

Potential for reduction in Non-Road Mobile Machinery emissions

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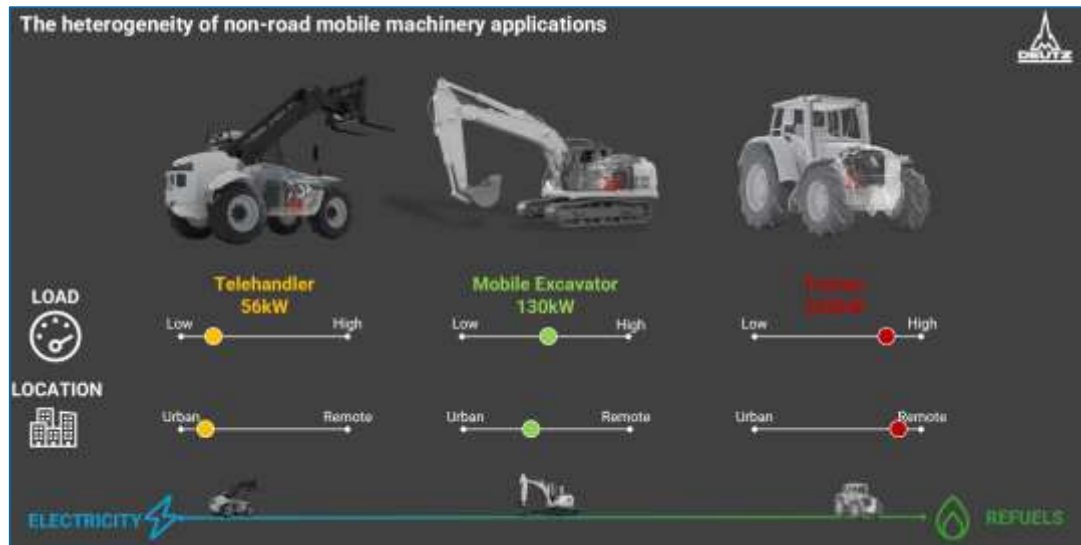
AECC is now the Association for Emissions Control and Climate

- AECC expands its scope
 - Air quality and **climate** requirements
 - Mobile and **stationary** emissions sources
 - Sustainable **components and systems**, including
 - Catalysts
 - Filters
 - Adsorbers
 - Fuel cells
 - Electrolysers
- AECC is listed in EU Transparency Register (# 78711786419-61) and has consultative status with the UN Economic and Social Council (ECOSOC)

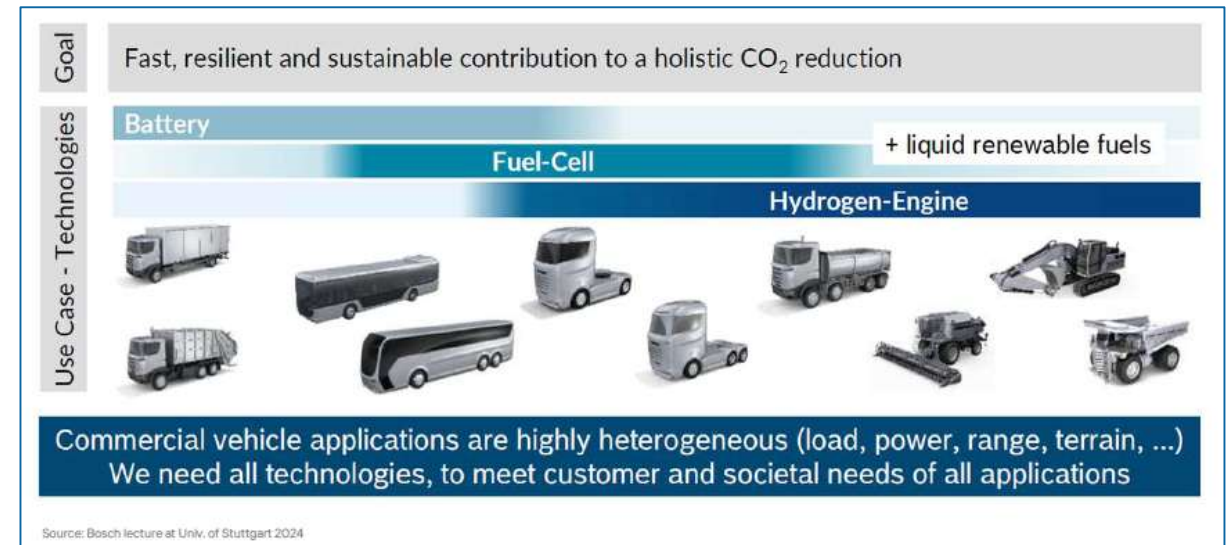


All powertrain technologies needed towards net-zero CO₂

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



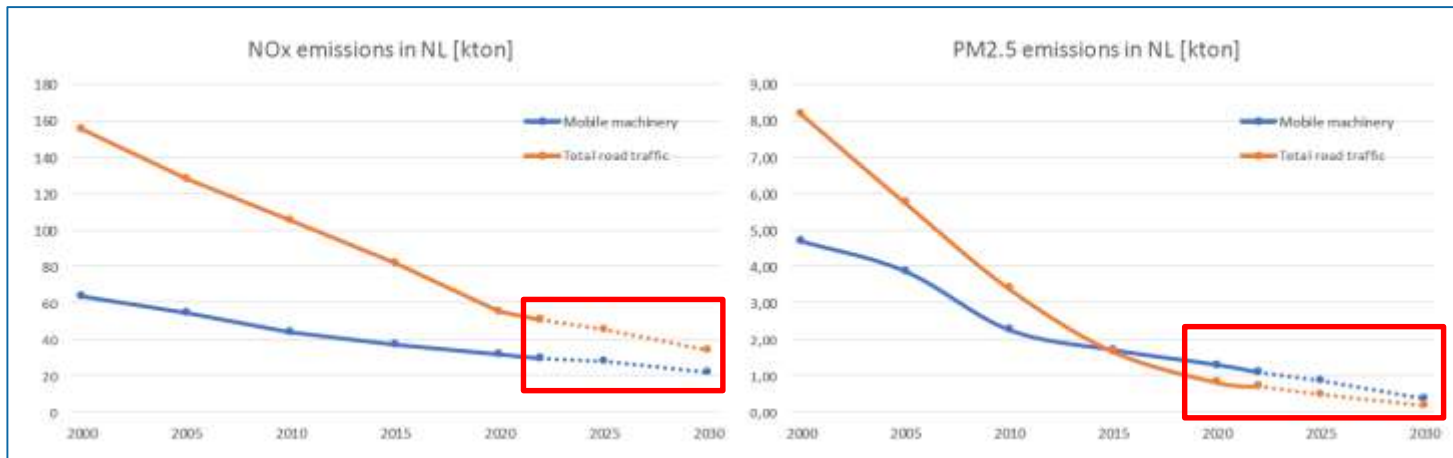
Deutz, Baden-Baden, 2024



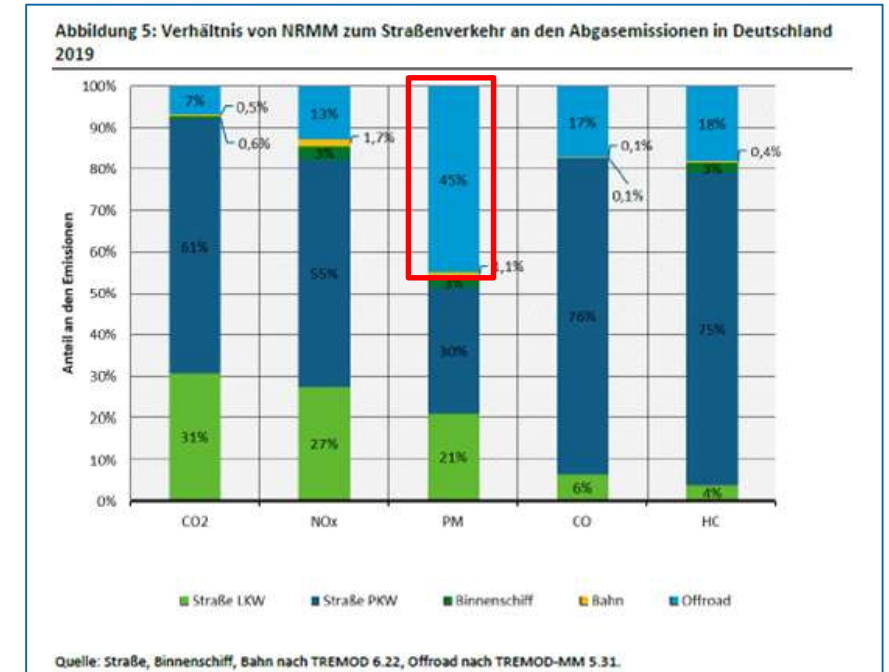
Bosch, lecture at Univ. Stuttgart, 2024

Further reduction of pollutant emissions needed as well

➤ Increasing contribution of NRMM to EU air quality impact



The Netherlands, [GRPE presentation](#), 2023



Germany, [UBA report](#), 2023

Further reduction of pollutant emissions needed as well

- NRMM typically follows on-road HDV legislation, which evolved already 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
- Ongoing initiatives
 - European Commission will review Stage V in 2025 based on PEMS monitoring data
 - Informal discussions at UNECE GRPE about UN Regulation No. 96
 - US CARB started [development for Tier 5](#) by 2029 since November 2021
 - China includes NRMM in China 7 considerations

PEMS: Portable Emissions Measurement System

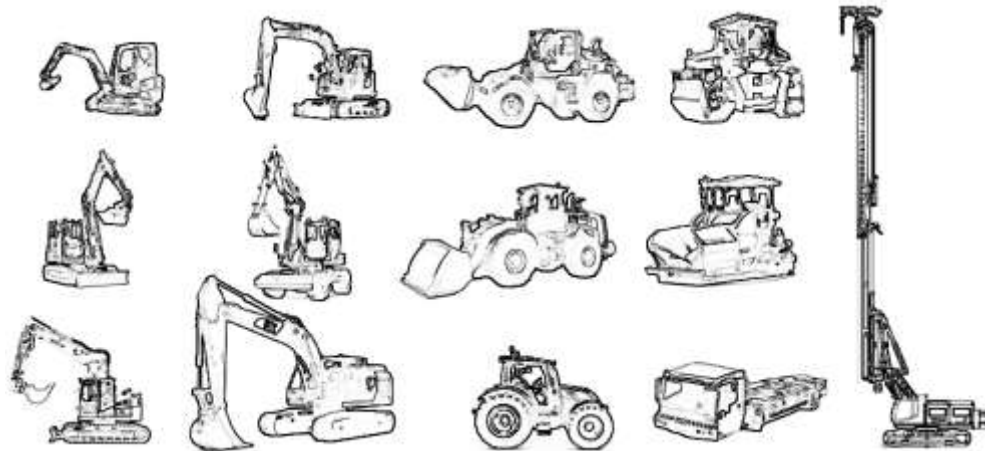


Agenda

- Real-world NO_x emissions of Stage V machines
- NRMM simulation study
 - Set-up with 3 emission control variants
 - NO_x and N₂O emissions
 - CO₂ emissions
- Conclusions

Scope and objective of the NRMM study

- Investigate NO_x emissions of NRMM during operation in the field
- Database of 13 Stage IV and V machines
 - Available data from projects of the Dutch Ministry of Infrastructure and Water Management
 - SEMS measurements done by TNO during daily operation in the Netherlands on range of categories
 - AECC asked TNO to apply new analysis on entire database



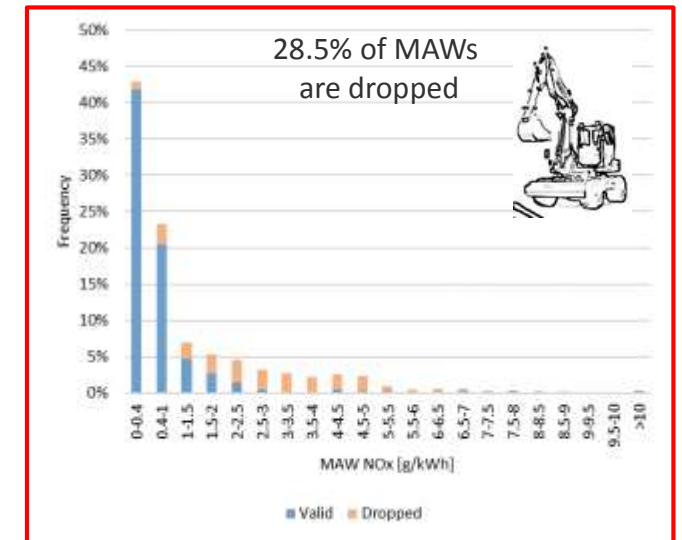
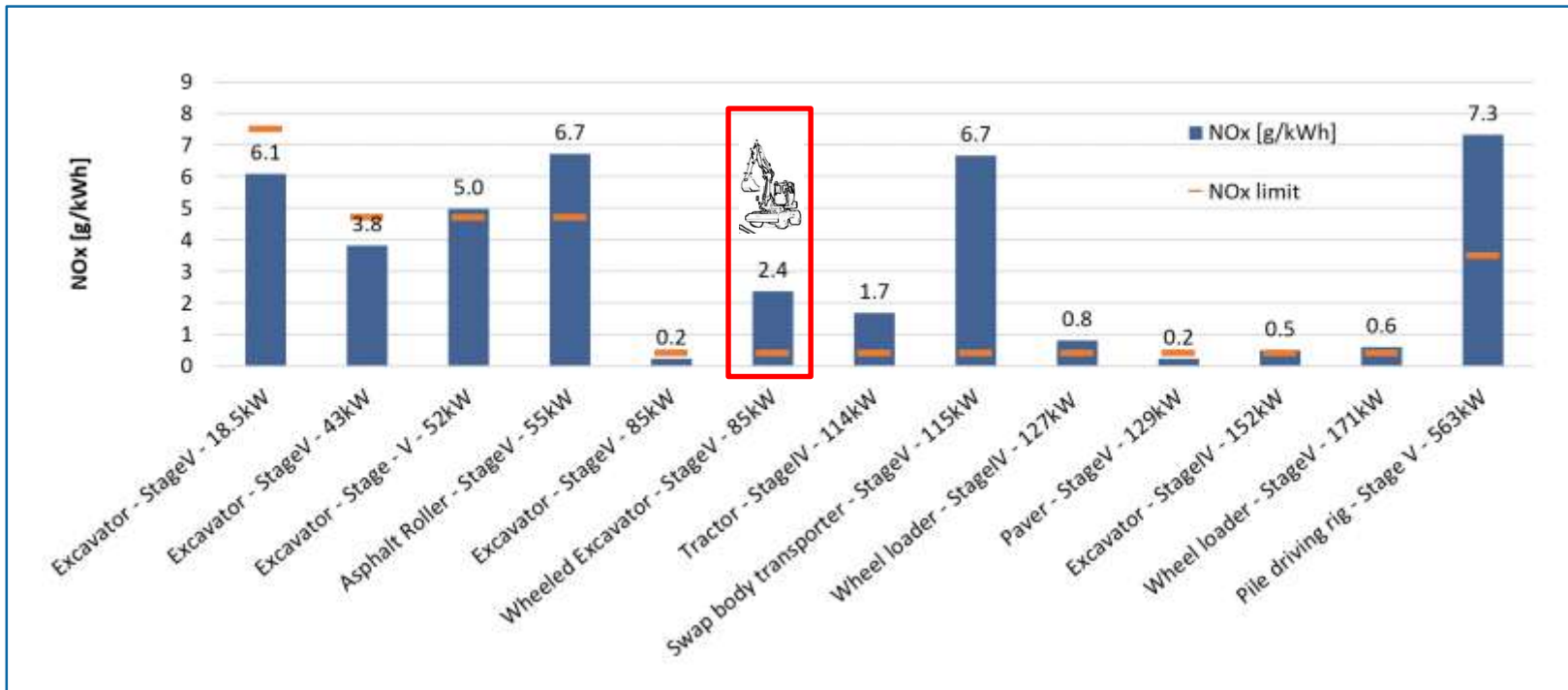
Further details available in: R. Vermeulen, et al.; [“Real-World NO_x emissions of Stage V NRMM”](#), Transport and Air Pollution Conference, 2023

SEMS: Smart Emissions Measurement Systems



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

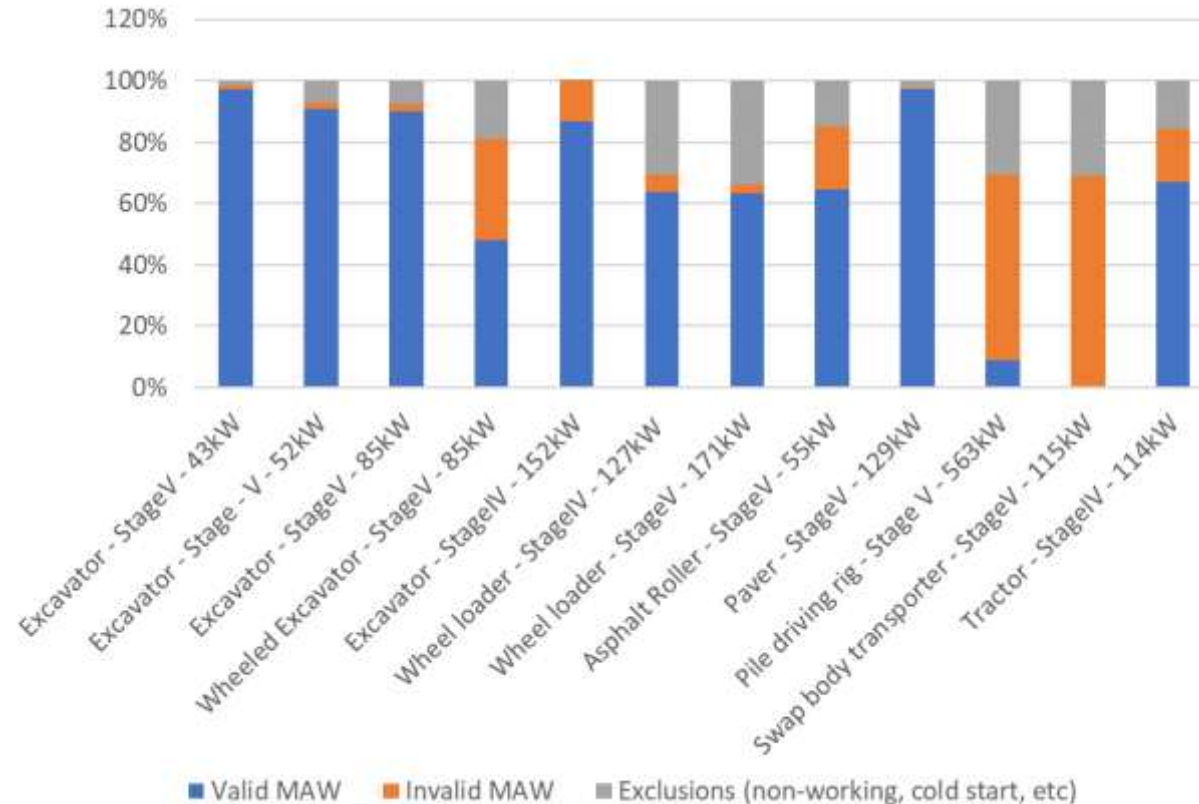


MAW: Moving Average Window

R. Vermeulen, et al.; “[Real-World NOx emissions of Stage V NRMM](#)”, Transport and Air Pollution Conference, 2023

Investigation of distribution of emissions

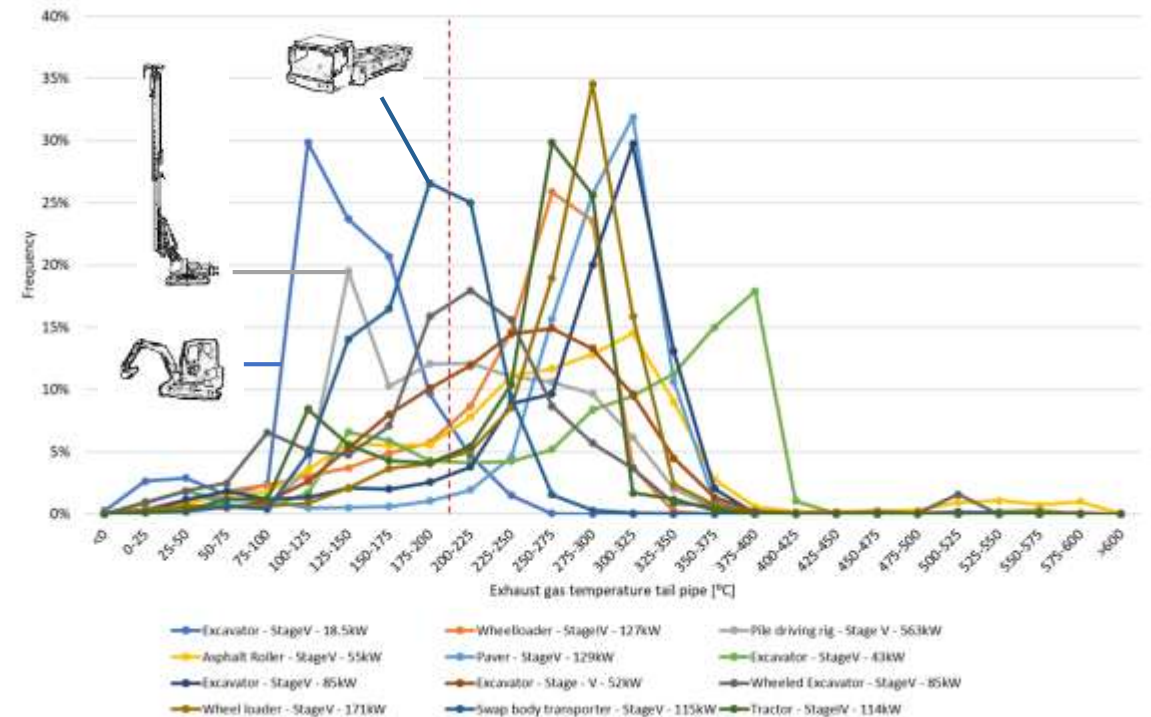
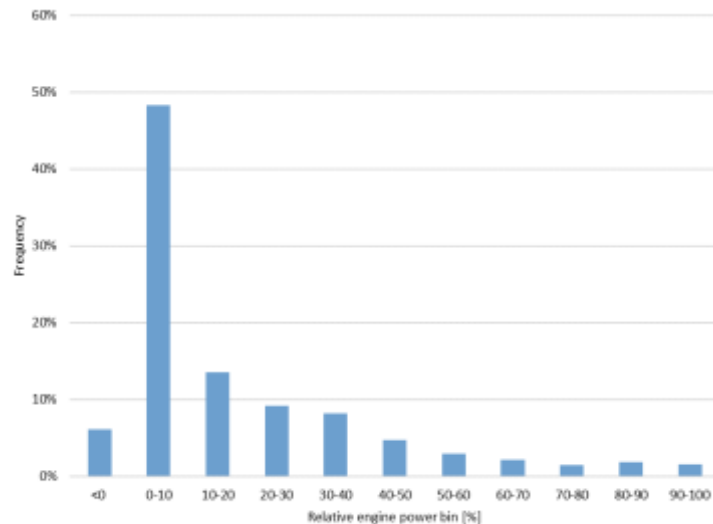
➤ Excluded data can be significant for some applications investigated



MAW: Moving Average Window

Potential root causes for higher NOx emissions

- Some applications with higher emission limits are not equipped with SCR
- Significant amount of low engine power operation
 - 68% of data < 20% of rated power
 - 37% of data < 200 °C exhaust gas temperature (no or limited urea dosing)



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Simulation study on 3 emission control systems

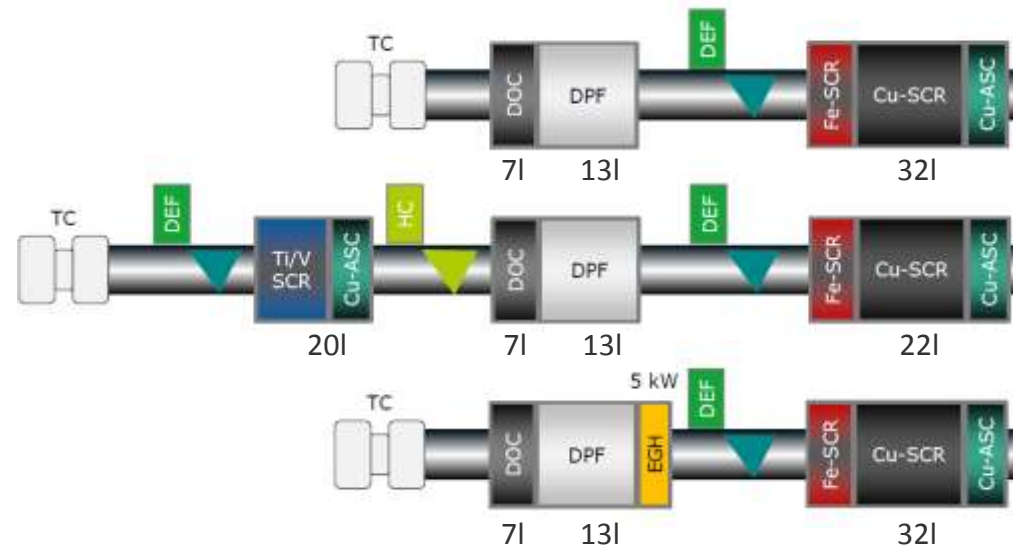
▶ AVL simulation set-up

▶ NRMM engine

- 9l class
- Uncooled High Pressure EGR
- 2-stage turbocharger
- 8-10 g/kWh engine-out NOx

▶ 3 emission control systems

- Variant 1 – enhanced Stage V
- Variant 2 – dual-SCR
- Variant 3 – variant 1 incl. EGH



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

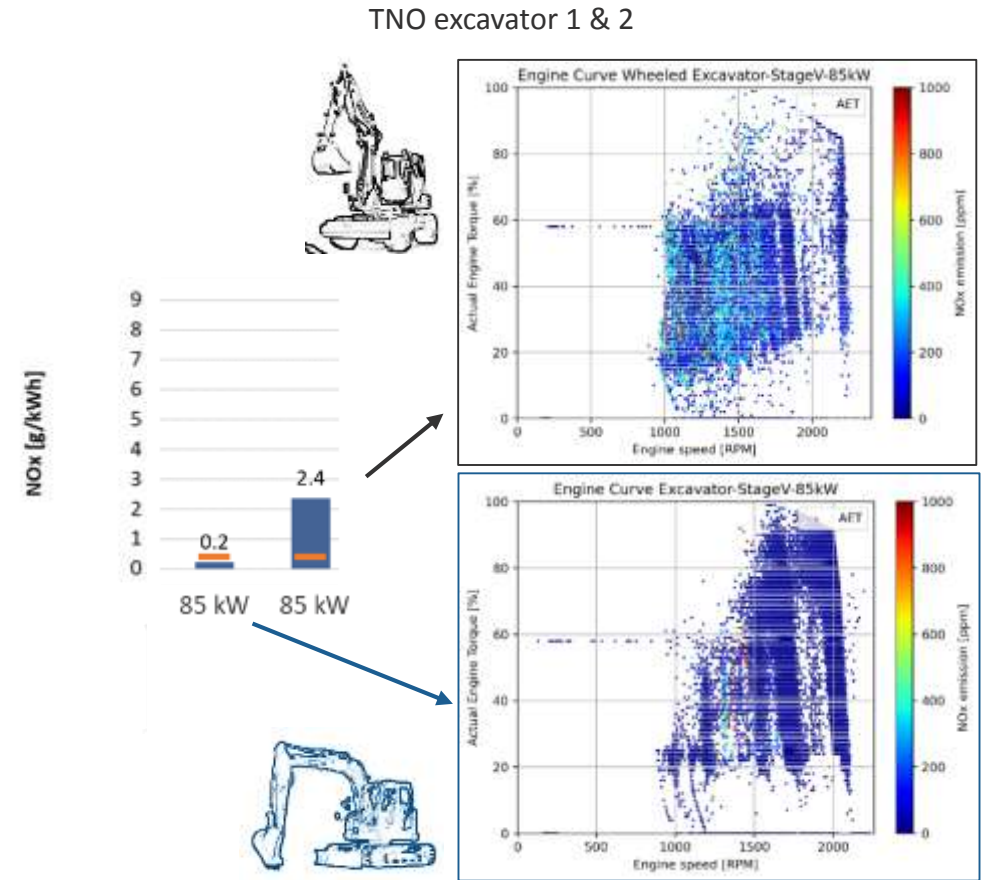
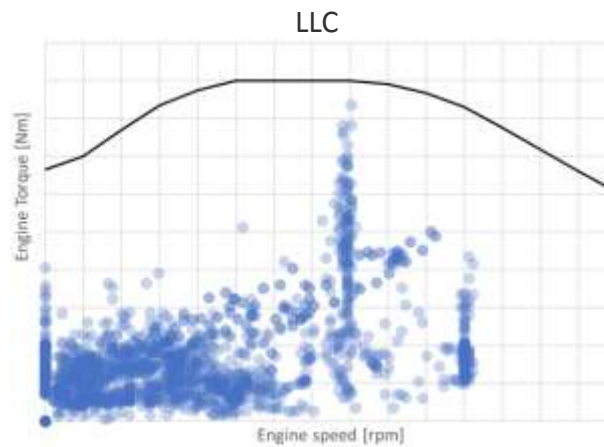
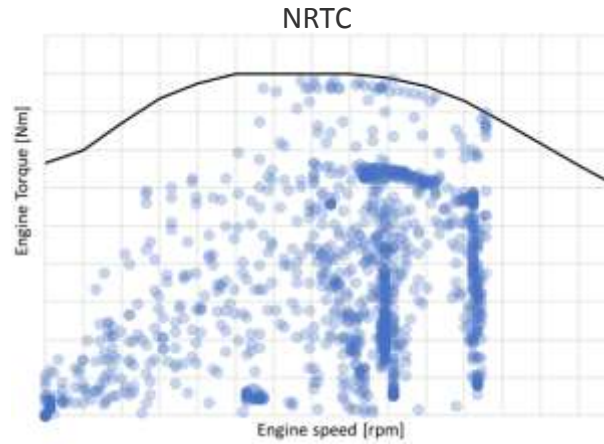
Covering wide variation in NRMM applications

▶ Type approval cycles

- ▶ NRTC cold and hot
- ▶ NRSC
- ▶ RMC
- ▶ LLC

▶ In-use application cycles

- ▶ AVL wheel loader 1
- ▶ AVL wheel loader 2
- ▶ AVL bulldozer
- ▶ AVL hay mover
- ▶ TNO excavator 1
- ▶ TNO excavator 2

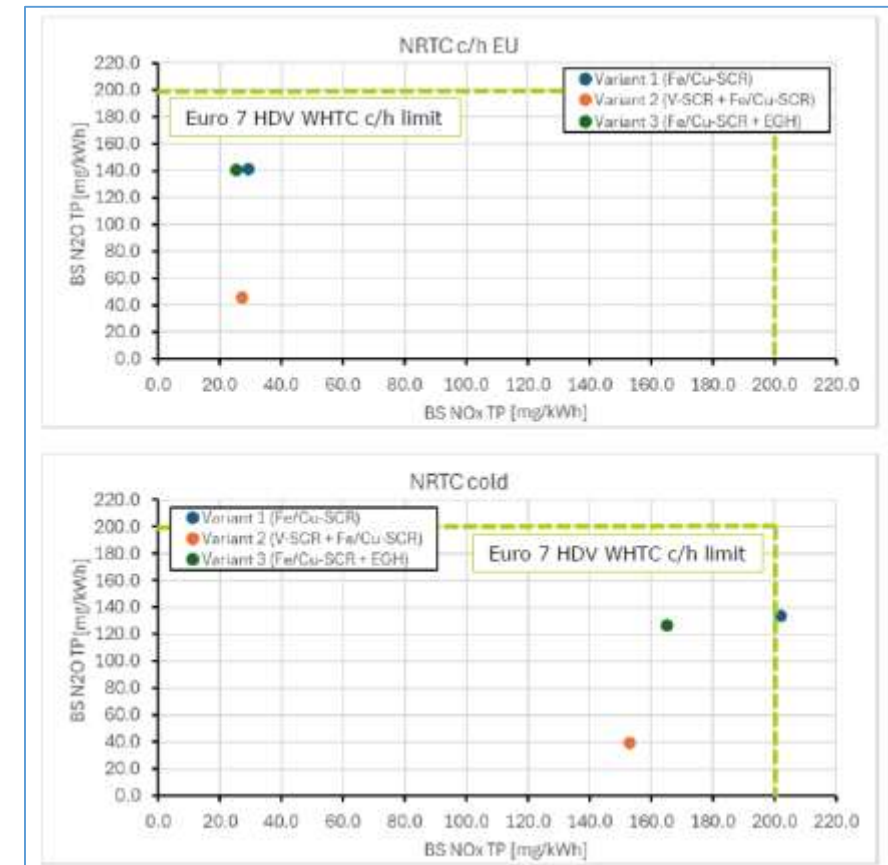
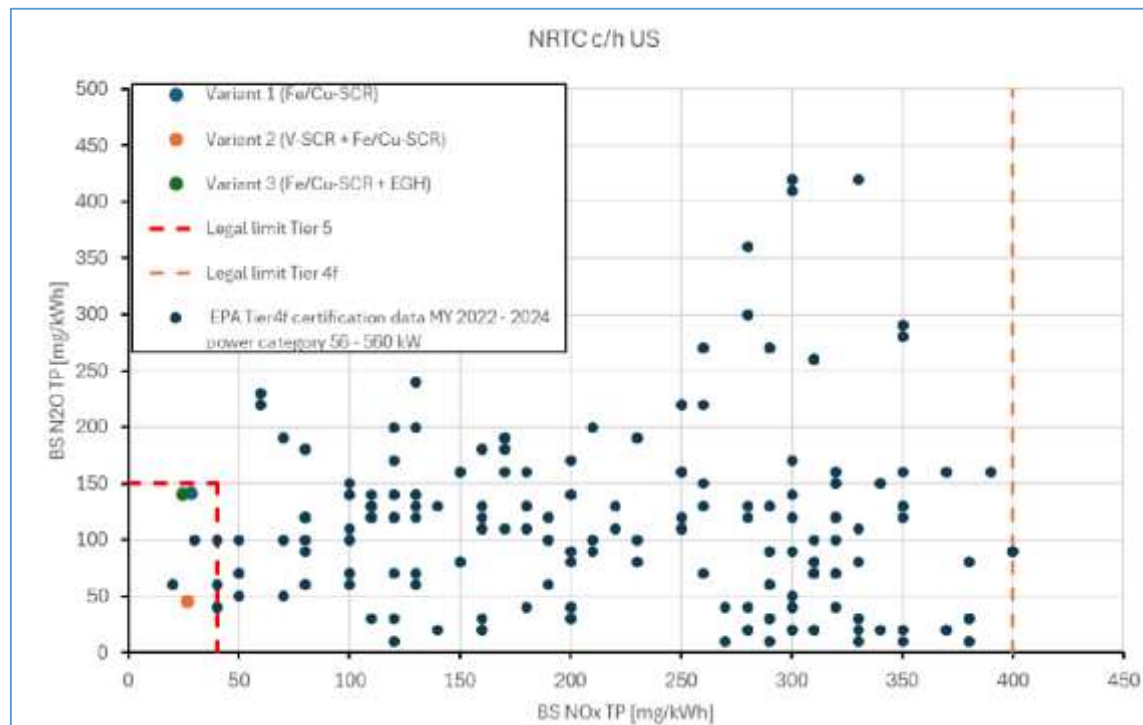


NRTC: Non-Road Transient Cycle
NRSC: Non-Road Steady-state Cycle

RMC: Ramped Mode Cycle
LLC: Low-load Cycle

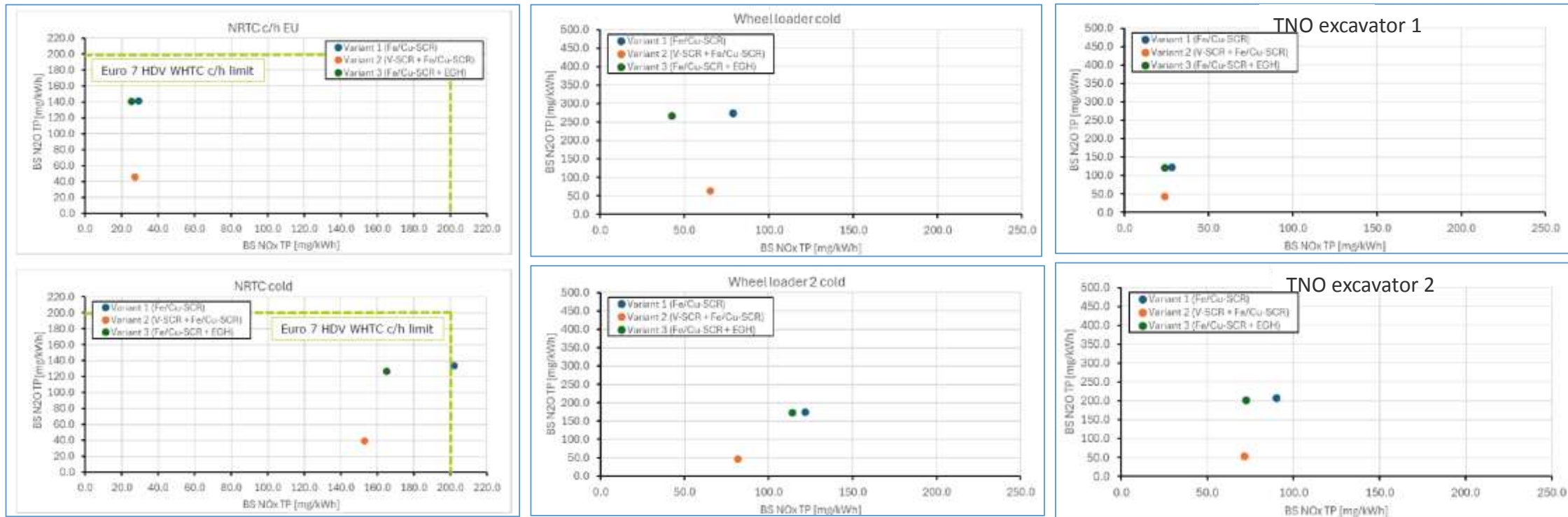
All 3 variants within CARB Tier 5 and Euro 7 limits on NRTC

- At lower end of existing US EPA Tier 4 [certification data](#)
- Variant 2 and 3 show lower cold-start emissions, but not visible after cold/hot weighing
- Variant 2 shows lower N₂O emissions



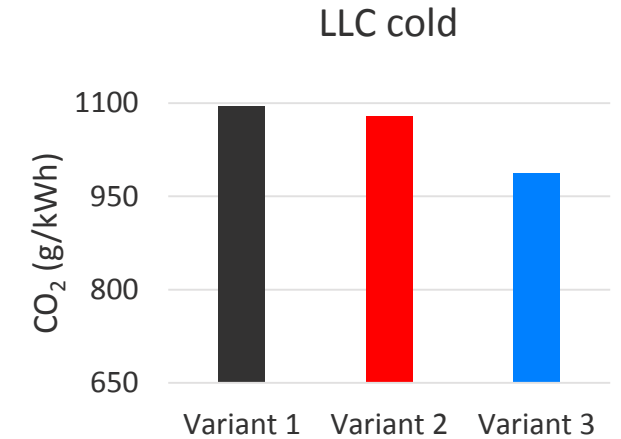
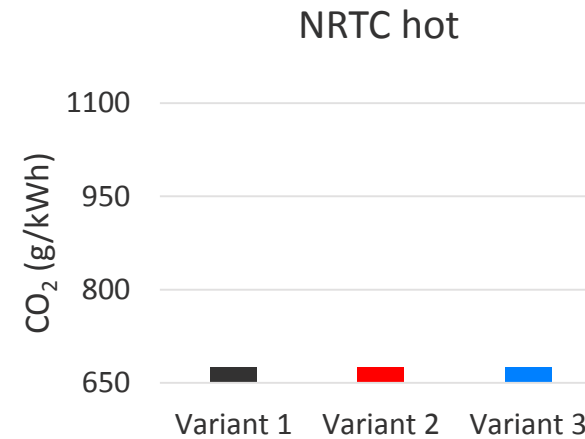
Consistent low emissions on in-use cycles

- Variation of in-use cycles is higher than NRTC with cold-hot weighing
- NRTC cold has highest result due to shorter cycle

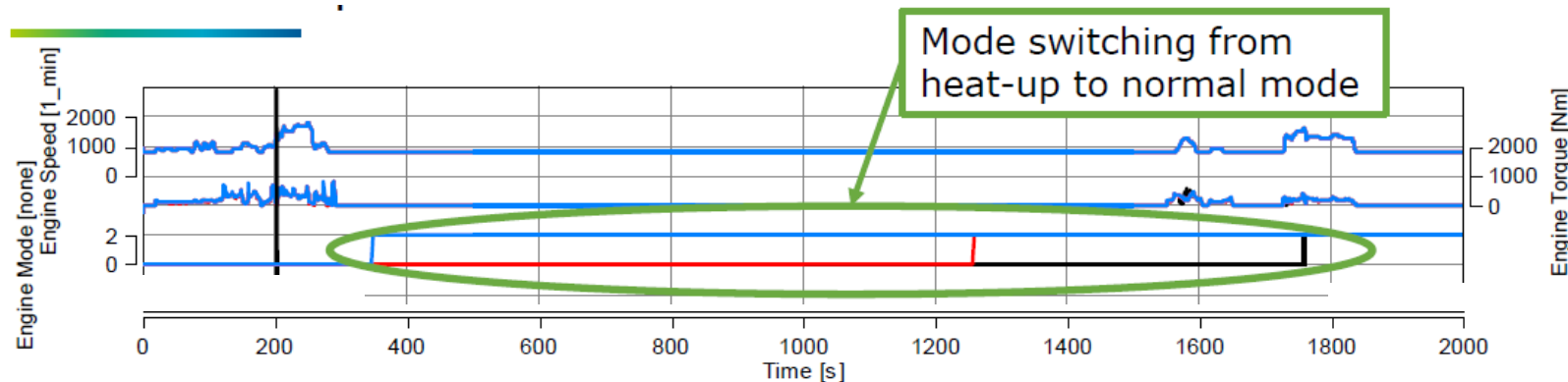


Tailpipe CO₂ emissions

- Similar for all 3 variants on most of the tests
- Except for low-load conditions
 - Up to 10% difference on LLC cold test



- Due to different occurrence of engine mode switching



Boundary Conditions:

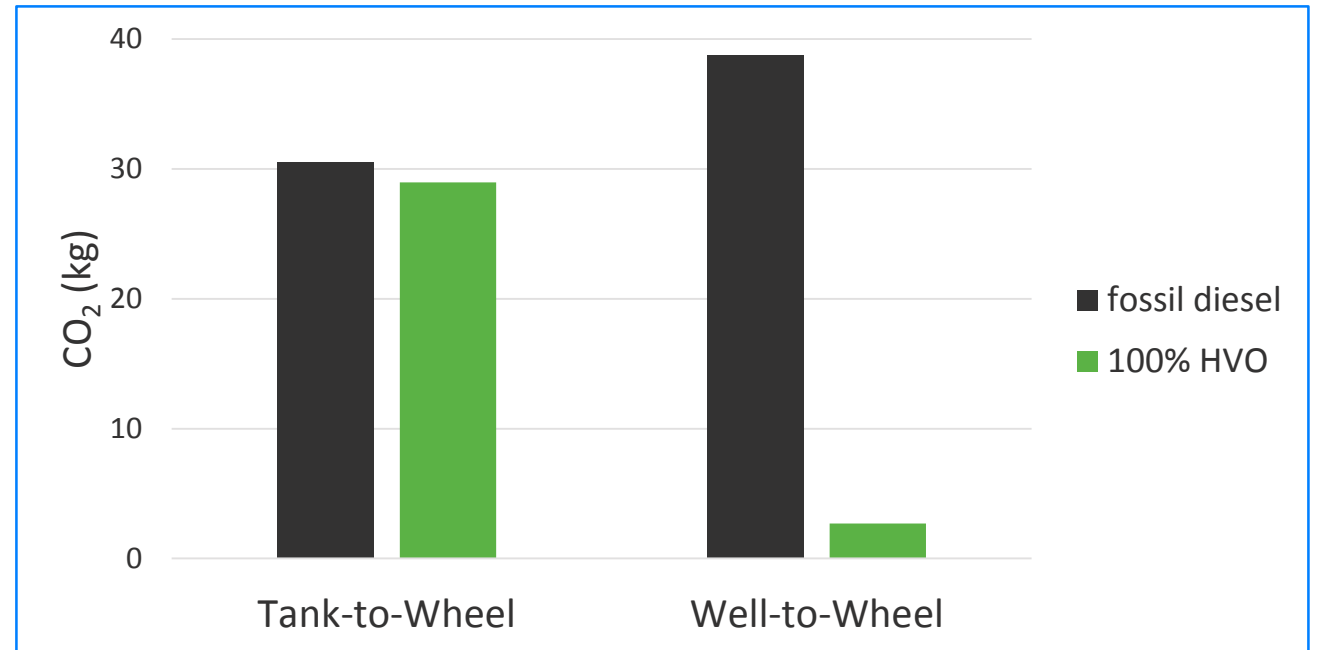
- LLC cold
 - 0 – 2000 seconds
- ATS Variant 1 (black)
- ATS Variant 2 (red)
- ATS Variant 3 (blue)

Well-to-Wheel (WtW) CO₂ emissions

➤ WtW CO₂ emissions can nearly be eliminated by running on CO₂-neutral fuels (CNFs)

➤ Exemplary calculation for NRTC hot

- Fossil diesel
- 100% HVO from waste cooking oil



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Conclusions


- The Internal Combustion Engine (ICE) is a key powertrain for the NRMM use cases
- Future-proof ICE concept requires zero-impact pollutant and net-zero GHG emissions
- Emission control technologies are available to achieve zero-impact 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 NO_x emission level
 - Alternating operating conditions
 - Continuous low-load operation
 - Initial cold-start
- Transition to CO₂-neutral fuels needed to achieve net-zero CO₂ emissions

THANK YOU

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