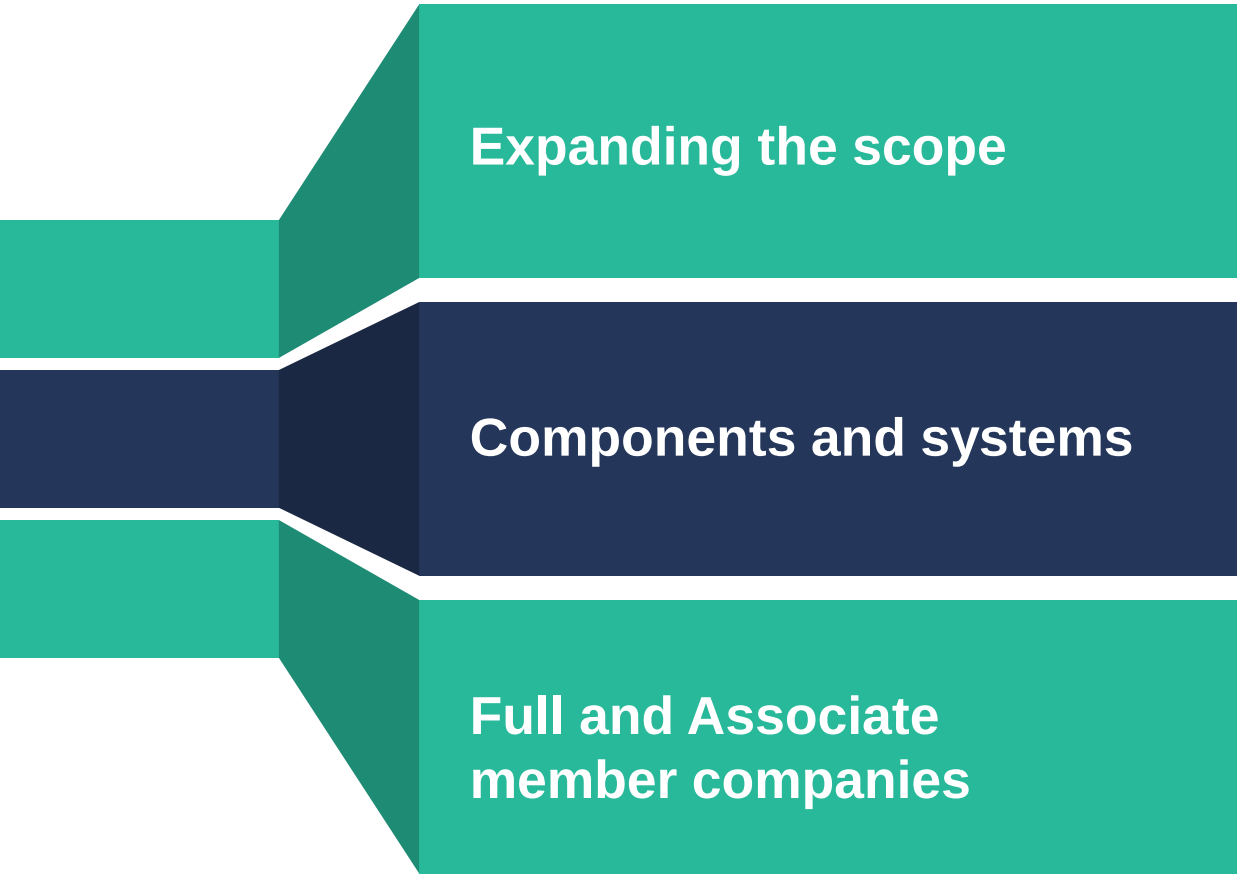
Advanced Emission Control Systems and Thermal Strategies for NRMM Emission Reduction

Joachim Demuynck

Non-Road Powertrain & Fuels Europe • Munich • 8 October 2025

AECC is now the Association for Emissions Control and Climate



- Air quality and **Climate** requirements
- Mobile and **Stationary** emissions sources
- Sustainable **components and systems**

- Catalysts
- Filters
- Adsorbers

- Fuel cells
- Electrolysers
- System integration

EU Transparency Register #78711786419-61, consultative status with the UN Economic and Social Council (ECOSOC)

NRMM is a key activity among the AECC policy focus areas

On-road vehicles

Non-Road Mobile Machinery

Industrial and Stationary

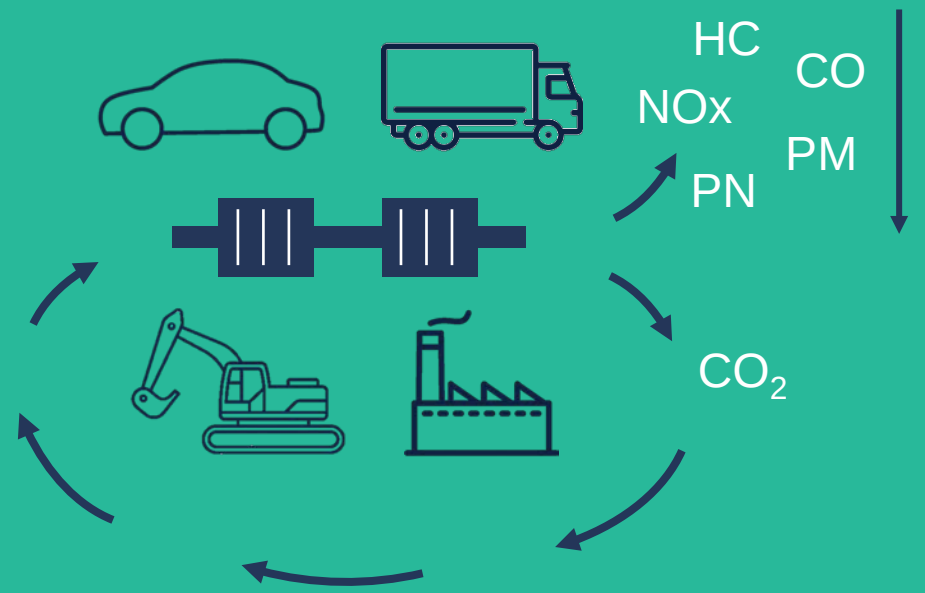
H_2 production and utilisation

Life cycle assessment and circular economy

AECC works in partnership with EU policymakers to target

Zero-impact pollutant emissions

Net-zero Greenhouse gas emissions



AECC member emission control systems ensure there's **no measurable negative impact** of these gases on the **environment or on public health**

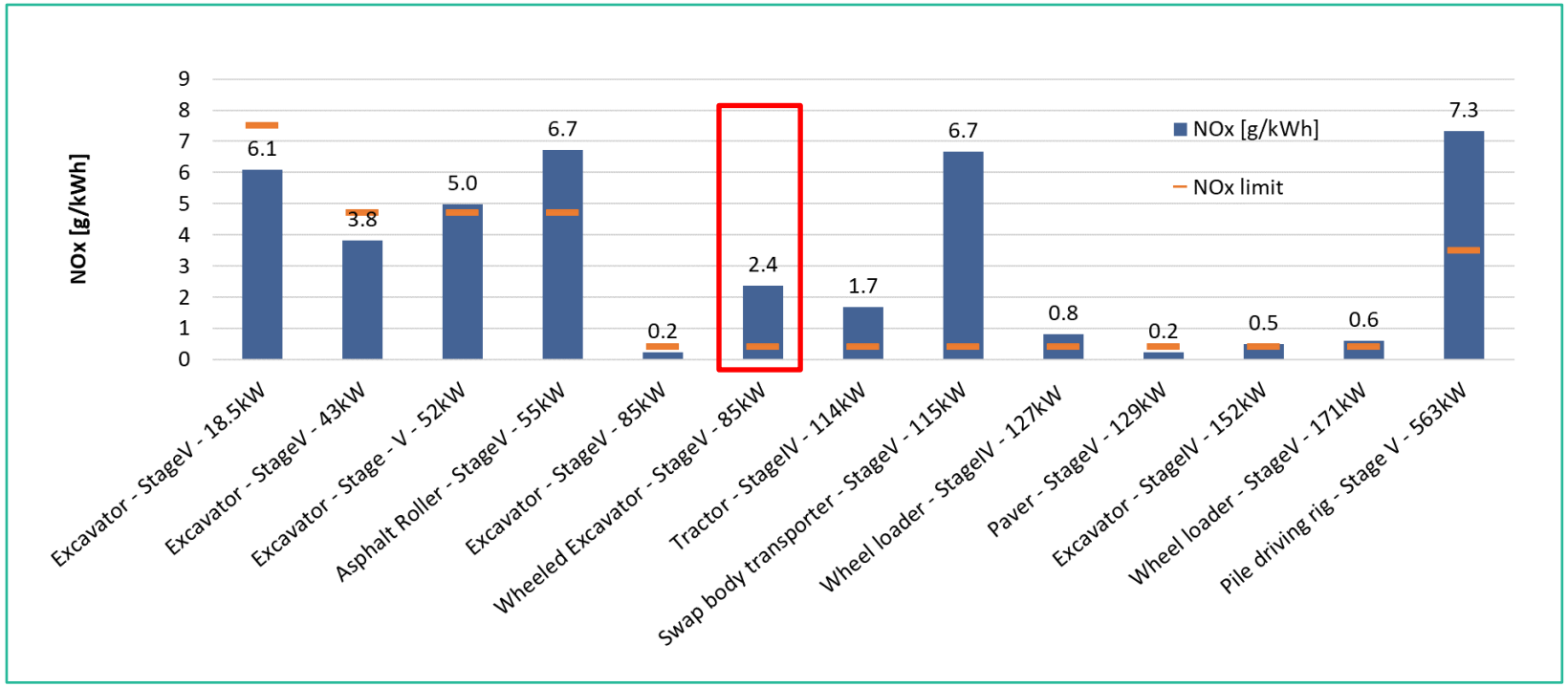
AECC member emission control systems are compatible with **CO_2-neutral fuels** for a closed carbon cycle

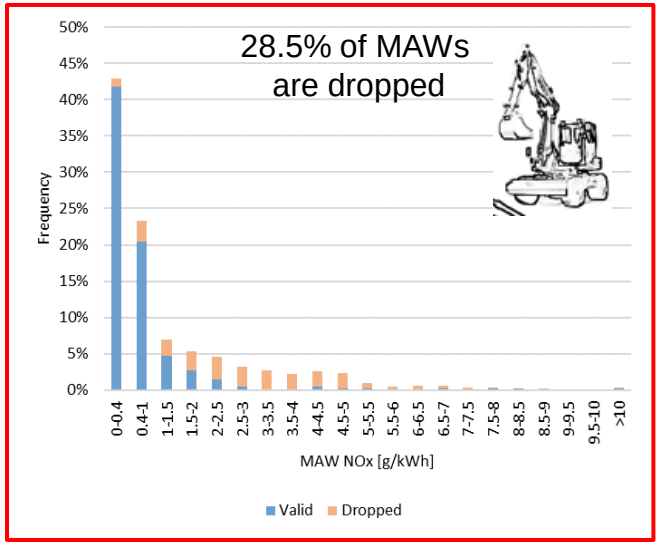
Evolution of NRMM Stage V legislation is expected

- NRMM legislation is several steps behind on-road HDV legislation
  - PEMS monitoring instead of In-Service Conformity (ISC) and Real-Driving Emissions (RDE)
  - More data exclusions
  - Higher limits than Euro 7
- Ongoing initiatives
  - European Commission will review Stage V in 2025 based on PEMS monitoring data
  - US CARB Tier 5 proposal for MY2029+, US EPA announcement from 2024 tbc
  - China expected to propose next step for NRMM in mid-2026
  - Informal discussions at UNECE GRPE about UN Regulation No. 96 and GTR No. 11

A large variation is observed in real-world NOx emissions

- Depending on the use case and applicable limit
- NRMM regulation does not consider a substantial share of the real working conditions





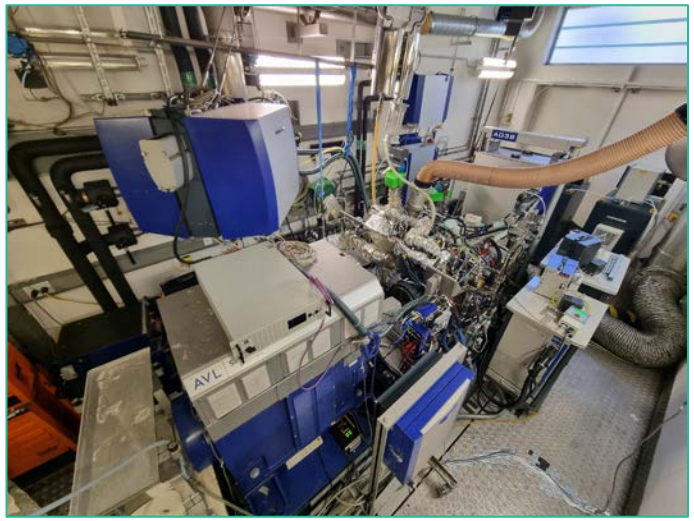
MAW: Moving Average Window

R. Vermeulen, et al.; "Real-World NOx emissions of Stage V NRMM", Transport and Air Pollution Conference, 2023

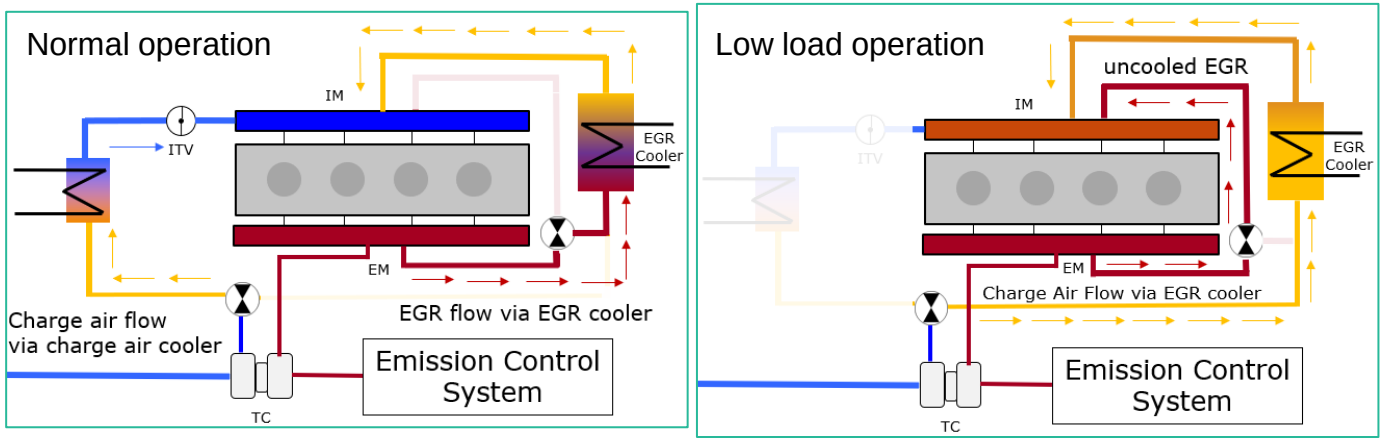
NRMM demonstrator project set-up

- Project partners

- NRMM engine
  - Base characteristics
    - 4l class, ~ 100 kW rated power
    - Cooled HP-EGR & intake throttle
    - ~ 4 g/kWh engine-out NOx



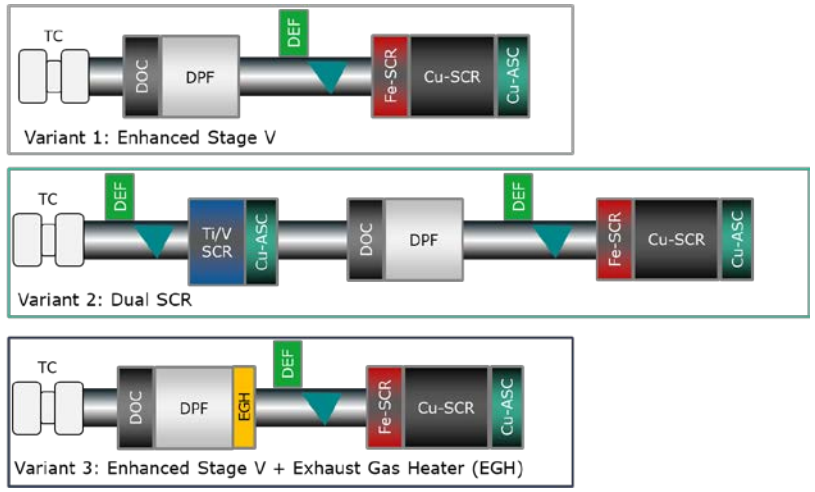
  - Project modifications at low-load operation
    - Uncooled EGR & charge air heating
    - EGR recalibration



TC: Turbocharger
ITV: Intake Throttle Valve
IM Intake Manifold
EM: Exhaust Manifold
EGR: Exhaust Gas Recirculation

NRMM demonstrator project set-up

- 3 emission control system configurations
  - Modular approach
  - Hydrothermal ageing in oven

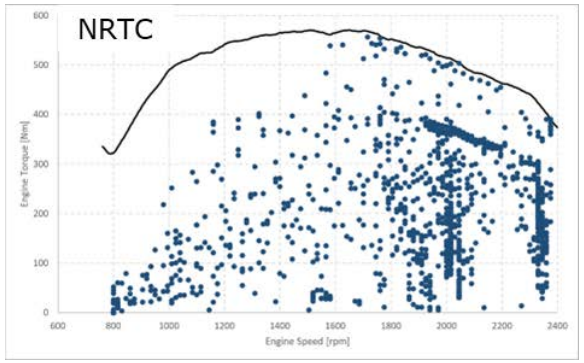


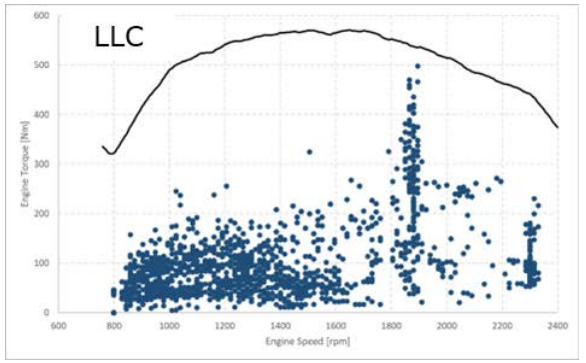
TC: Turbocharger
EGH: Exhaust Gas Heater
SCR: Selective Catalytic Reduction
ASC: Ammonia Slip Catalyst
DOC: Diesel Oxidation Catalyst
DPF: Diesel Particulate Filter

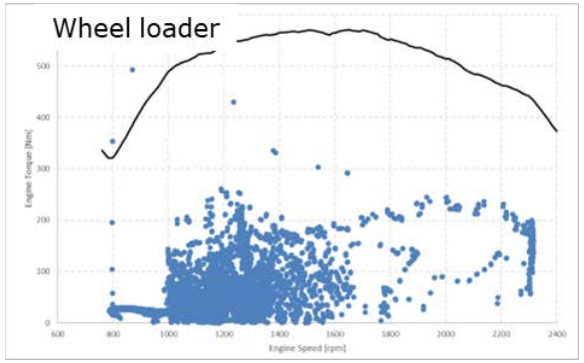
Testing of wide variation in NRMM applications

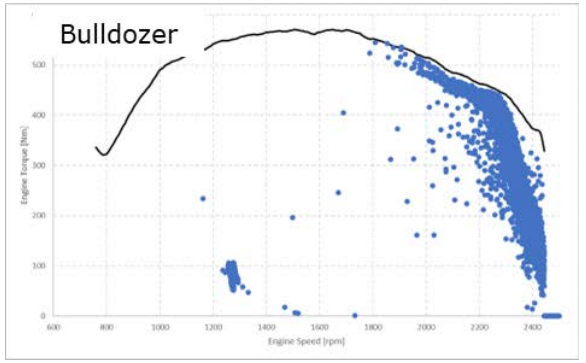
- Type approval cycles
  - NRTC cold and hot
  - RMC
  - LLC
- In-use application cycles
  - Wheel loader 
  - Bulldozer 
  - Excavator 
  - Forklift 

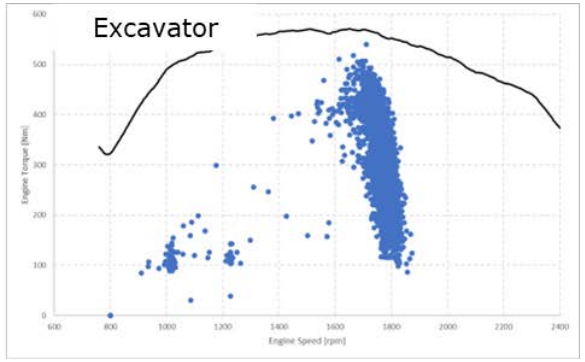
NRTC: Non-Road Transient Cycle
RMC: Ramped Mode Cycle
LLC: Low-load Cycle

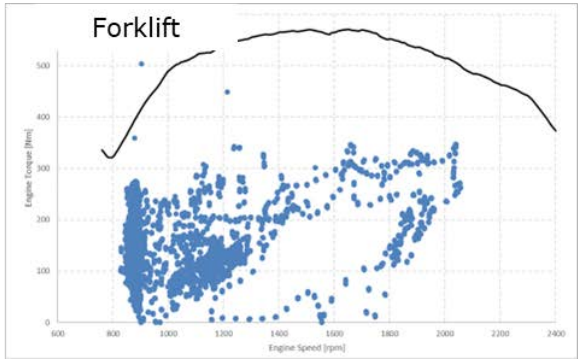








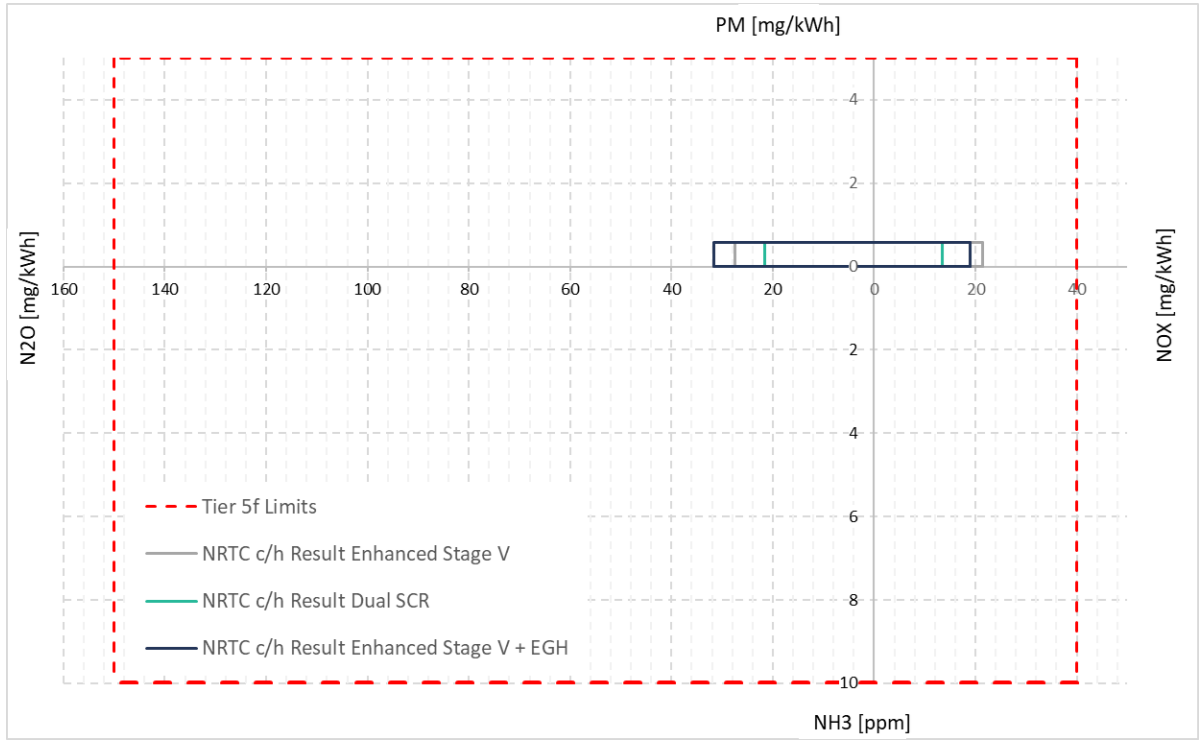




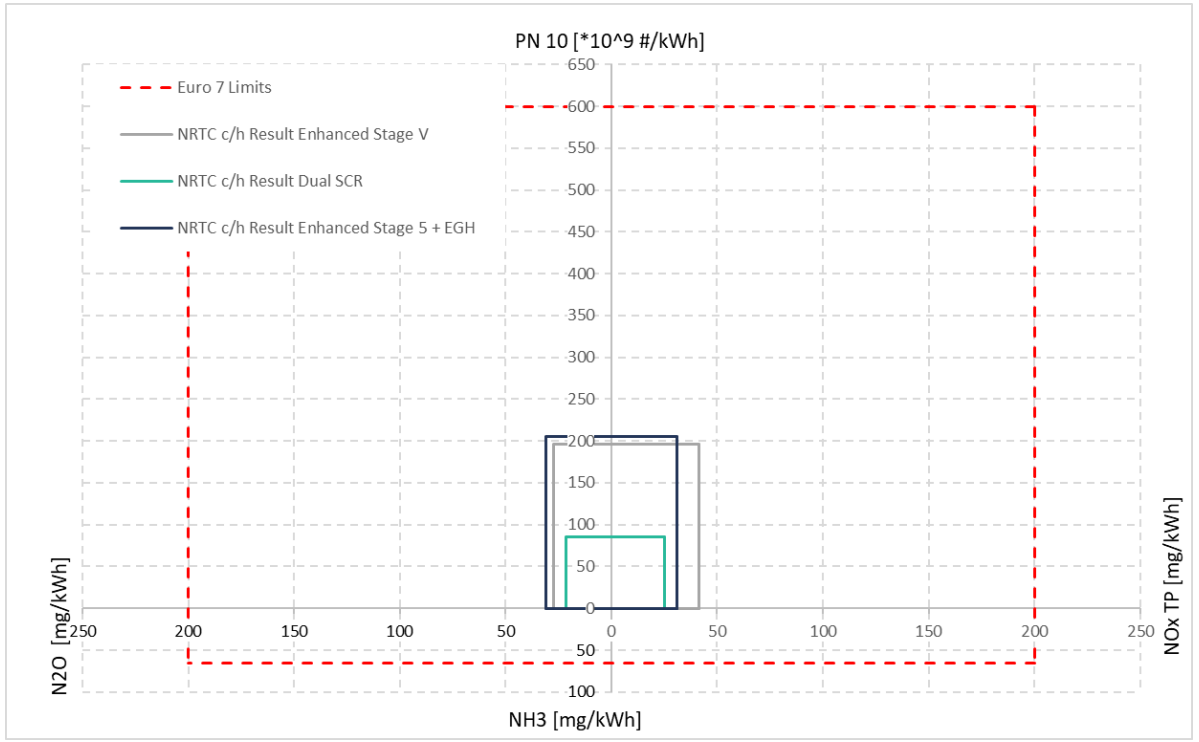
All 3 variants within CARB Tier 5 and Euro 7 on NRTC

- Small differences between variants on NRTC after cold-hot weighing

CARB Tier 5 NRTC c/h

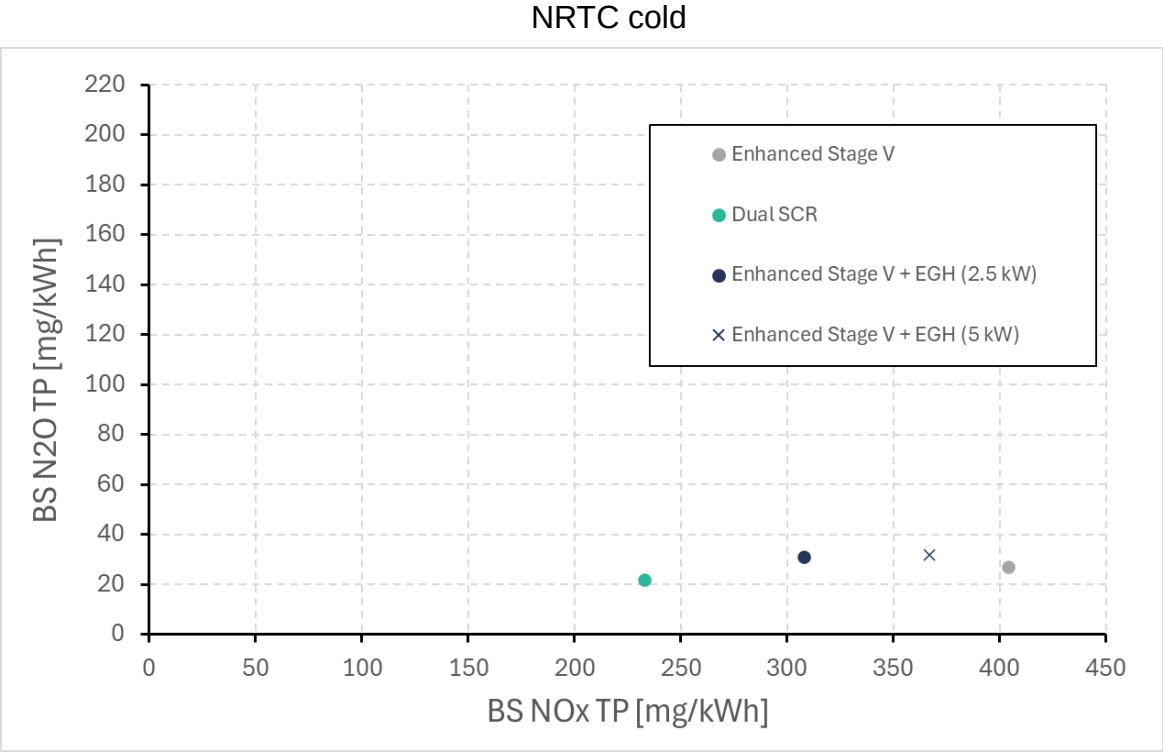


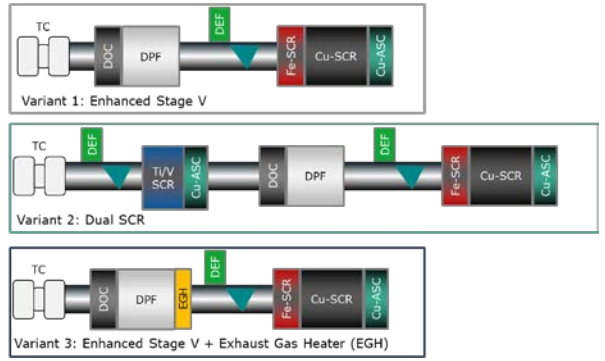
Euro 7 HDV NRTC c/h



All 3 variants within CARB Tier 5 and Euro 7 on NRTC

- Differences between variants mainly seen on NRTC cold
  - Dual SCR configuration shows the lowest NOx level





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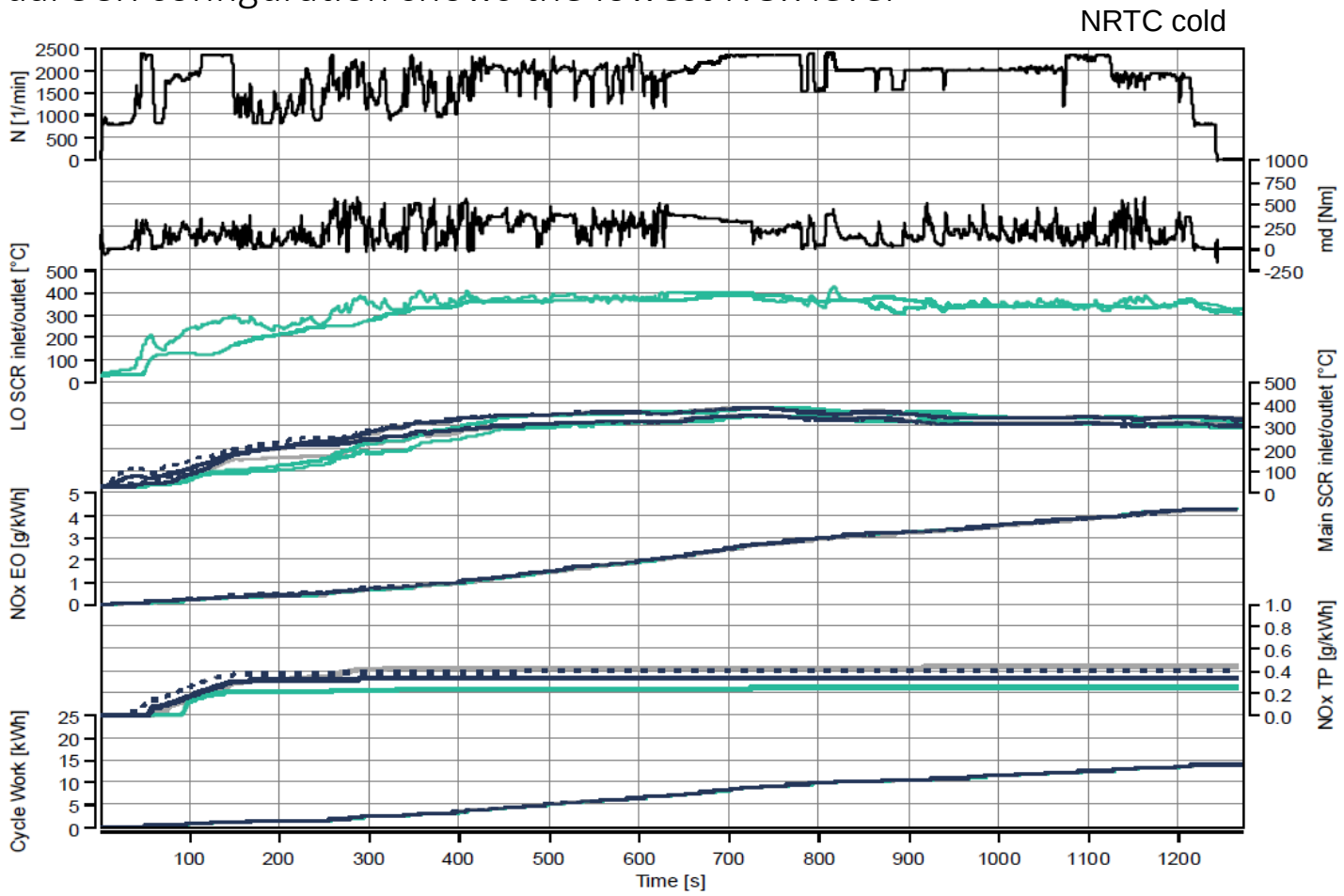
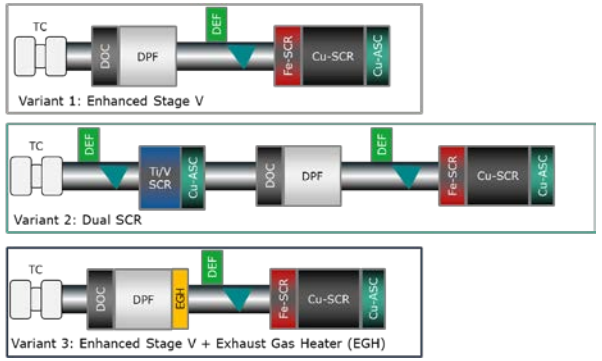
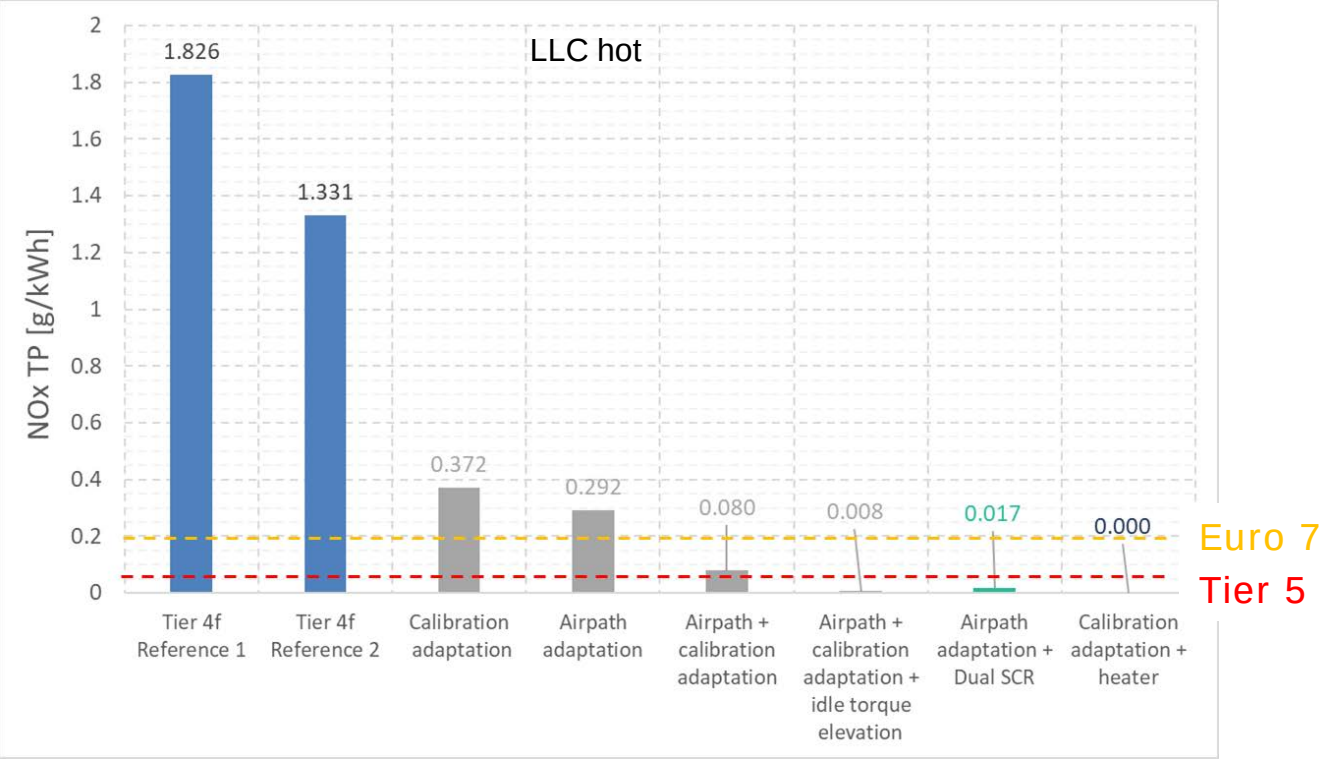
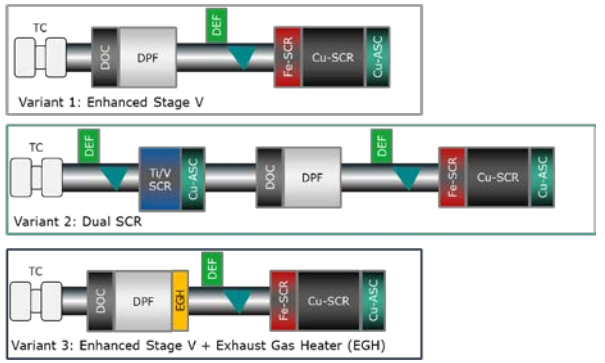




All 3 variants significantly improve emissions at low load

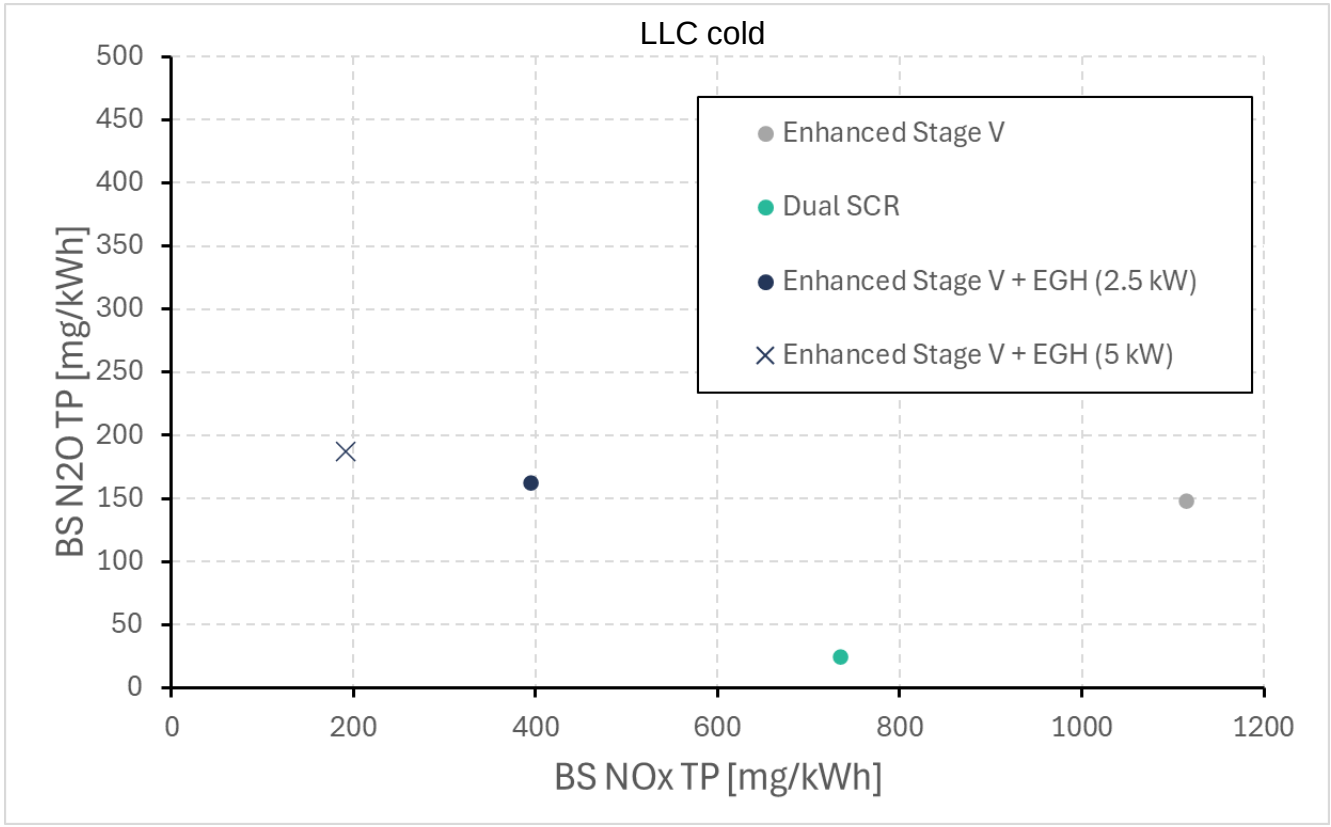
- Data on LLC hot is compared to SwRI data of Tier 4 engines
- Variant 2 and 3 meet the Tier 5 NOx limit on LLC hot
- For variant 1, the idle load needs to be increased from 44 to 66 Nm

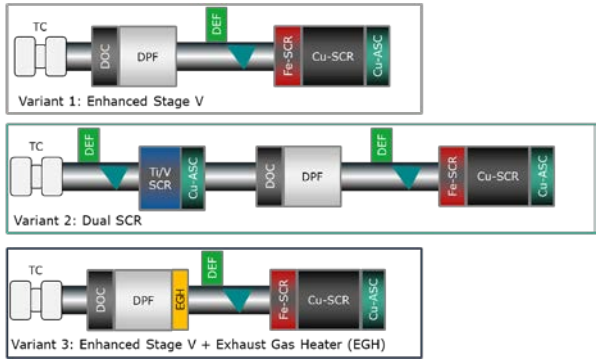




All 3 variants significantly improve emissions at low load

- Engine heating measures are insufficient for Variant 1 and 2 on LLC cold
- NOx below 200 mg/kWh is observed for Variant 3 with 5 kW EGH heating power





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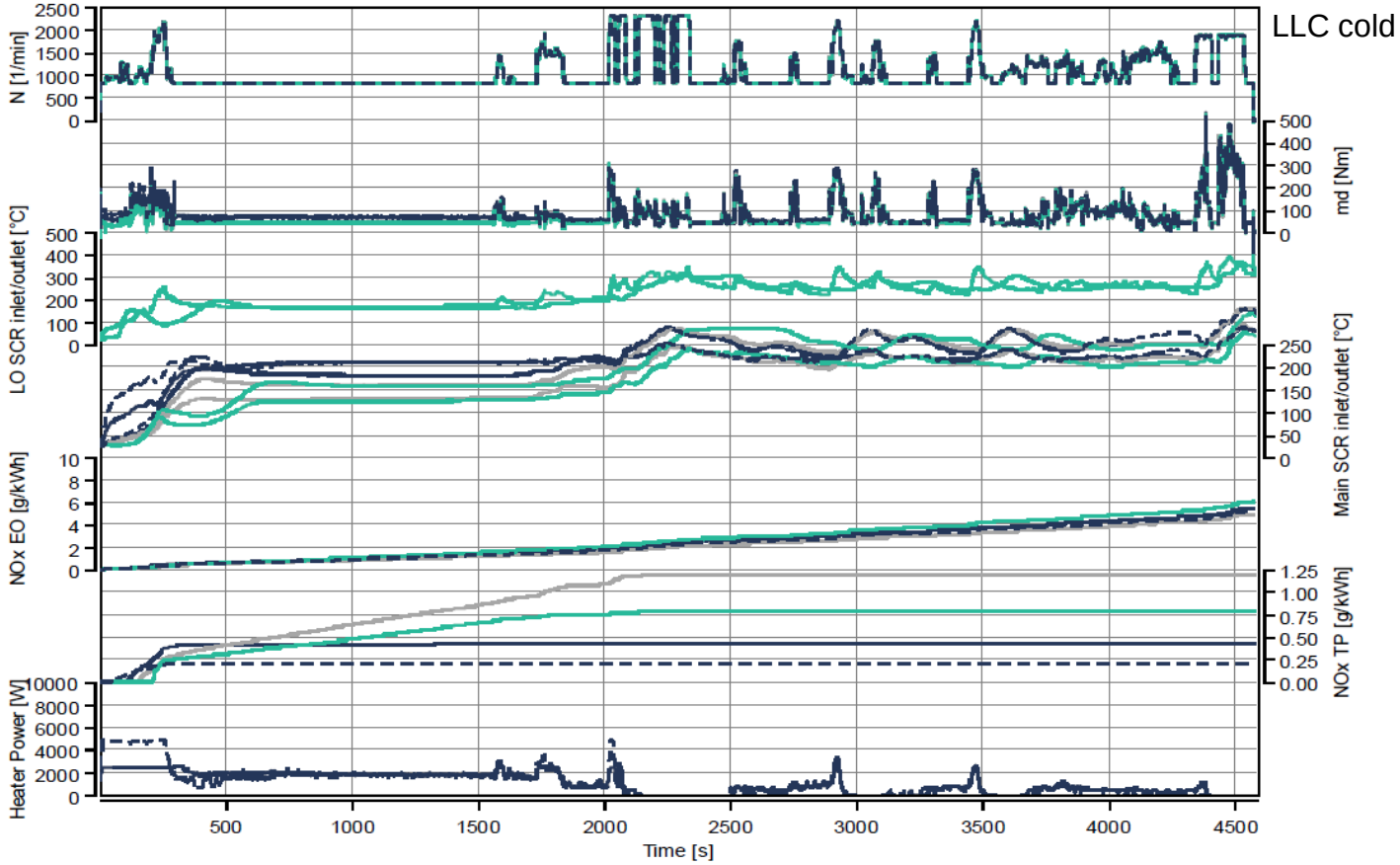
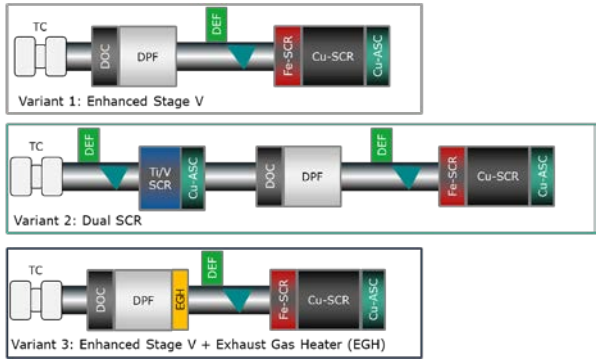
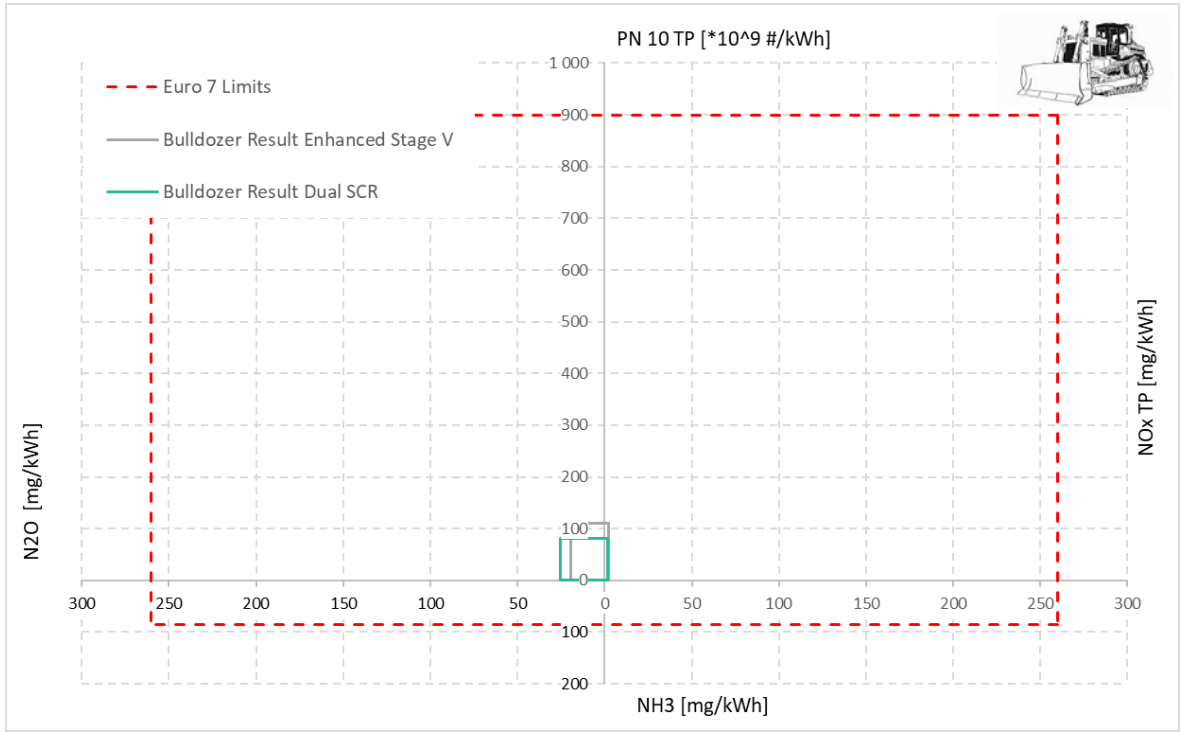
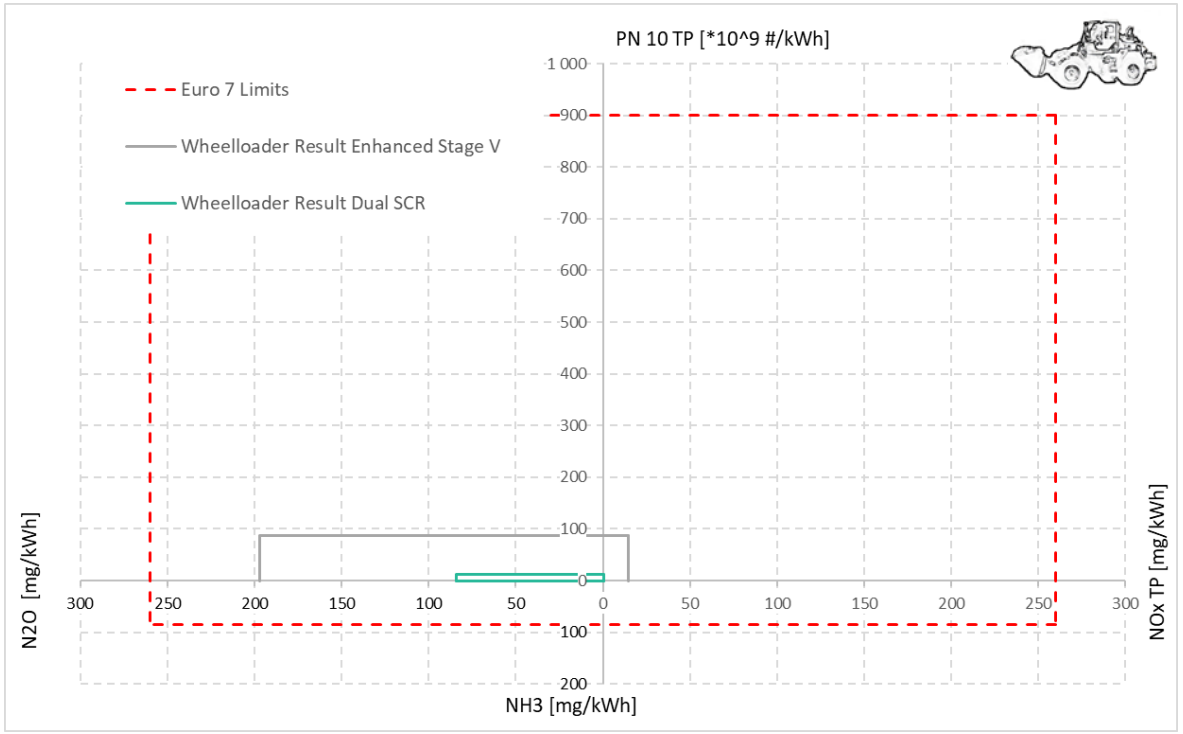




Consistent low emissions on in-use cycles

- All Variants generally meet Euro 7 ISC limits on in-use cycles
- No significant differences are observed over medium- to high-load profile (e.g. bulldozer)
- Variant 2 shows benefit over low-load profile (e.g. wheel loader)





* Variant 3 not measured given same results as variant 1 on these hot start in-use cycles

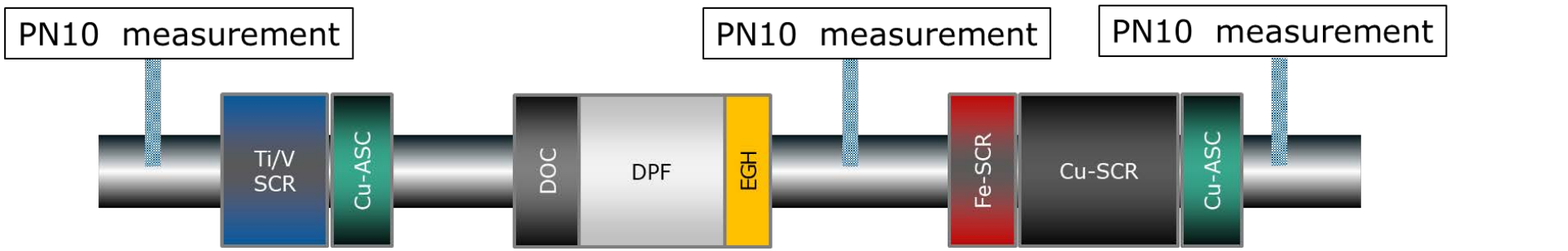
PN emissions are within Euro 7 on all tests

- PN reduction over DPF from 10^{14} #/kWh engine-out emissions
  - To 10^{8} #/kWh on NRTC and LLC
  - To 10^{11} #/kWh on RMC, due to passive soot oxidation at high load
- Tailpipe PN10 emissions on NRTC and LLC reach $10^{10\text{-}11}$ #/kWh due to urea born particles

Cycle	PN10 EO
	#/kWh
NRTC	1.70E+14
RMC	1.10E+14
LLC	1.62E+14

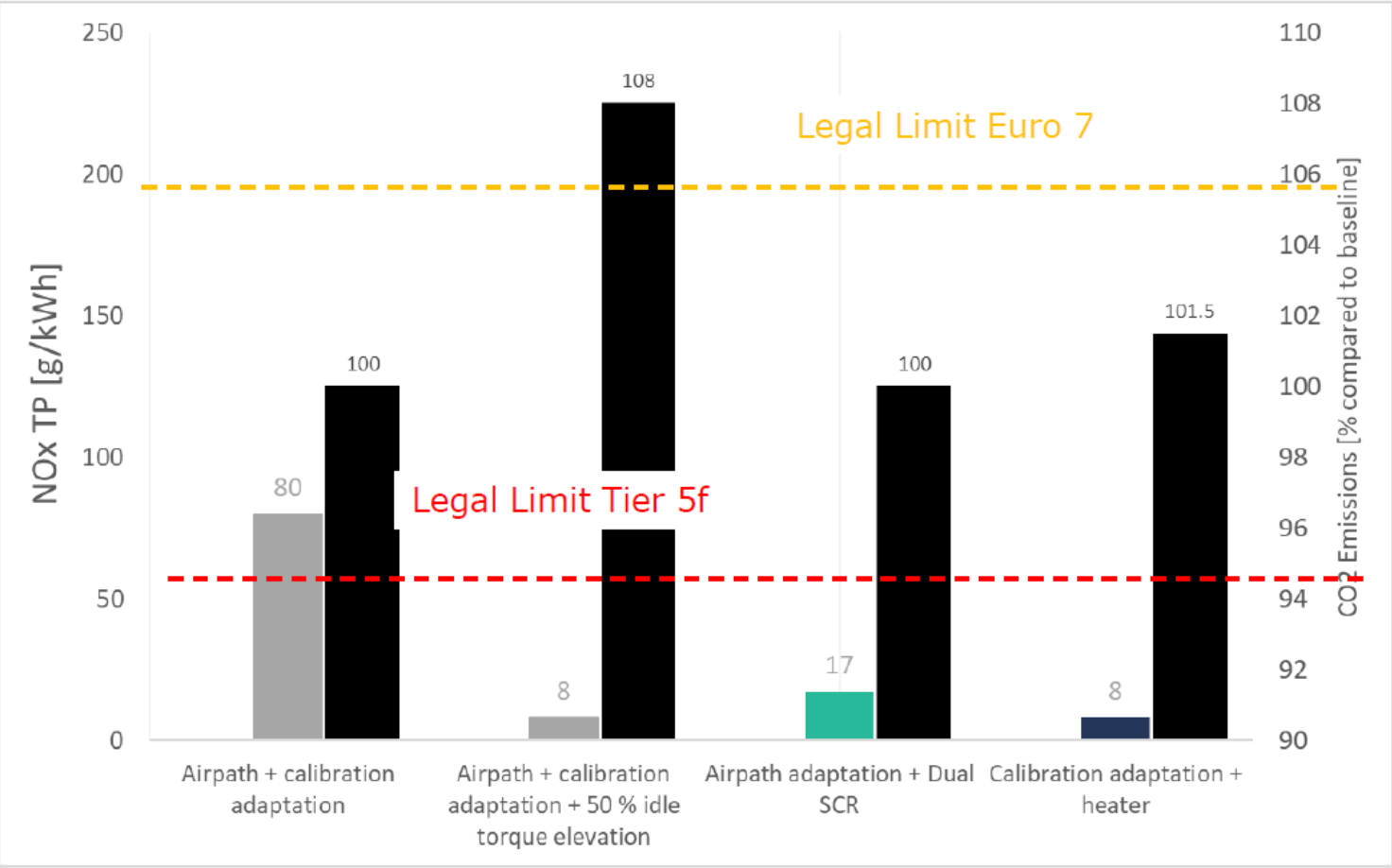
Cycle	PN10 ds Filter	Filtration Efficiency
	#/kWh	%
NRTC	4.11E+08	99.9998
RMC	3.60E+11	99.6730
LLC	4.94E+08	99.9997

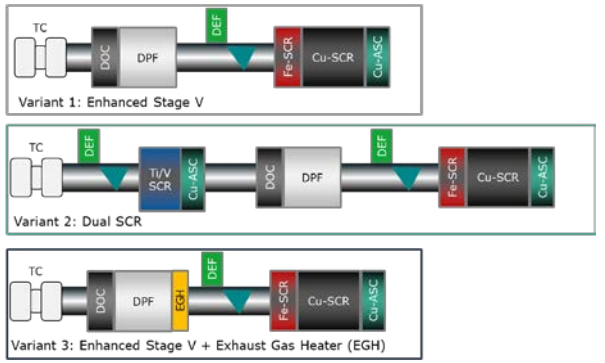
Cycle	PN TP	Urea Particle Formation	Share of Urea Particles
	#/kWh	#/kWh	%
NRTC	2.07E+11	2.07E+11	99.8
RMC	4.22E+11	6.23E+10	14.8
LLC	3.19E+10	3.14E+10	98.5



NOx reduction achieved with nearly no impact on CO_2 emissions

- Largest difference is observed on LLC test





Well-to-Wheel CO_2 emissions nearly eliminated on CO_2-neutral fuels

- Exemplary WtW calculation for NRTC hot of simulation study presented in 2024
  - Fossil diesel
  - 100% HVO from Used Cooking Oil (UCO)
- Demonstrator results have also been validated on 100% HVO

Conclusions

- Emission control technologies are available to achieve low NRMM pollutant emissions
- Single-dosing SCR system can already address some shortcomings of Stage V regulation
- Dual-dosing SCR and Exhaust Gas Heater are available with further benefits to cover the varying needs of wide range of NRMM applications
  - Depending on OEM engine concept and engine-out NOx emission level
  - Alternating operating conditions
  - Continuous low-load operation
  - Initial cold-start
- Together with operation on CO_2-neutral fuels including HVO, e-diesel and H_2; the Internal Combustion Engine is a future-proof NRMM powertrain option

THANK YOU!

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AECC AISBL
Rue Belliard 40 b24
B-1040 Brussels, Belgium