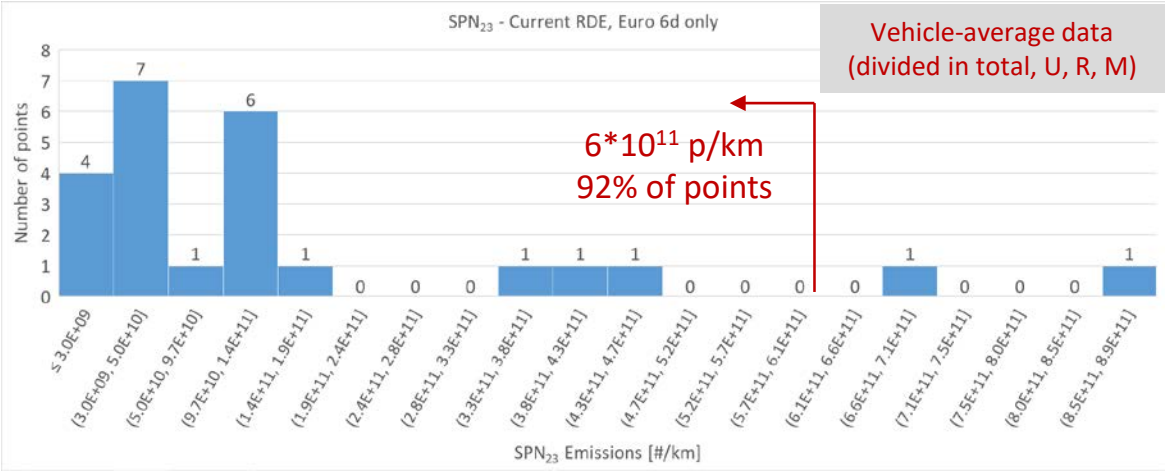


- → Most vehicles (currently in regulation) already at low levels, well below $6*10^{11}$ p/km.
- → High variations in PHEV-GDI
- → Diesel at the lowest end

Emissions database preliminary results for SPN_{23} emissions – Current RDE, Euro 6d only

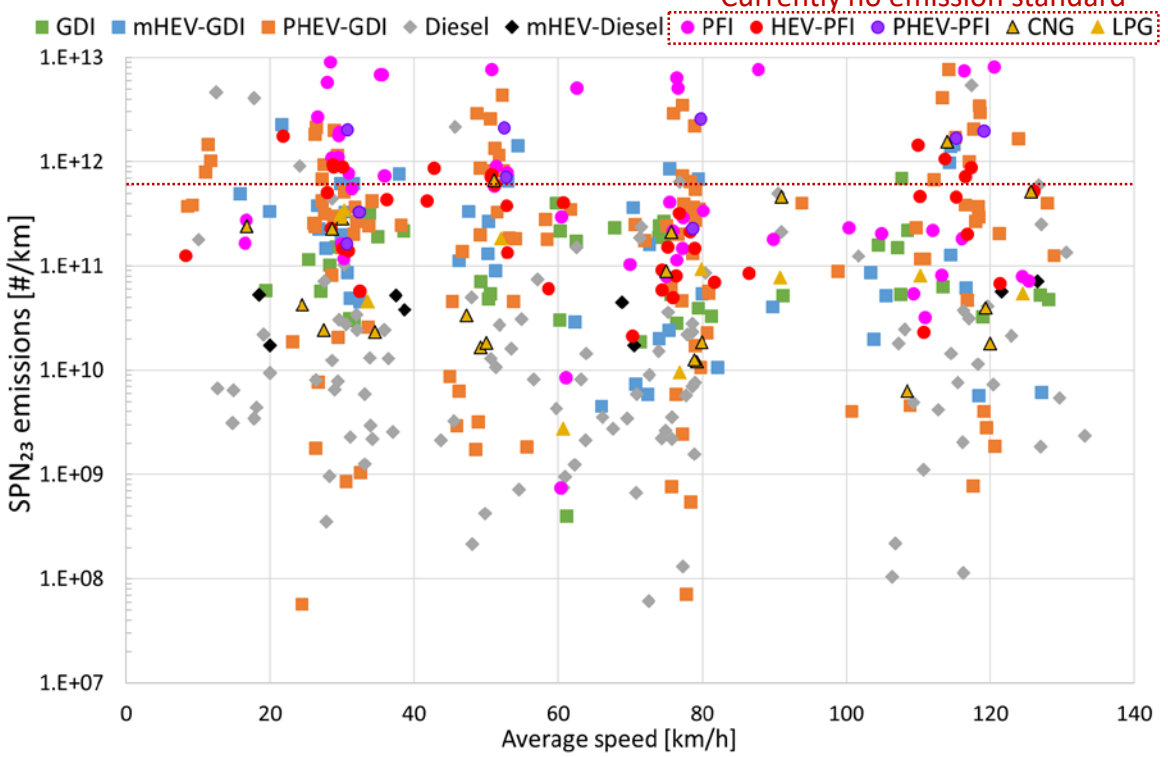


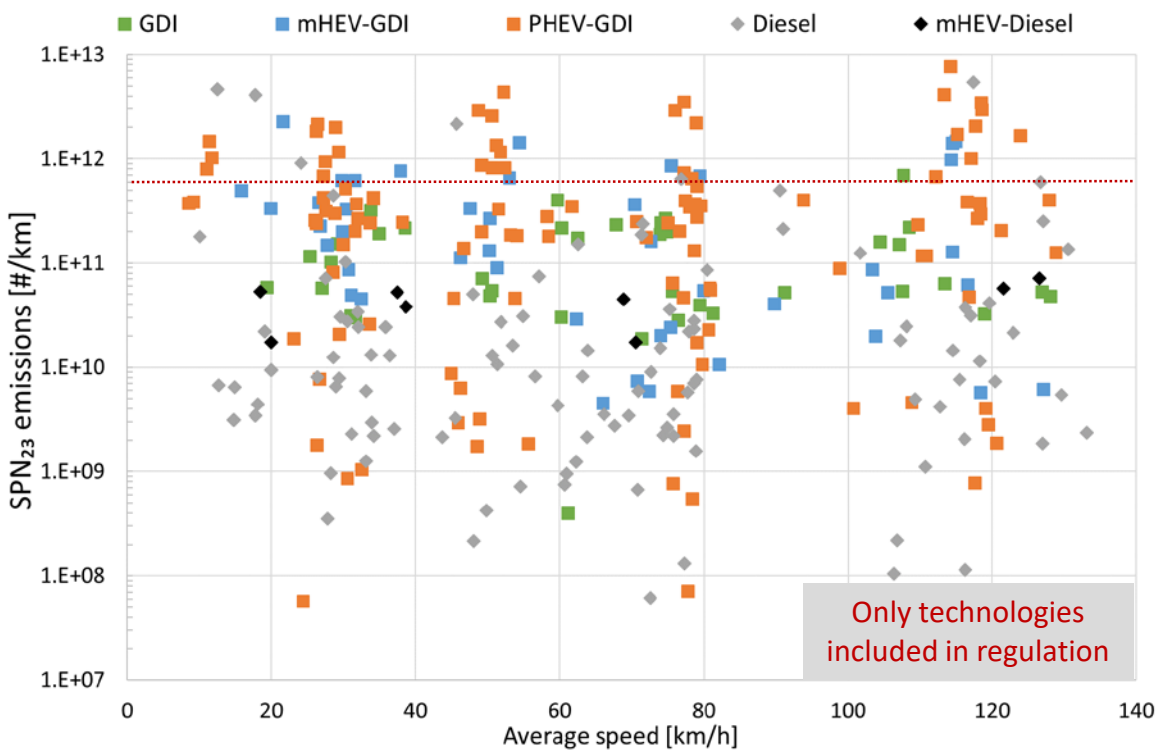


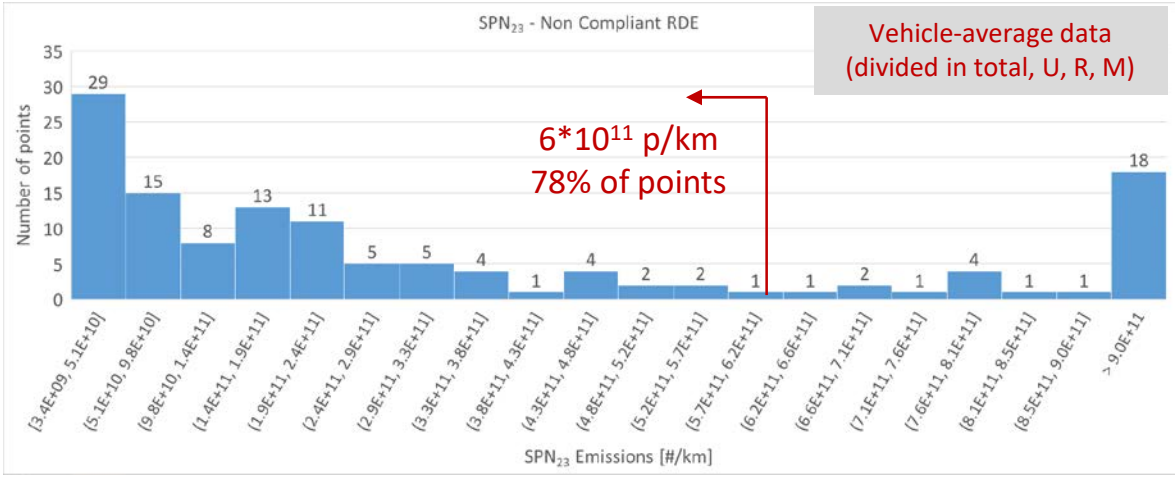


Emissions database preliminary results for SPN_{23} emissions – Non-compliant RDE, Euro 6d-temp and 6d

Currently no emission standard

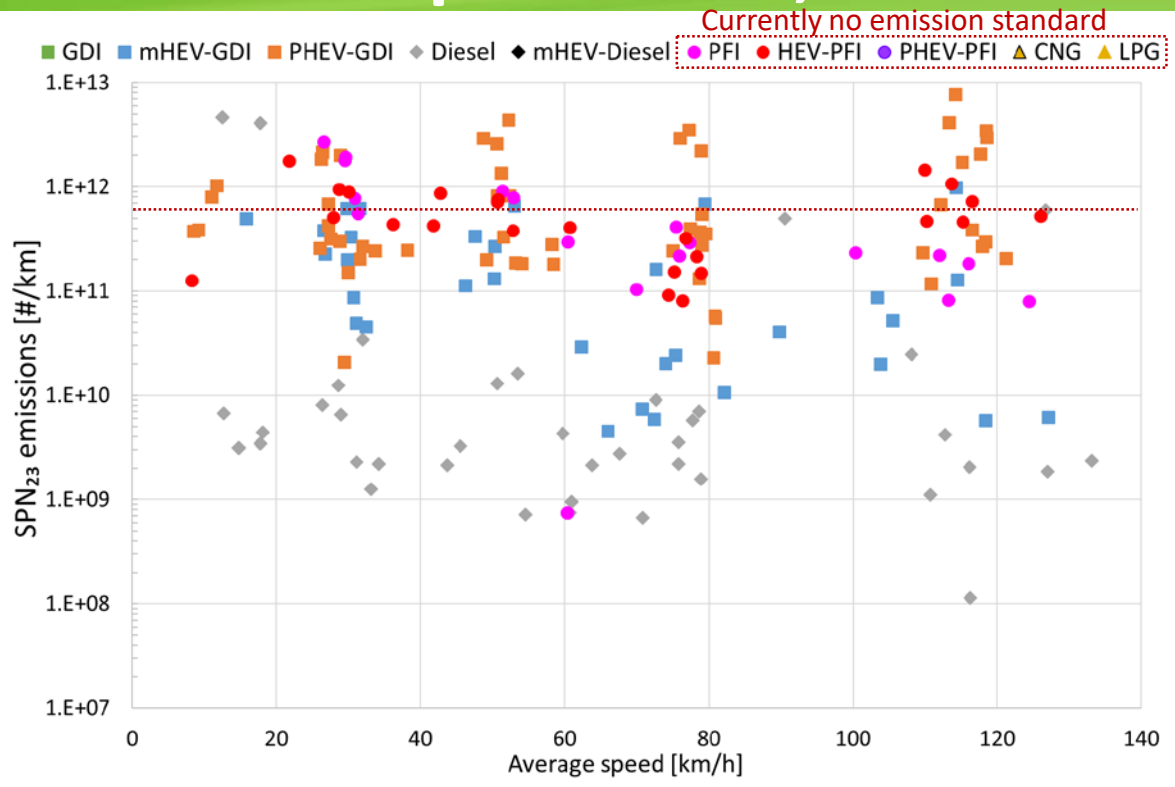


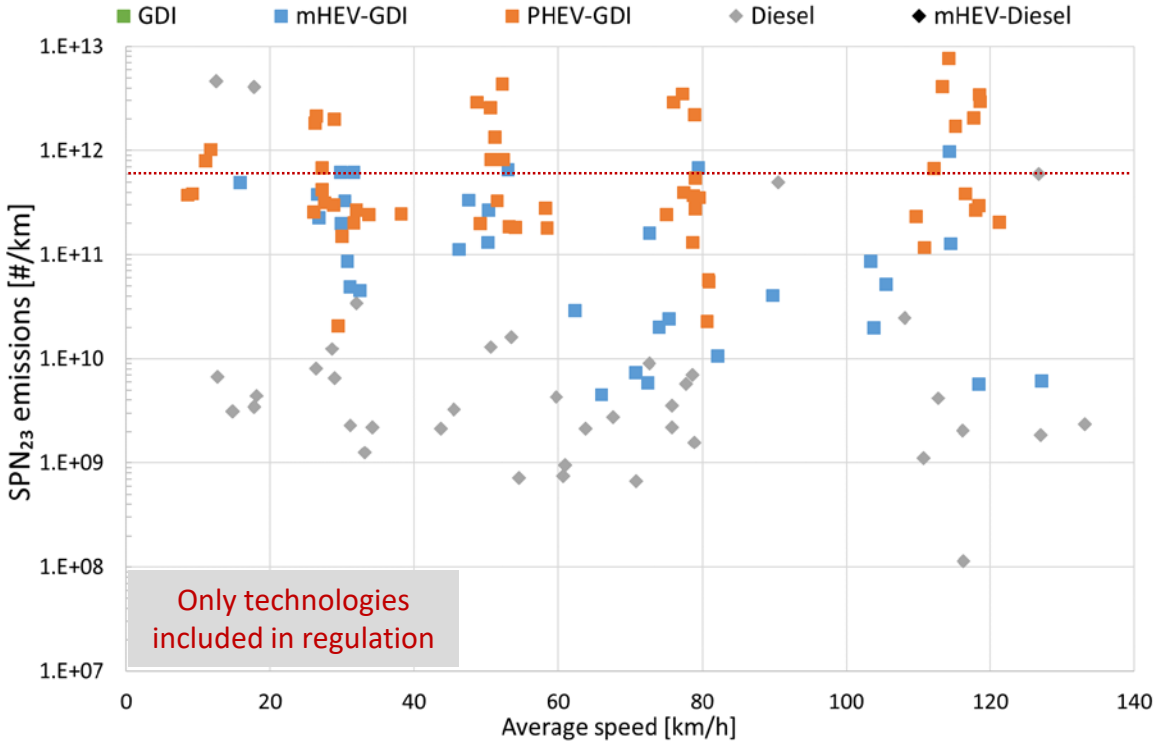


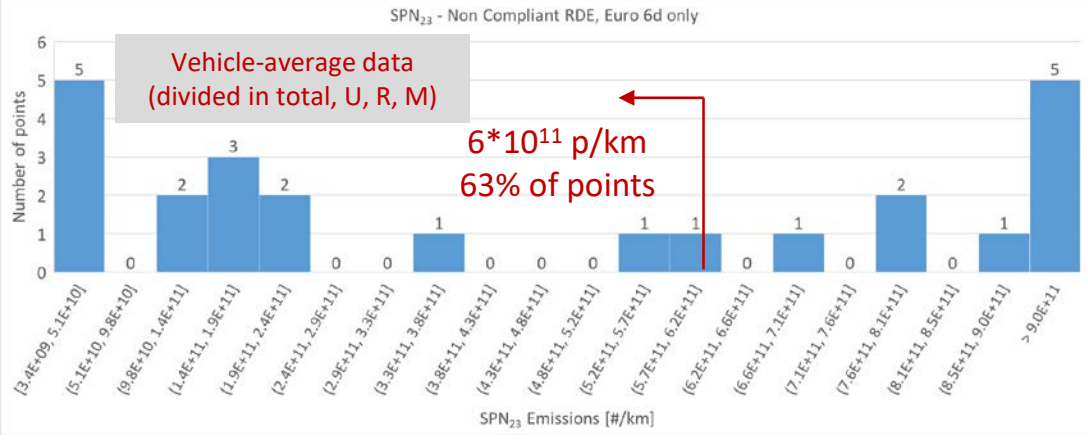


- → Shift of emissions to higher levels compared to current RDE tests.
- → High variations in PHEV-GDI
- → Diesel and CNG remain low in most cases

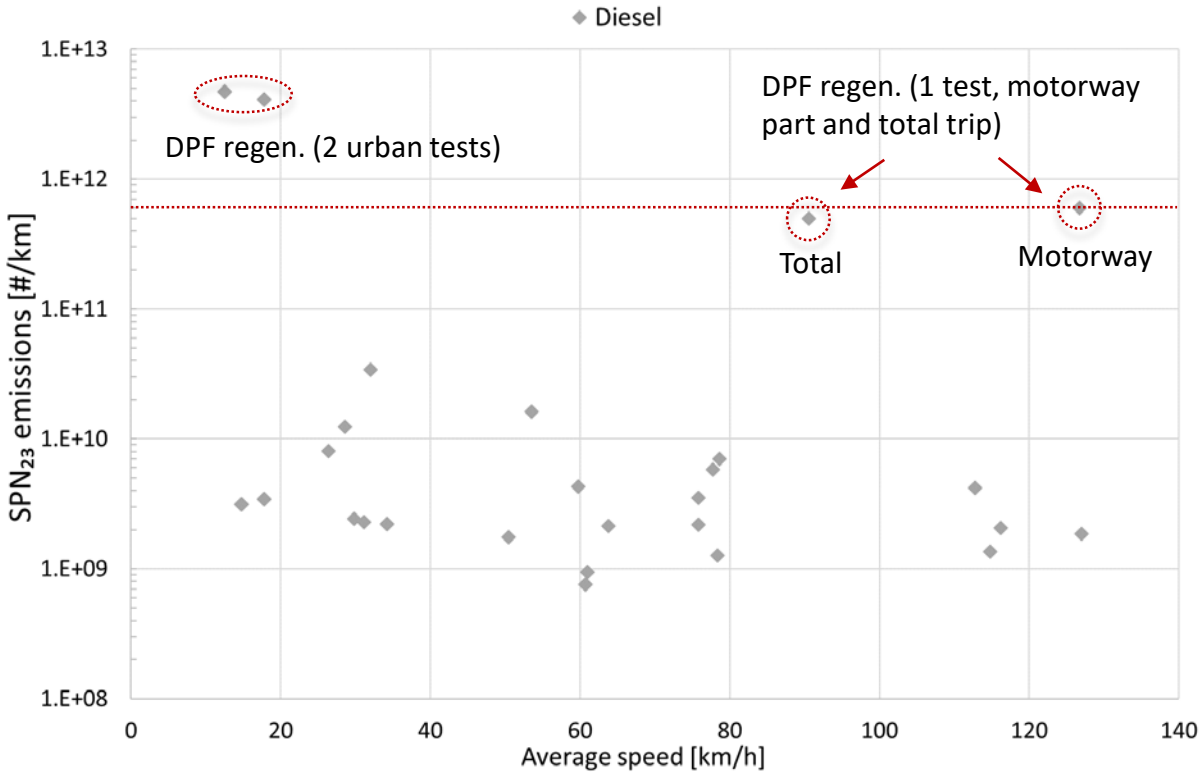
Emissions database preliminary results for SPN_{23} emissions – Non-compliant RDE, Euro 6d only

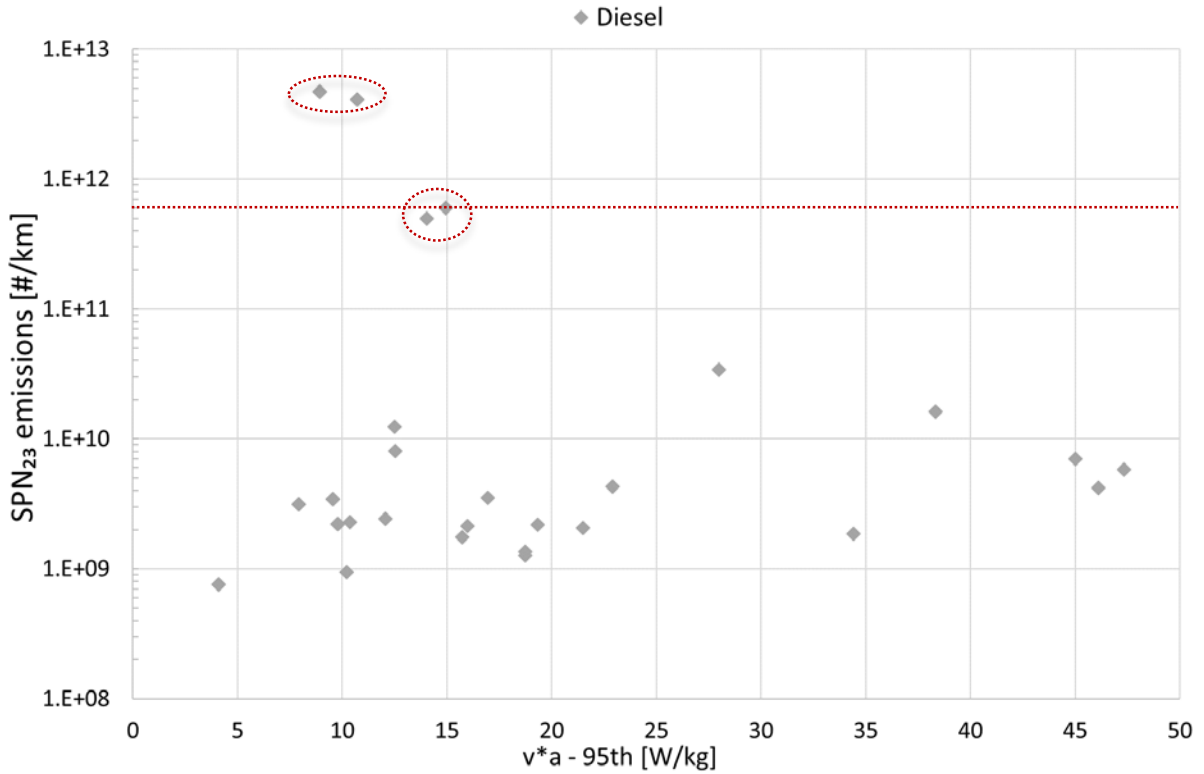






Euro 6d diesel (DOC+sDPF+SCR+ASC), SPN_{23} All RDE tests + regeneration



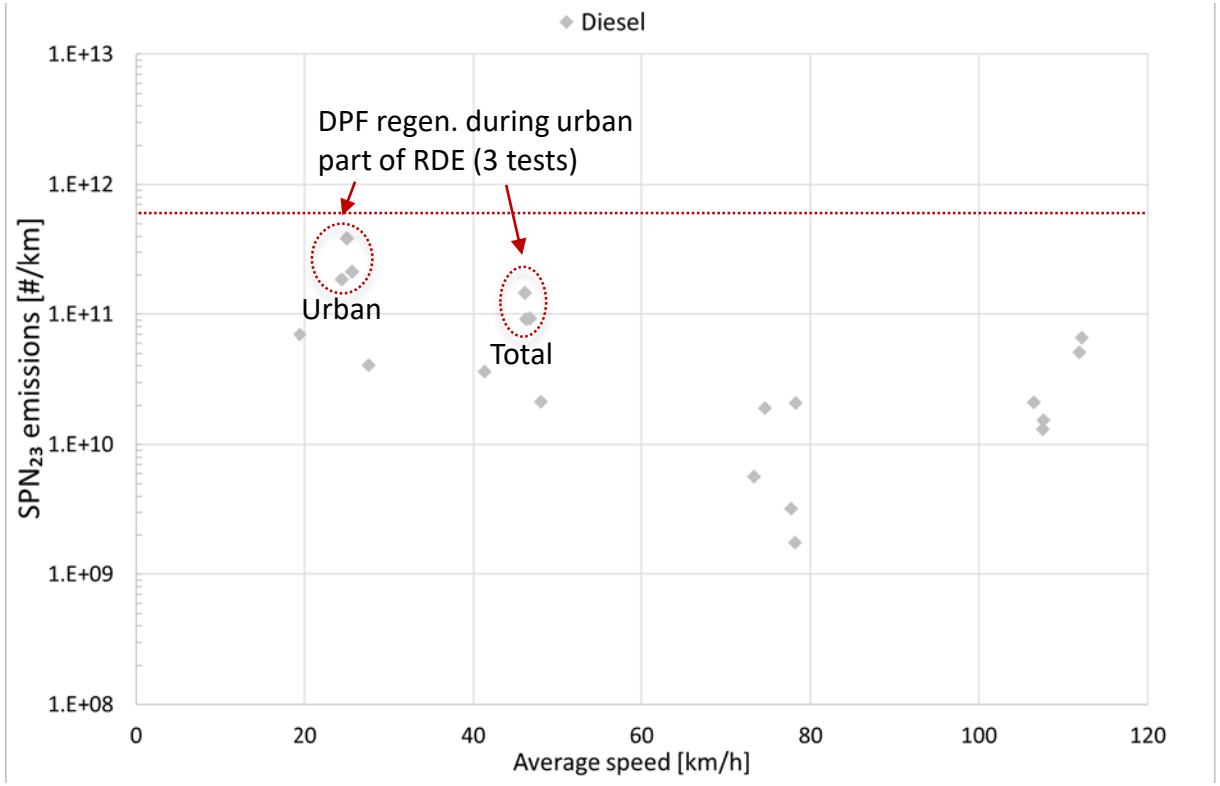


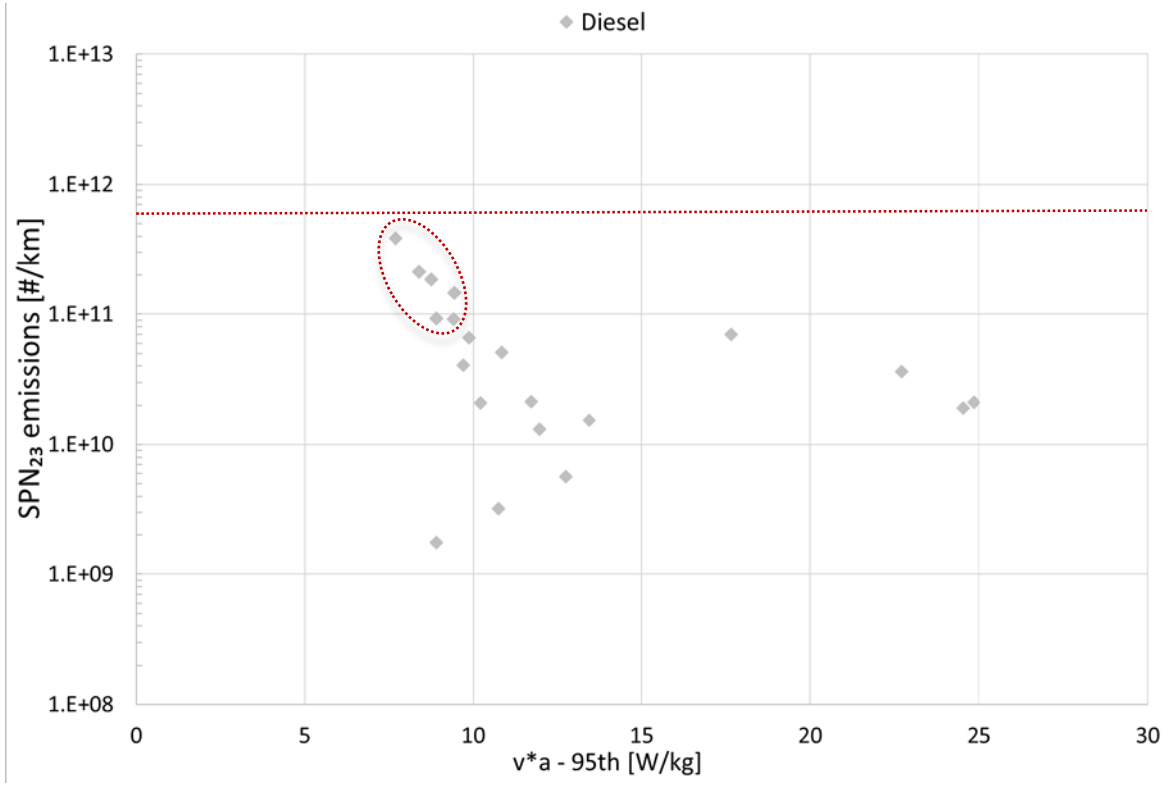
→ Low SPN_{23} emissions under a wide range of test conditions, even beyond current RDE, excluding DPF regeneration.

→ DPF regeneration: High SPN_{23} emissions [p/km] in urban trips due to shorter distance (18 km) compared to motorway (156 km).

Avg. emissions	w/o DPF Regen.	Incl. DPF Regen.
SPN_{23} [#/km]	$5*10^{9}$	$5.8*10^{11}$

Euro 6d diesel LCV, SPN_{23}
All RDE tests + regeneration

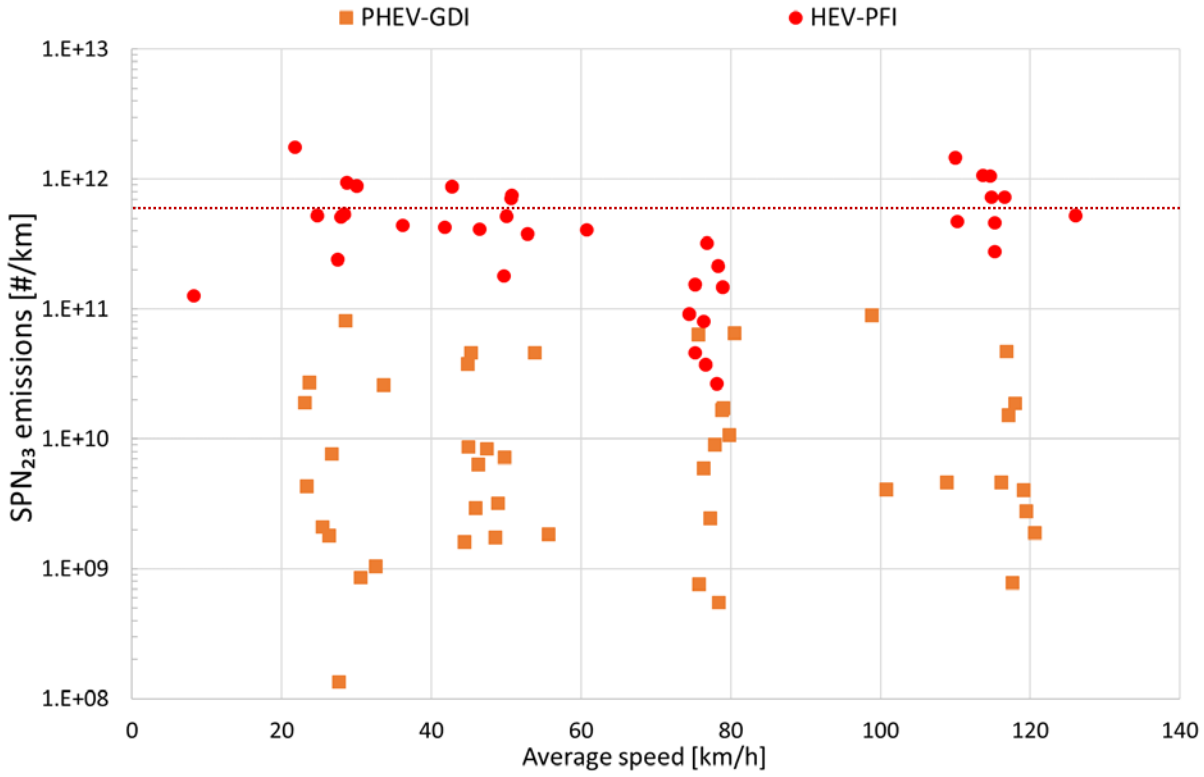


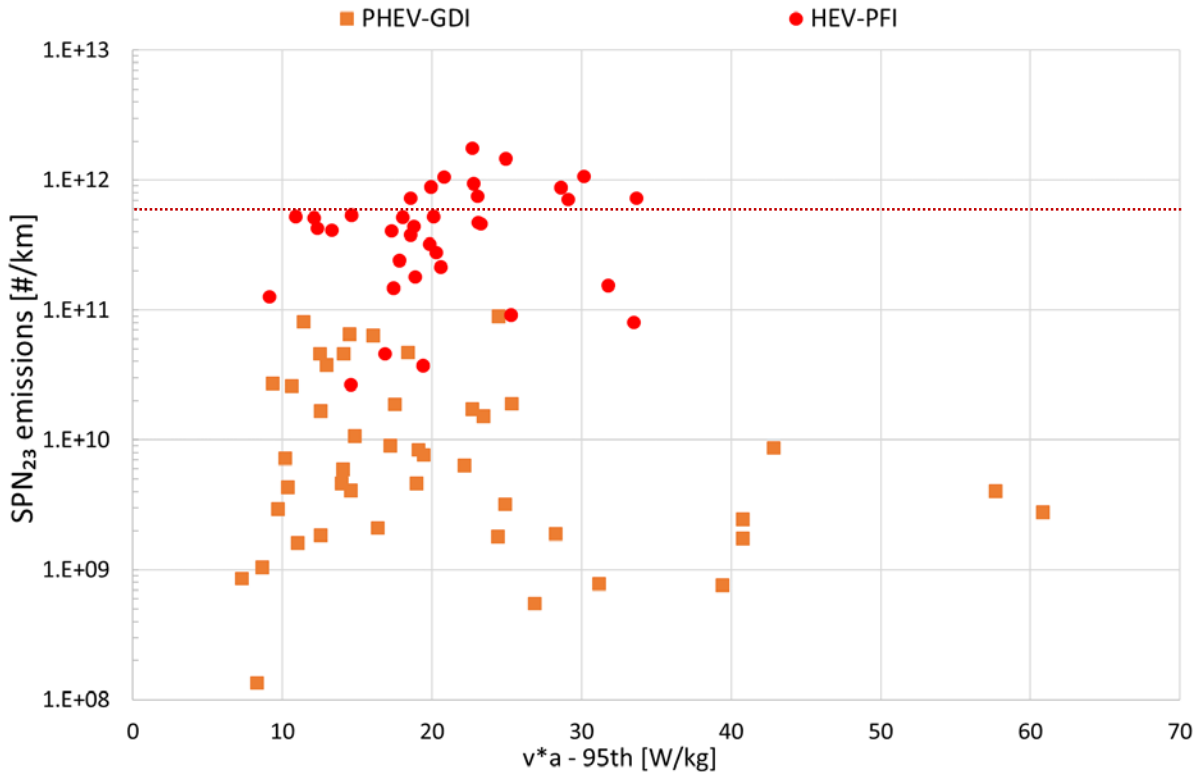


→ Low SPN_{23} emissions under a wide range of test conditions, even during and after regeneration.

Avg. emissions	w/o DPF Regen.	Incl. DPF Regen.
SPN_{23} [#/km]	$2.8*10^{10}$	$1.9*10^{11}$

Euro 6d gasoline HEV-PFI (TWC), all RDE, SPN_{23} - Comparison with PHEV GDI w/ GPF (Euro 6d-temp)

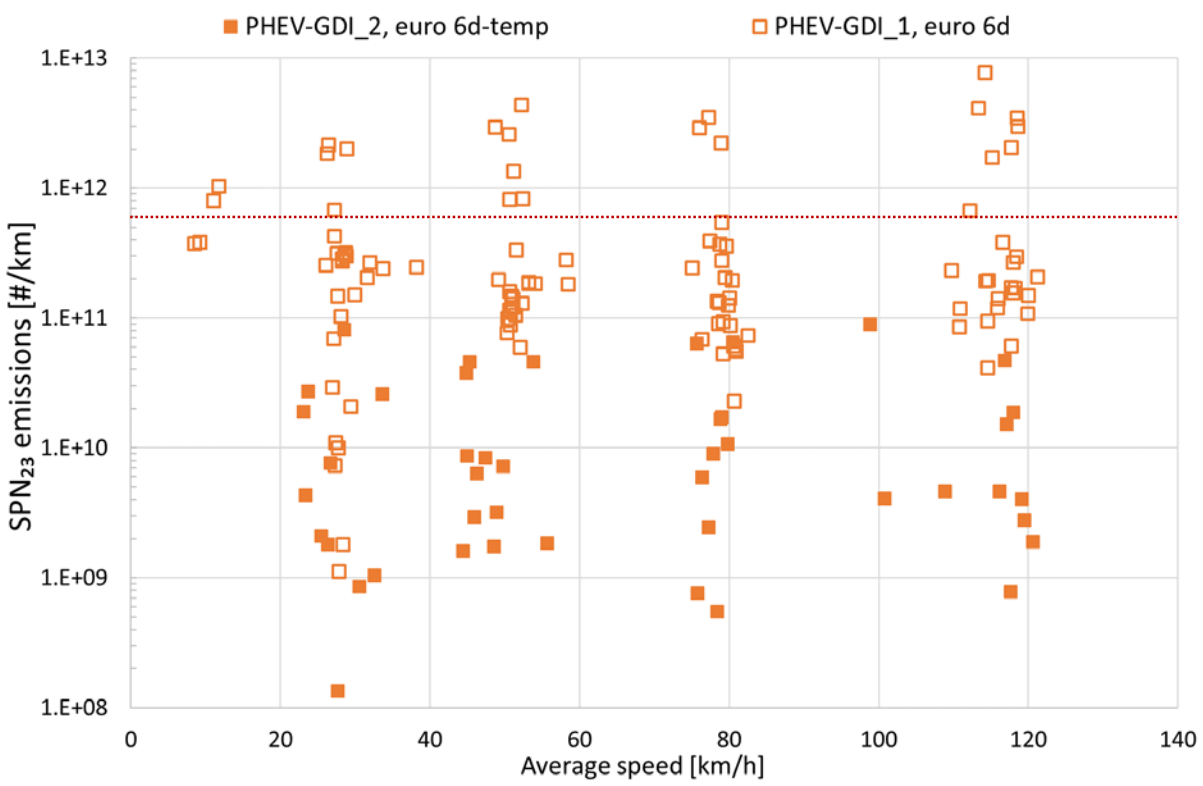


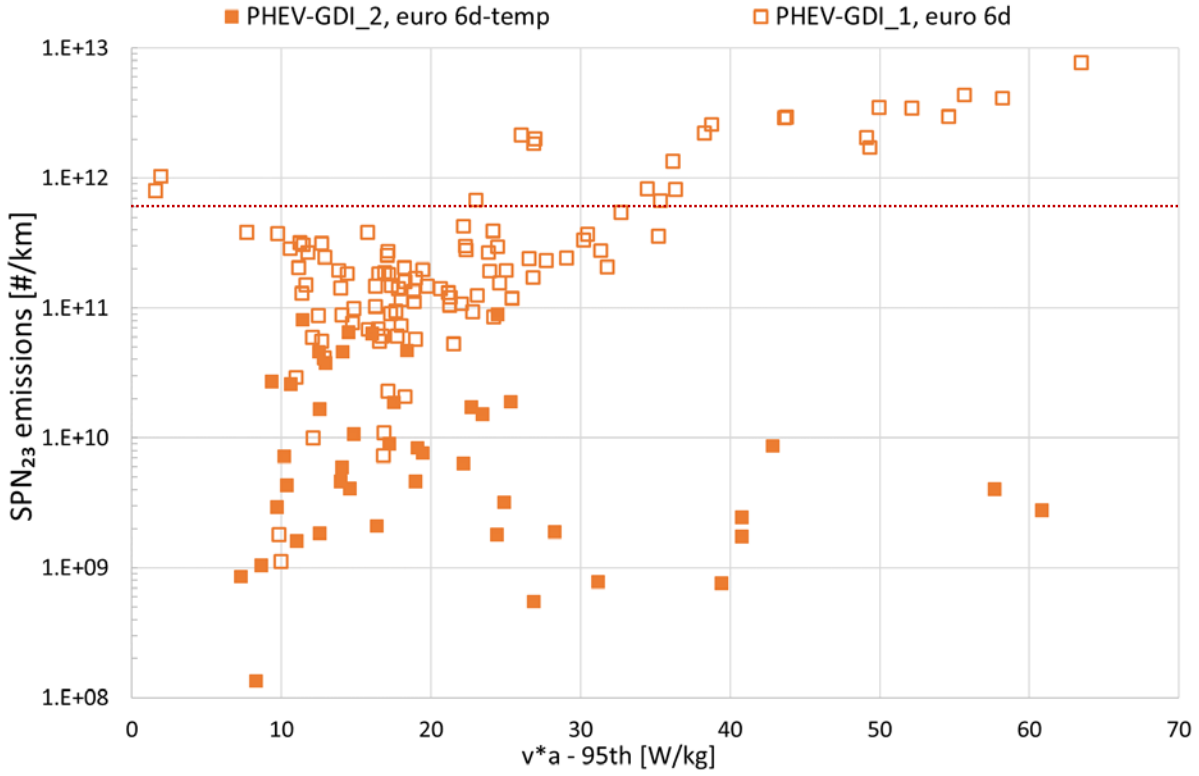


→ Significantly lower SPN_{23} emissions in PHEV-GDI under a wide range of test conditions within and beyond current RDE (both vehicles tested by the same lab).

→ Indication that SPN_{23} reduction technology is already here → High efficiency GPF

PHEV-GDI (TWC+GPF), All tests – GPF comparison





→ 1 order of magnitude difference ($1.5*10^{10}$ vs $4*10^{11}$ p/km) between 2 PHEV-GDIs, tested by the same lab under similar test conditions, within and beyond current RDE test conditions.

→ Compliance with stricter limits even beyond current RDE can be achieved with high-efficiency GPFs.

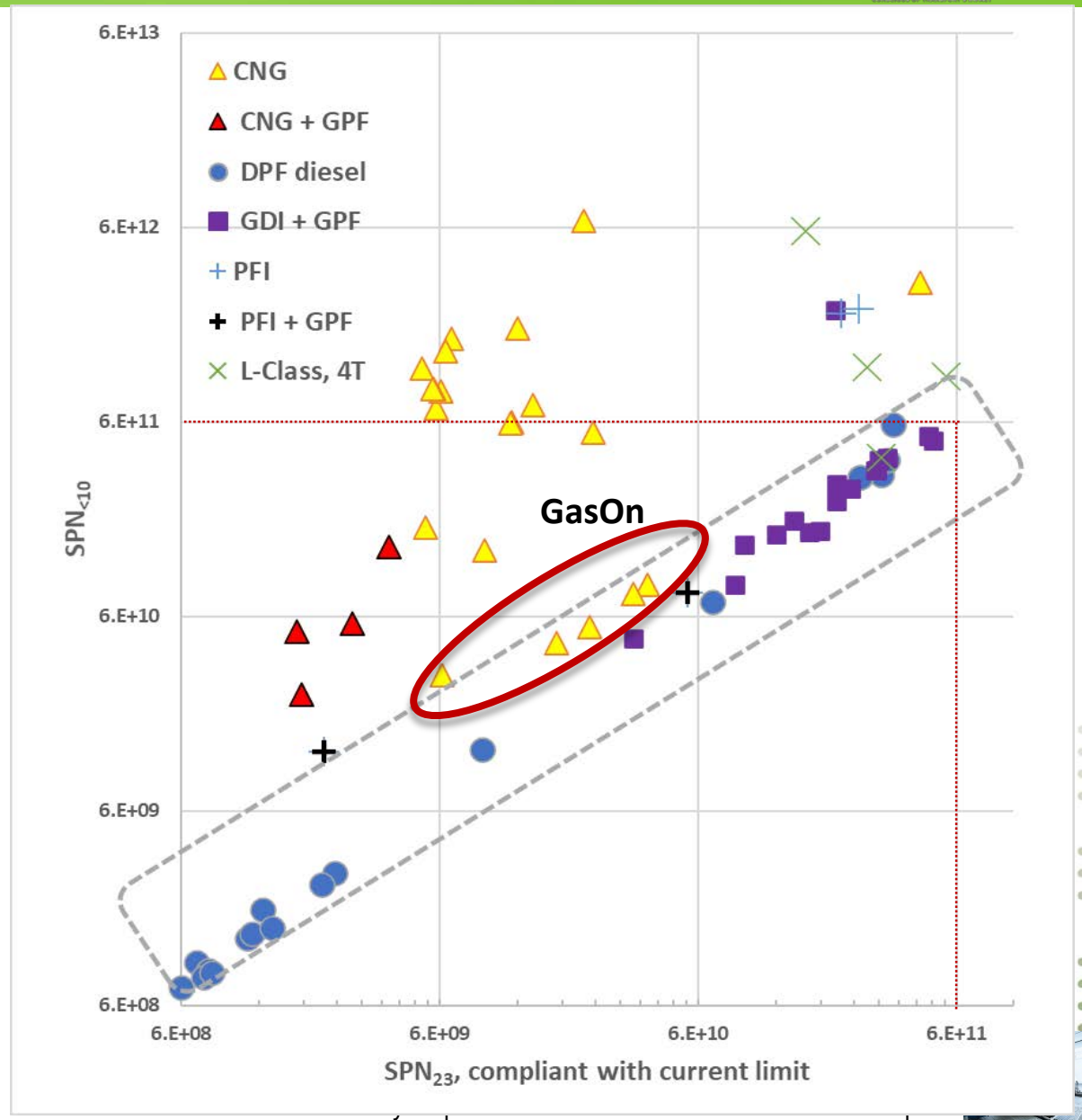
SPN_{23} vs $SPN_{<10}$ Emissions – Input from H2020 DownToTen

→ $SPN_{<10}$ and SPN_{23} appear to correlate for some technologies:

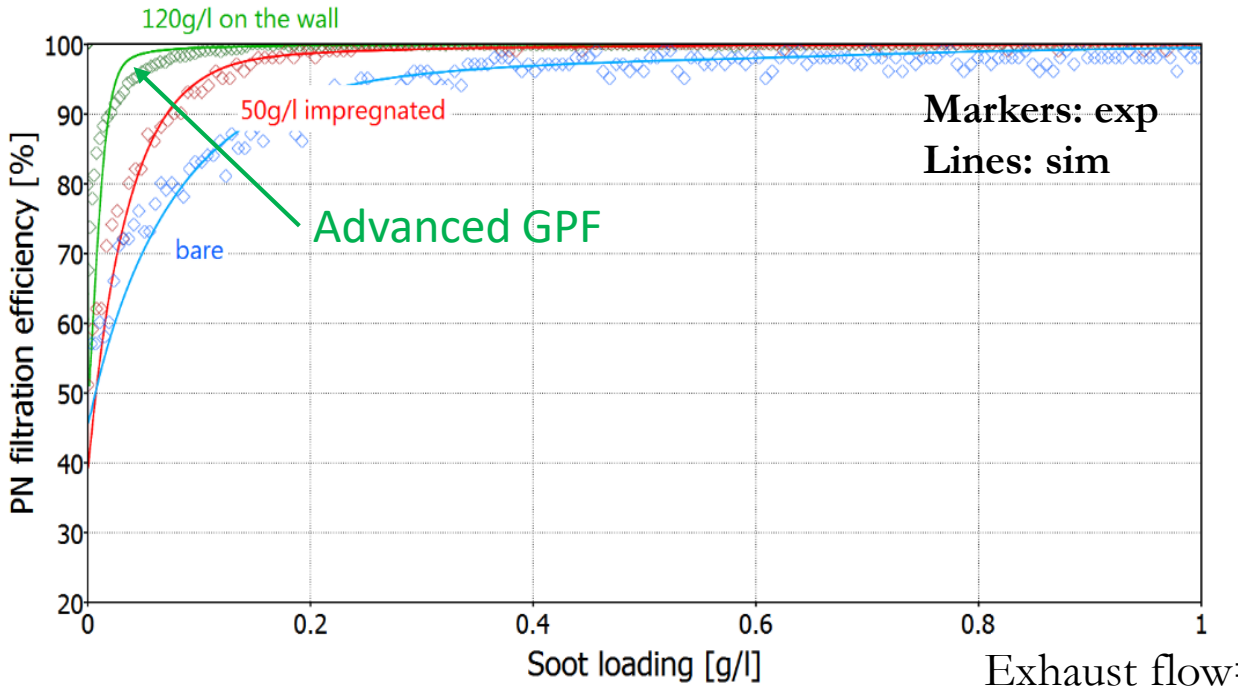
- Diesel and GDI with DPF
- One prototype CNG w/o GPF (**H2020 GasOn, red circle**) → This technology appears to present a route to achieving low <10nm PN emissions without a filter.
- One PFI retrofitted with GPF

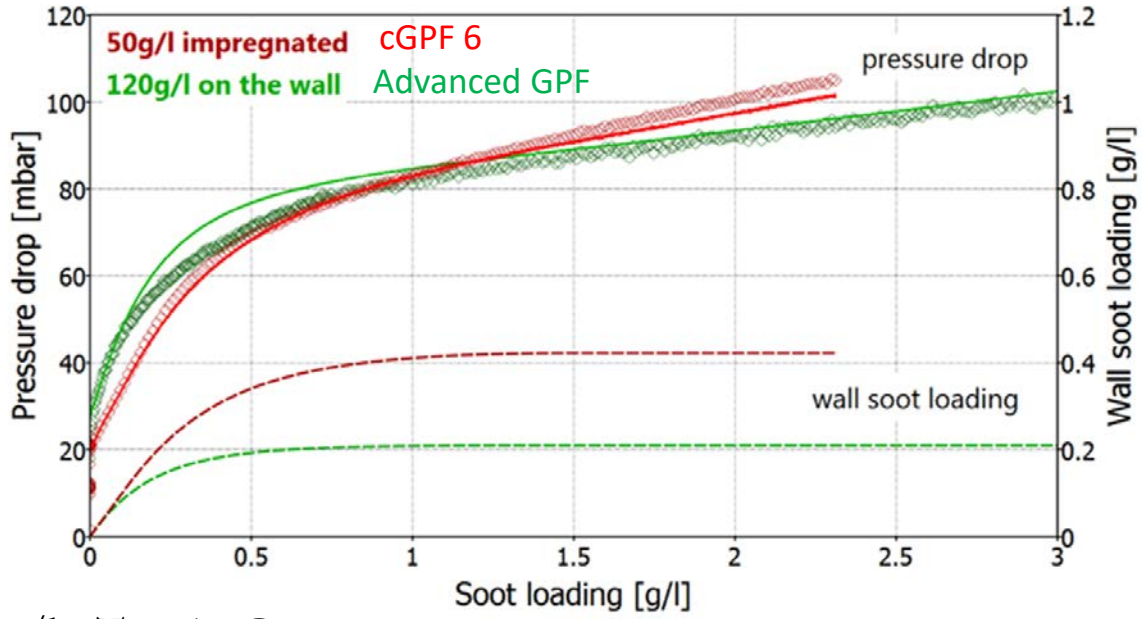
→ This correlation defines desirable behaviour of technologies. Some do not comply:

- In particular, other CNG with TWC
- Production CNG with retrofit particle filter
- PFI (including with retrofit GPF)
- L-class 4-stroke applications



GPF filtration efficiency and pressure drop – Input from H2020 Upgrade project





Exhaust flow=250kg/h, T=250°C

→ High filtration efficiency of advanced GPF even with low soot loading
→ Small effect on pressure drop and only in low soot loading
→ Such technology can bring low post-GPF emissions across a wide range of soot loading and test conditions.

Total (solid + volatile) PM/PN

- PM comprises particulate species of different volatility
- PN effectively controls emissions of non-volatile particles only
- Semi- and intermediate-volatile species are practically undetected by current FID
- There is the need to retain control of semi-volatile and intermediate-volatile species (high molecular mass species)
  - These can significantly increase during PF regenerations (and to bullet proof regulations over any future emission control, fuel or lube oil developments)
  - These significantly contribute to the formation of secondary organic aerosol in the atmosphere
- Proposal:
  - Retain PM measurement (possibly with the adoption of PTFE filter to avoid artifacts)
  - Decrease the limit to where current BAT lies (e.g. 1-2 mg/km including the impact of regeneration)
  - Request from PMP to investigate procedures that can lead to better measurement and more efficient control, e.g. total PN measurement

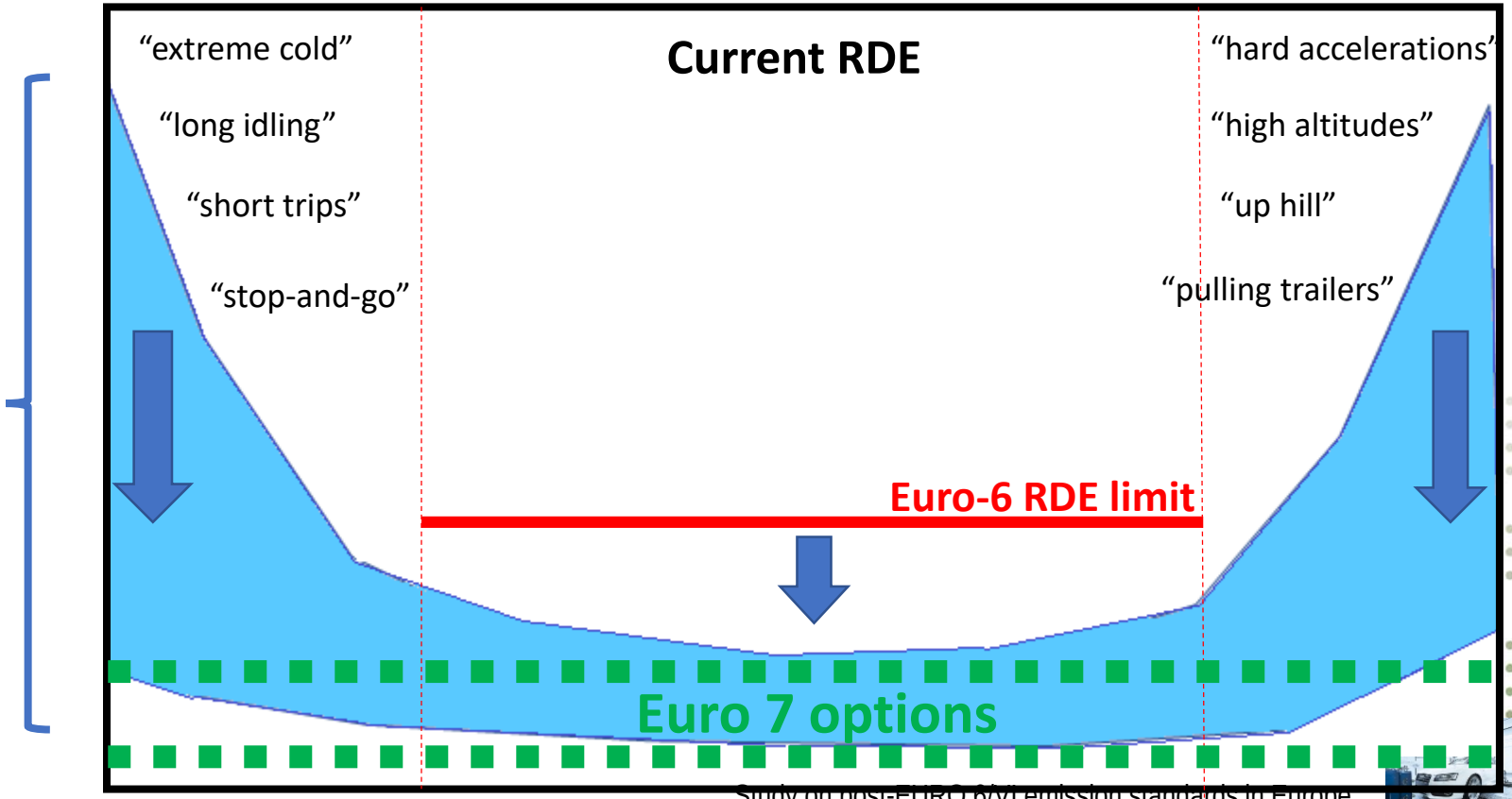
Agenda

- Objectives and approach
- Proposed Euro 7 test regime and pollutants
- Emissions database – background and preliminary findings on emissions
- Possible limits and technologies to meet them
- Evaporative losses
- Consultation

CLOVE proposal for emission limits setting

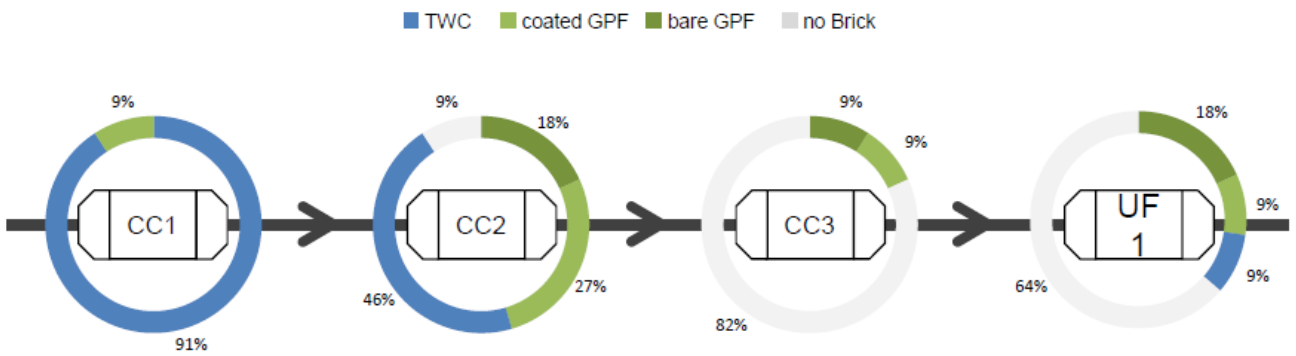
Objectives:

- Cover conditions not controlled in current RDE, although falling under "all driving conditions" → **wide on-road testing**
- Euro 7 limits lower than current limits, compatible with today's BAT
- Technology- and fuel-neutral limits

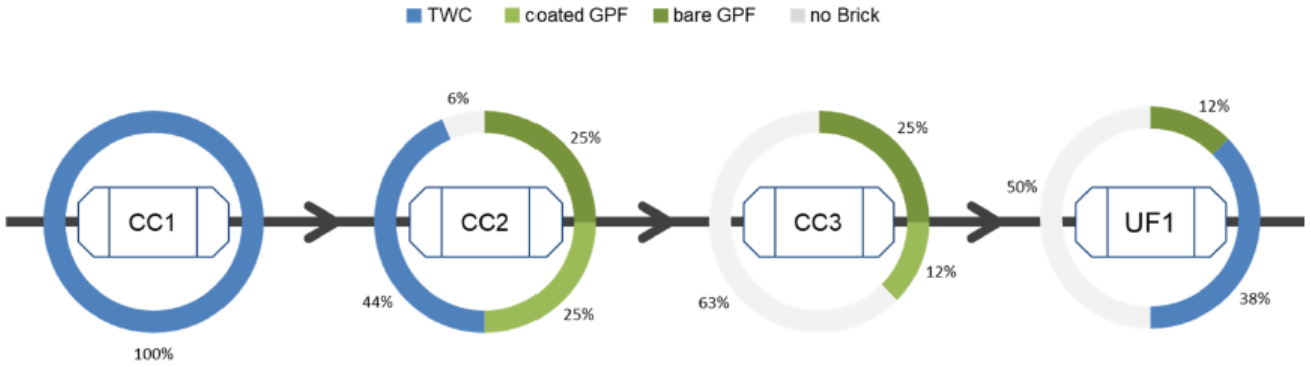


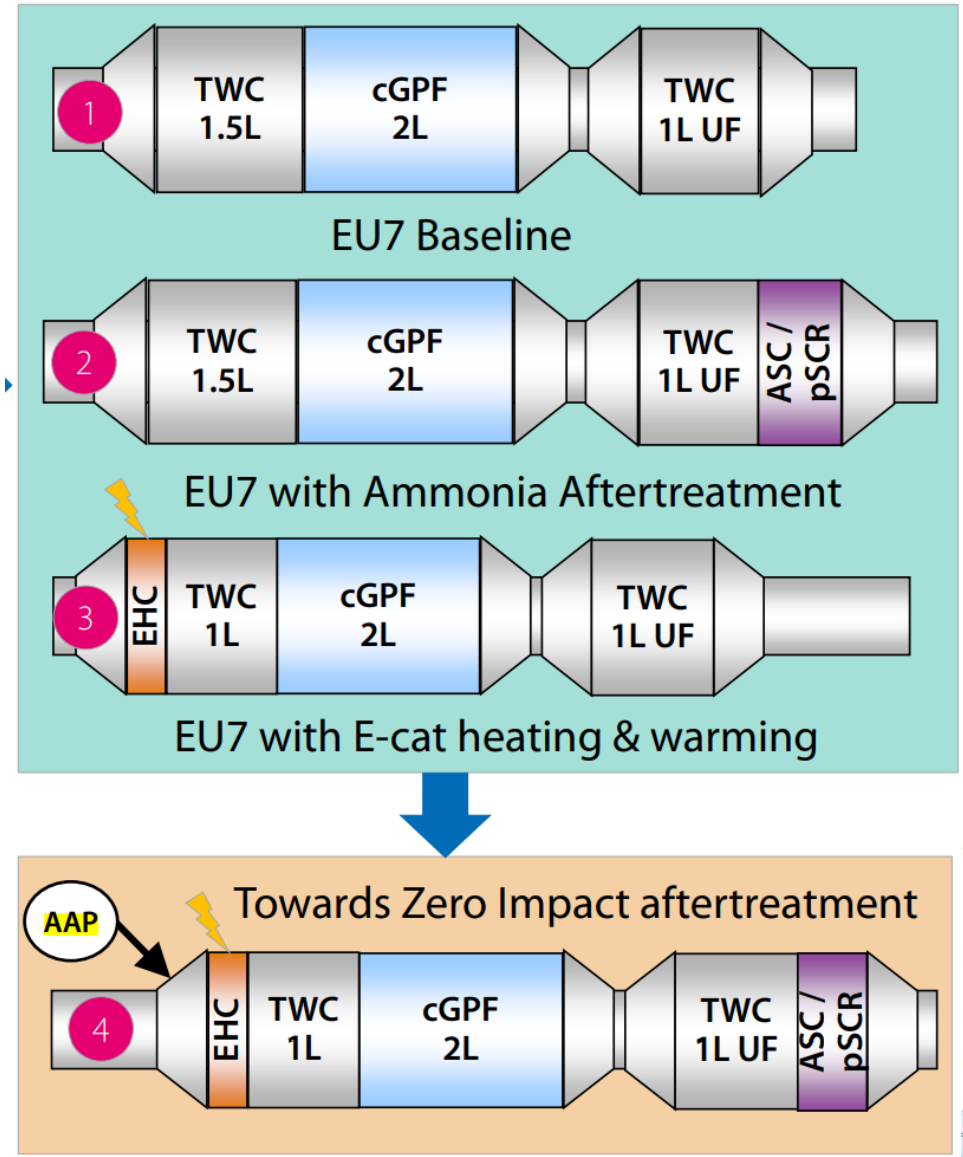
Gasoline: Published views on technologies for Euro 7

Euro 6d Applications



Euro 7 Applications

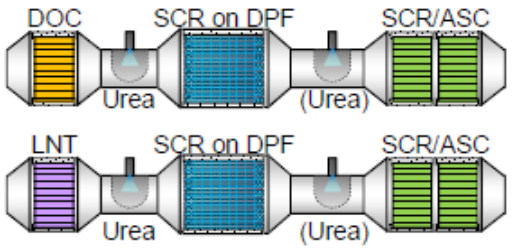




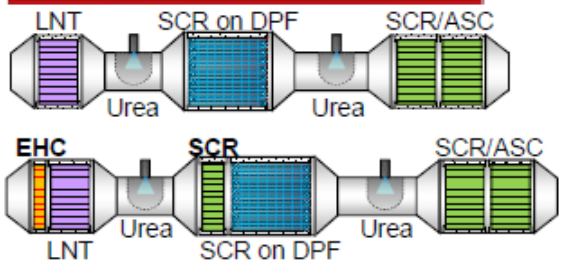
Diesel: Published views on technologies for Euro 7

Euro6d TEMP

Euro6d



Euro7

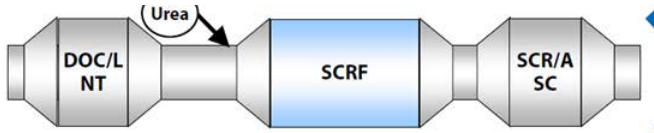


Focus Euro6d

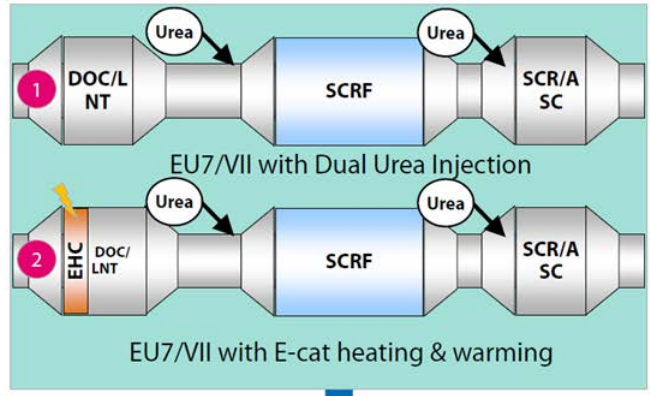
- Optimize cold-start behavior ⇒ close coupled DeNOx
- Optimize high T conversion ⇒ increase SCR volume, optimize SCR control

Focus Euro7

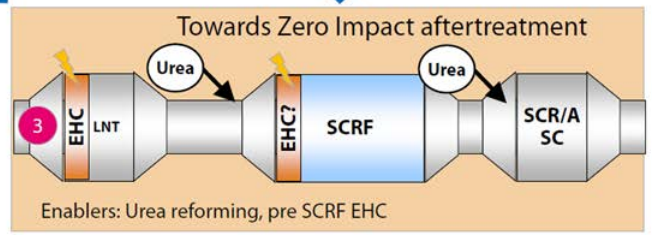
- Further optimization of thermal management ⇒ EHC? SCR-slice?
- "Use" hybridization (48V, HV?) to optimize emission control: faster heat up, stabilization of rich engine operation, etc…



EHC: Electrically Heated Catalyst
ASC: Ammonia Slip Catalyst



System	Cost	Package	Unregs	Control	Durability
1	→	→	→	→	↑
2	↓	↓	→	→	→
3	↓	↓	→	→	→



Potential technologies for compliance with Euro 7 scenarios

- Pre-heated catalyst (electrical, fuel burner) – possibly coupled with adsorption catalyst or phase change materials
- Optimised sizing and positioning of the ATS – possible size increase to address the necessary space velocities
- High GPF/DPF filtration efficiency from clean state
- High DPF filtration efficiency during and immediately after regeneration, in conjunction with regeneration frequency control
- Ammonia clean up catalyst functionality for PI engines
- (PI) Accurate combustion control (full map lambda = 1 etc.)
- Optimised system calibration
- HEV/PHEV control strategy optimization to take advantage of the synergies with electrifications

Euro 7 emission limits scenarios – LDV in mg/km, #/km

Euro 7 scenarios	NOx	SPN_{10}	CO	CH_4 (1)	N_2O (1)	NH_3
EURO 6	60/80 (PI/CI)	6×10^{11} (SPN_{23})	1000/500 (PI/CI)	-	-	-
A	**30**	**1×10^{11}**	**300**	**10**	**10**	**5**
B	**10**	**6×10^{10}**	**100**	**5**	**5**	**2**

- **One comprehensive limit with no conformity or other correction factor**
- **Limits fuel and technology agnostic**
- **The same limits also applicable to PCs and LCVs**
- **All limits applicable during particle filter regeneration**
- Possible emission limits still being discussed for:
  - NO_2
  - THC and NMOG/NMHC
  - HCHO

(1) Suggested to limit weighted sum of CH_4 and N_2O instead of separate limits

Lifetime Compliance LDV – proposed Euro 7 approach

Type	Name	Regulation	Current status	Euro 7 approach
5	Durability	UNECE R83 EU 2017/1151	Whole vehicle durability Component testing in lab Deterioration factors	Whole vehicle durability, 240k km and 15 years(1) (Tier 3, US approach)

- At the TA stage:
  - Testing at 'fresh' conditions
  - OEM declaration for 'aged' conditions
  - Checked by ISC/MaS up to end of useful life

(1) Final proposal and if there is need to cover longer periods will be determined by a running project on LD Lifetime emissions

Euro 7 limits scenarios for HDVs

- Same rational for the scenarios as for LDVs
- Similarly to LDVs, HD limit scenarios were established by:
  - Using EURO VI D test data from “best performing vehicles” as basis
  - Literature on test results for advanced HDE technologies
  - Simulation of advanced HDE technologies (NOx and CO_2)
- Limits are shown in g/kWh to be comparable with current values
- For HDVs the analysis suggests to stick to g/kWh unit (topic for follow up meeting since possible conversions to e.g. g/GVW-t-km can be done as post processing when g/kWh are agreed)

EURO 7 technology scenarios for HDVs

Scenario A: Best known technology

- Improved combustion to meet down to 1g NOx/kWh engine out if EAT is cold (for CNG engines optimised λ=1 control or technology like diesel for HPDI)
- Closed coupled DOC+SCR+ASC (3WC for λ=1 engines) for fast heat up and low N2O and NH_3 formation, possibly increased catalyst volumes and advanced materials
- Further optimised thermal management for faster heat up and preventing cool down (e.g. cylinder deactivation, hot EGR, throttle, late injection) aligned with HEV and WHR strategies
- Pre heating of EAT, possibly coupled with storage catalyst or to further reduce cold start extra emissions
- Improved DPF/GPF substrates for high filtration efficiency from clean state
- High DPF filtration efficiency during and immediately after regeneration, in conjunction with regeneration frequency and temperature control

Scenario B: Apply emission levels achieved in Scenario A for WHTC as limit in entire wide on-road range

Euro 7 emission limits scenarios – HDV in mg/kWh, #/kWh

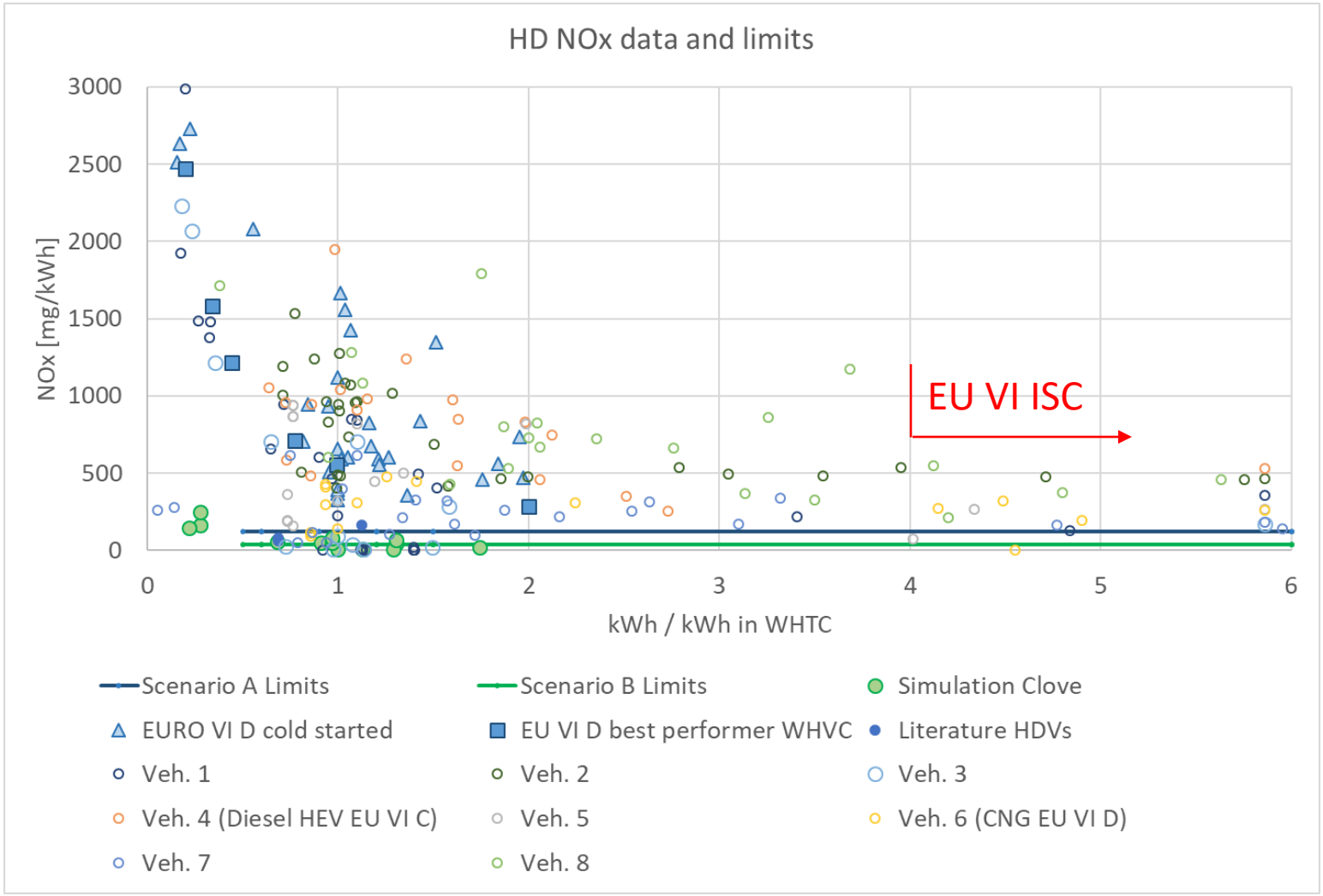
Euro 7 scenarios	NOx	SPN_{10}	CO	CH_4 (1)	N_2O (1)	NMHC	NH_3
EURO VI	460	6×10^{11} (SPN_{23})	4000	500 (PI)	-	160 (CI, THC)	10ppm ~40 mg/kWh]
A	**120**	**4×10^{11}**	**1500**	**100**	**50**	**50**	**20**
B	**40**	**1×10^{11}**	**400**	**50**	**25**	**25 (2)**	**10**

- **One comprehensive limit with no conformity or other correction factor**
- **Limits fuel and technology agnostic**
- **All limits applicable during particle filter regeneration**
- Possible emission limits still being discussed for:
  - NO_2
  - HCHO

(1) Suggested to limit weighted sum of CH_4 and N_2O instead of separate limits

(2) Impact of HC-burner for EAT heating on NMHC emissions and durability for CNG tbd

Illustration of HD proposed NOx emission limits

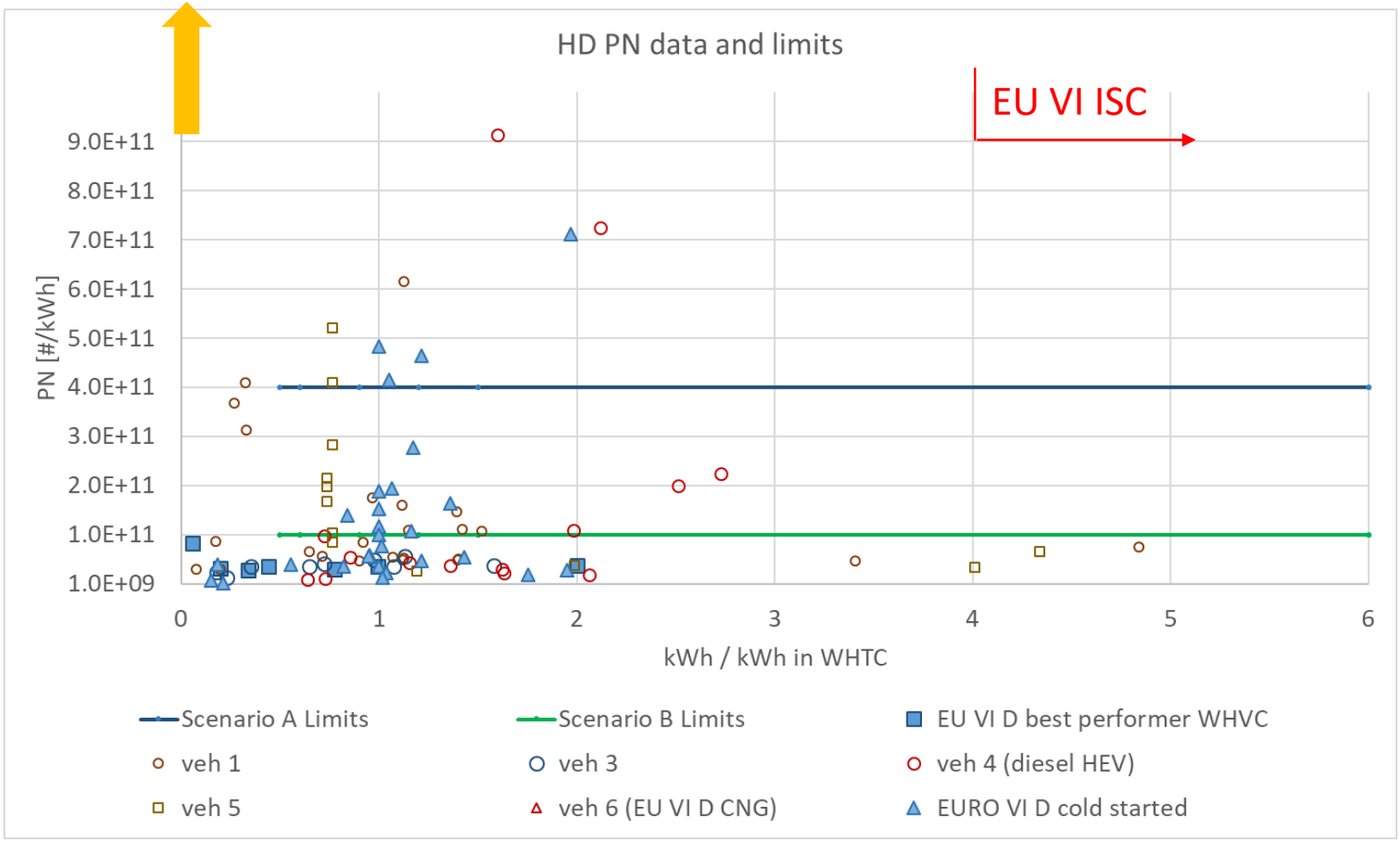


Notes:

- EURO VI:
  - valid ISC > 400% kWh_{WHTC}
    ISC limit = 1.5 x 460 mg/kWh
- Limit scenarios:
  - Scenario A considers “worst case” conditions (low loaded trip, 0.5xWHTC-work, -10°C at start)
- Measured data:
  - EURO VI D HDVs in various test scenarios
    (not only and not all in worst case!)

Illustration of HD proposed PN limits

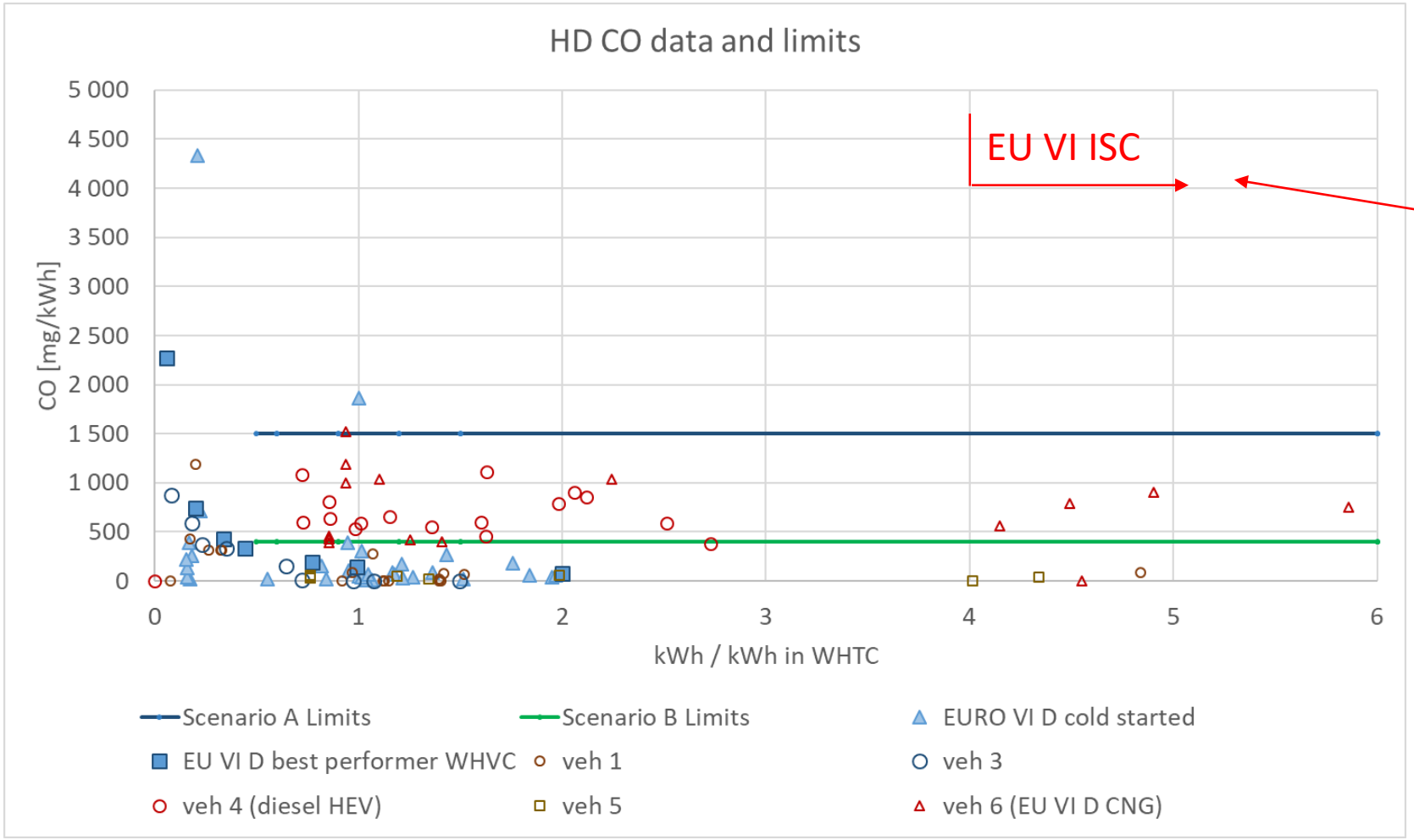
Max. CNG: 7.0E+12, Max with DPF regeneration: 5 E+13



Notes:

- EURO VI:
  - valid ISC > 400% kWh_{WHTC}
    ISC limit = 1.5 x 6.0 E11 #/kWh
    valid for PN_{23}!
- Limit scenarios for PN_{10}:
  - "worst case" conditions (high load uphill with DPF regeneration for diesel and empty GPF for CNG)
  - Scenario B: level ca. as without regeneration
- Measured data:
  - EURO VI D HDVs in various test scenarios, all PN_{23}!
    (worst cases outside of scale of graph!)

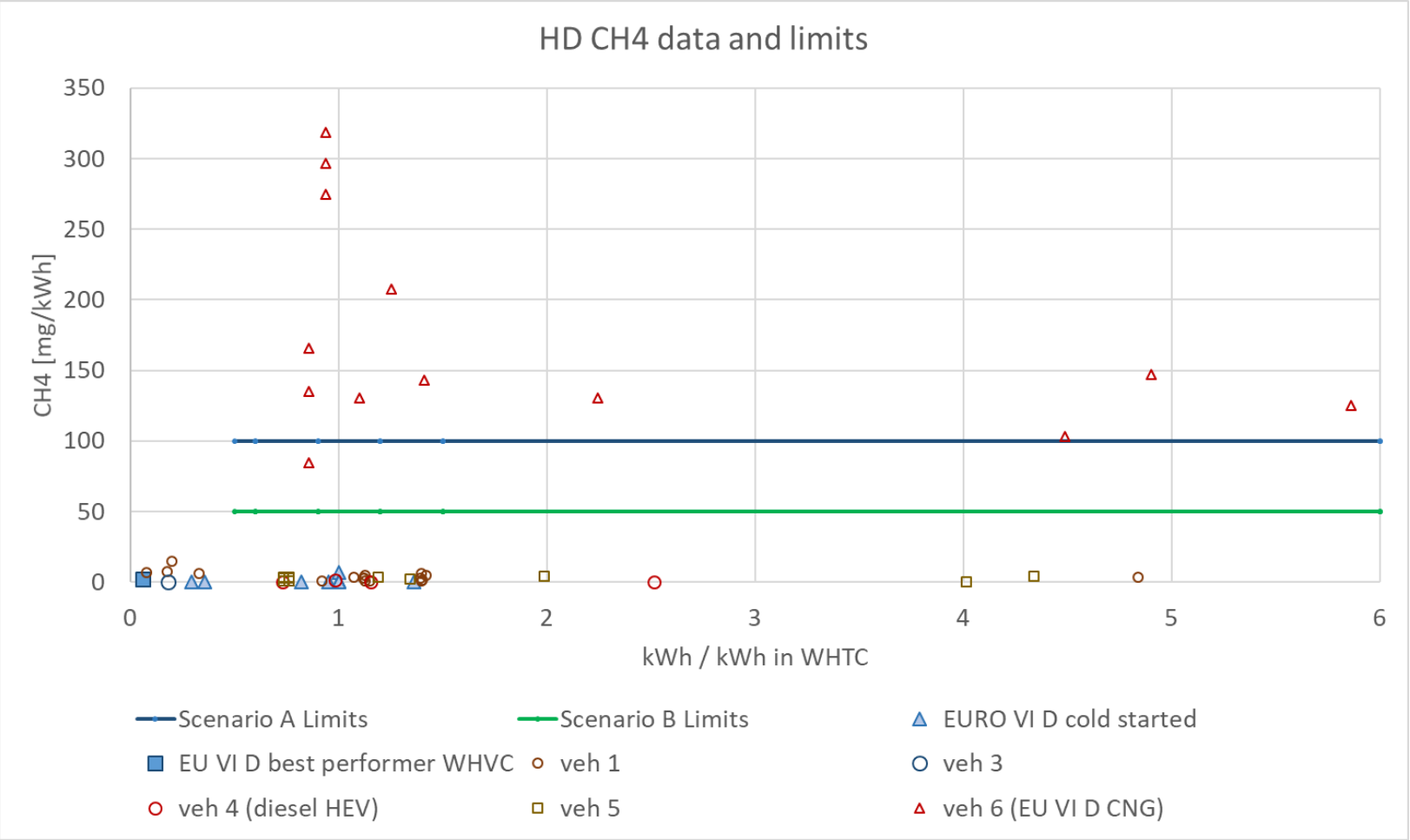
Illustration of HD proposed CO limits



Notes:

- EURO VI:
  - valid ISC > 400% kWh_{WHTC}
    $_{L}$imit = 4000 mg/kWh
- Limit scenarios:
  - Limit considers alignment with LDV limit for 3.5t TPMLM vehicles
- Measured data:
  - EURO VI D HDVs in various test scenarios
    (not only and not all in worst case!)

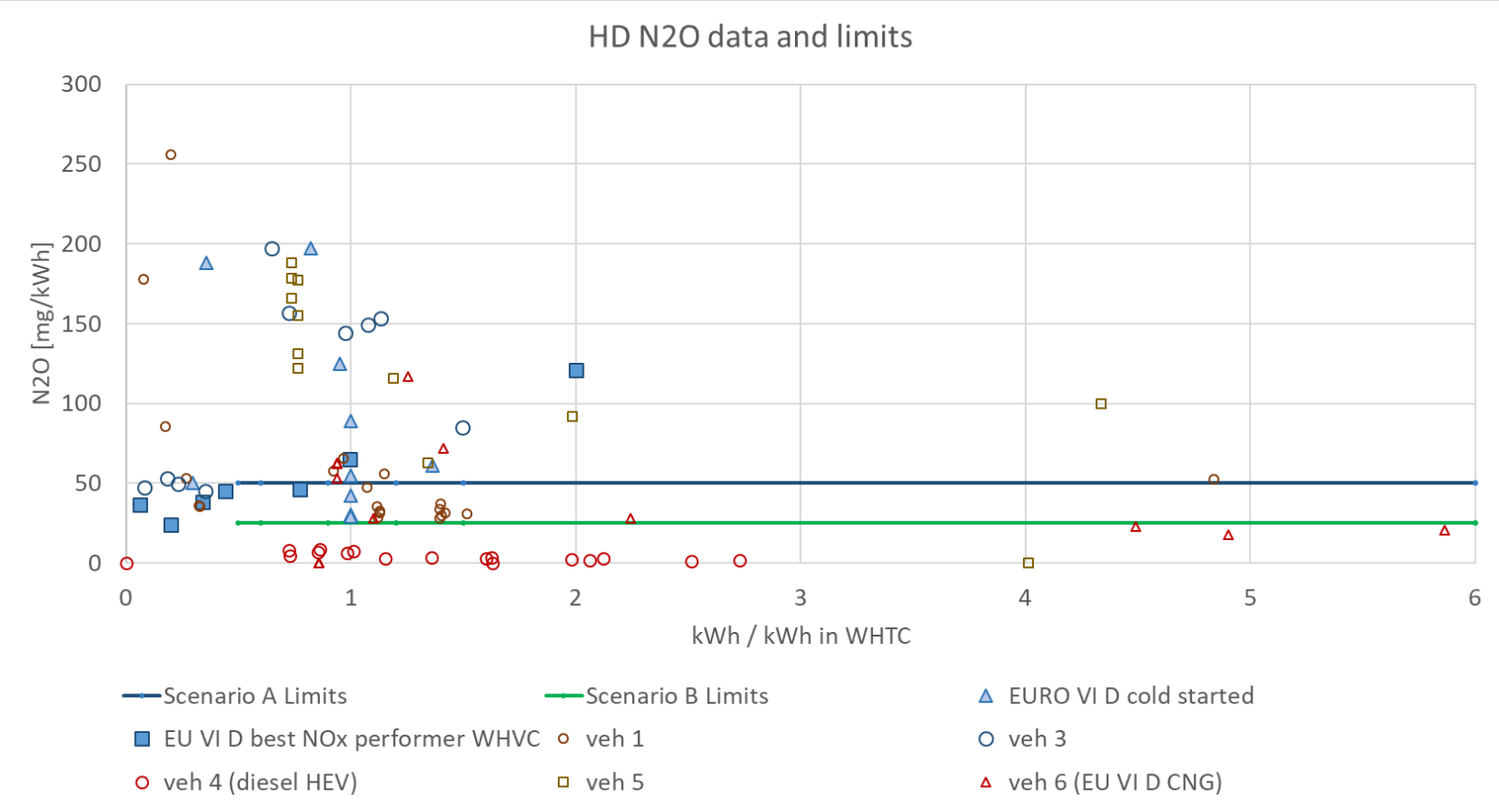
Illustration of HD proposed CH4 limits



Notes:

- EURO VI :
  - WHSC limit for CNG = 500mg/kWh
- Limit scenarios:
  - Limit should consider “worst case” conditions, which seem to be CNG-HPDI engine driven at low loads, short cold start test
  - Limits aligned with LDV 3.5t
- Measured data:
  - EURO VI D HDVs in various test scenarios
    (not only and not all in worst case!)

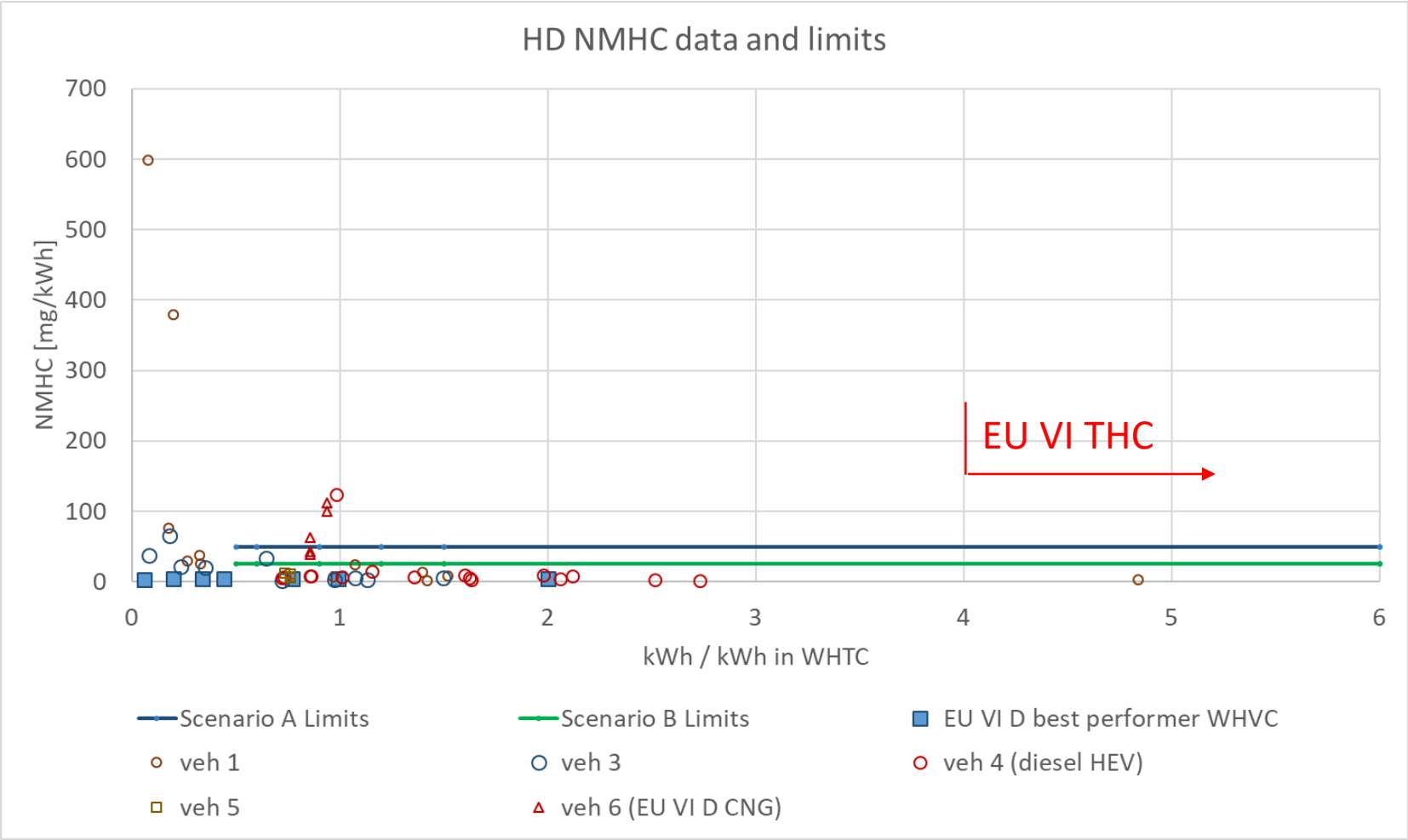
Illustration of HD proposed N2O limits



Notes:

- No limits in EURO VI
- Limit scenarios:
  - Limit should consider “worst case” conditions, which is high NOx-conversion in EAT
  - Limits aligned with LDV 3.5t
- Measured data:
  - EURO VI D HDVs in various test scenarios
    (not only and not all in worst case!)

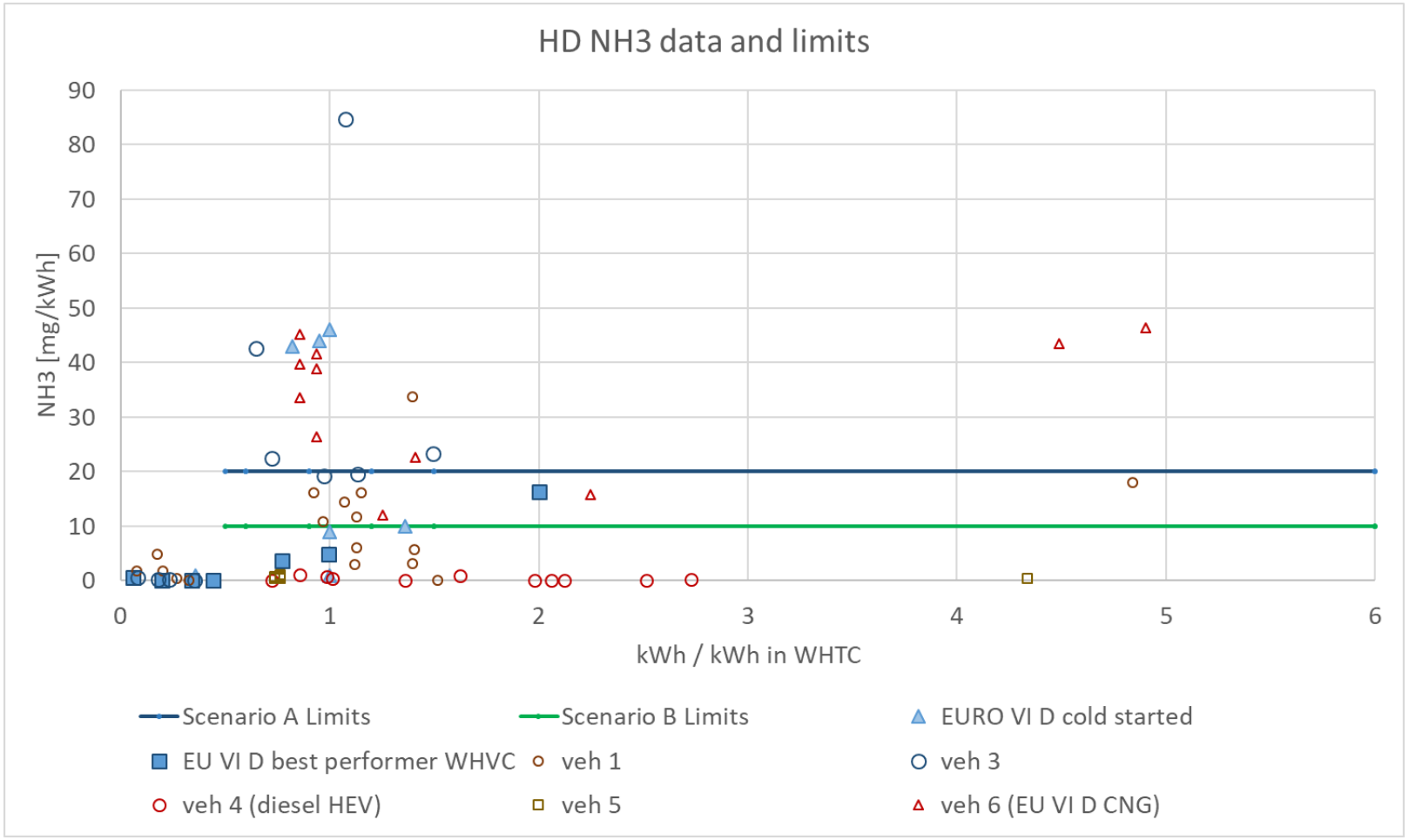
Illustration of HD proposed NMHC limits



Notes:

- No limits in EURO VI
- Limit scenarios:
  - Limit should consider “worst case” conditions, which seem to be HPDI in short test at cold start
- Measured data:
  - EURO VI D HDVs in various test scenarios
    (not only and not all in worst case!)

Illustration of HD proposed NH3 limits



Notes:

- Limits in EURO VI =10ppm
- Limit scenarios:
  - Scenario A: worst case for “best CNG technology” in highly transient cold cycle
- Measured data:
  - EURO VI D HDVs in various test scenarios
    (not only and not all in worst case!)

Agenda

- Objectives and approach
- Proposed Euro 7 test regime and pollutants
- Emissions database – background and preliminary findings on emissions
- Possible limits and technologies to meet them
- Evaporative losses
- Consultation

Evap control technologies – Euro 6d-temp / 6d

Activated carbon canister size	1.0 – 1.5 L (50 – 75 L fuel tank)	Assumed canister GWC 45 – 55 g/L (granular carbon)
Fuel vapour generation	41 – 62 g/test (50 – 75 L fuel tank)	Total over two days (48 h) test
Purging strategy	12 – 16 L/km	Average purge rate
Diurnal emissions	< 2.0 g/test 1.0 – 1.5 g (canister) + 0.3 – 0.4 g (permeation)	Total over two days (48 h) test
	< 1.0 g/day *0.5 – 0.8 g (canister)* *+ 0.15 – 0.2 g (permeation)*	*Worst of two days*
Refuelling emissions (uncontrolled)	70 – 105 g/refuelling (50 – 75 L fuel tank)	–
Stage II control	20 – 30 g/refuelling (50 – 75 L fuel tank)	70% efficiency assumed (55 – 85%)

Evap control technologies – Post Euro 6

Activated carbon canister size	1.5 – 2.2 L (50 – 75 L fuel tank)	Assumed canister GWC 70 – 80 g/L (pelletized carbon)
Fuel vapour generation	41 – 62 g/test (50 – 75 L fuel tank)	Total over two days (48 h) test
Purging strategy	25 – 30 L/km	Average purge rate
Diurnal emissions	< 0.3 g/test 0.1 – 0.15 g (canister) + 0.1 – 0.15 g (permeation)	Worst of two days
Refuelling emissions (uncontrolled)	70 – 105 g/refuelling (50 – 75 L fuel tank)	–
ORVR	2.0 – 3.0 g/refuelling (50 – 75 L fuel tank)	97% efficiency assumed
OBD leak detection	0.5 mm (~0.02 inch) diameter	–

Euro 7 evap scenarios – diurnal emissions

	Options / suggestion	Technology
Diurnal emissions limit	0.5 g/day (48 h, worst of 2 days)	• Increased canister capacity • High flow purge valve
	0.30 g/day (48 h, worst of 2 days)	• Increased canister capacity • High flow purge valve • *(ultra low permeation fuel tanks)*
Preconditioning	• Reduce drive time • Soak and drive temperature between 25 and 38°C	• High flow purge valve
Running losses	• No limit during certification • Emissions checked during ISC and MaS	

Euro 7 evap scenarios – refuelling and leaks

	Options / suggestion	Technology
Refuelling emissions		
ORVR	0.05 g/L	• Increased canister capacity • High flow purge valve • Fuel system design (fill pipe, vent line, etc.)
OBD leak detection		
Leak threshold	0.5 mm (~0.02 inch) diameter	• Pump system (active leak detection) • Passive leak detection (less accurate)

Agenda

- Objectives and approach
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Reminder: Consultation remains open; we welcome your input particularly on costs of technologies

Questionnaire: https://www.surveymonkey.co.uk/r/PostEuro6ImpactAssessment

Example Aftertreatment systems

Technology package	Emission levels achievable (in mg/km)[1]												Vehicle category / Testing conditions	Cost as an increment from the baseline in €/vehicle [3]	Expected durability of the technology package (in km)
	NO_x (mg/km)	NO_2 (mg/km)	N_2O (mg/km)	NH_3 (mg/km)	THC (mg/km)	NMHC (mg/km)	CH_4 (mg/km)	NMOG (mg/km)	CH_2O (mg/km)	CO (mg/km)	PM (mg/km)	PN10 capable?[2]			
Baseline (Euro 6d): GDI+TWC+ GPF	*12 (4-35)*	*1*	*1.2*	*20*	*50*	*40*	*10*	*45*	*1.5*	*400*	*0.3*	*Yes, lower level possible*	*Car / WLTP 23°C*	*0*	*160 000 km*
	Enter text	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*			*Enter text*
Post Euro 6 example system: ***EHC+TWC+GPF***	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Click here to enter text*	*Enter text Prompt: What are the additional costs of EHC if fully integrated*	*Click here to enter text*
Post Euro 6 example system: ***TWC+GPF+TWC+ASC***	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Click here to enter text*	*Click here to enter text*	*Click here to enter text*
[please indicate other technologies]	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Enter text*	*Click here to enter text*	*Click here to enter text*	*Click here to enter text*
Click here to add a new row															

On behalf of the CLOVE consortium: **Thank you!**