

# Ultra-low NOx and PN with integrated emission control systems for light-duty gasoline and heavy-duty diesel vehicles

Dr. Pablo Mendoza Villafuerte

Powertrain Systems for Net-Zero Transport  
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# Association for Emissions Control by Catalyst (AECC AISBL)

AECC members : European Emissions Control companies



- Exhaust emissions control technologies for original equipment, retrofit and aftermarket for all new cars, commercial vehicles, motorcycles, and non-road mobile machinery
- AECC is # 78711786419-61 in EU Transparency Register and has consultative status with the UN Economic and Social Council (ECOSOC)

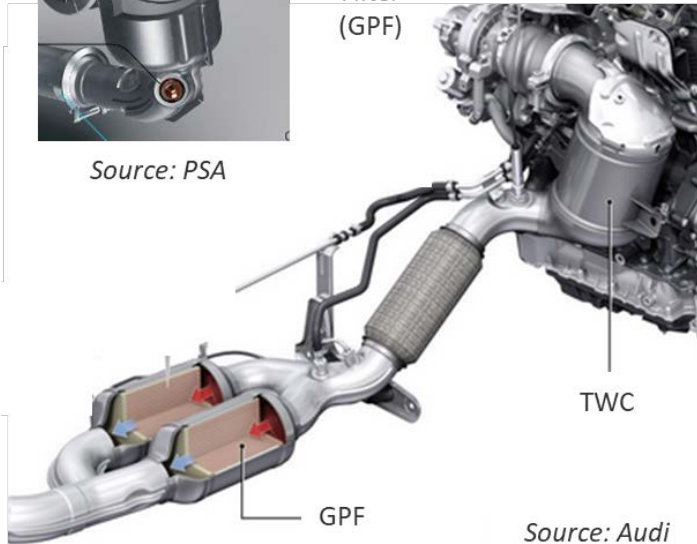
# Advanced emission control systems for light- and heavy-duty

- LD Gasoline – introduction of Gasoline Particulate Filter



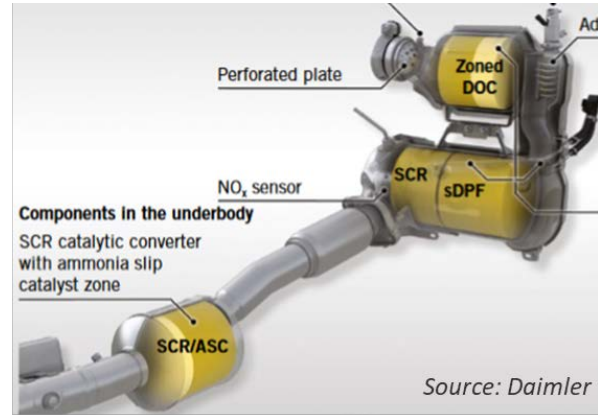
TWC  
Gasoline  
Particulate  
Filter  
(GPF)

Source: PSA

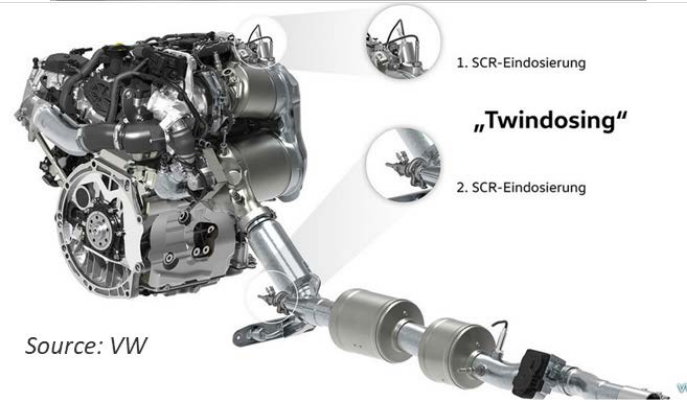


Source: Audi

- LD Diesel – combination of deNOx technologies

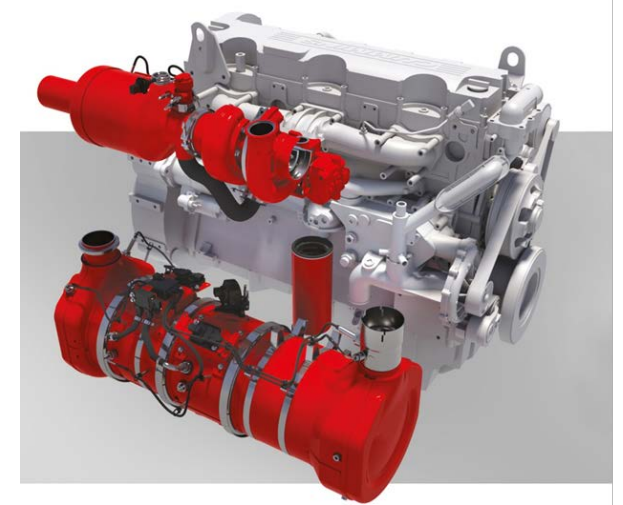


Source: Daimler



Source: VW

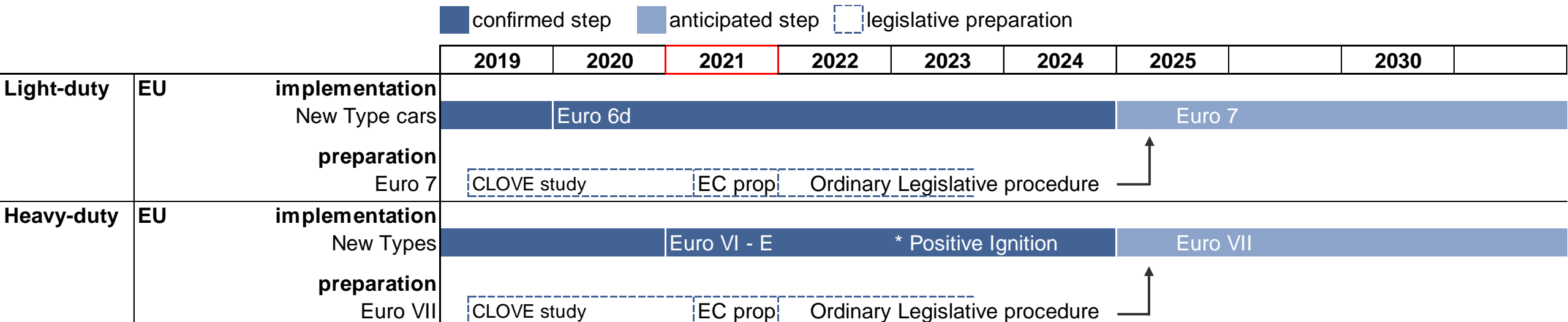
- HD Diesel – announcement of system with close-coupled components



Source: Cummins

# Emission legislation evolution expected towards Euro 7

- The AGVES expert working group met until end of April 2021
- CLOVE consortium
  - Presented scenarios for light- and heavy-duty vehicles
  - Provided further input for the European Commission impact assessment
- The actual European Commission proposal is expected in begin 2022 followed by the ordinary legislative procedure with European Parliament and Council



# LD gasoline demonstrator concept

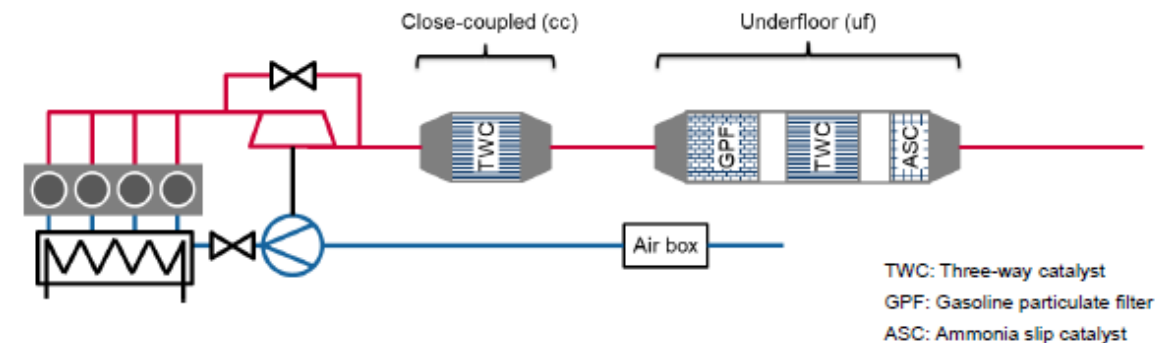
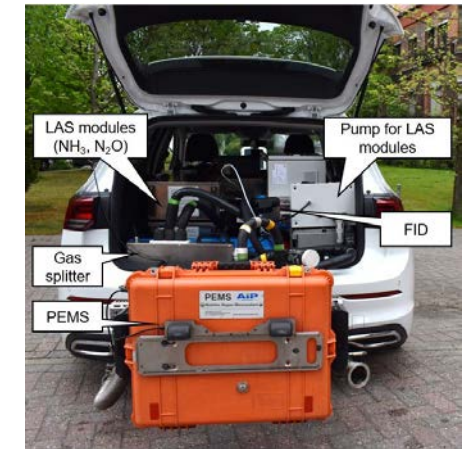
## ➤ Base vehicle

- C-segment vehicle
- 1.5l engine with 4 cylinders
- Variable valve train and cylinder deactivation
- 48V mild-hybrid (belt-driven, P0 configuration)
- Euro 6d type-approval baseline with GPF + TWC

## ➤ AECC emission control system

- Cc TWC, uf cGPF+TWC+ASC
- Bench aged components targeting 160k km

## ➤ Instrumented with prototype PEMS to measure $\text{CO}_2$ , $\text{NO}_x$ , $\text{CO}$ , $\text{THC}$ , $\text{PN}_{10}$ , $\text{NH}_3$ and $\text{N}_2\text{O}$



# LD gasoline demonstrator data

## ➤ Tests conducted to characterise the emission performance

### ➤ Road

- RDE ~90 km
- Calibration test (CaliTest) ~20 km

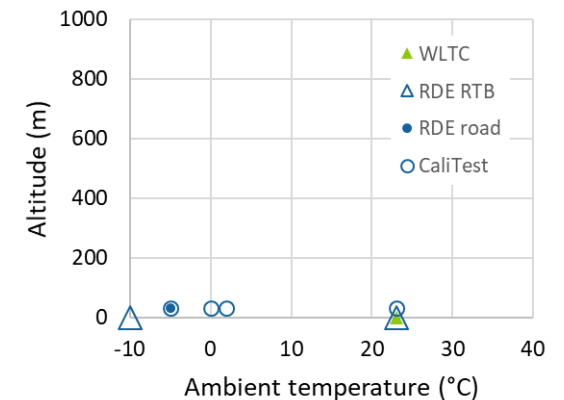
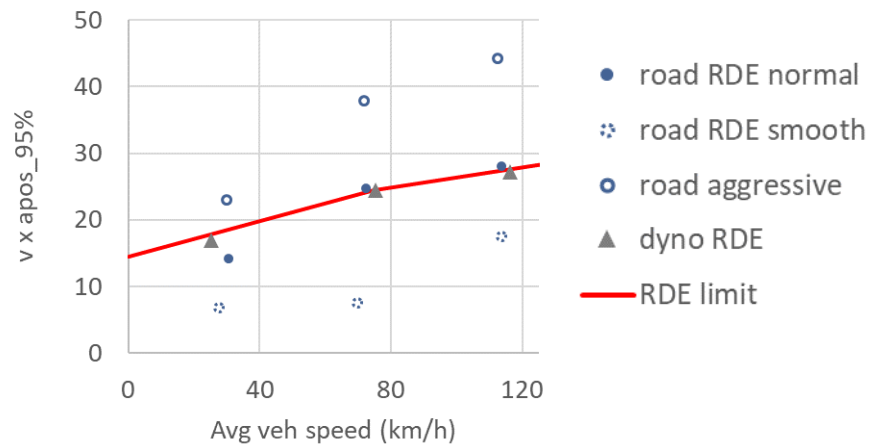
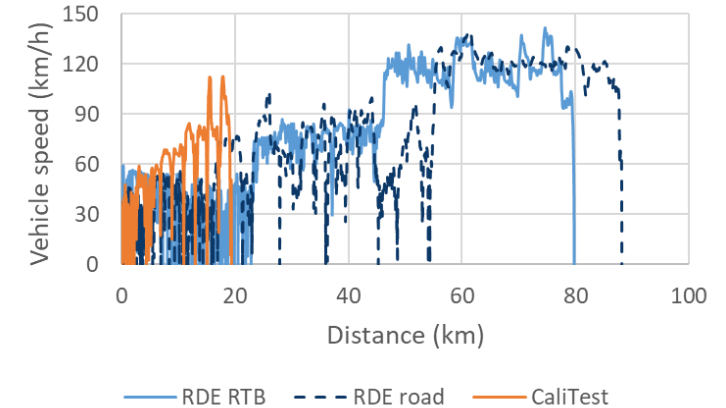
### ➤ Chassis dyno

- WLTC
- RDE aggressive

## ➤ Exploring beyond Euro 6 RDE boundary conditions for

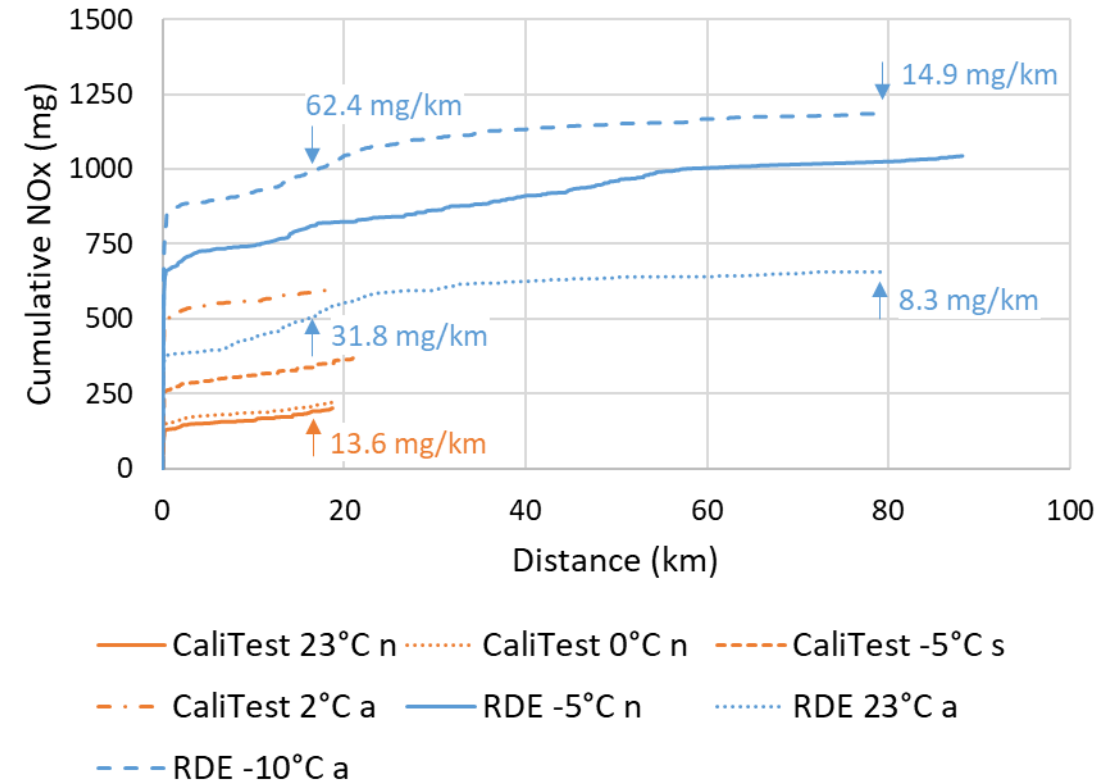
### ➤ Ambient temperature

### ➤ Driving style



# NO<sub>x</sub> emissions

- Near-zero emissions under warm operation independent from test conditions
- Initial cold-start emissions impacted by
  - ambient temperature
  - driving dynamics



<sup>1</sup> The results are reported as measured by the PEMS under the specified test routes and conditions

<sup>2</sup> Urban values are evaluated at a trip length of 16 km



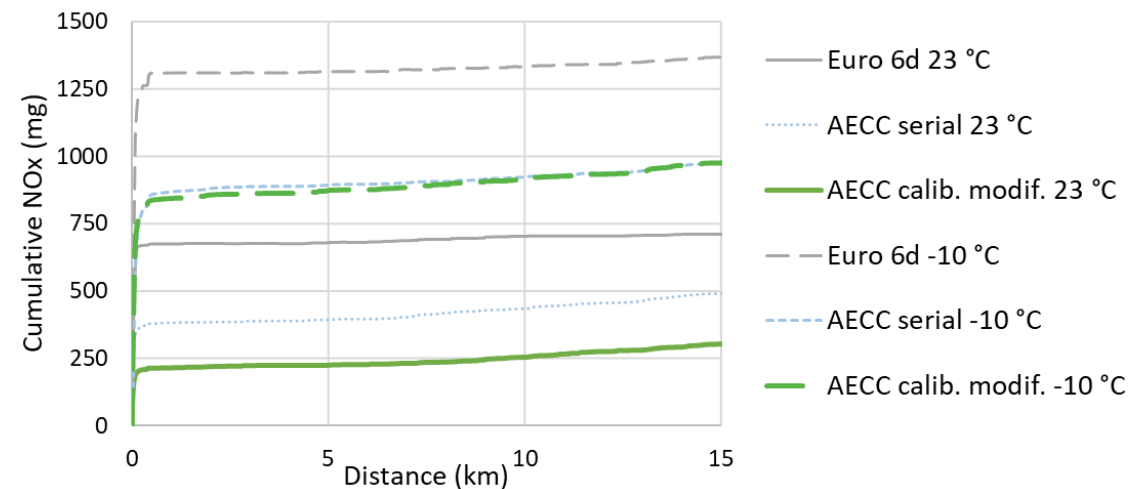
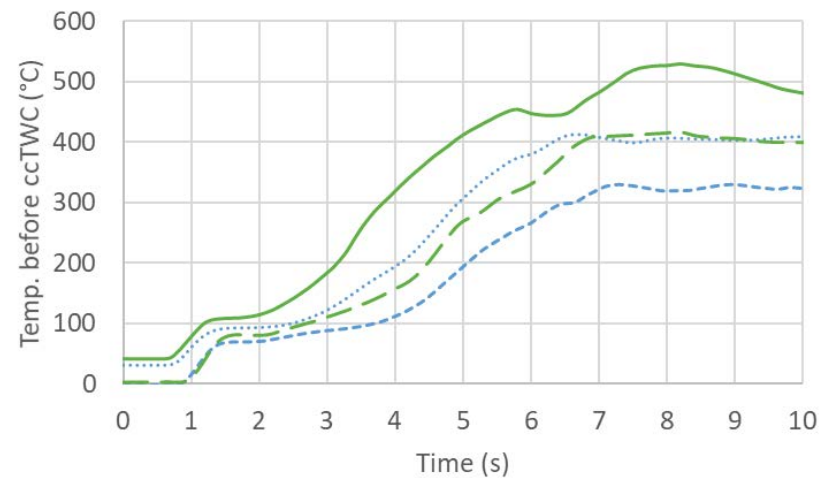
# NO<sub>x</sub> emissions – Calibration modification

## ➤ Applied changes

- Early closed-loop lambda control
- Retarded spark timing

## ➤ Observations

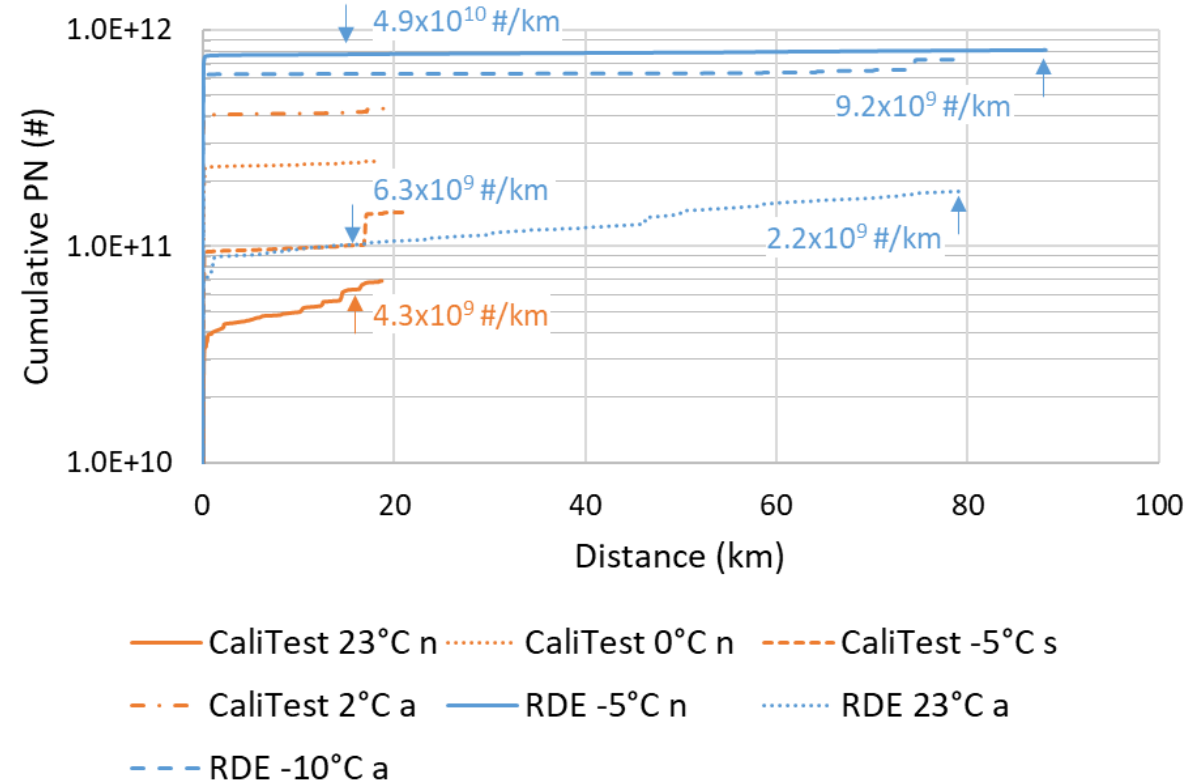
- TWC light-off achieved ~1 second earlier
- Reduction in initial cold-start peak at 23 °C, but limited effect at -10 °C





# PN10 emissions

- Soot and ash accumulation during ageing of parts supports filtration efficiency
- Initial cold-start effect is observed
- Near-zero emissions during the rest of the tests



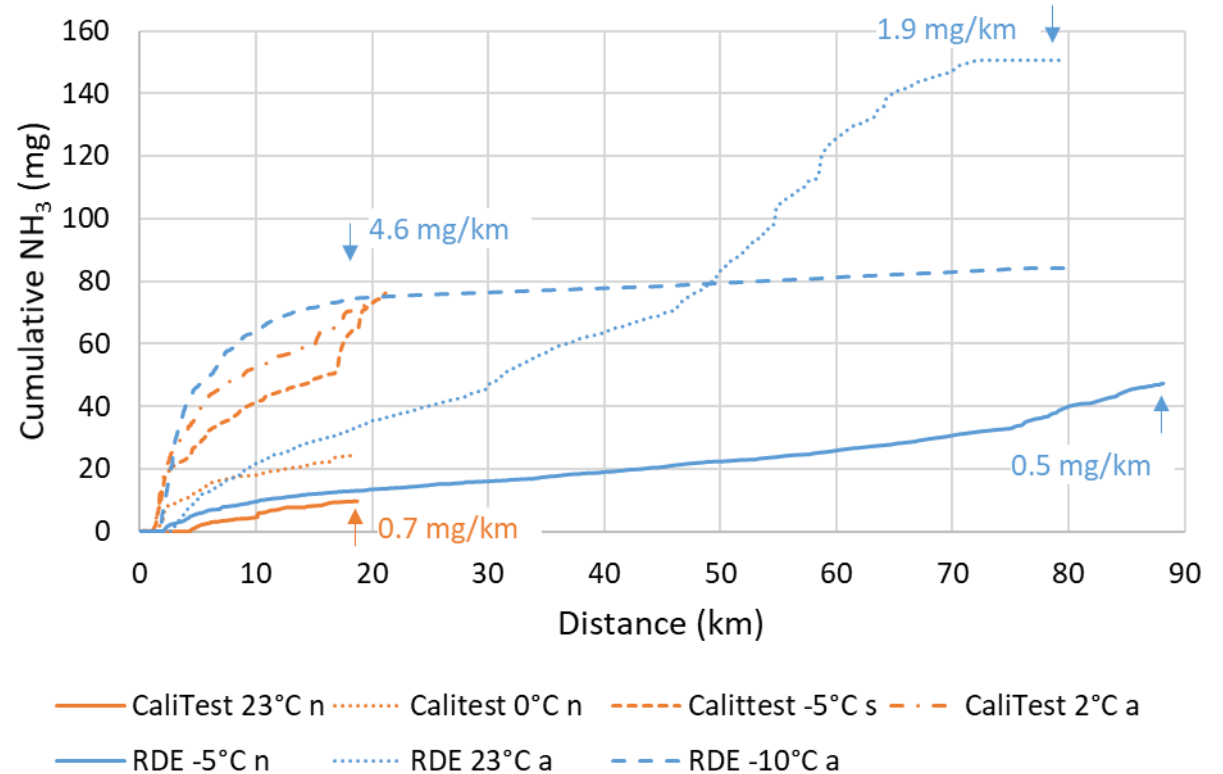
<sup>1</sup> The results are reported as measured by the PEMS under the specified test routes and conditions

<sup>2</sup> Urban values are evaluated at a trip length of 16 km

# NH<sub>3</sub> emissions

➤ ASC operation strategy for gasoline investigated in addition to improved lambda control

- Storage functionality captures emissions during first 1-3 km
- Emissions increase under aggressive driving style but remain significantly below 10-40 mg/km reported for Euro 6 vehicles<sup>3-4</sup>



<sup>1</sup> The results are reported as measured by the PEMS under the specified test routes and conditions

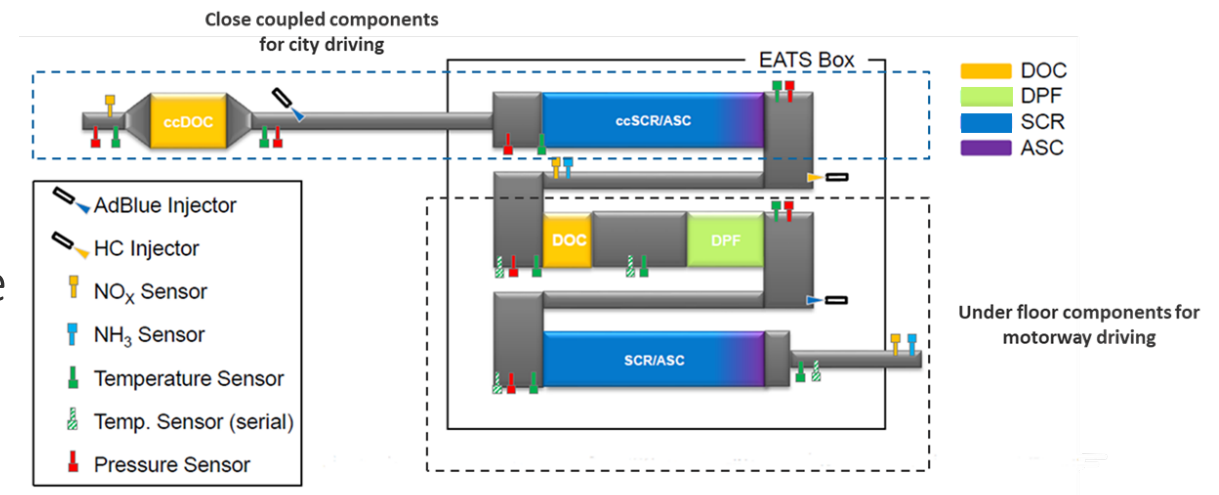
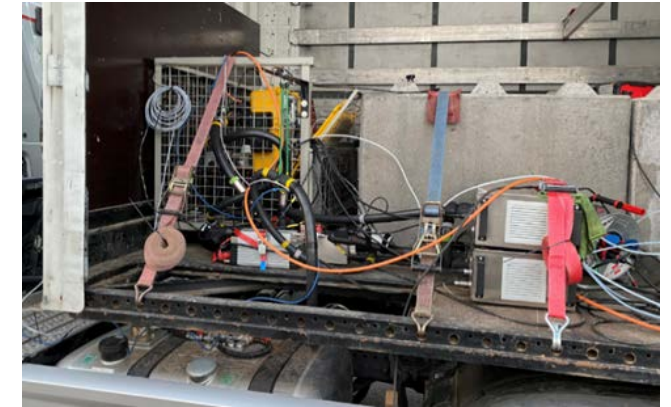
<sup>2</sup> Urban values are evaluated at a trip length of 16 km

<sup>3</sup> R. Suarez-Bertoa, et al.; Transp. Res. Part D Transp. Environ. 49 (2016) 259-270

<sup>4</sup> R. Suarez-Bertoa, et al.; Atmospheric Environment 166 (2017) 488-497

# HD demonstrator concept

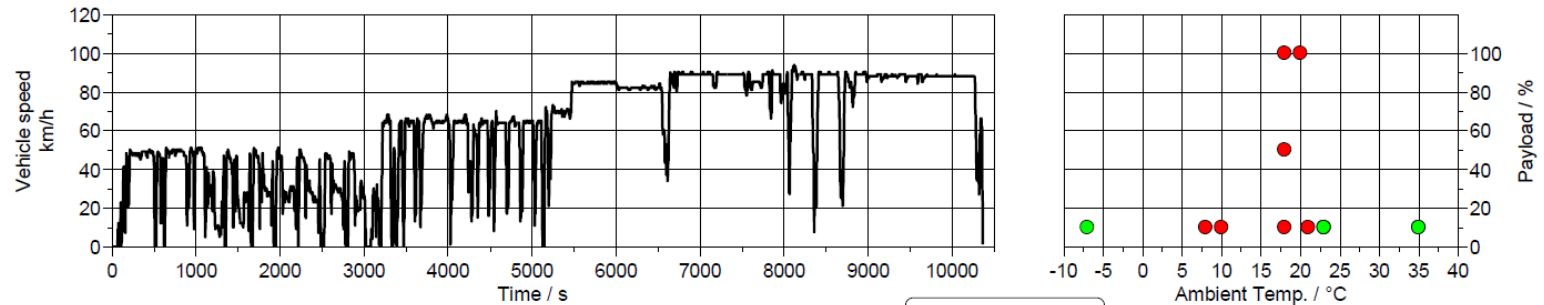
- Base vehicle description
  - MB Actros 1845 LS 4x2
  - Engine OM 471
    - Euro VI C certified
    - 12.8 litres, 6 cylinder in-line
    - High Pressure EGR
- AECC emissions control system
  - Components are hydrothermally aged targeting 500k km
- Instrumented with prototype PEMS to measure  $\text{CO}_2$ ,  $\text{NO}_x$ ,  $\text{CO}$ ,  $\text{PN}_{10}$ ,  $\text{NH}_3$  and  $\text{N}_2\text{O}$



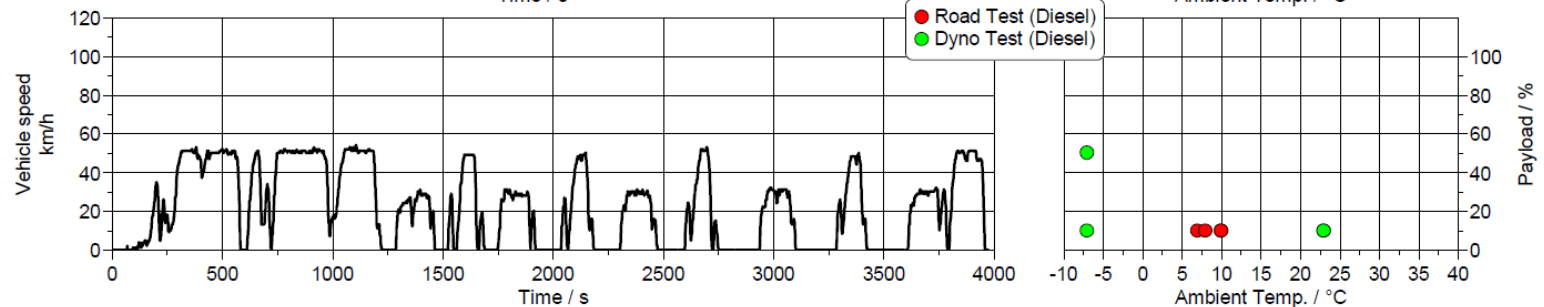
# HD diesel demonstrator testing

## ➤ Overview of testing conditions on the chassis dyno and on-road

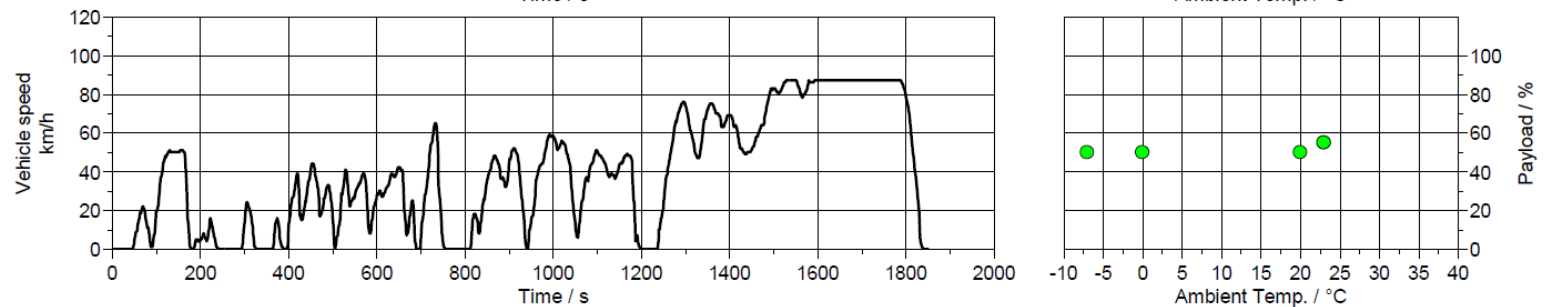
➤ On-road ISC  
Chassis dyno RWT



➤ Urban delivery



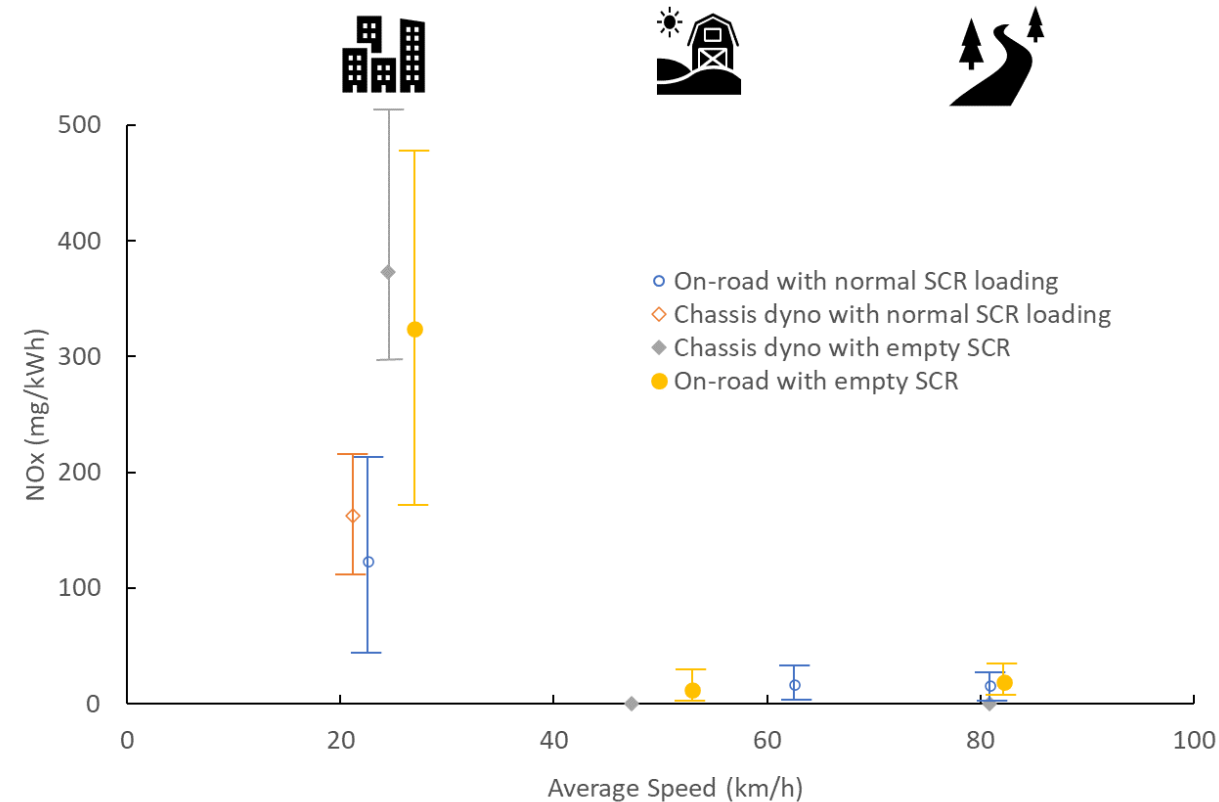
➤ WHVC<sup>1</sup>



<sup>1</sup> The WHVC emission test results are also available but not included in this presentation as results are in-line to what has been observed on the other trip profiles

# HD diesel demonstrator overall results

- On-road and chassis dyno test campaigns<sup>1,2</sup> confirm significant improvement for urban emissions including cold-start compared to Euro VI-D
- Near-zero emissions under warm operation
- Impact of ammonia storage depletion procedure shows robust control is needed for AdBlue<sup>®</sup> dosing, ammonia storage and thermal management

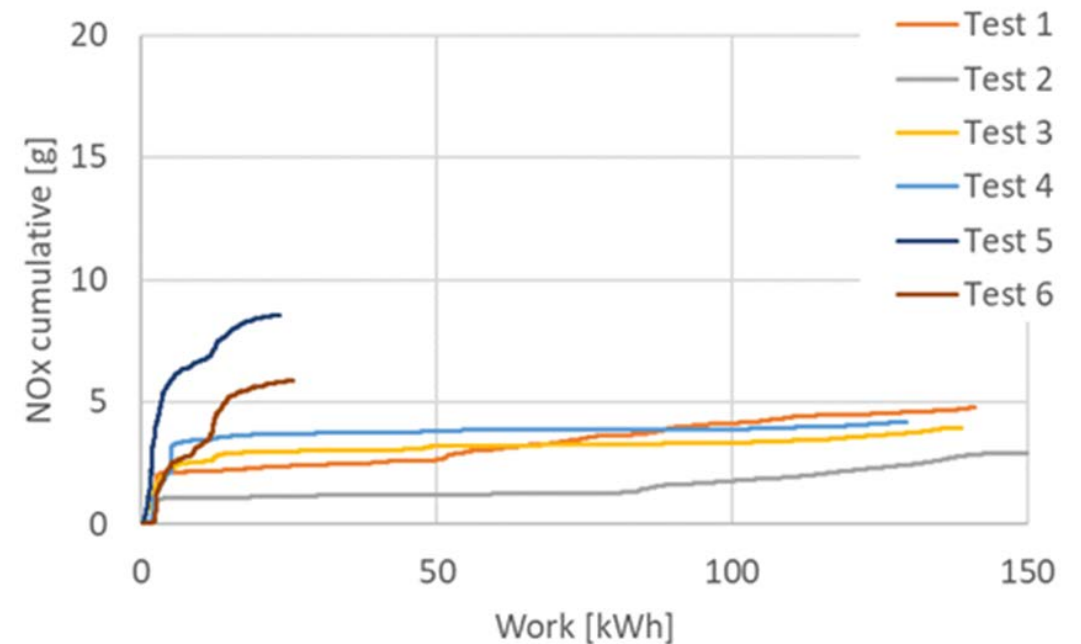


<sup>1</sup> P. Mendoza Villafuerte, et al.; "Demonstration of Extremely Low NOx Emissions with Partly Close-Coupled Emission Control on a Heavy-duty Truck Application", 42<sup>nd</sup> Vienna Motor Symposium 2021, [https://www.aecc.eu/wp-content/uploads/2021/05/210219\\_Vienna\\_HD-diesel-AECC-FEV-paper-final\\_v2.pdf](https://www.aecc.eu/wp-content/uploads/2021/05/210219_Vienna_HD-diesel-AECC-FEV-paper-final_v2.pdf)

<sup>2</sup> P. Mendoza Villafuerte, et al.; "Ultra-Low NOx Emissions with Close-Coupled Emission Control System on a Heavy-duty Truck Application", 30<sup>th</sup> Aachen Colloquium Sustainable Mobility 2021, [https://www.aecc.eu/wp-content/uploads/2021/10/32\\_C3.3\\_Mendoza-Villafuerte\\_AECC.pdf](https://www.aecc.eu/wp-content/uploads/2021/10/32_C3.3_Mendoza-Villafuerte_AECC.pdf)

# Cold-start NOx emissions remaining challenge

- NOx results<sup>1,2,3</sup> show that cold-start remains the main emission event
- The close-coupled catalysts result in a shortened heat-up time of the system
- Emissions are well controlled once the system is warm



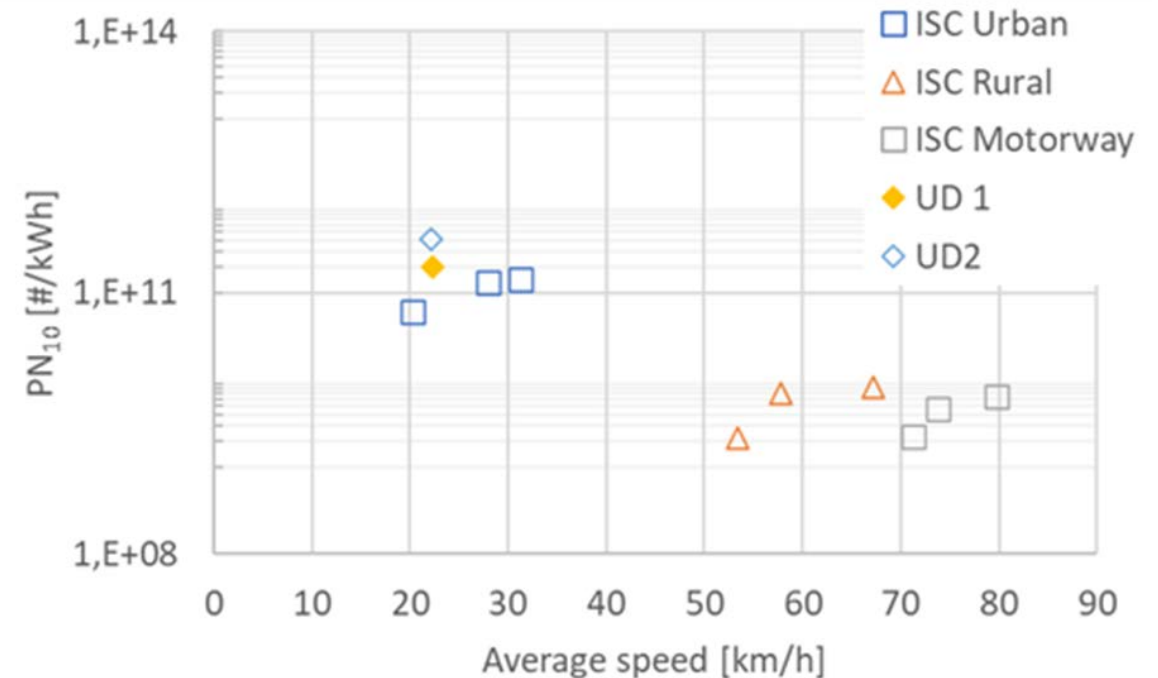
<sup>1</sup> Urban delivery (<50 km/h) with stops (varying from 1-3 min duration), total trip duration is ~1 hour and work completed is about 23-25 kWh

<sup>2</sup> ISC N3 Euro VI route

<sup>3</sup> The results are reported as measured under the specified test routes and conditions and cover a range of ambient temperatures from 4-10 °C

# PN10 emissions are impacted by temperature and payload

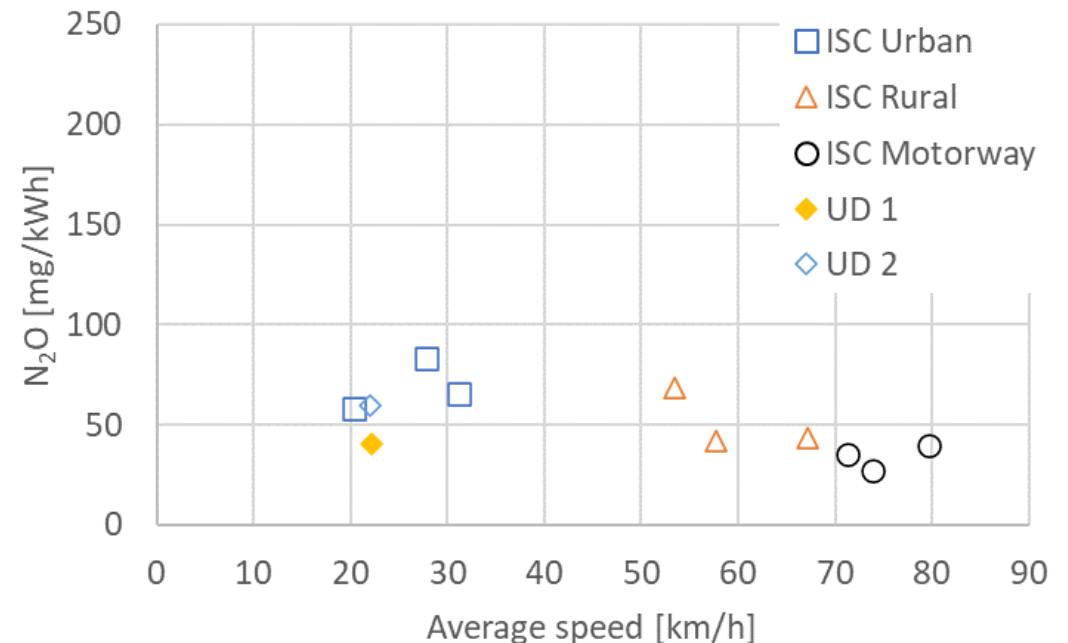
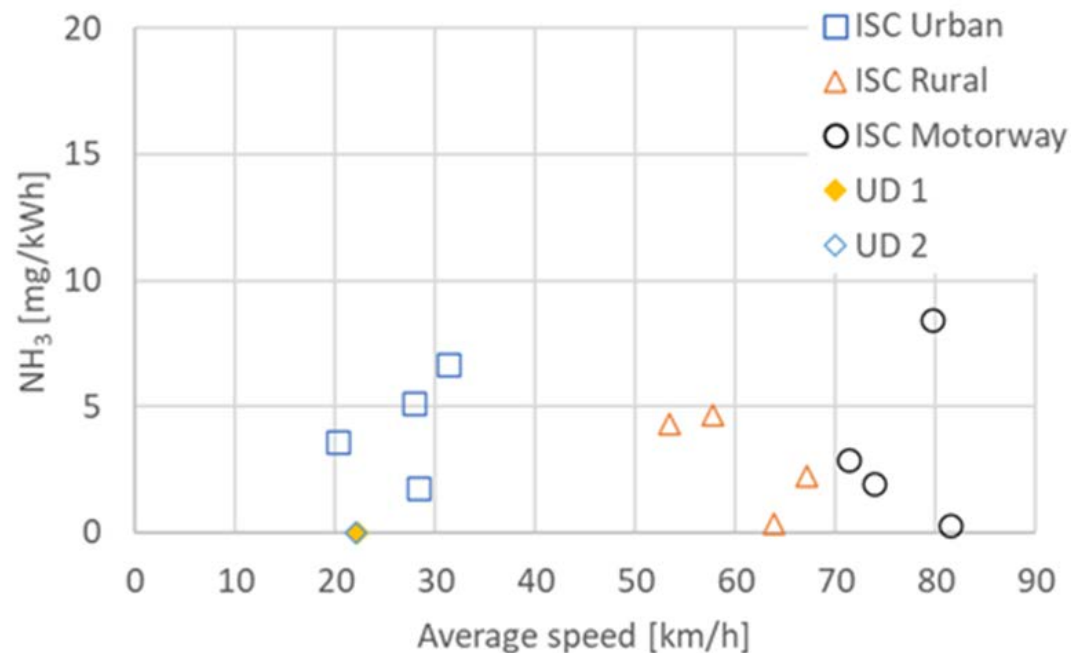
- Low PN10 achieved within broad range of driving conditions
- Most PN10 emissions are produced within the cold-start of the trip
- Tests are not covering all possible critical conditions for PN





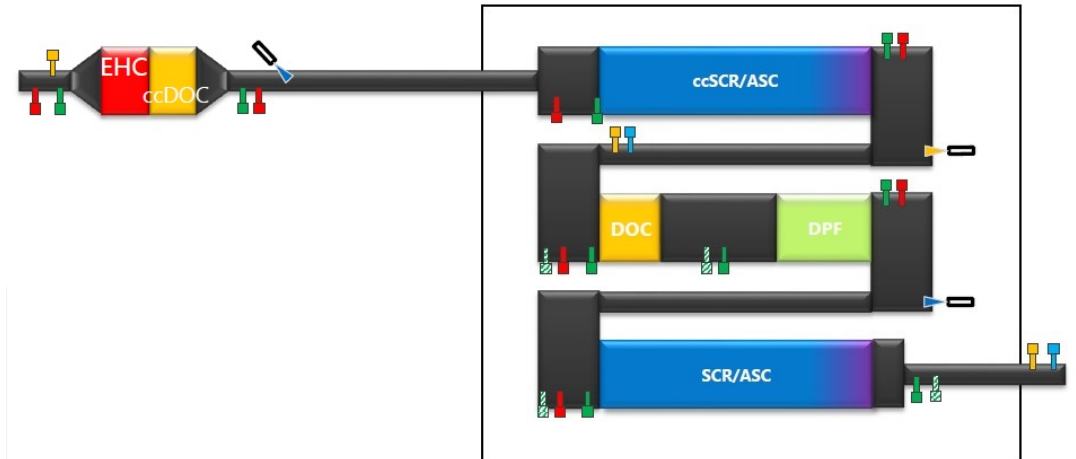
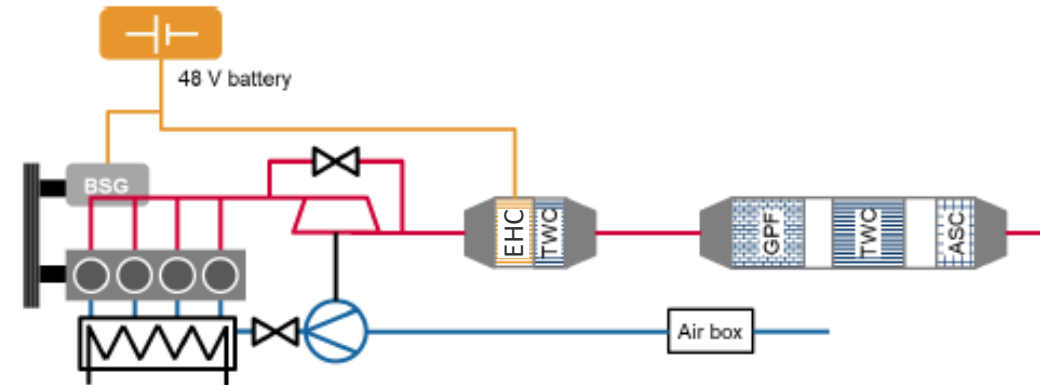
# Low $\text{N}_2\text{O}$ and $\text{NH}_3$ emissions in a broad range of operations

- Low  $\text{N}_2\text{O}$  during high  $\text{NO}_x$  conversion operation
- Near-zero  $\text{NH}_3$  emissions in a broad range of operating conditions



# Outlook

- Light-duty vehicle project scope extension
  - Implementation of EHC as part of cc TWC
  - Evaluation of fresh GPF
  - Testing on Blue Gasoline and e-gasoline to validate low pollutant emissions including WtW CO<sub>2</sub> emissions<sup>1</sup>
- Heavy-duty vehicle project scope extension
  - Implementation of EHC as part of cc DOC
  - Simulation of combined NO<sub>x</sub> and CO<sub>2</sub> reduction
  - Testing on HVO and e-diesel to validate low pollutant emissions including WtW CO<sub>2</sub> emissions



<sup>1</sup> Joint publication with Concauwe <https://www.aecc.eu/wp-content/uploads/2021/11/sustainability-13-12711.pdf>

# Summary

- Low pollutant emissions over wide range of driving conditions shown with the use of advanced emission control systems
  - Light-duty gasoline car
  - Heavy-duty diesel truck
- Significant reductions of Well-to-Wheel CO<sub>2</sub> emissions are possible with the use of sustainable renewable fuels. Emission control technologies fully operating in combination with drop-in sustainable renewable fuels enable ultra-low pollutant emissions and contribute towards net-zero CO<sub>2</sub> emissions.
- Internal Combustion Engine is part of the solutions to contribute to EU Green Deal goals towards 2050 along with electrification

# THANK YOU !

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