




Challenges of real emission measurement of NRMM

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**Passat TDI
Clean Diesel**



**Reduction of Non-Road Mobile Machines
(NRMM) real emissions**
Piece of cake or mission impossible?

Non Road Mobile Machines, NRMM



NRMM vs. cars

- More versatility than in car sector
 - Machines, manufacturers, users, environment, ...
- Emission regulations are different – Engines not machines
- There are no official test cycles for NRMMs

We know the engine emission in the lab but we do not know the real emissions of machines

NRMM emission regulations

Emission limits for nitrogen oxides (NO_x) and particulate matter (PM) are now 90 % lower than 20 years ago

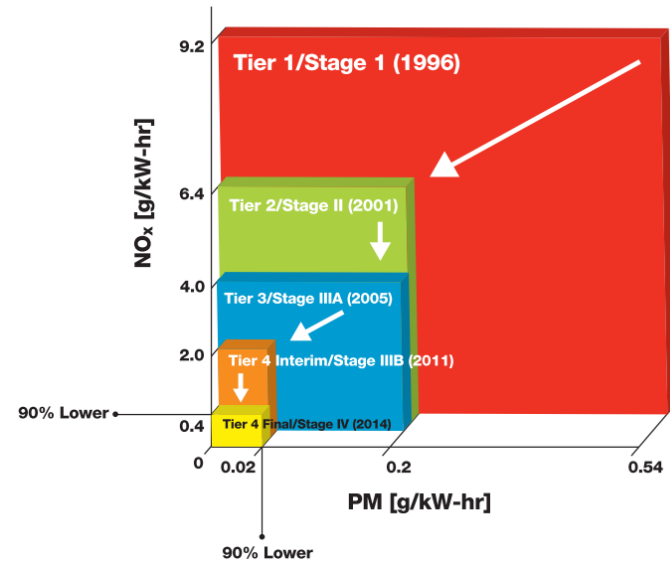
This has caused more complex engines and bigger exhaust after treatment systems – Cost increase

EU Stage V

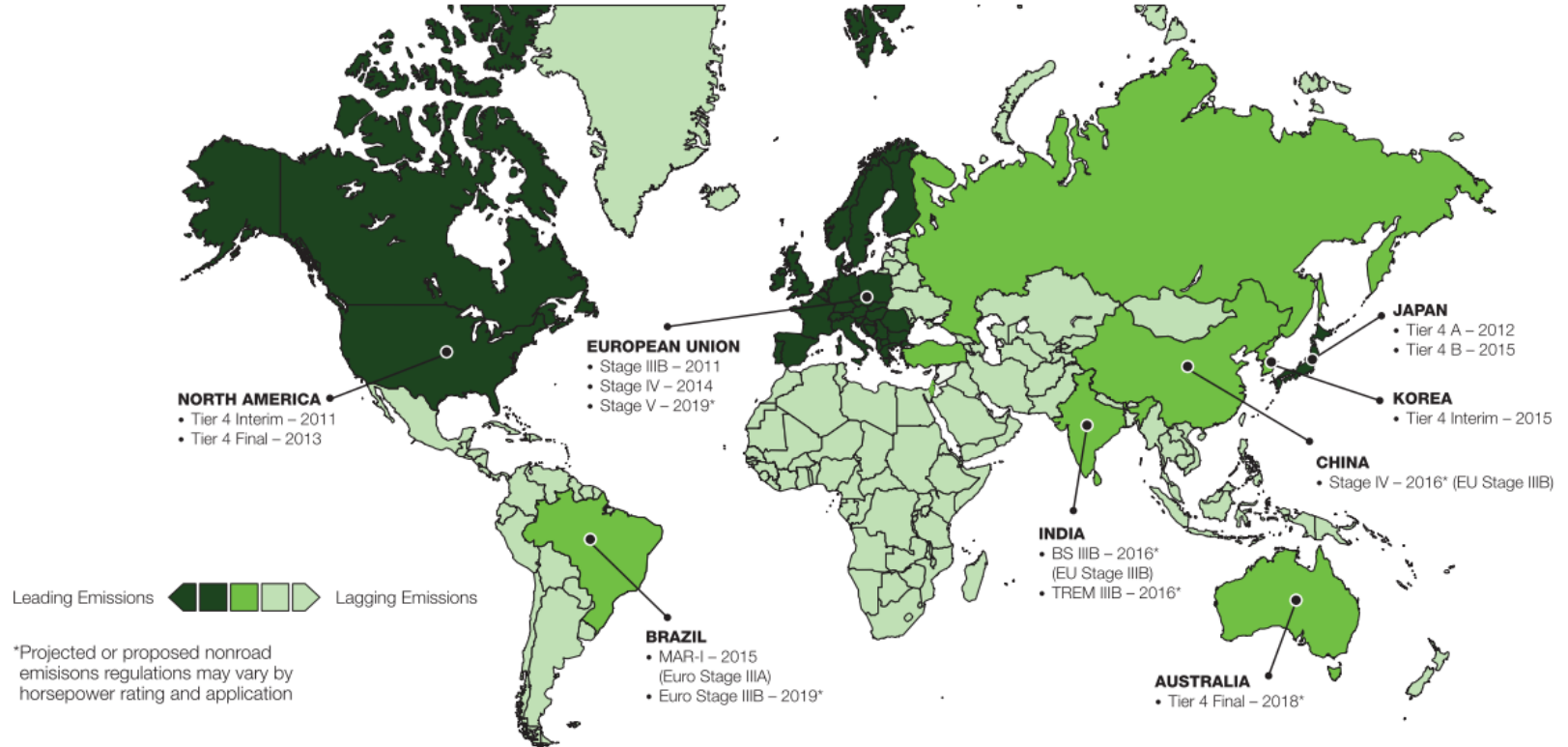
- regulation include Particle Number limits
- In-use test are introduced for NRMMs

Source: Cummins

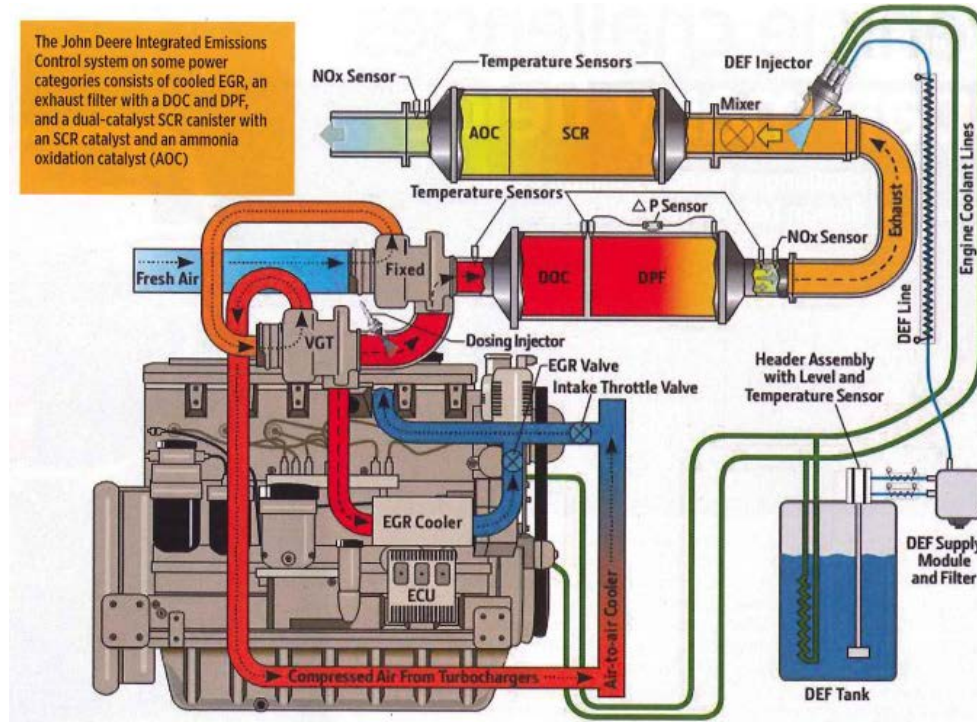
Off-Highway Emissions Evolution.



NRMM emission regulations



NRMM emission reduction



Picture: Off-highway engines advance beyond Tier 4 b Morey, 2014, SAE Off-highway engineering July 2014.

NRMM emissions reduction

Exhaust after treatment systems

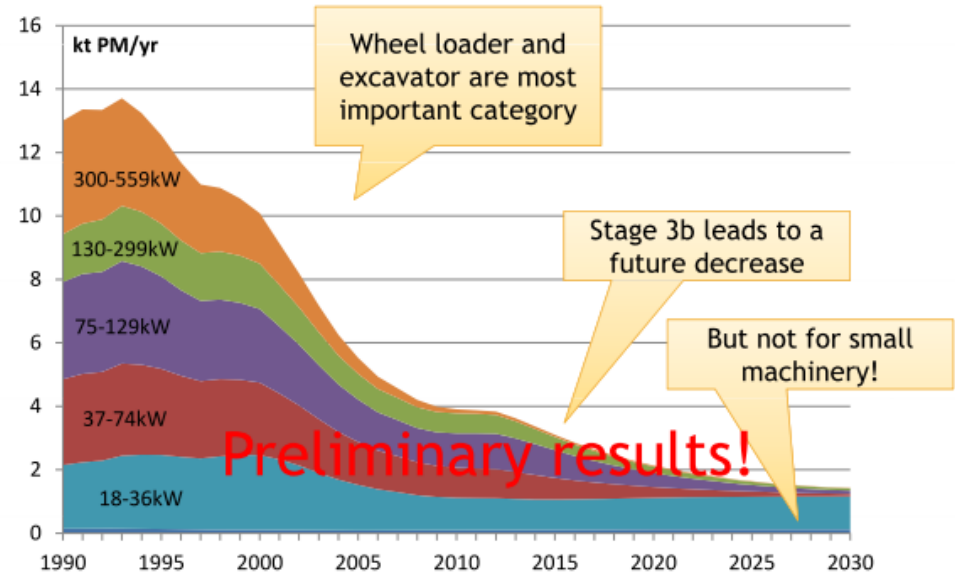
- Volume 5 – 8 times engine displacement
- Towards integrated packages



NRMM emissions

Total amount of emissions are **estimations** based on assumptions and models.

Construction machinery (Germany)
Example: Diesel particle emissions by power class



Source: TREMOD-MM

Hinrich Helms & Christoph Heldt

27.11.2012

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NRMM emission formation

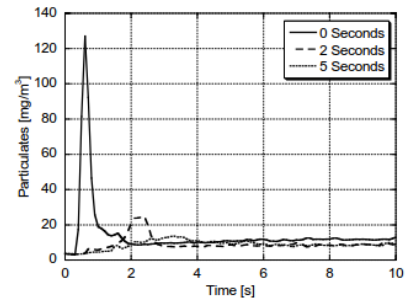
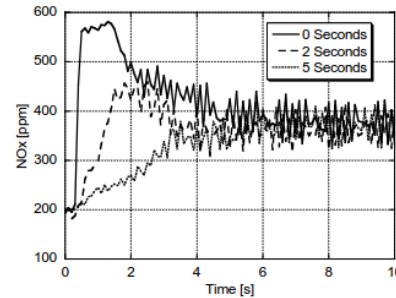
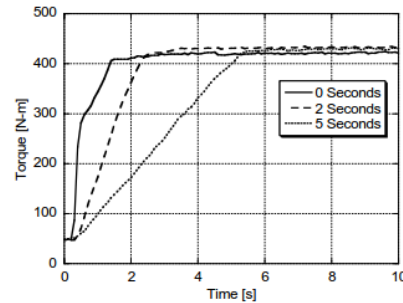
NOx formation requires high local temperatures

Particles are result of incomplete combustion and agglomeration

Changes in operation point increase both NOx and particle matter emissions

- It is approximated that 50 % of harmful emissions of NRMM are caused by transients

Figures show effect of load step duration on the emissions



Source: SAE 2006-01-1151 Transient diesel emissions: analysis of engine operation during a tip-in Hagena, Filipi, Assanis

NRMM emissions

NRMM emissions are depending on

- Engine
- Machine
- Operator
- Processed material
- Environment, weather

In real emission measurements we should consider all these aspects

This results that reduction of real emissions is complex optimization task

NRMM emissions

Our interests are related to the real emissions

How much the real emissions be reduced by

- Controls of machine
- Hybridization
- Autonomous operation vs. human operated

At the beginning the initial state should be defined by measurements.

Our test machine

Wille 655C loader (5.5 tn)

- Used in widely in cities for street cleaning and spreading salt, sand
- CAT 4.4 Tier 3 engine
 - 97 kW, 516 Nm
- Hydrostatic transmission
- Various tools and equipment's available



Our test machine

Loader is equipped with

- Model based control system development environment with matlab/Simulink and Rexroth BODAS control system
- Various sensors for autonomous operation
- Hydraulic system energy recovery capable
- AVL KMA fuel consumption measurement system
- AVL GAS PEMS
- AVL PM PEMS

Our test machine



Our test machine



Experiences on installation

PEMS installation requires considerably amount of work

- Space requirement - big machines has no space
 - Impossible for smaller machines
- Hoses and cables
- Power supply (Batteries and aggregate)
- Burn gas for FID
- System weight is considerable for smaller machines
- Weather cover – rain and below zero conditions



Pictures 2 – 4: AVL

Experiences on measurements

Calibration gases – ppm-levels depend on the measured emission
Measurements

- Success rate low at the beginning – learning takes time
- Time constants
- Particle mass – weighting
 - Accuracy requirement – process and scale, room

Measurement analysis

- Currently the easiest part

Some results

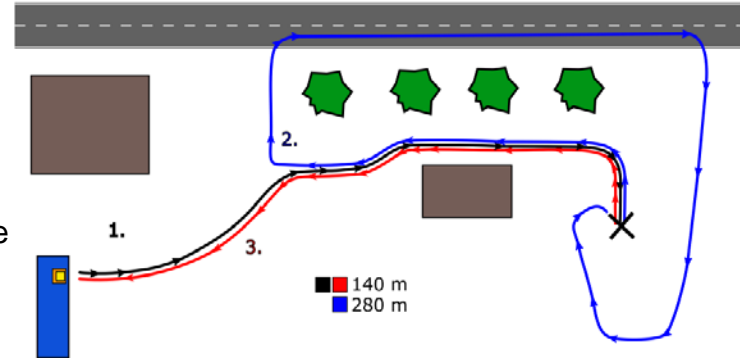
Effect of “driving style”

Load and carry cycle (6 rounds)

- Driving with and without load of 1,5 ton
 - With load: Red and black line, Without load: Blue line
- The load was picked and returned from top of the container
- Up and down hills

Two operators with different driving style:

- Operator A: Smooth
- Operator B: Aggressive

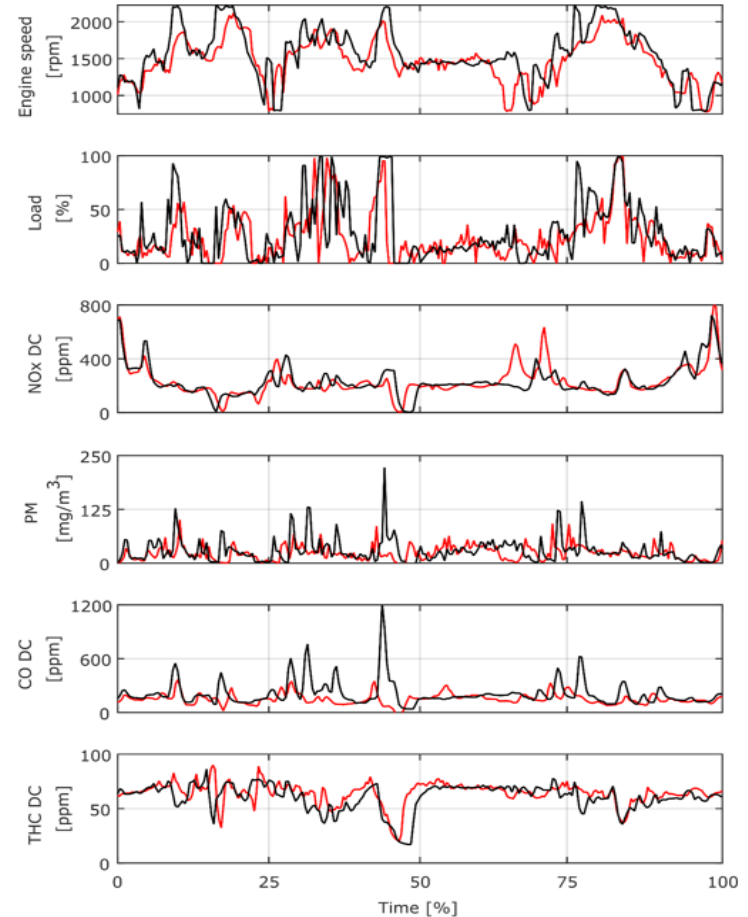


Some results

Operator	Engine speed [rpm]	Engine Torque [Nm]	Fuel consumption [l]	Time [s]
A	1479	99	2,90	1715
B	1575	114	3,18	1478

Operator	NOx [g/kWh]	PM [g/kWh]	CO [g/kWh]	THC [g/kWh]
A	4,86	0,30	2,34	0,41
B	4,53	0,42	3,33	0,36

There is difference between operators but not exactly what was expected





Reduction of Non-Road Mobile Machines (NRMM) emissions

**Neither measurements nor reduction
is not an easy task**



Solutions

Electrification of smaller machines

Hybridization and optimization of bigger machines and naturally engine and combustion development