

# Potential real-world NO<sub>x</sub> and CO<sub>2</sub> emissions reduction for Non-Road Mobile Machinery 非道路机械在实际应用中同时降低NO<sub>x</sub>和CO<sub>2</sub>的技术

Joachim Demuynck

Meeting with VECC • 6 November 2024 • Chengdu

# AECC is now the Association for Emissions Control and Climate 欧洲排放控制与气候联盟

## ► AECC expands its scope AECC涉及的范围

- Air quality and climate requirements 大气质量和气候要求
- Mobile and stationary emissions sources 移动源和固定源
- Sustainable components and systems, including 可持续零部件和系统

- Catalysts 催化剂
- Filters 过滤器
- Adsorbers 吸附剂
- Fuel cells 燃料电池
- Electrolysers 电解槽

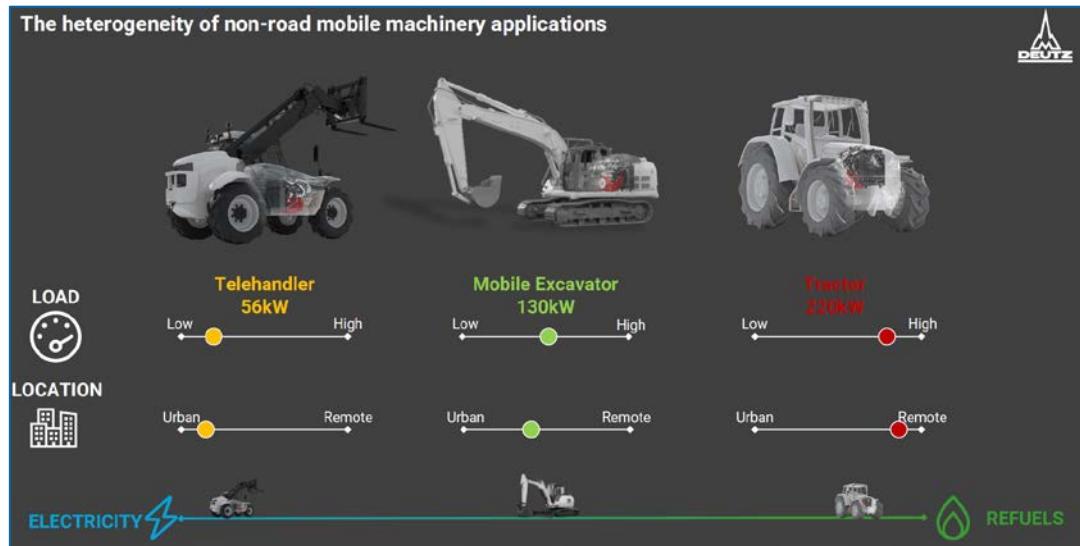
## ► AECC is listed in EU Transparency Register (# 78711786419-61) and has consultative status with the UN Economic and Social Council (ECOSOC)

在欧盟注册、在联合国经合组织框架内的咨询服务

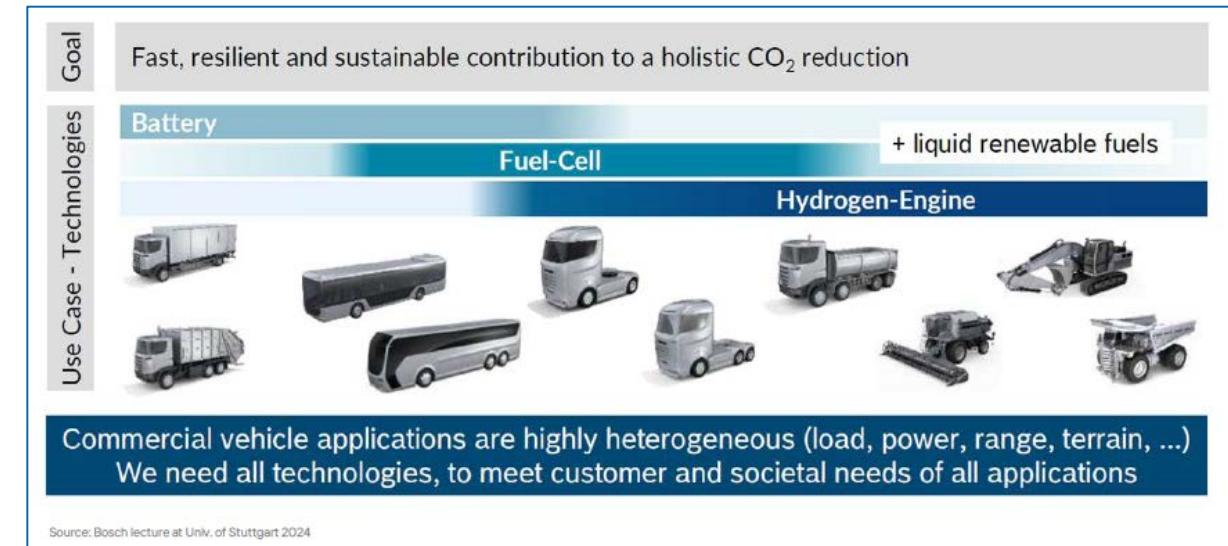


# All powertrain technologies needed towards net-zero CO<sub>2</sub> 所有动力系统都需要实现净零CO<sub>2</sub>排放

- Internal Combustion Engine (ICE) remains key for the NRMM use cases  
内燃机是非道路移动机械的核心动力
- Different sustainable renewable fuels are investigated to reduce the carbon footprint  
为减小碳足迹，不同的可持续燃料在开发中



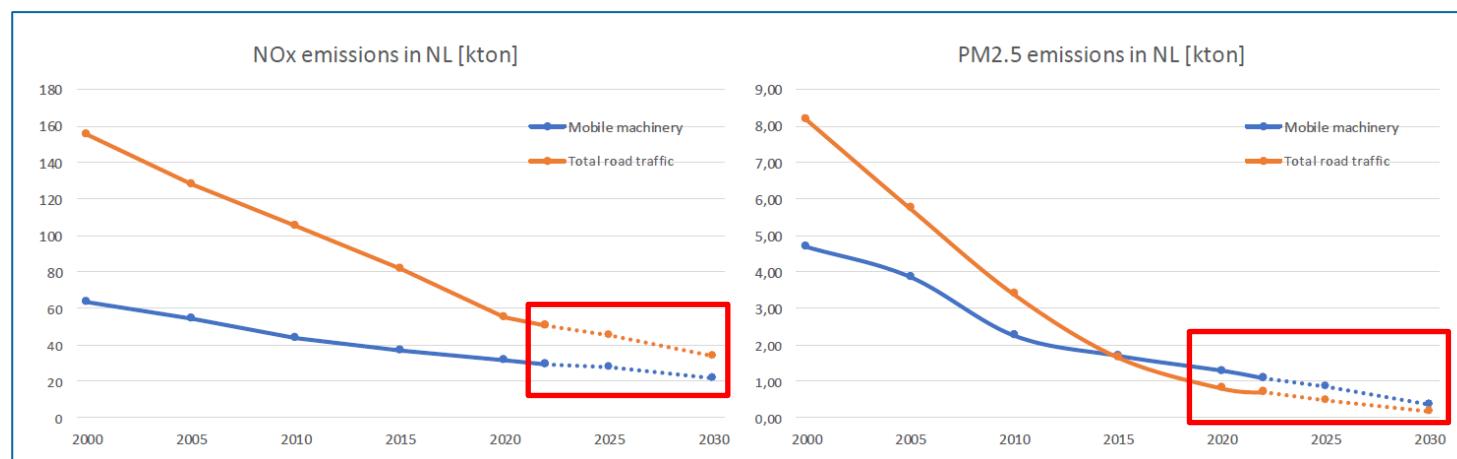
Deutz, Baden-Baden, 2024



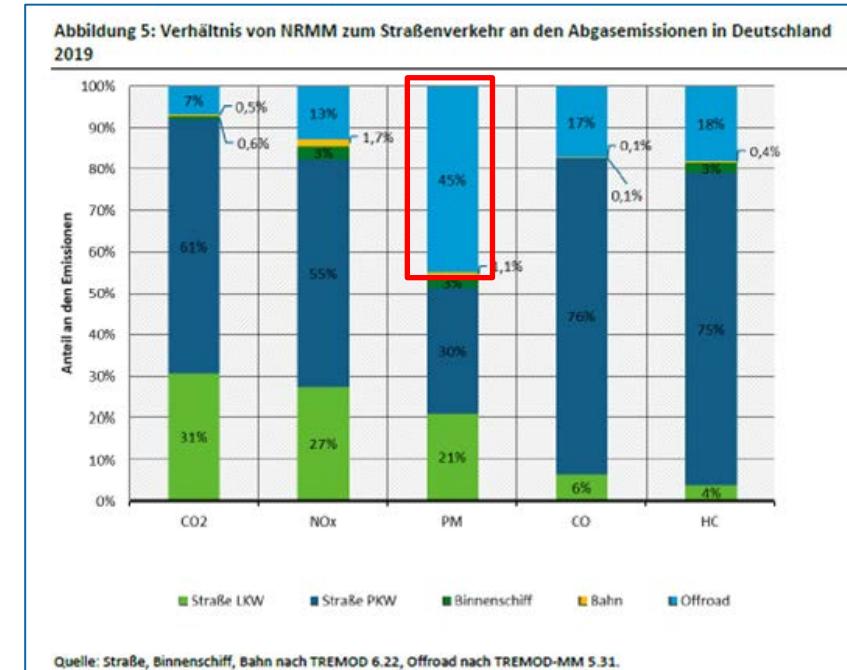
Bosch, lecture at Univ. Stuttgart, 2024

# Further reduction of pollutant emissions needed as well 常规污染物也必须降低

- Increasing contribution of NRMM to EU air quality impact  
非道路机械对欧盟的空气质量的影响在增加



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



Germany, [UBA report](#), 2023

# Further reduction of pollutant emissions needed as well 常规污染物也必须降低

- ▶ NRMM typically follows on-road HDV legislation, which evolved already towards Euro 7  
非道路机械排放法规一般紧随重型车法规，重型目前已经发布了欧七
  - ▶ Applying PEMS In-Service Conformity (ISC) instead of monitoring only 基于PEMS的在用符合性
  - ▶ Removing data exclusions which significantly impact the measurement results 包括所有测试数据
  - ▶ Reducing the emission limits 降低排放限值
- ▶ Ongoing initiatives 目前的进展
  - ▶ European Commission will review Stage V in 2025 based on PEMS monitoring data  
欧盟2025年开始审核非道路五阶段PEMS测试数据
  - ▶ Informal discussions at UNECE GRPE about UN Regulation No. 96 联合国96号法规在非正式讨论中
  - ▶ US CARB started development for Tier 5 by 2029 since November 2021, US EPA started as well  
加州从2021年11月开始非道路五阶段立法，EPA也已经开始

PEMS: Portable Emissions Measurement System

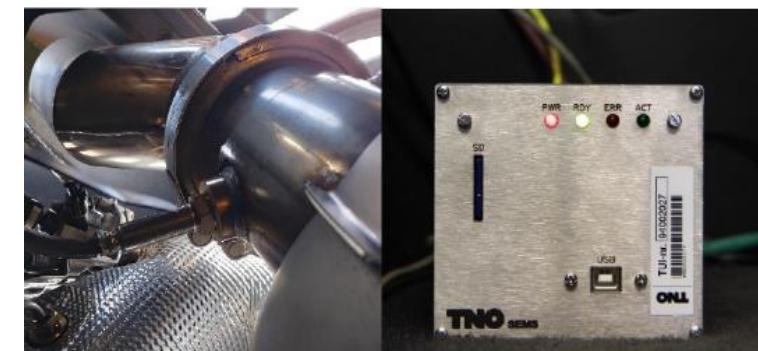
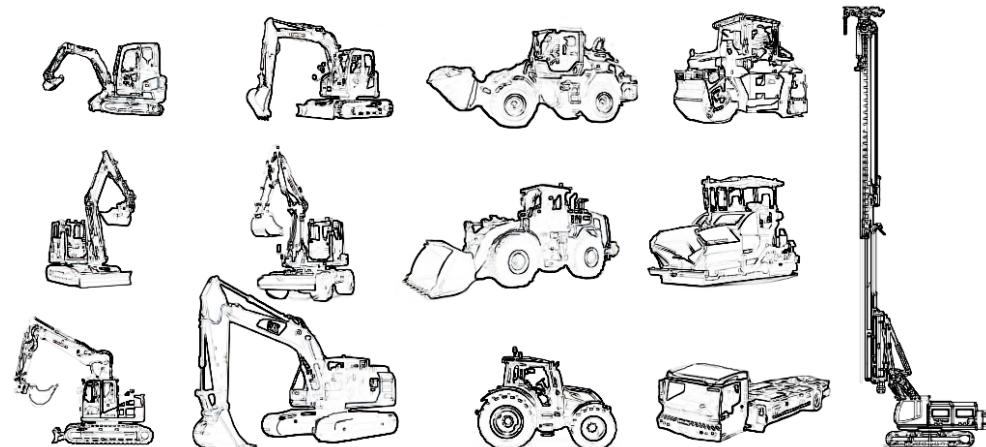


# Agenda

- ▶ Real-world NOx emissions of Stage V machines 五阶段非道路机械在实际运行中的NOx排放
- ▶ NRMM simulation study 模拟研究
  - ▶ Set-up with 3 emission control variants 三个排放控制变量
  - ▶ NOx and N<sub>2</sub>O emissions NOx和N<sub>2</sub>O排放
  - ▶ CO<sub>2</sub> emissions CO<sub>2</sub>排放
- ▶ Conclusions 结论

# Scope and objective of the NRMM study 项目目的及内容

- ▶ Investigate NOx emissions of NRMM during operation in the field 非道路运行时的NOx排放
- ▶ Database of 13 Stage IV and V machines 13辆四阶段及五阶段移动机械
  - ▶ 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 采用智能排放测试系统对非道路机械的日常运行进行排放测试
  - ▶ AECC asked TNO to apply new analysis on entire database

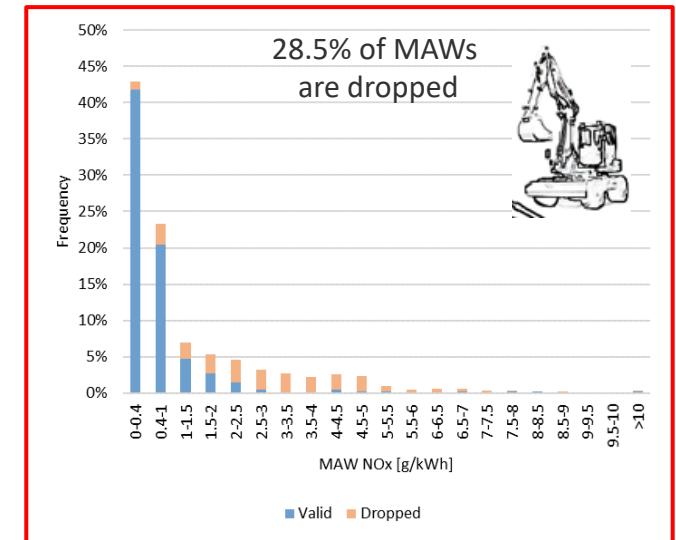
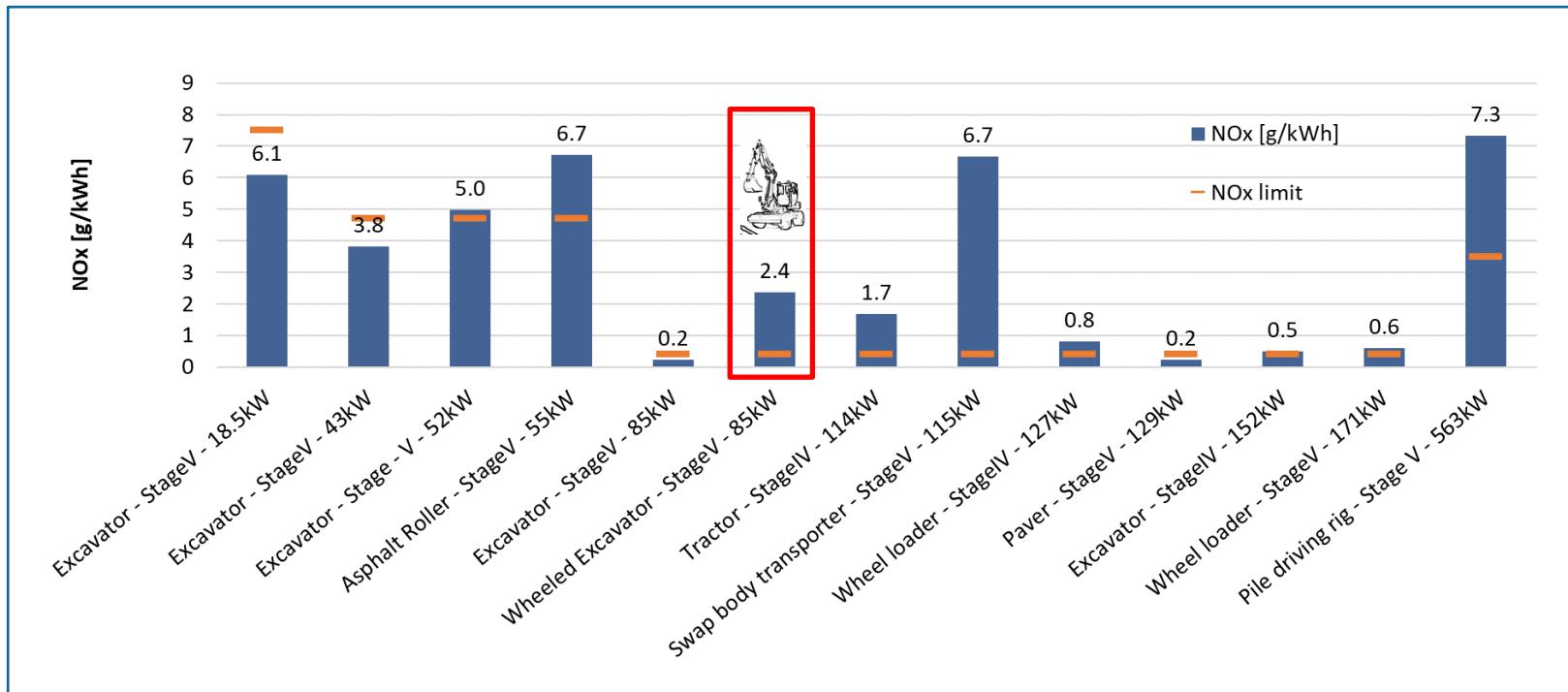


Further details available in: R. Vermeulen, et al.; "[Real-World NOx emissions of Stage V NRMM](#)", Transport and Air Pollution Conference, 2023

SEMS: Smart Emissions Measurement Systems

# A large variation is observed in real-world NOx emissions 不同机械在实际运行的NOx排放有显著差异

- ▶ Depending on the use case and applicable limit 取决于实际应用及相应的法规限值
- ▶ NRMM regulation does not consider a substantial share of the real working conditions 法规对实际运行的工况代表性不足



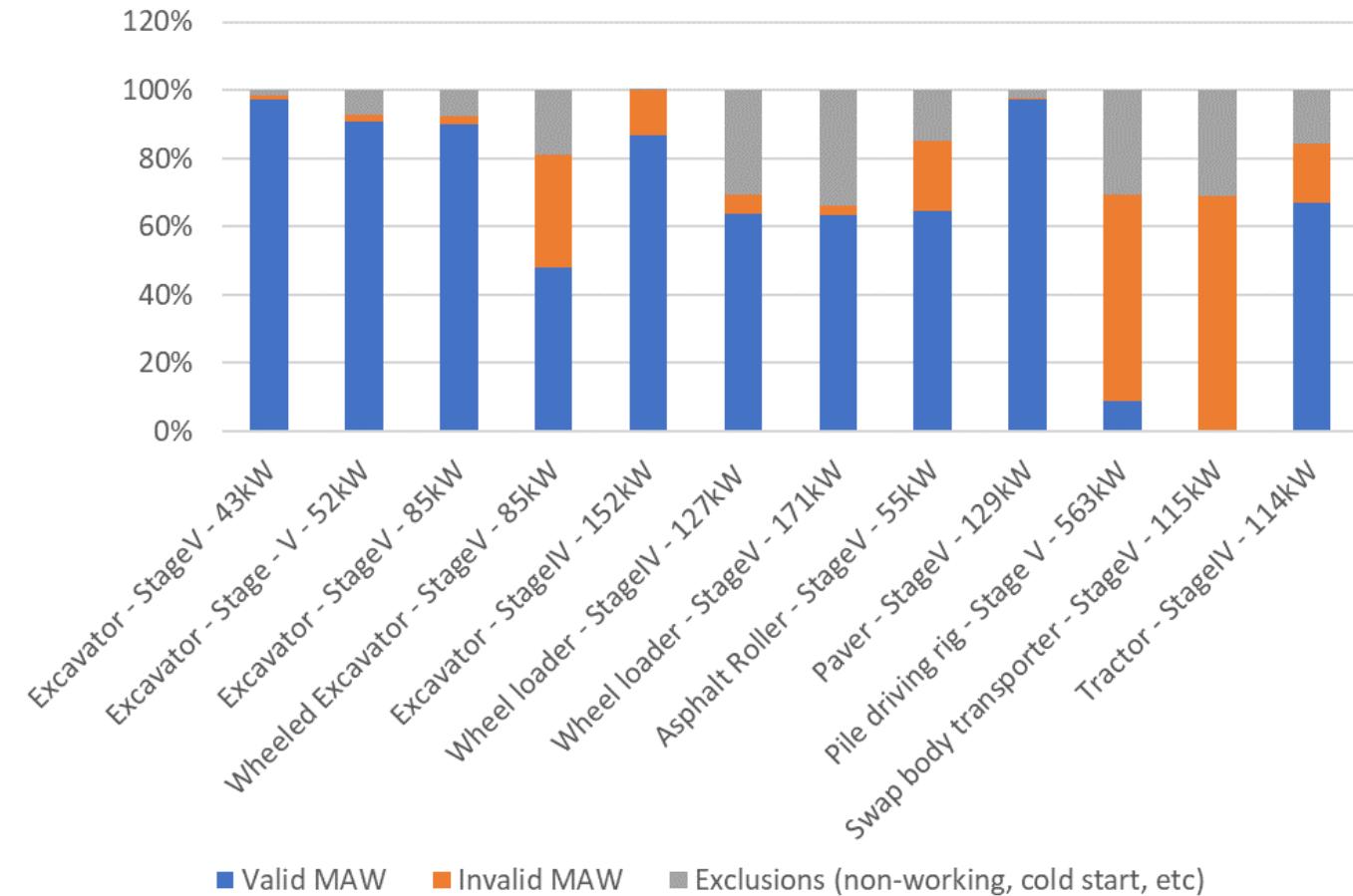
MAW: Moving Average Window

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

# Investigation of distribution of emissions 排放结果分布

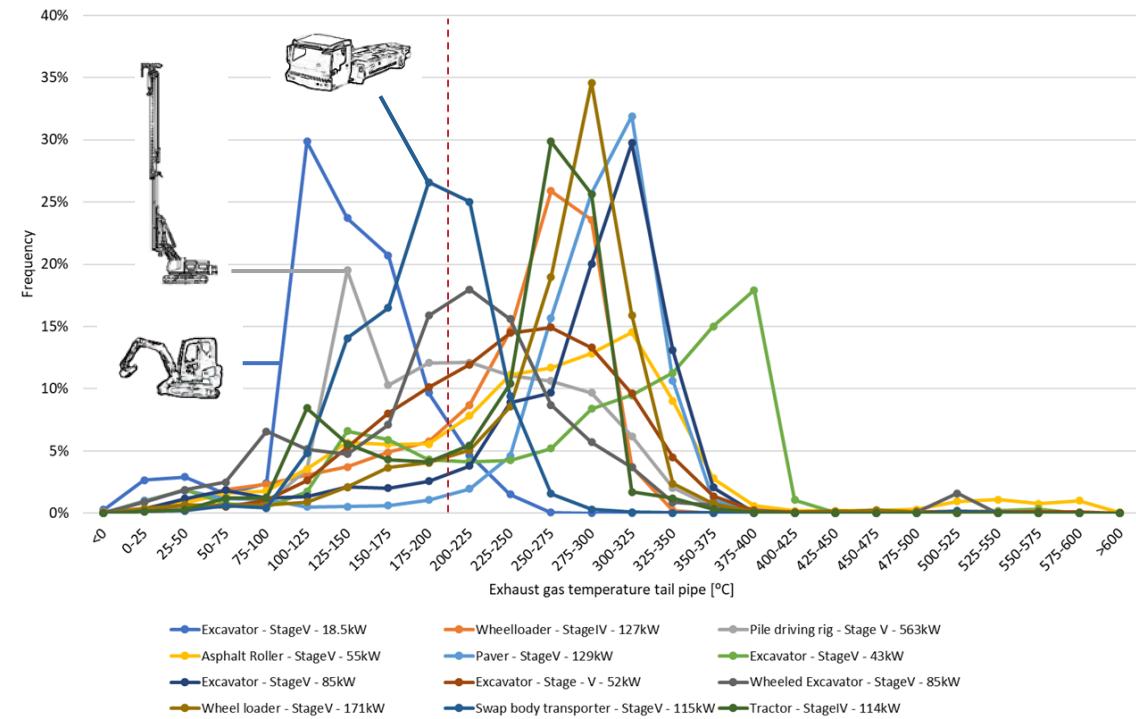
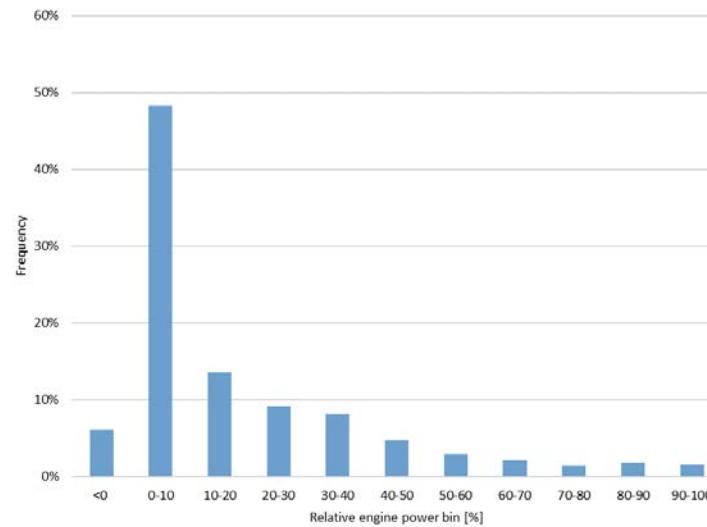
- Excluded data can be significant for some applications investigated

去除某些数据对结果影响明显



# Potential root causes for higher NOx emissions 高排放的根本原因

- Some applications with higher emission limits are not equipped with SCR 有的机械没有SCR
- Significant amount of low engine power operation 低功率运行
  - 68% of data < 20% of rated power 低于20%功率的运行数据占68%
  - 37% of data < 200 °C exhaust gas temperature (no or limited urea dosing) 排温低于200°C占37%



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# Simulation study on 3 emission control systems 模拟研究

## ➤ AVL simulation set-up

### ➤ NRMM engine 发动机

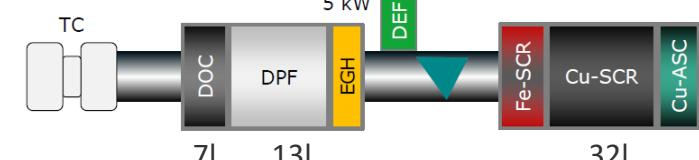
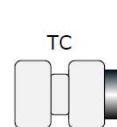
- 9l class 9L
- Uncooled High Pressure EGR 无冷却高压EGR
- 2-stage turbocharger 两级涡轮增压器
- 8-10 g/kWh engine-out NOx 发动机出口NOx

### ➤ 3 emission control systems 三套后处理系统

- Variant 1 – enhanced Stage V 加强版五阶段

- Variant 2 – dual-SCR 双喷SCR

- Variant 3 – variant 1 incl. EGH . 电加热



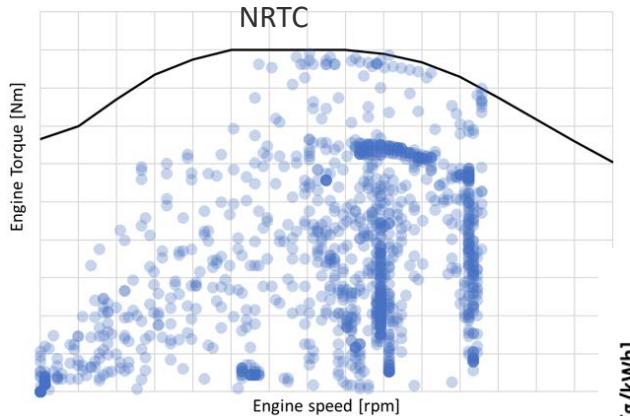
EGR: Exhaust Gas Recirculation  
TC: Turbocharger  
EGH: Exhaust Gas Heater  
SCR: Selective Catalytic Reduction  
ASC: Ammonia Slip Catalyst  
DOC: Diesel Oxidation Catalyst  
DPF: Diesel Particulate Filter

# Covering wide variation in NRMM applications

## 涵盖广泛的非道路应用

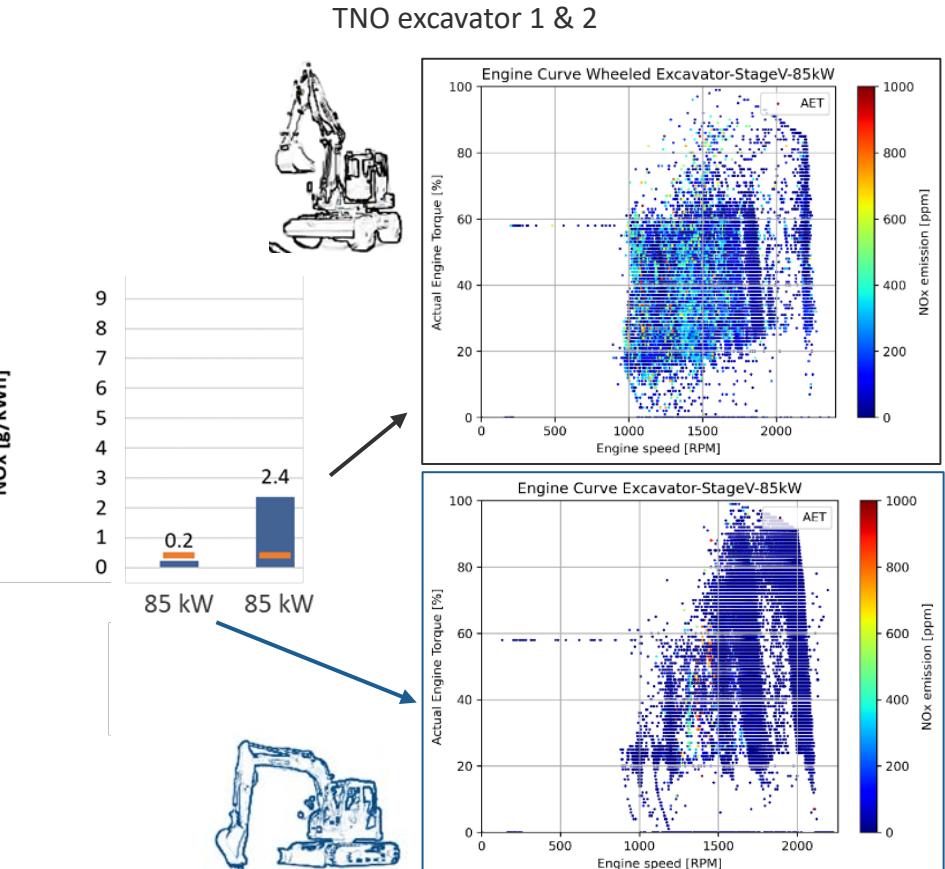
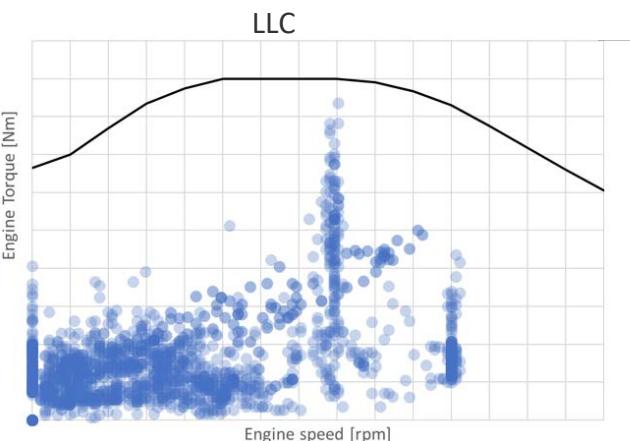
### ▶ Type approval cycles 认证工况

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



### ▶ In-use application cycles 实际工况

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



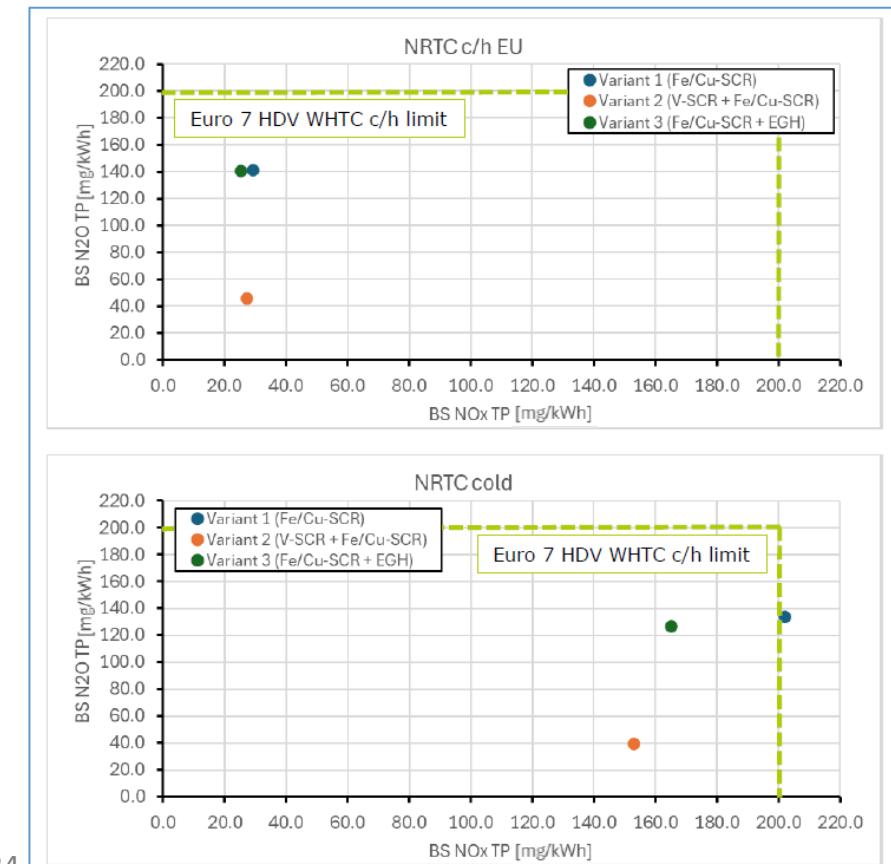
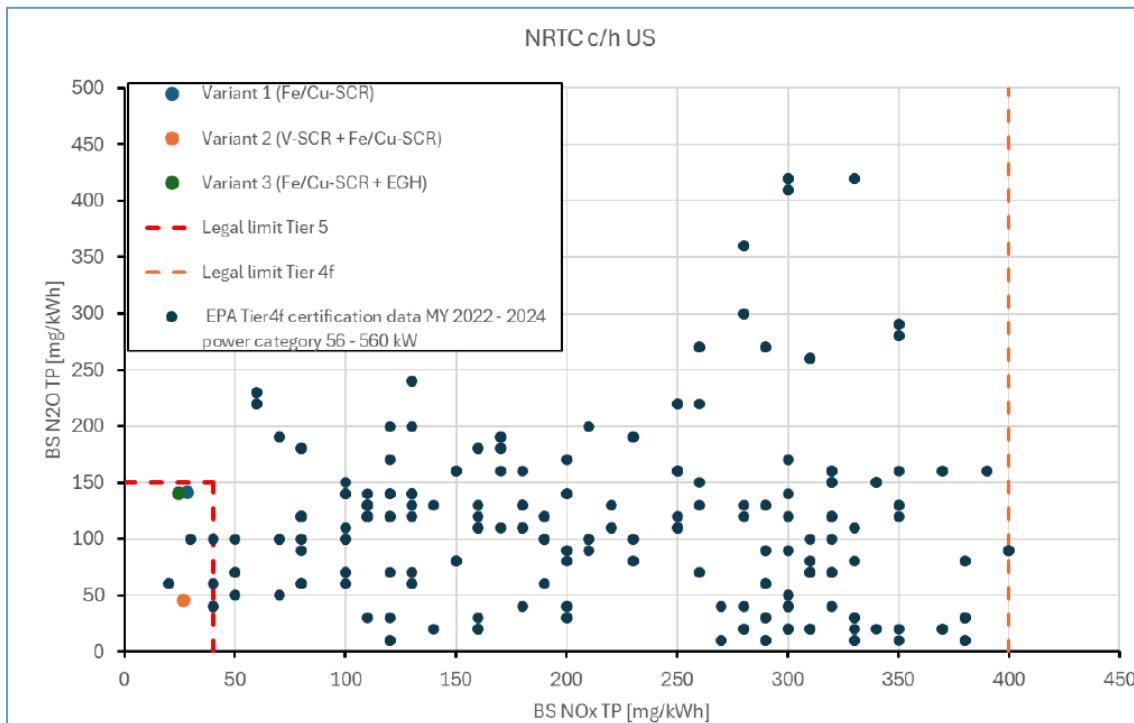
NRTC: Non-Road Transient Cycle  
NRSC: Non-Road Steady-state Cycle

RMC: Ramped Mode Cycle  
LLC: Low-load Cycle

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

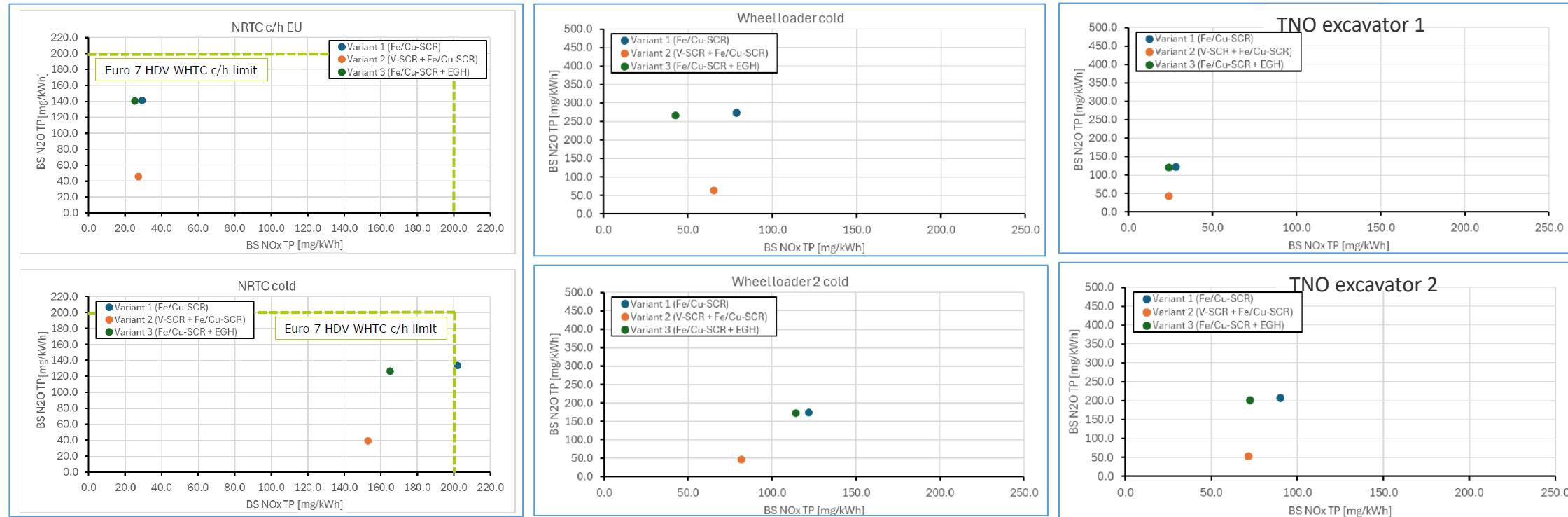
三套后处理都可以在NRTC工况满足加州五阶段和欧七NOx限值

- 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 N<sub>2</sub>O emissions



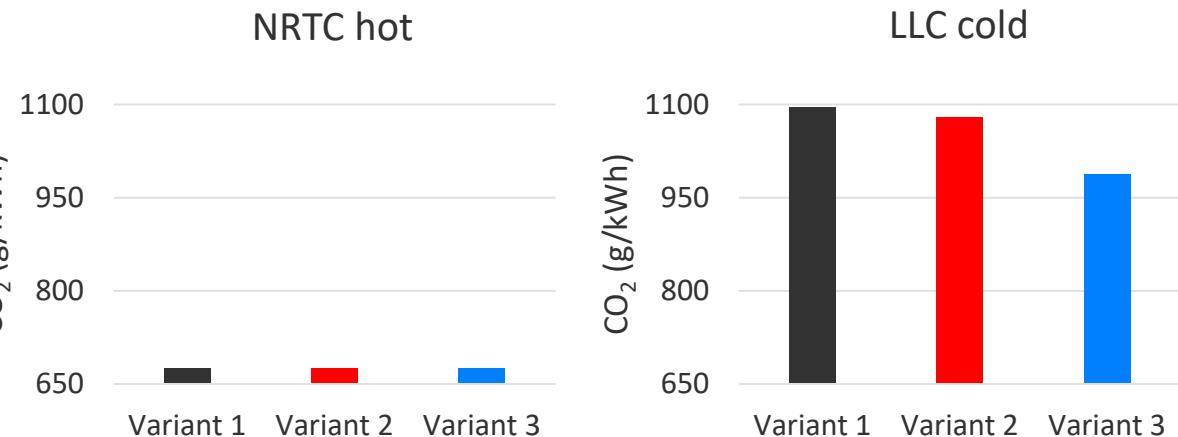
# Consistent low emissions on in-use cycles 实际工况下低排放

- Variation of in-use cycles is higher than NRTC with cold-hot weighing 实际工况比NRTC变化大
- NRTC cold has highest result due to shorter cycle 冷启动NRTC排放最高，原因是工况较短

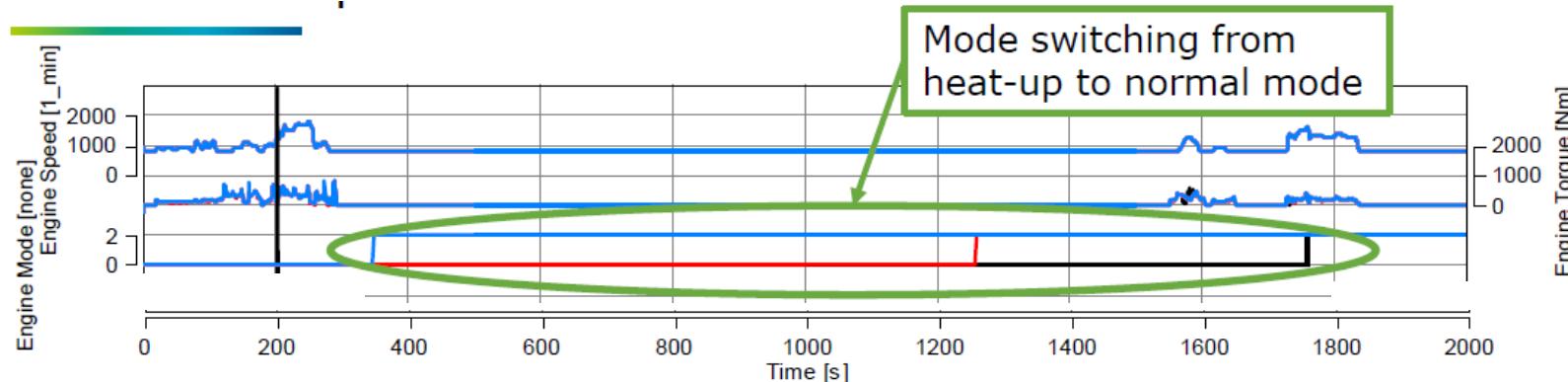


# Tailpipe CO<sub>2</sub> emissions

- ▶ Similar for all 3 variants on most of the tests
- ▶ Except for low-load conditions 低负荷工况
  - ▶ Up to 10% difference on LLC cold test  
冷启动低负荷工况CO<sub>2</sub>排放最多增加10%



- ▶ Due to different occurrence of engine mode switching 动发动机控制模式变化的影响



**Boundary Conditions:**

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

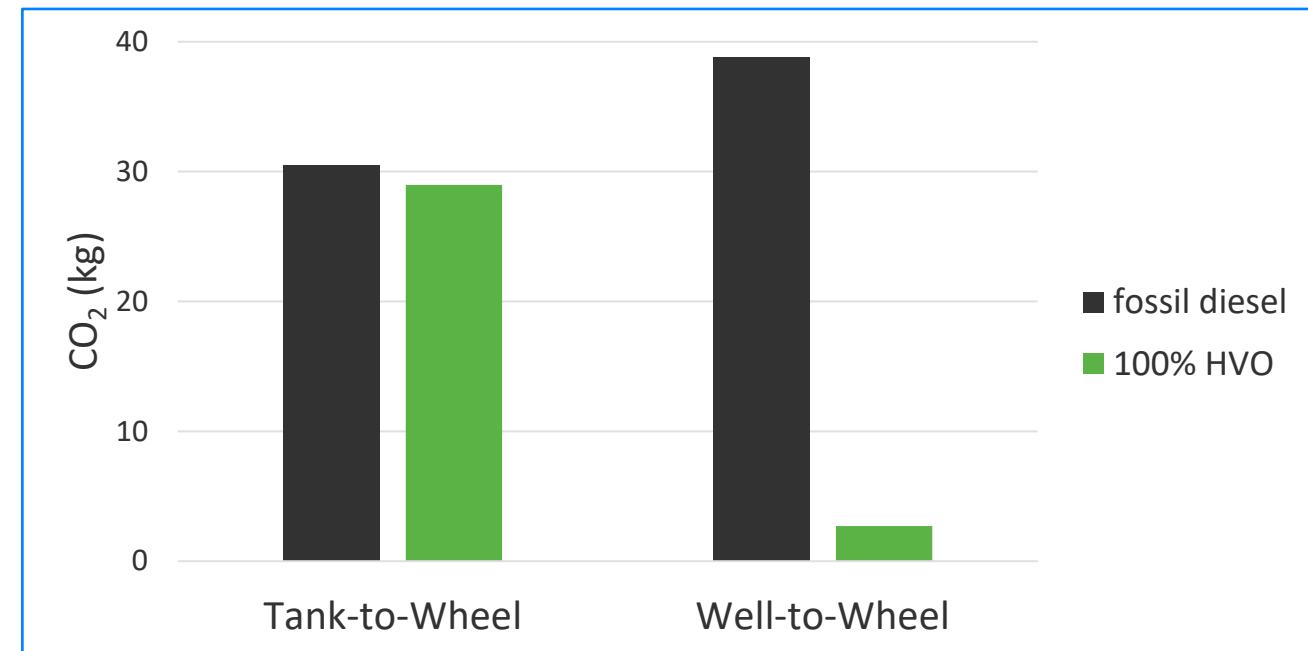
# Well-to-Wheel (WtW) CO<sub>2</sub> emissions 油井到车轮CO<sub>2</sub>排放

► WtW CO<sub>2</sub> emissions can nearly be eliminated by running on CO<sub>2</sub>-neutral fuels (CNFs)

碳中和燃料可以消除油井到车轮的碳排放

► Exemplary calculation for NRTC hot 以热启动NRTC为例计算

- Fossil diesel 石油柴油
- 100% HVO from waste cooking oil 100%加氢地沟油



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# Conclusions 结论

- 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 双喷+电加热可以进一步大范围降低非道路机械NOx排放
    - Depending on OEM engine concept and engine-out NOx emission level 取决于发动机本身及出口NOx水平
    - Alternating operating conditions 变工况运行
    - Continuous low-load operation 连续低负荷运行
    - Initial cold-start 冷启动
- Transition to CO<sub>2</sub>-neutral fuels needed to achieve net-zero CO<sub>2</sub> emissions 碳中和燃料

# THANK YOU