



# Demonstration of Potential for Reduction in NRMM Real-World Emissions

SAE HD Symposium • 7 May 2025 • Gothenburg

# AECC is now the Association for Emissions Control and Climate

Expanding the scope

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

Components and systems

- Catalysts
- Filters
- Adsorbers
- Fuel cells
- Electrolysers

Full and Associate member companies



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 Stationary



## H<sub>2</sub> production and utilisation

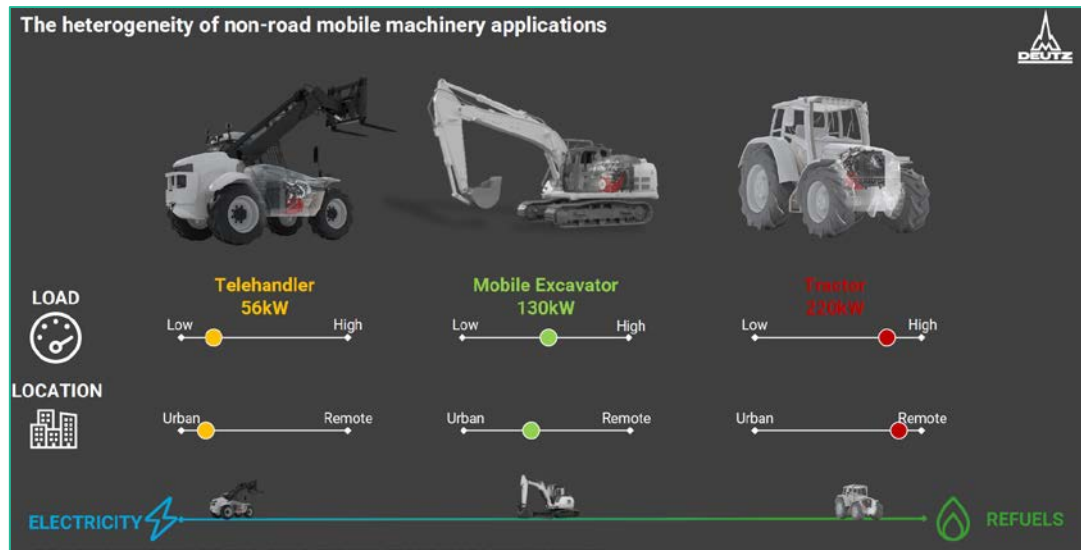


## Life cycle assessment and circular economy

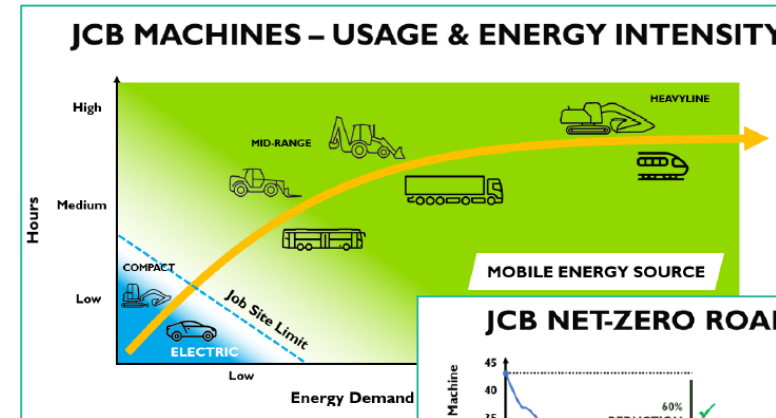


# All powertrain technologies needed towards net-zero CO<sub>2</sub>

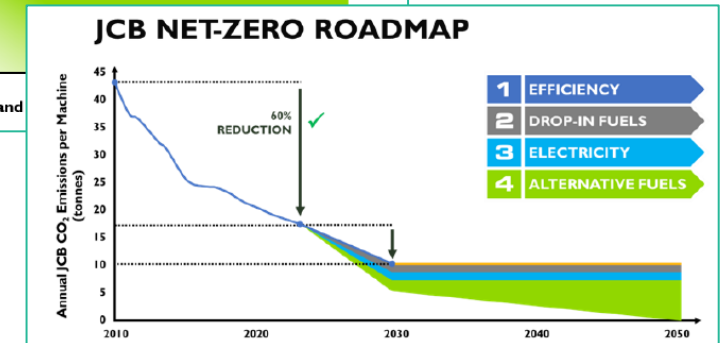
- Internal Combustion Engine (ICE) remains key for the NRMM use cases
- Different sustainable renewable fuels are investigated to reduce the carbon footprint



Deutz, Baden-Baden, 2024

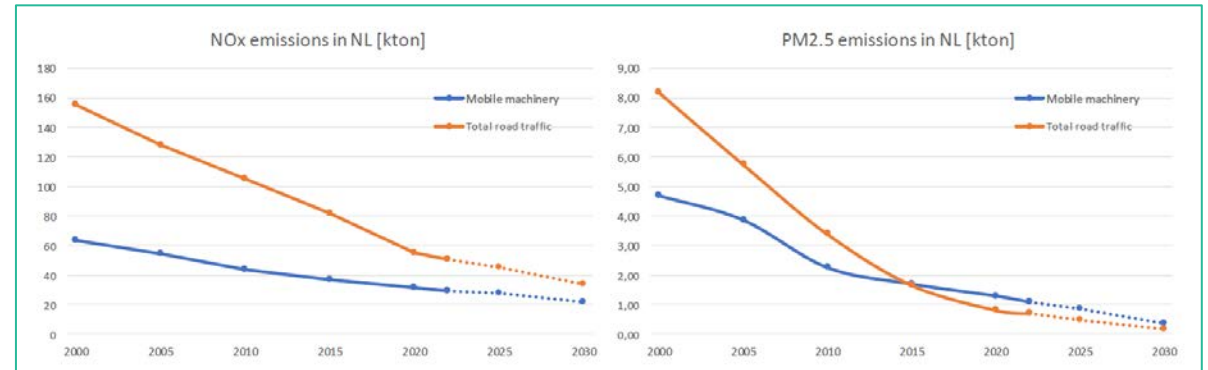


JCB, EA NRMM, 2024

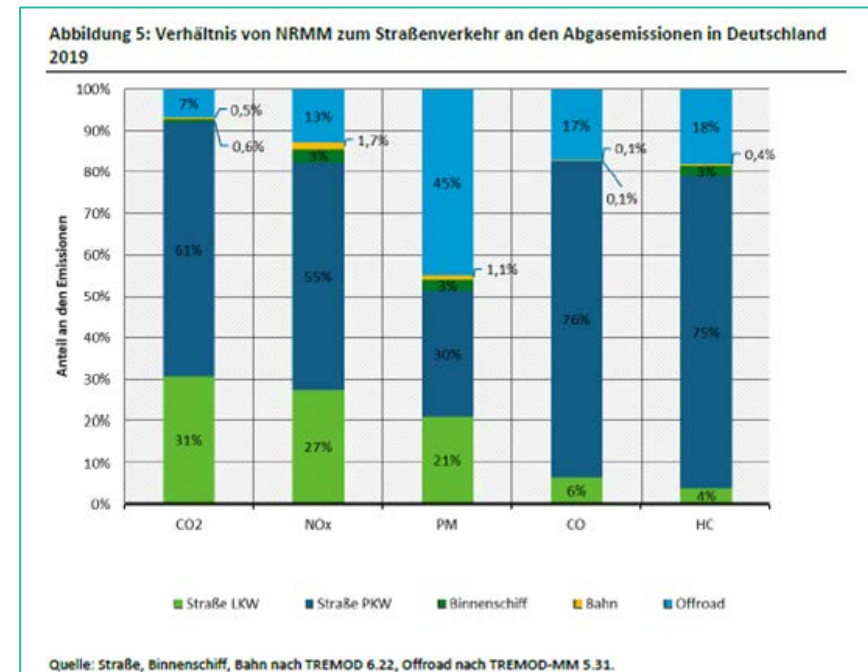


# Increasing contribution of NRMM to air quality impact

- In the Netherlands, [GRPE presentation](#), 2023



- In Germany, [UBA report](#), 2023

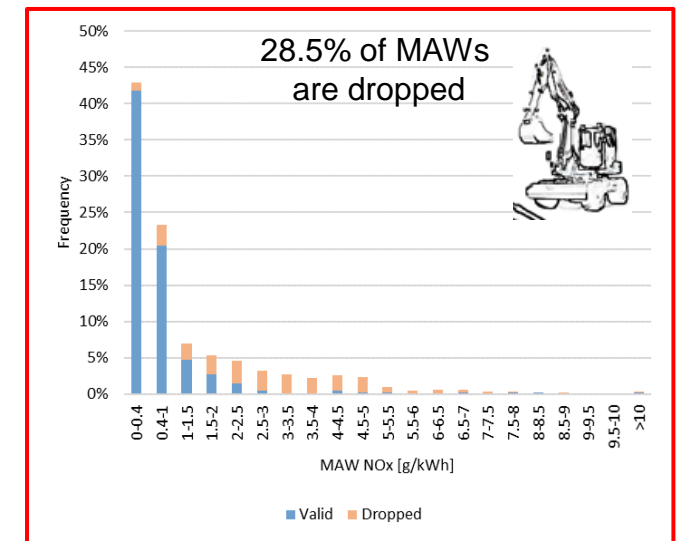
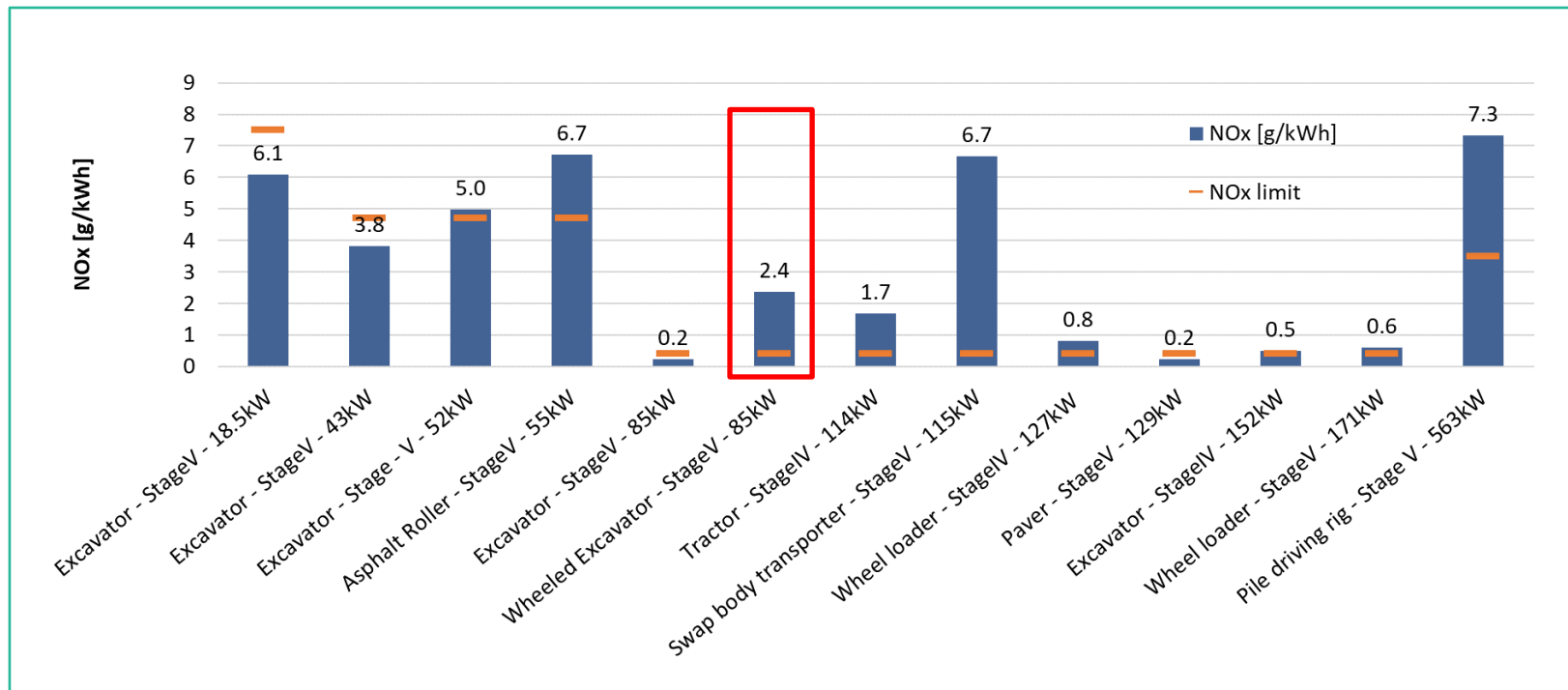


# Evolution of NRMM Stage V legislation is expected

- NRMM legislation typically follows on-road HDV legislation, which evolved towards Euro 7
  - Applying PEMS In-Service Conformity (ISC) instead of monitoring only
  - Removing data exclusions which significantly impact the measurement results
  - Reducing the emission limits
  - Introducing limits for new species (PN10, N<sub>2</sub>O)
- 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
  - Informal discussions at UNECE GRPE about UN Regulation No. 96 and GTR No. 11
  - China expected to consider next steps for NRMM

# Large variation observed in Stage V 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

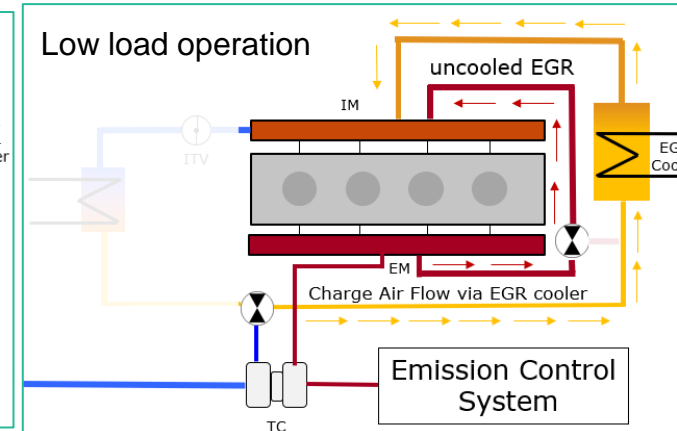
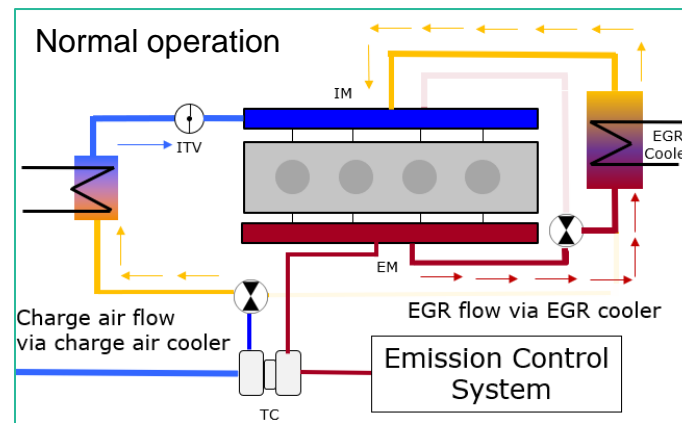
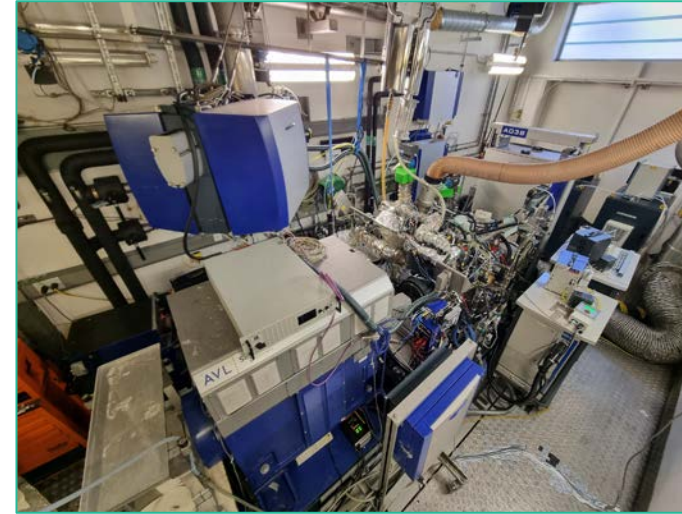


MAW: Moving Average Window

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

# NRMM demonstrator project set-up

- 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

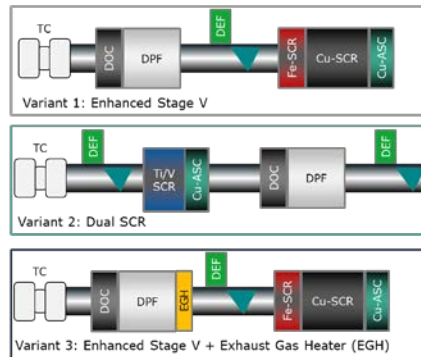


TC: Turbocharger  
ITV: Intake Throttle Valve  
IM Intake Manifold  
EM: Exhaust Manifold  
EGR: Exhaust Gas Recirculation

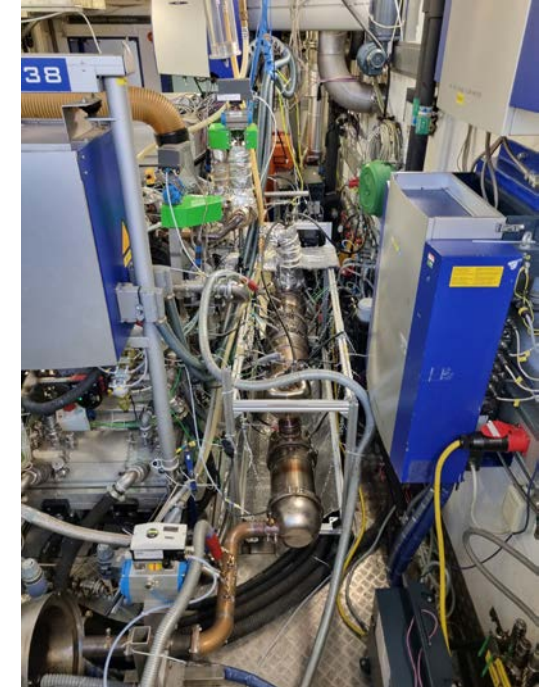


# NRMM demonstrator project set-up

- 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

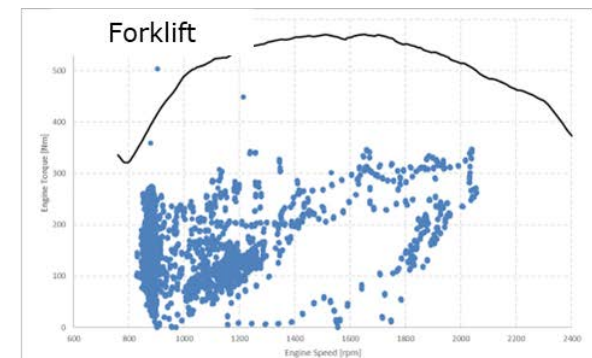
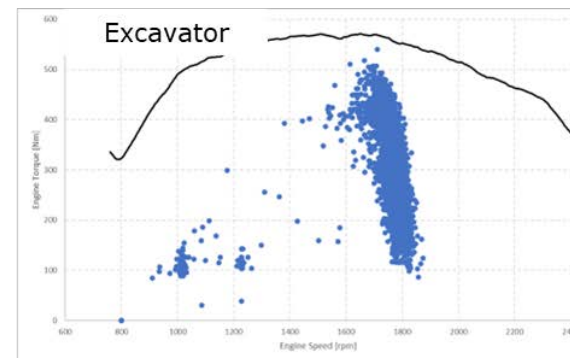
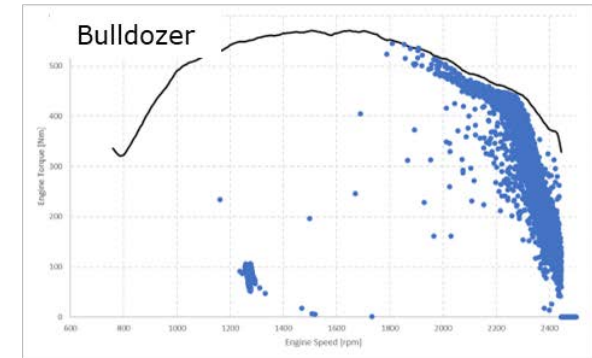
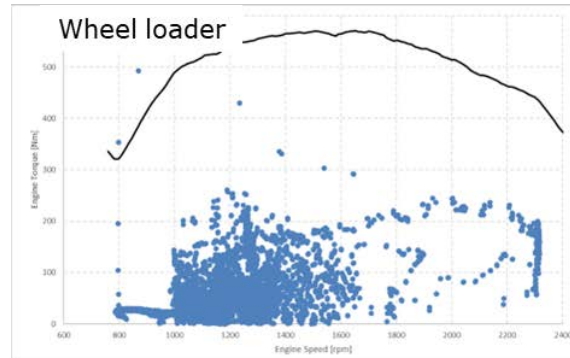
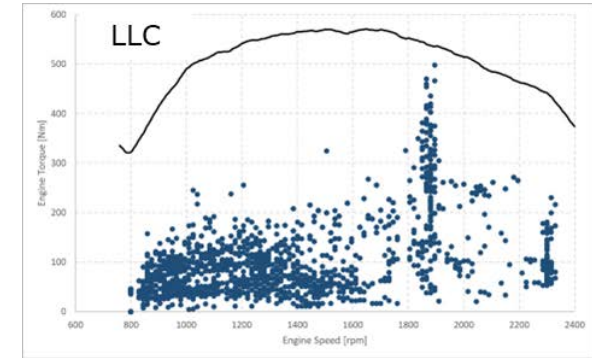
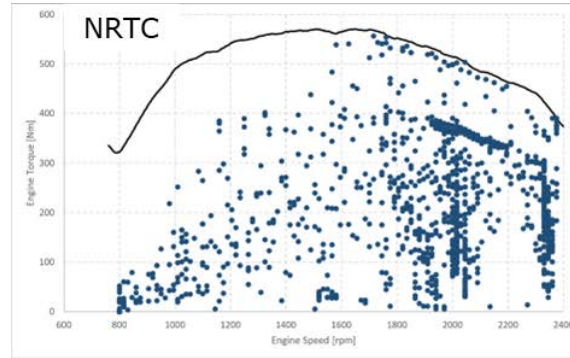


- Complementary simulation study

*J. Demuyne, et al.; "Potential for Reduction in NRMM Real-World Emissions", SAE WCX, Paper 2025-01-8489, 2025*

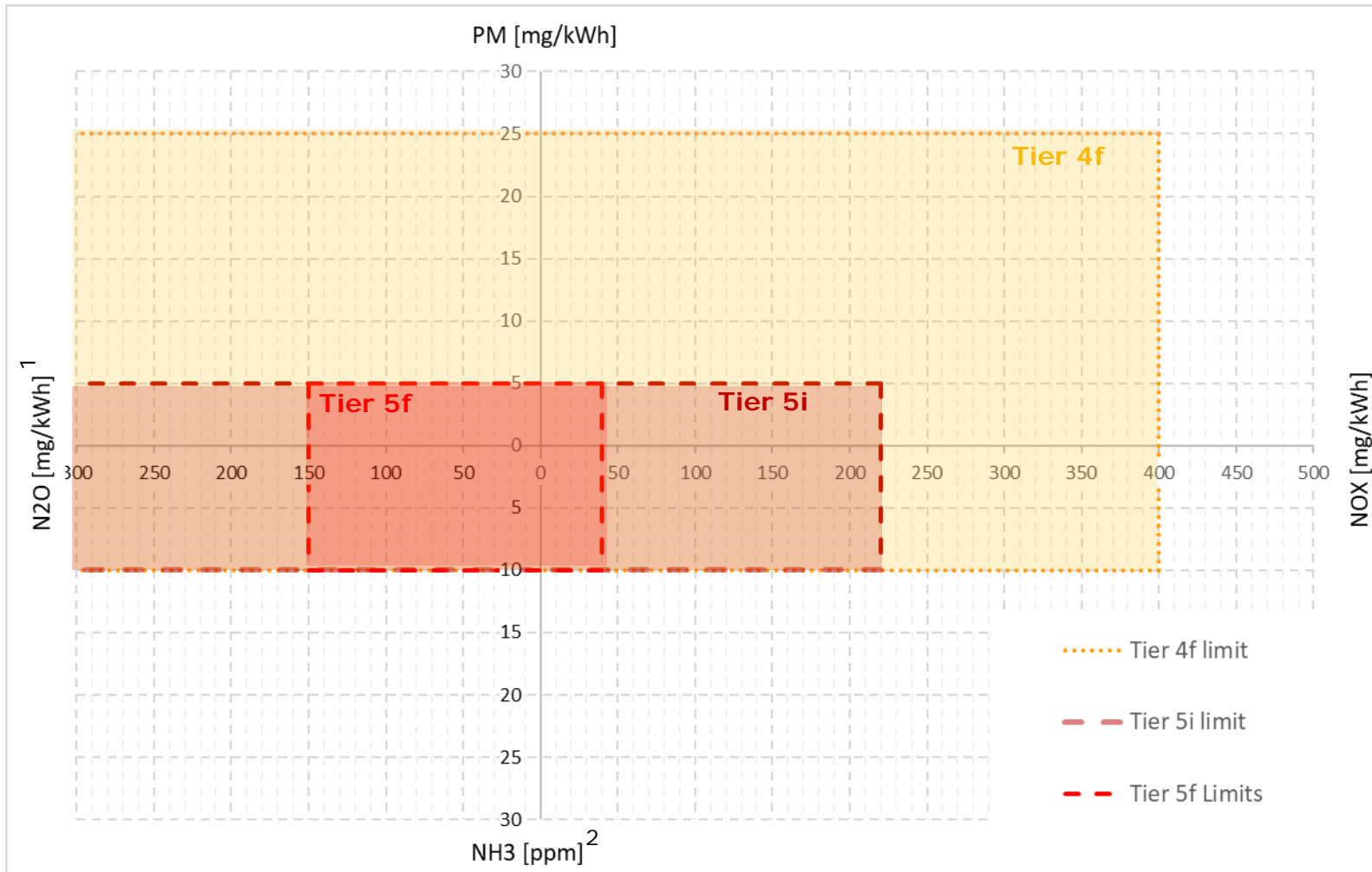
# Testing of wide variation in NRMM applications

- 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

# US CARB Tier 5 proposal



<sup>1</sup> no N<sub>2</sub>O limit for T4f and T5i

<sup>2</sup> 10 ppm NH<sub>3</sub> slip limit according to EPA guideline

## Emission Limits

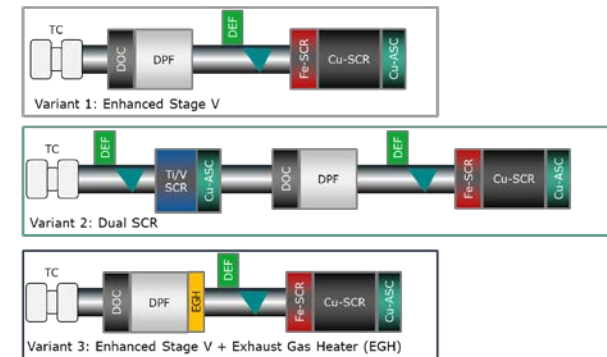
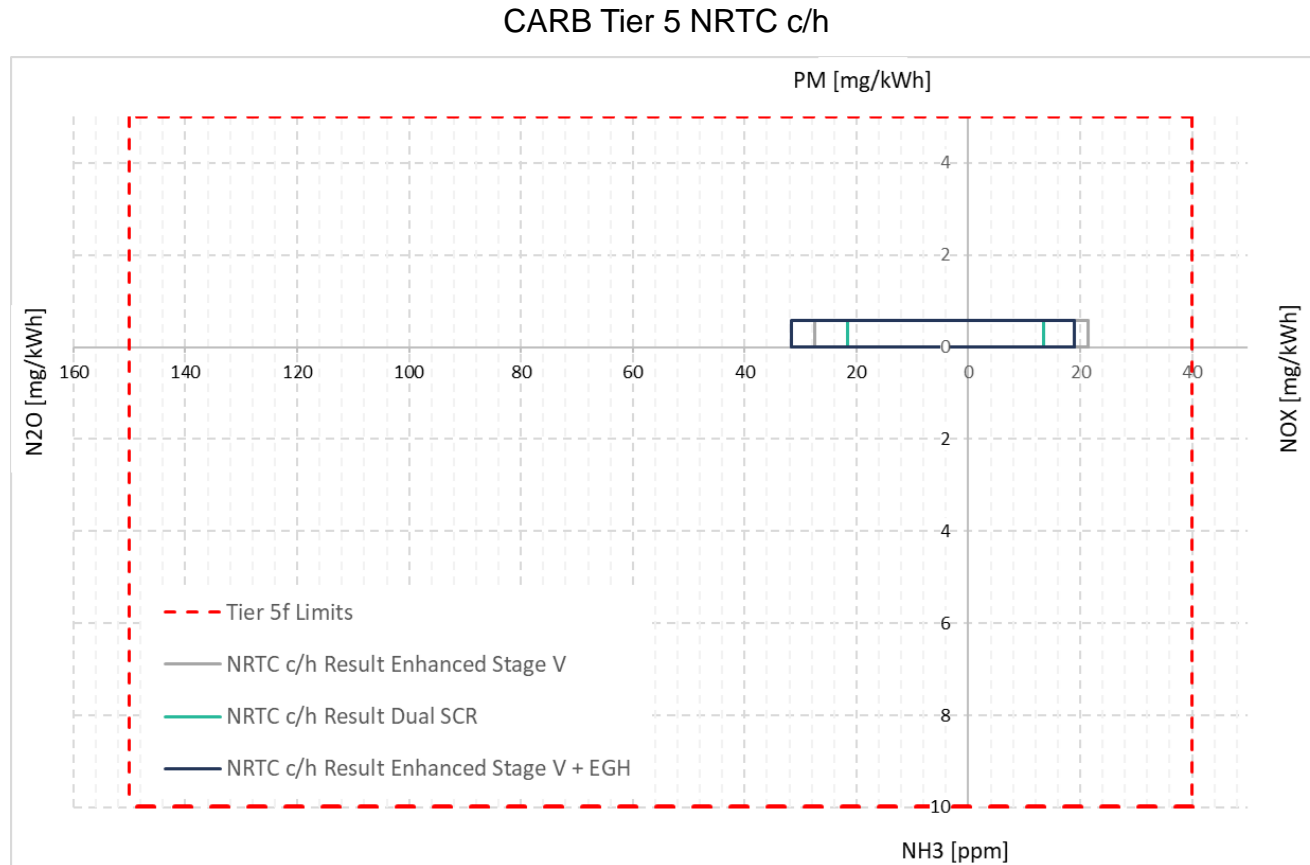
- Two step introduction, dependent on power categories (different options)
- **Tier 5i** with more stringent emission limits
- **Tier 5f** additionally **LLC** or **Idle Standards** depending on power category
- Introduction of **N<sub>2</sub>O limit** (150mg/kWh)

## Off-Cycle Emission

- **Tier 5f** foresees **in-use performance monitoring** of emission control system.
- NO<sub>x</sub> sensor data 3-bin evaluation:
  - NRTC/RMC limit (high bin)
  - LLC limit (low bin)
  - Low idle limit (idle bin)
- Also, PM monitoring is foreseen

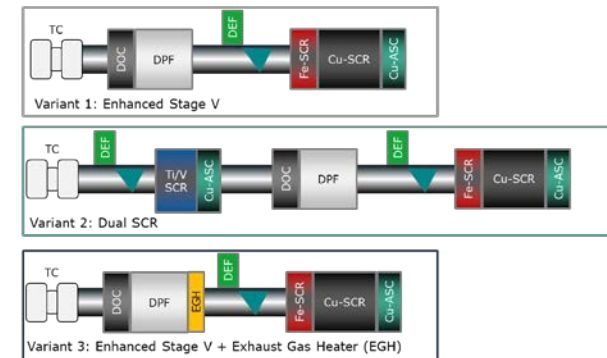
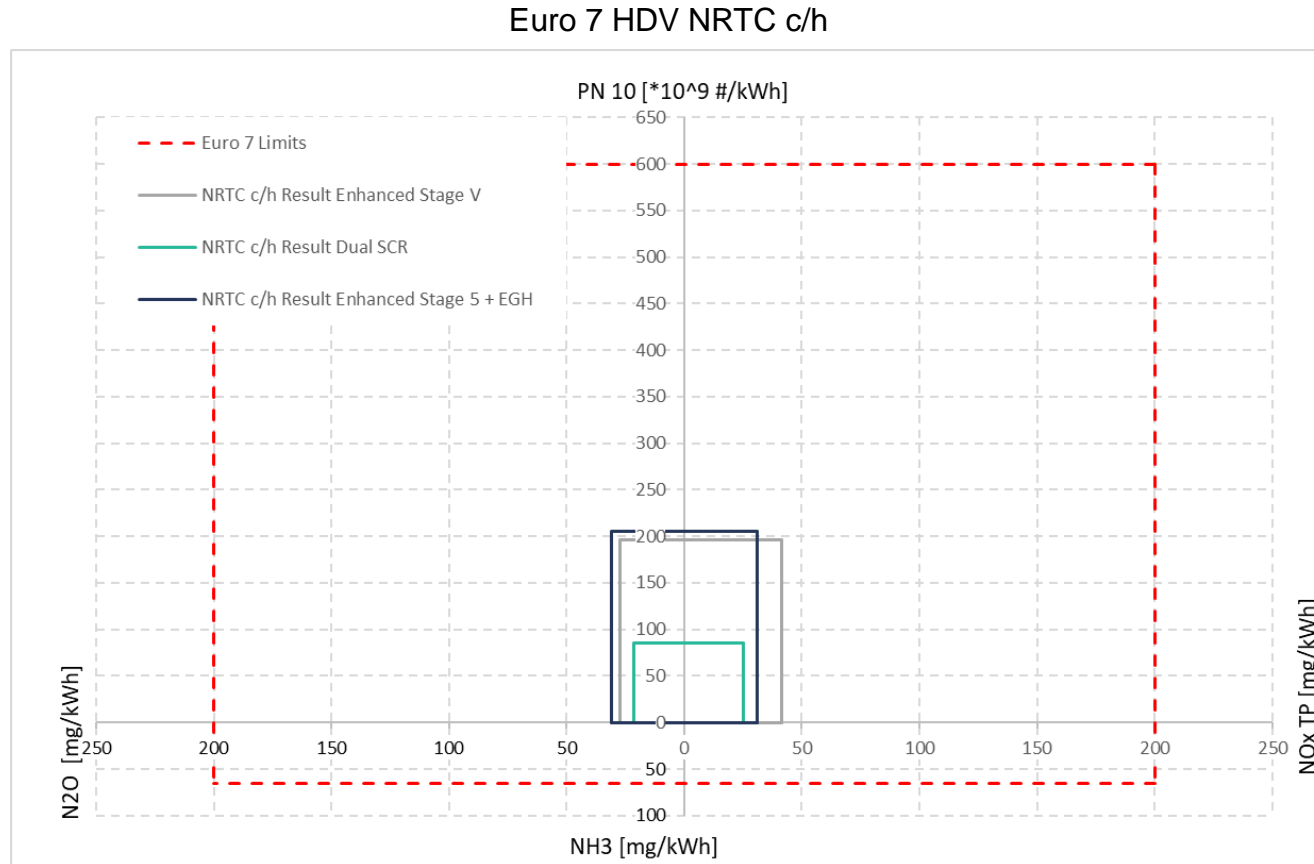
# All 3 variants within CARB Tier 5 and Euro 7 on NRTC

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



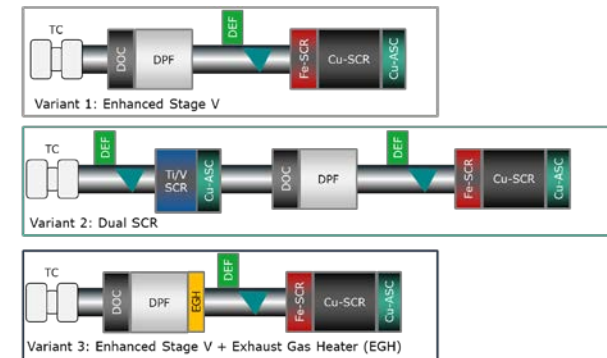
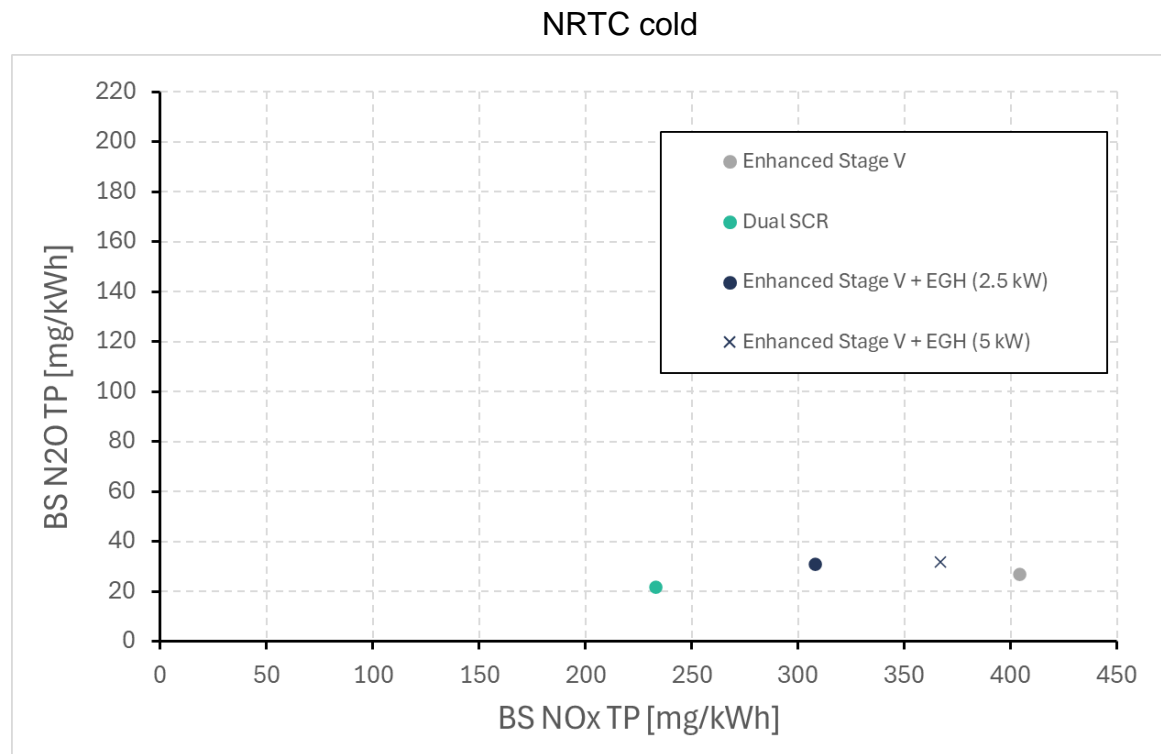
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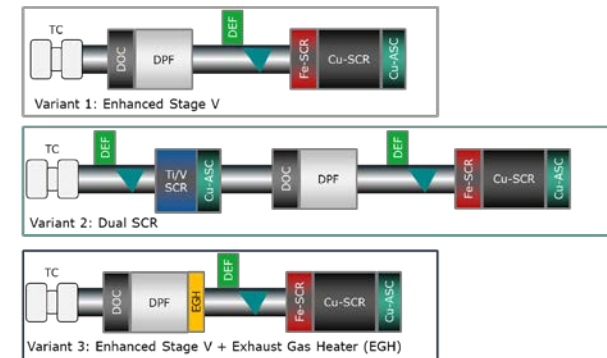
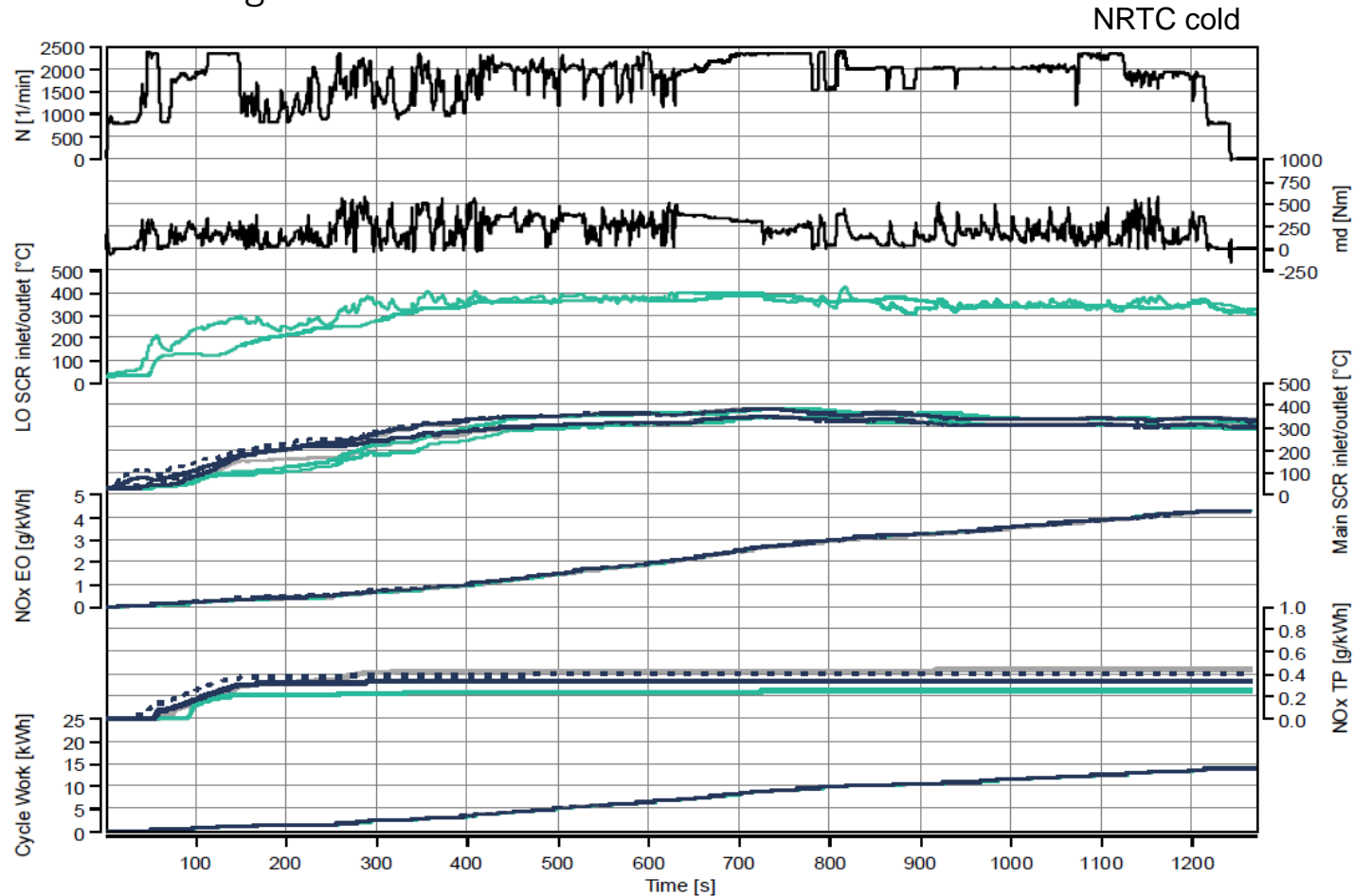
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- Differences between variants mainly seen on NRTC cold
  - Dual SCR configuration shows the lowest NOx level



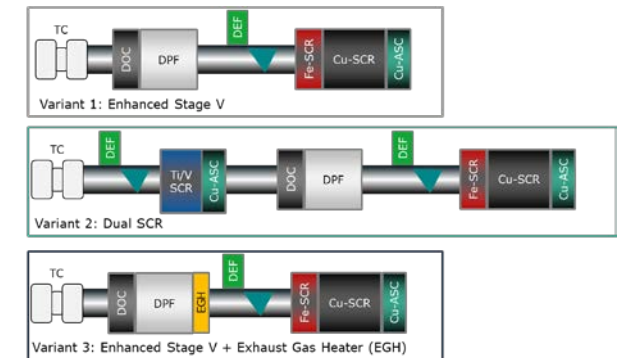
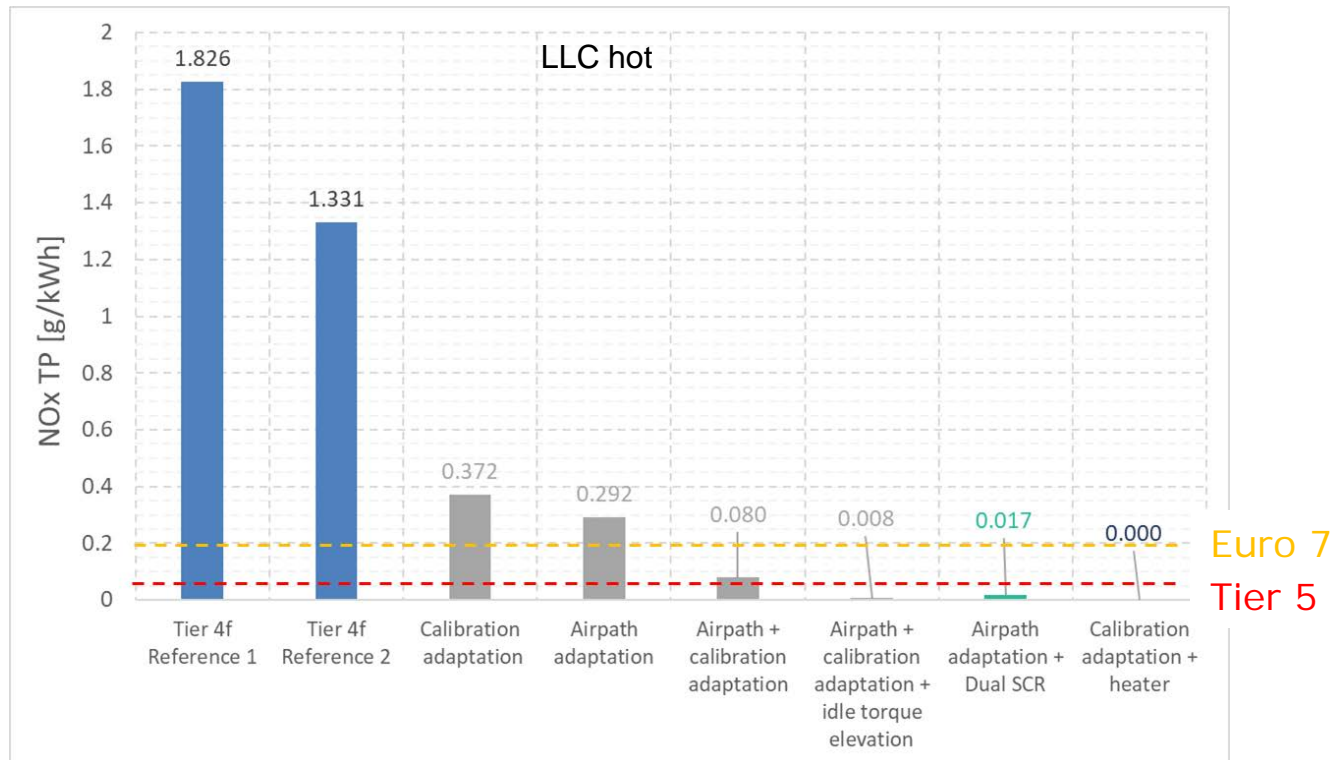
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# All 3 variants significantly improve emissions at low load

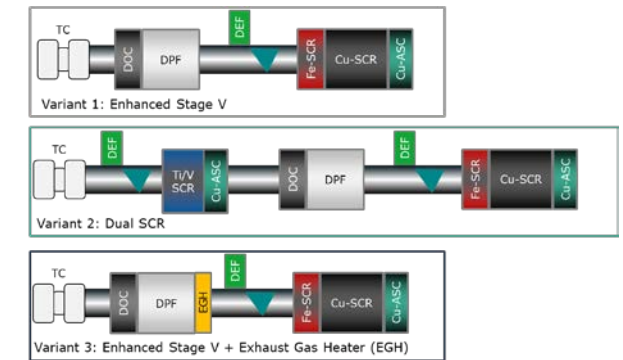
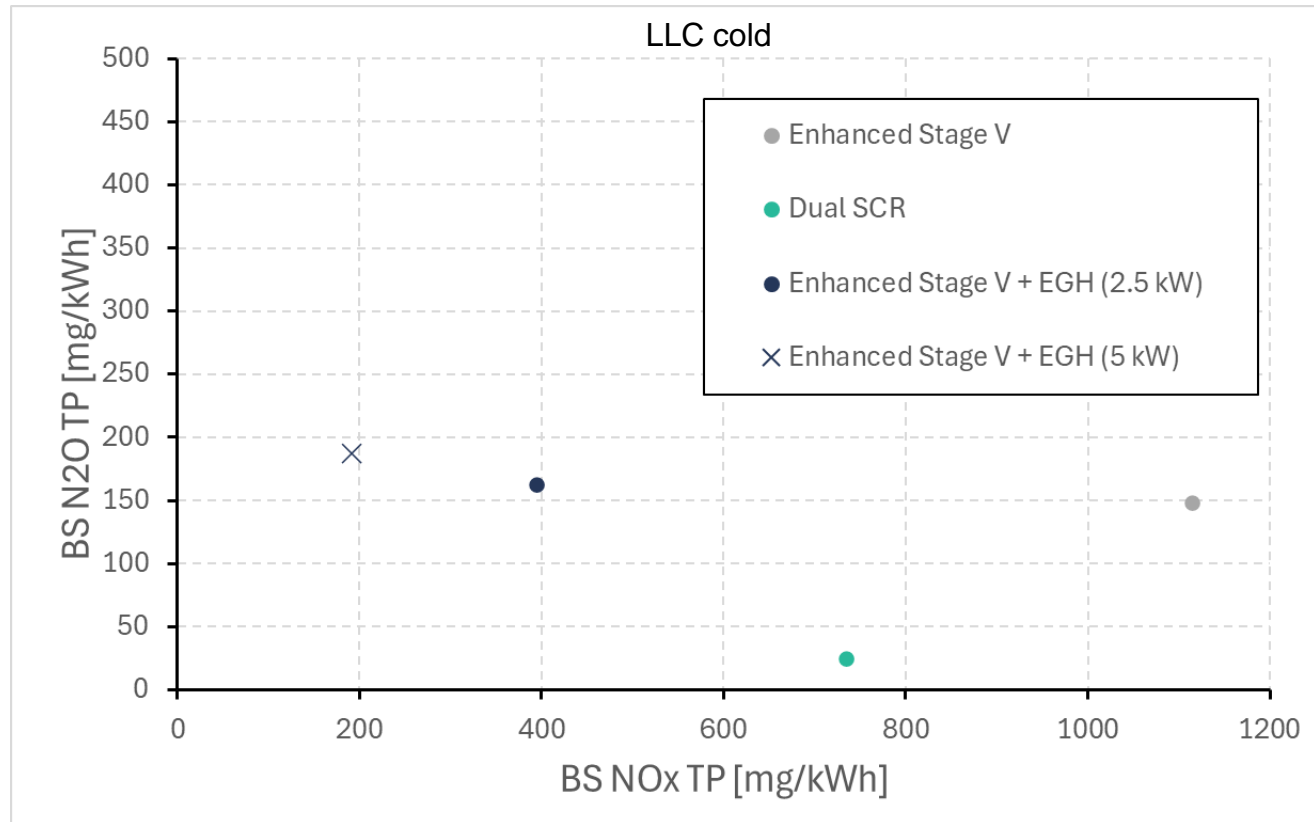
- Data on LLC hot is compared to SwRI [data](#) of Tier 4 engines
- Variant 2 and 3 meet the Tier 5 NOx limit on LLC hot
- For variant 1, the idle load needs to be increased from 44 to 66 Nm





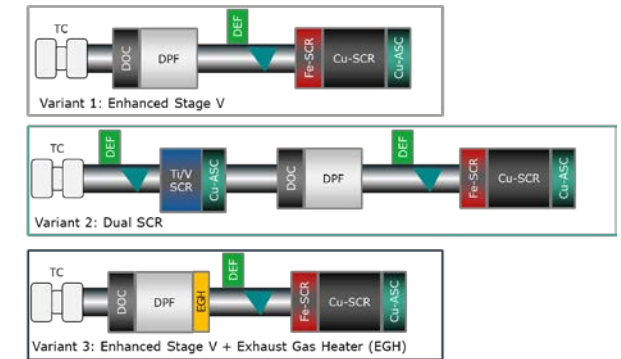
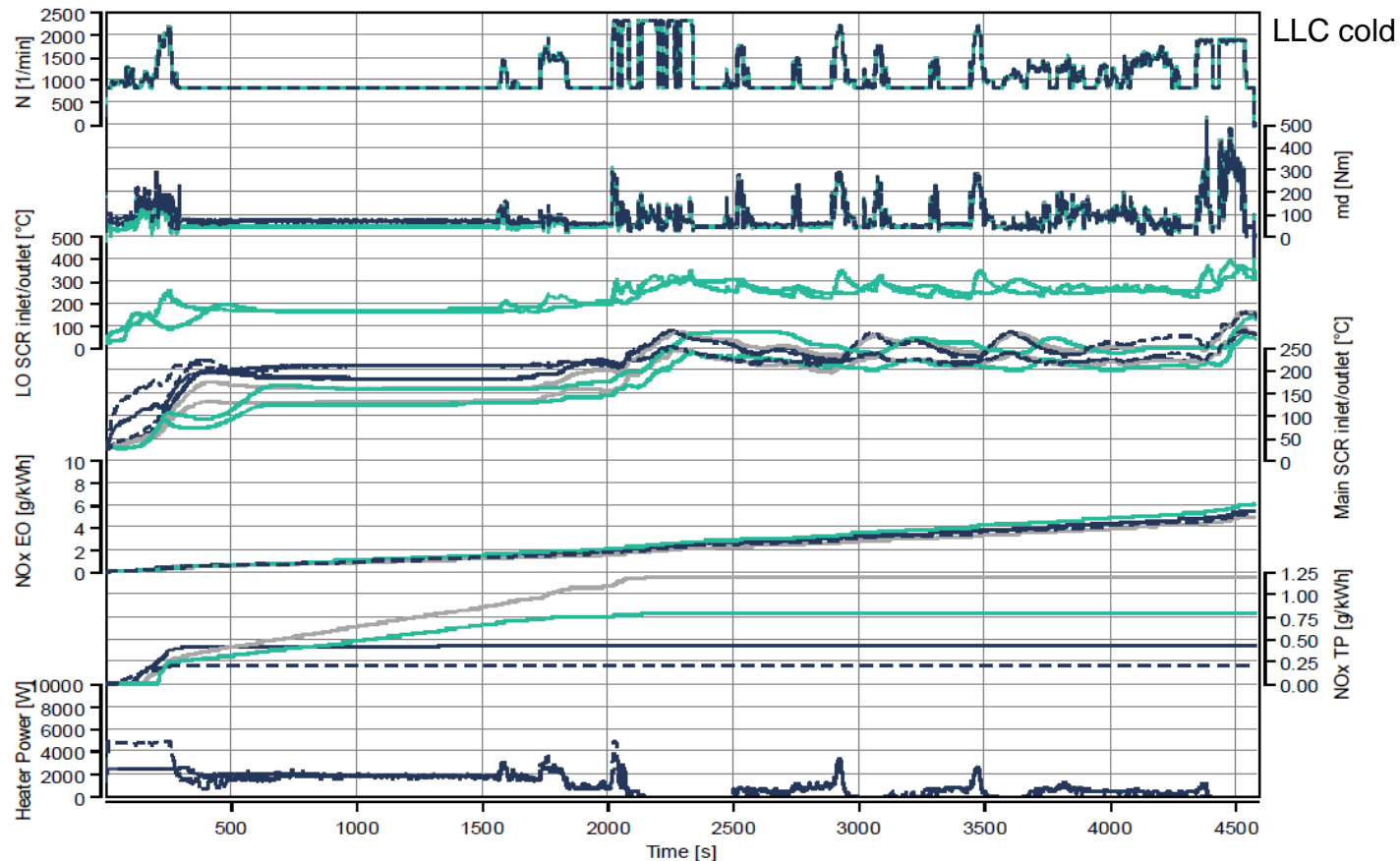
# All 3 variants significantly improve emissions at low load

- 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



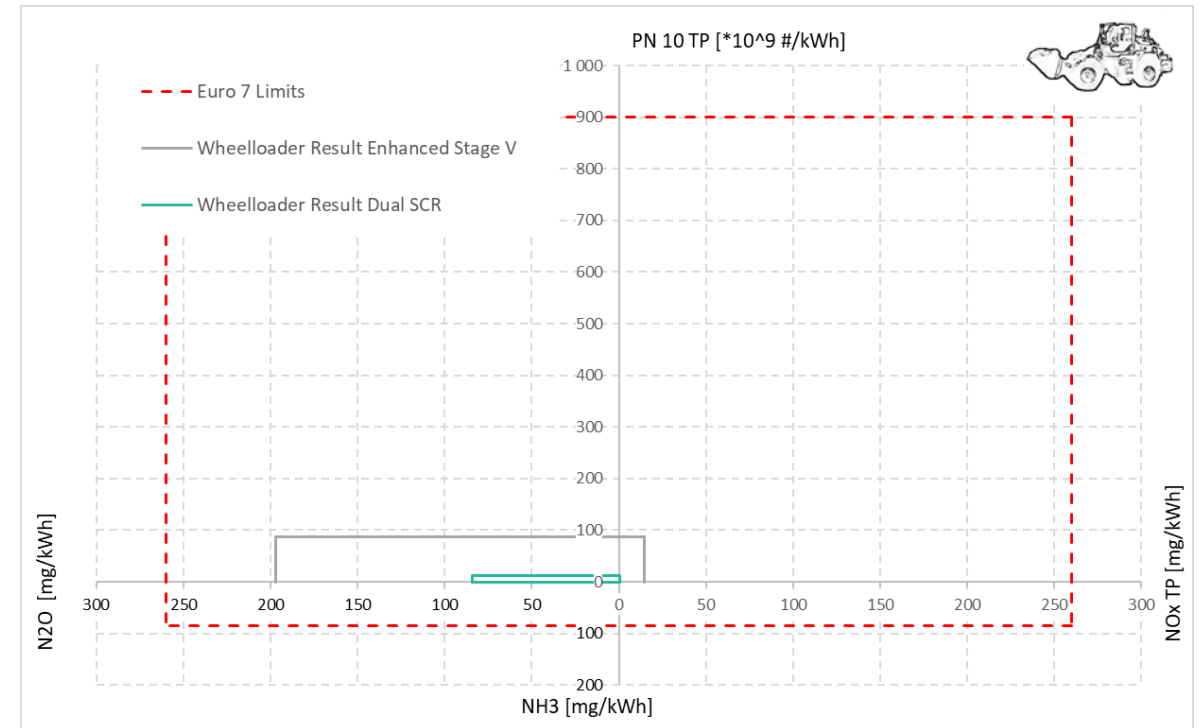
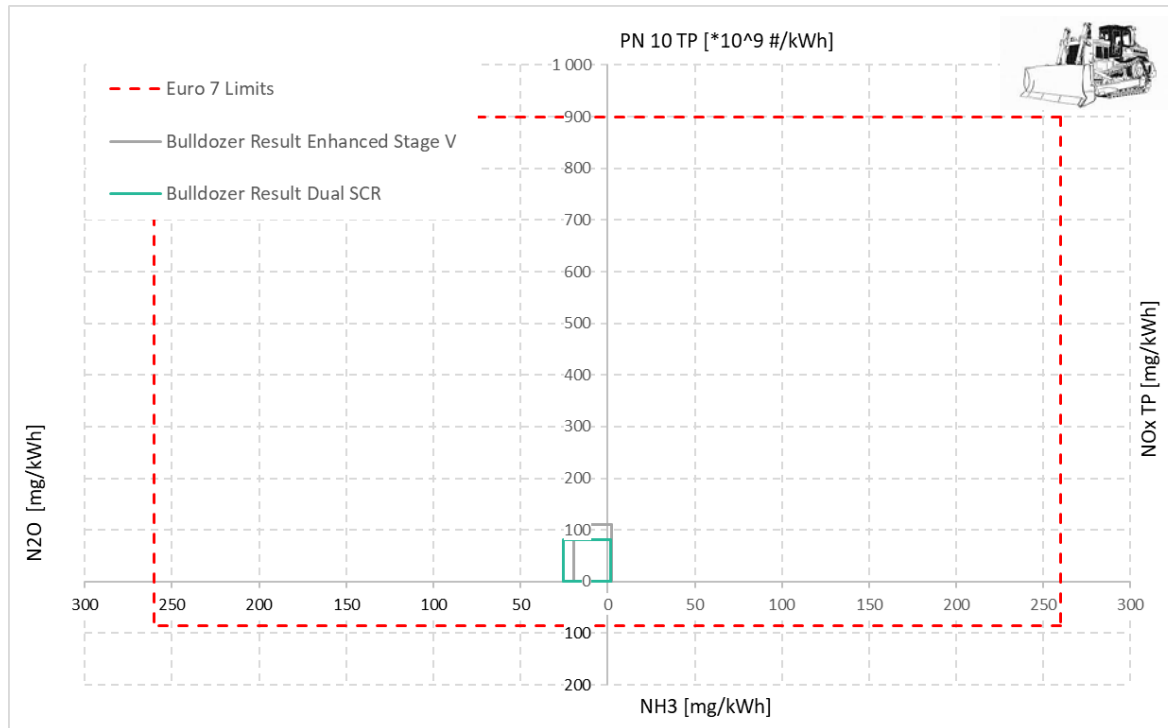
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# Consistent low emissions on in-use cycles

- 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)



# 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<sub>2</sub>-neutral fuels including HVO, e-diesel and H<sub>2</sub>; the Internal Combustion Engine is a future-proof NRMM powertrain option

# THANK YOU!

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