New emission information on shipping emissions

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EUROPEAN RESEARCH ON MOBILE EMISSION SOURCES
2024 ERMES PLENARY
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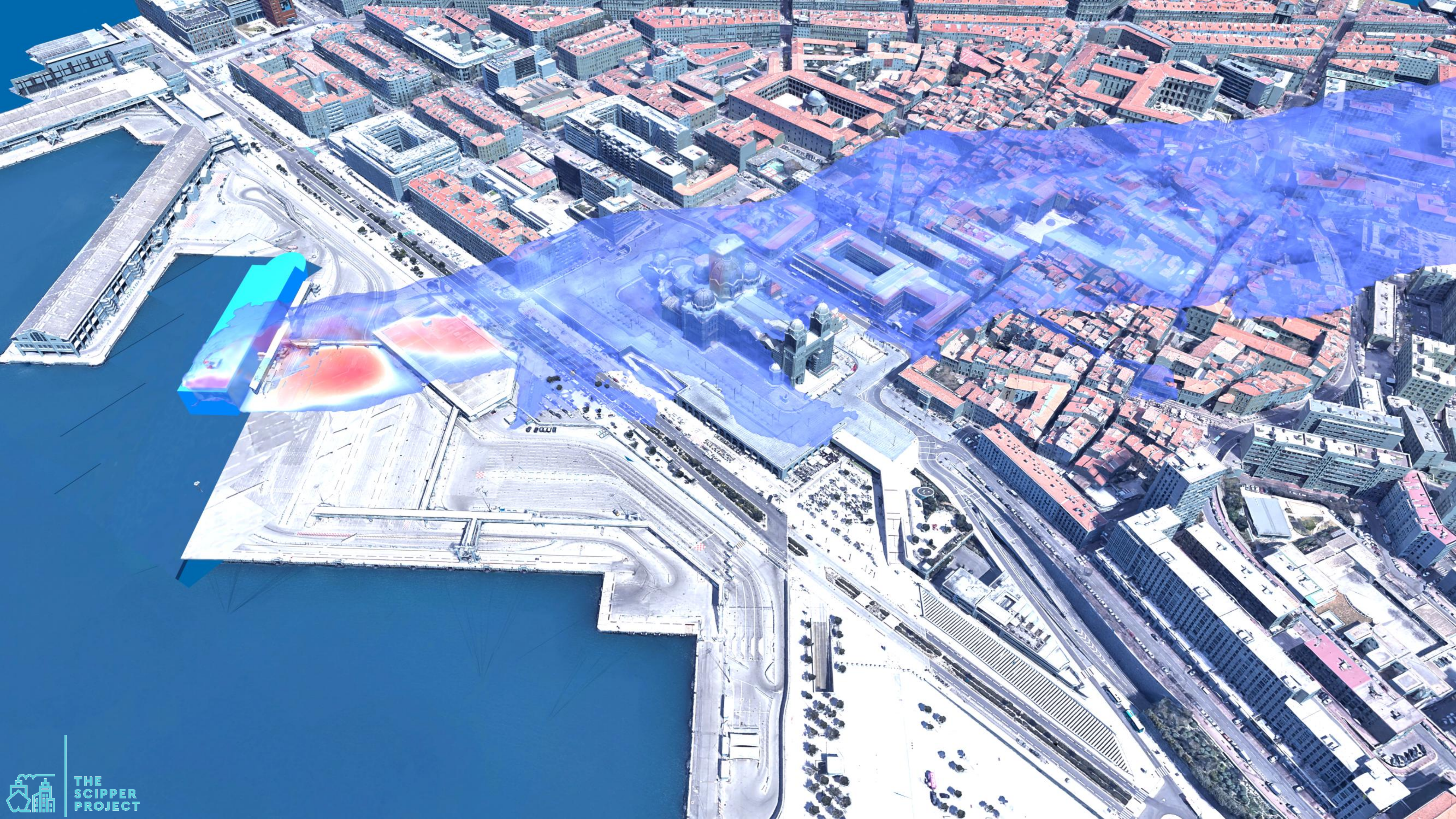
LABORATORY
OF APPLIED
THERMODYNAMICS

Background

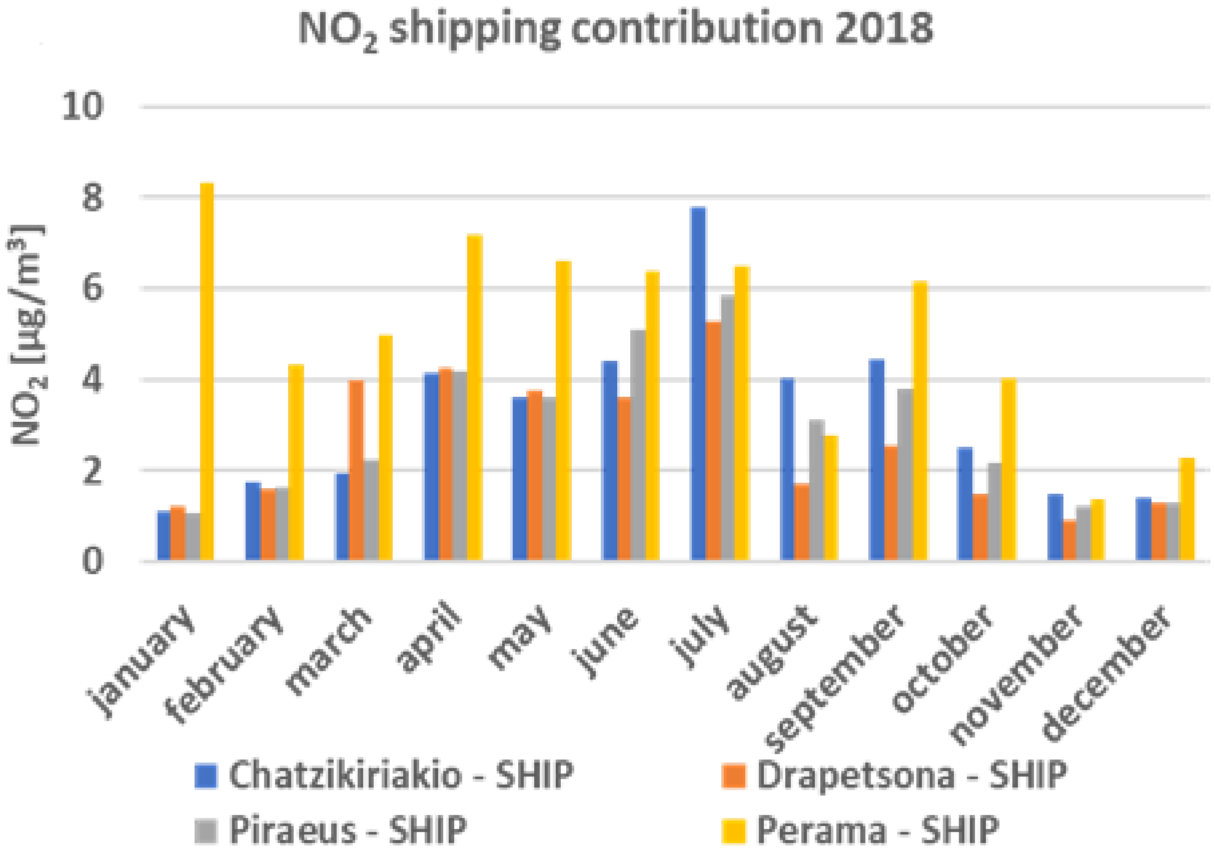
- Environmentally, major emphasis of shipping given on **decarbonization** (= zero out fossil CO_2)
- Vessels are major sources of air pollutants (NO_x, SO_x, PM, HC, PAH…)
- Vessels are also major sources for water pollution, primarily through scrubbers’ effluent
- New fuels (LNG, MeOH, NH_3,…) mean new pollutants

There is the need to continue monitoring pollutants produced from vessels both to the air and to the water



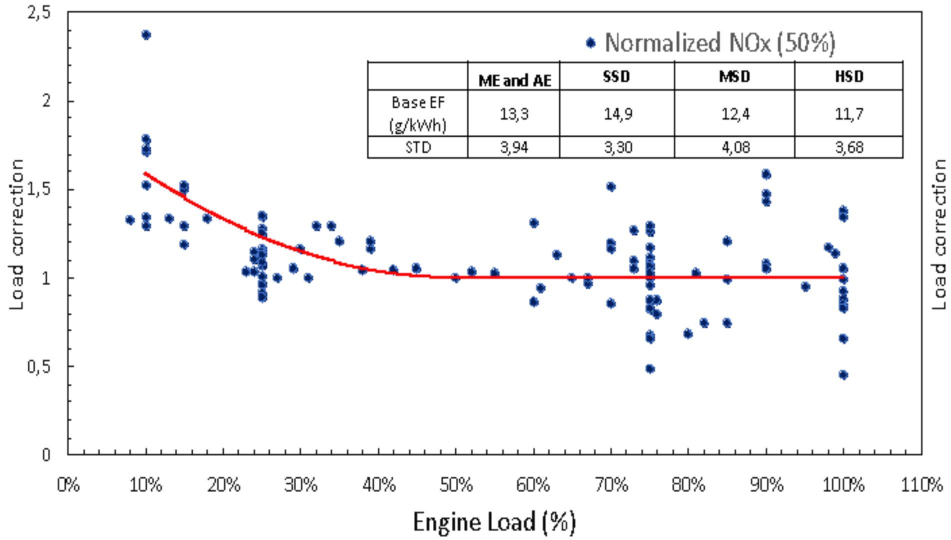
THE SCIPPER PROJECT

Contribution of shipping to air pollution

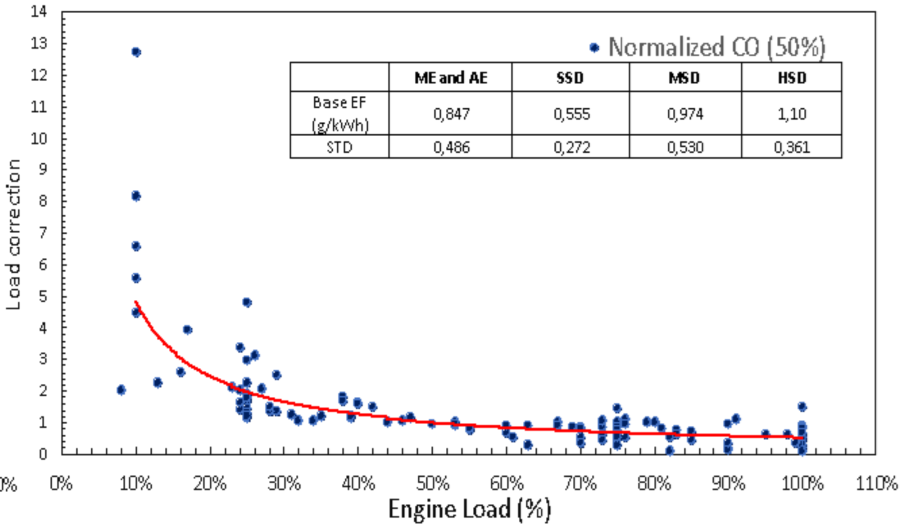


Contribution of 18-20% to air pollution around the port of Piraeus, in terms of SO_2 and NO_x

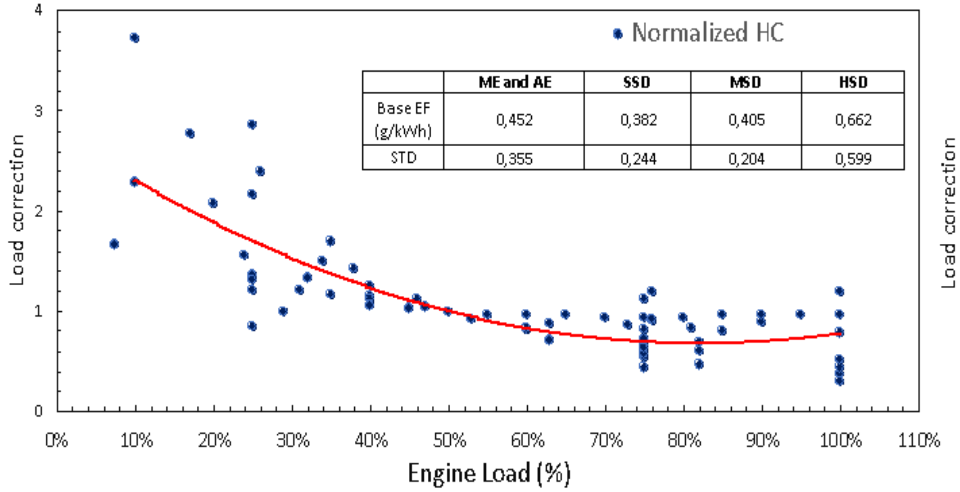
Emission level dependance on engine load



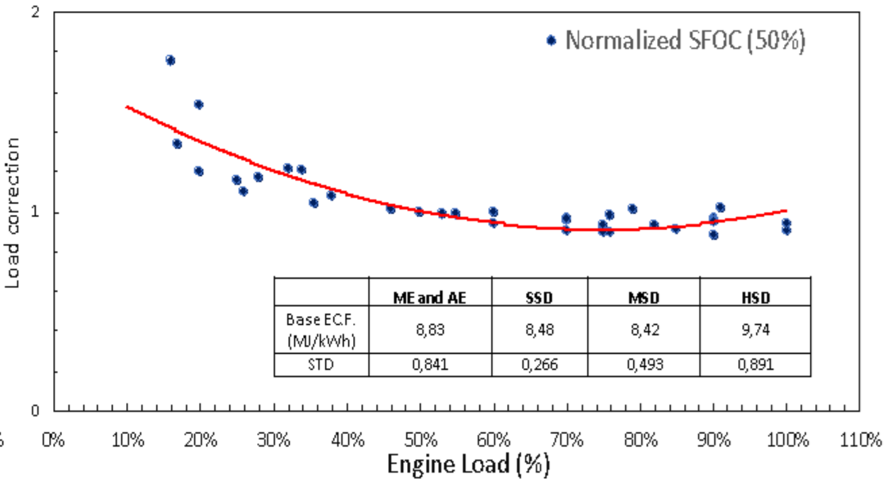
	ME and AE	SSD	MSD	HSD
Base EF (g/kWh)	13,3	14,9	12,4	11,7
STD	3,94	3,30	4,08	3,68



	ME and AE	SSD	MSD	HSD
Base EF (g/kWh)	0,847	0,555	0,974	1,10
STD	0,486	0,272	0,530	0,361



	ME and AE	SSD	MSD	HSD
Base EF (g/kWh)	0,452	0,382	0,405	0,662
STD	0,355	0,244	0,204	0,599



	ME and AE	SSD	MSD	HSD
Base E.C.F. (MJ/kWh)	8,83	8,48	8,42	9,74
STD	0,841	0,266	0,493	0,891

Latest Update of the Guidebook in 2021

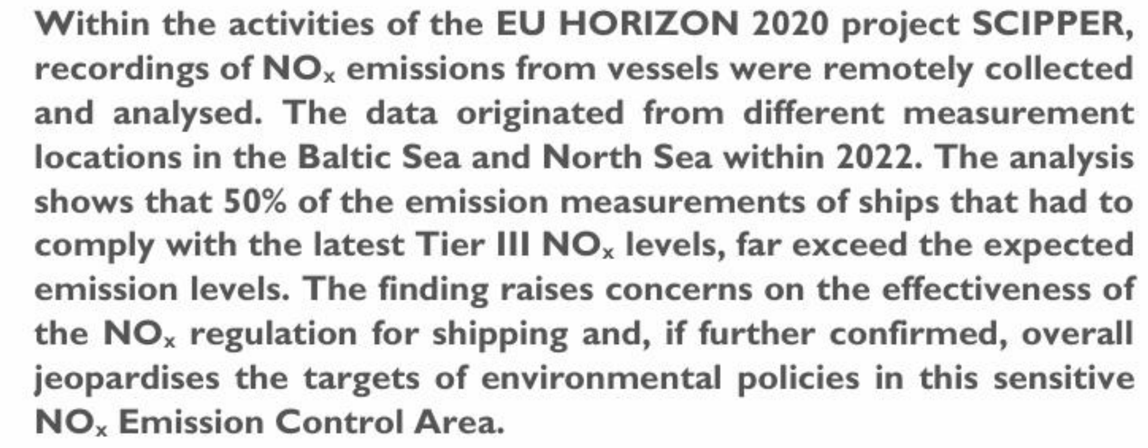
Efficiency of emission control technologies

- Overview of emission reduction percentage of different emission control technologies

Emission control technology	Fuel	SFOC (%)	CO (%)	NO_X (%)	SO_2 (%)	NMVOC (%)	PM (%)
Wet Scrubber	Bunker Fuel Oil	-2,15	18.2	5,84	98,8	36.3	35,8
	MDO/MGO	n.r.	n.r.	n.r.			n.r.
SCR	Bunker Fuel Oil	0,495	-63,0	89,6	23,5	68,6	34,8
	MDO/MGO	-1,48	-55,8	70,2	6,57	78,3	6,10
DOC	Bunker Fuel Oil	1,09	31.1	-0,629	-1,30	50,0	50,0
	MDO/MGO	1,09	31				
DPF	Bunker Fuel Oil	n.r.	n.				
	MDO/MGO	-1,50	0,0				
SCR+Scrubber	Bunker Fuel Oil	-2,98	-11				
	MDO/MGO	n.r.	n.				
SCR+DPF	Bunker Fuel Oil	n.r.	n.				
	MDO/MGO	-1,50	-55				
DOC+Scrubber	Bunker Fuel Oil	1,09	42,9	5,66	99,1	50,0	50,0
	MDO/MGO	n.r	n.r	n.r	n.r	n.r	n.r

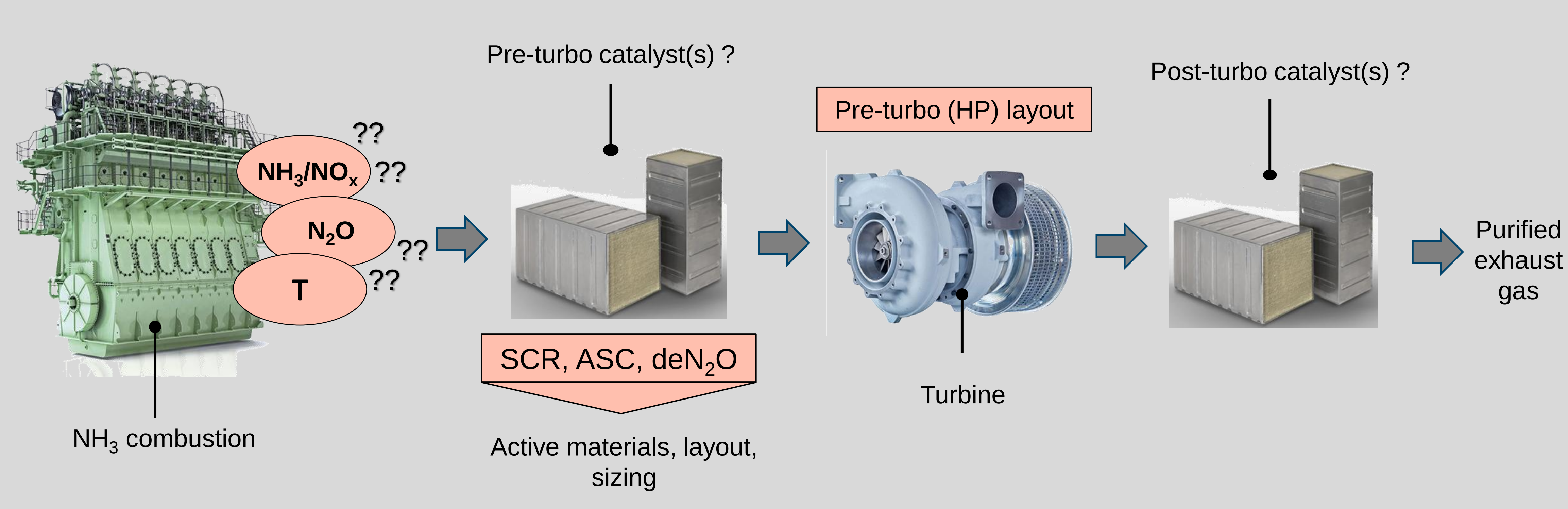
If SCR is operational!!!!

Evidence growing that Tier III SCR is largely not operational for a large number of vessels



Within the activities of the EU HORIZON 2020 project SCIPPER, recordings of NO_x emissions from vessels were remotely collected and analysed. The data originated from different measurement locations in the Baltic Sea and North Sea within 2022. The analysis shows that 50% of the emission measurements of ships that had to comply with the latest Tier III NO_x levels, far exceed the expected emission levels. The finding raises concerns on the effectiveness of the NO_x regulation for shipping and, if further confirmed, overall jeopardises the targets of environmental policies in this sensitive NO_x Emission Control Area.

Ammonia combustion emission challenges



NH_3/NO_x ??

N_2O ??

T ??

??

NH_3 combustion

Pre-turbo catalyst(s) ?

SCR, ASC, deN_2O

Active materials, layout, sizing

Pre-turbo (HP) layout

Turbine

Post-turbo catalyst(s) ?

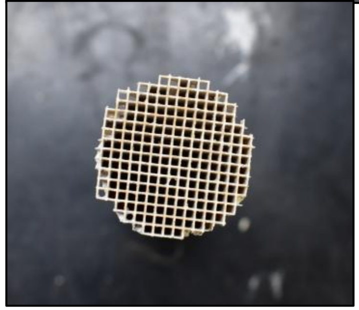
Purified exhaust gas

Objective: Development of the EATS of large ammonia engines to simultaneously achieve:

- NO_x emissions below Tier III levels
- Minimize NH_3 slip
- Minimize N_2O emissions

ENGIMMONIA

Approach in developing NH_3 EATS



1D+1D modeling approach (single channel):

- Uniform flow distribution.
- Negligible heat losses.

Quasi- steady state balance equations for heat and mass transfer:

$$\rho_g C_{p,g} v_g \frac{\partial T_g}{\partial z} = -h \cdot \left(\frac{S_F}{\varepsilon}\right) \cdot (T_g - T_s)$$

$$\frac{\partial (v_g y_{g,j})}{\partial z} = -k_j \cdot \left(\frac{S_F}{\varepsilon}\right) \cdot (y_{g,j} - y_{s,j})$$

Transient energy balance in solid phase (wall temperature):

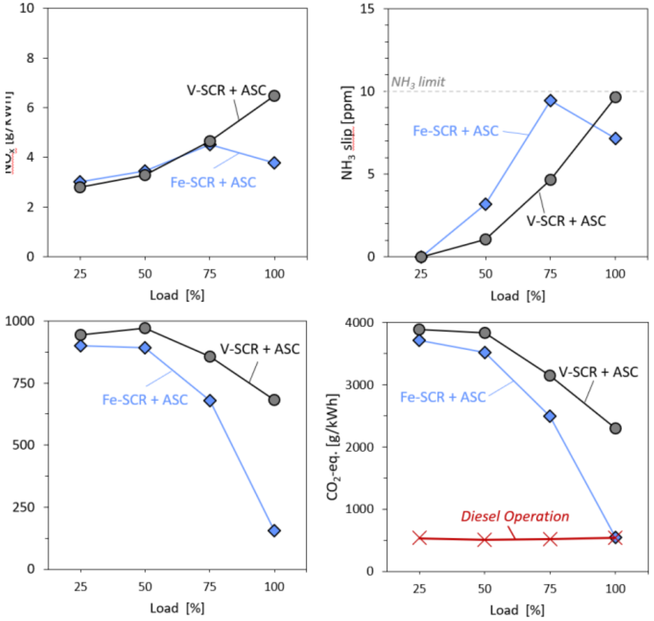
$$\rho_s C_{p,s} \frac{\partial T_s}{\partial t} = \lambda_{s,z} \frac{\partial^2 T_s}{\partial z^2} + S$$

Catalyst matrix
V-SCR
Fe-SCR
Pt-AOC

Diesel
'reference'

The calibrated models are applied in assumed NH_3 engine exhaust gas.

ANR>1 with high N_2O engine-out emissions



1. Small-scale catalyst testing in SGB

2. Kinetic model development

3. Real-scale model application

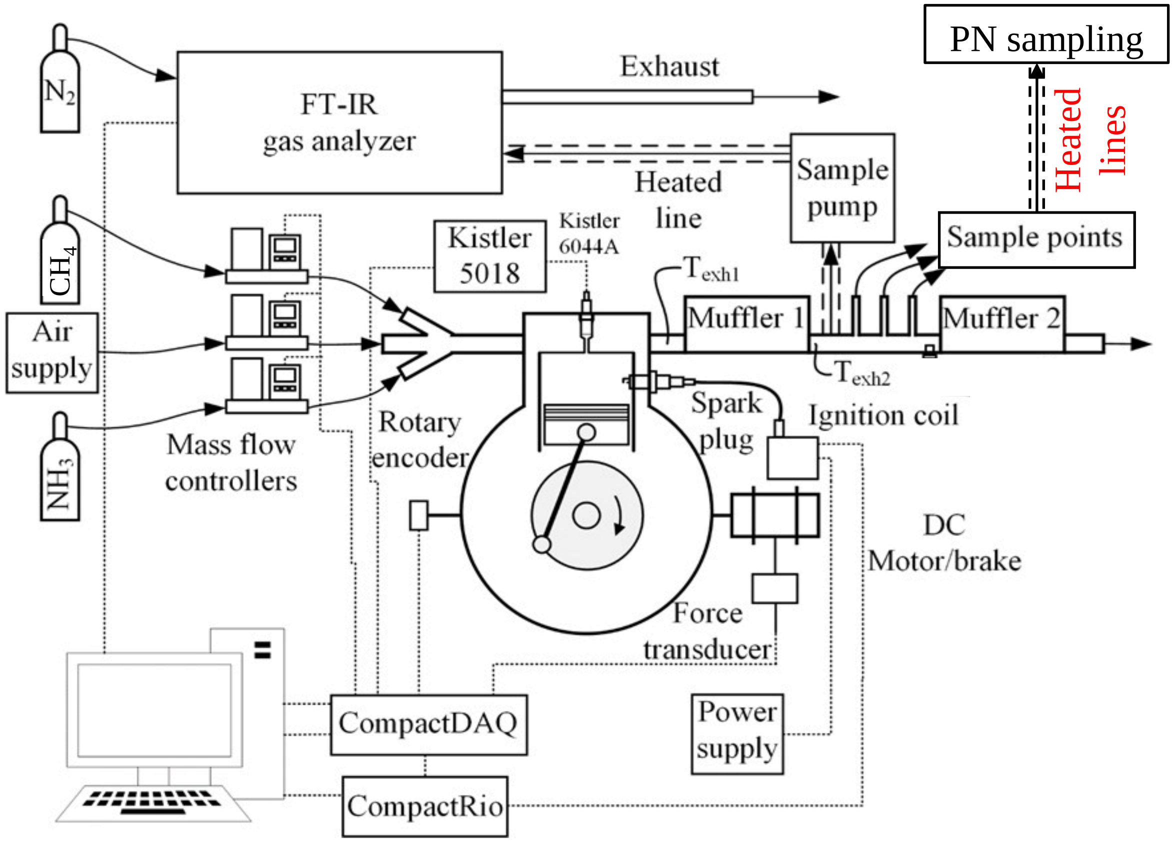
4. System optimization

Type	Reaction
NH_3 storage/release	$NH_3 \leftrightarrow NH_3^*$
Standard SCR	$4\ NH_3^* + 4\ NO + O_2 \rightarrow 4\ N_2 + 6\ H_2O$
Fast SCR	$4\ NH_3^* + 2\ NO + 2\ NO_2 \rightarrow 4\ N_2 + 6\ H_2O$
NO_2 SCR	$NH_3^* + 3/4\ NO_2 \rightarrow 7/8\ N_2 + 3/2\ H_2O$
N_2O formation	$2\ NH_3^* + 2\ NO + O_2 \rightarrow N_2 + N_2O + 3\ H_2O$ $2\ NH_3^* + 2\ NO_2 \rightarrow N_2 + N_2O + 3\ H_2O$
NO oxidation	$NO + ½\ O_2 \leftrightarrow NO_2$
NH_3 oxidation	$4\ NH_3^* + 5\ O_2 \rightarrow 4\ NO + 5\ H_2O$ $2\ NH_3^* + 3/2\ O_2 \rightarrow N_2 + 3H_2O$ $4\ NH_3^* + 4\ O_2 \rightarrow 2\ N_2O + 6\ H_2O$

Reaction modeling based on test data with NH_3 combustion relevant synthetic gas.

Geometrical, dosing parameters optimization for Tier III compliance

Test engine at DTU

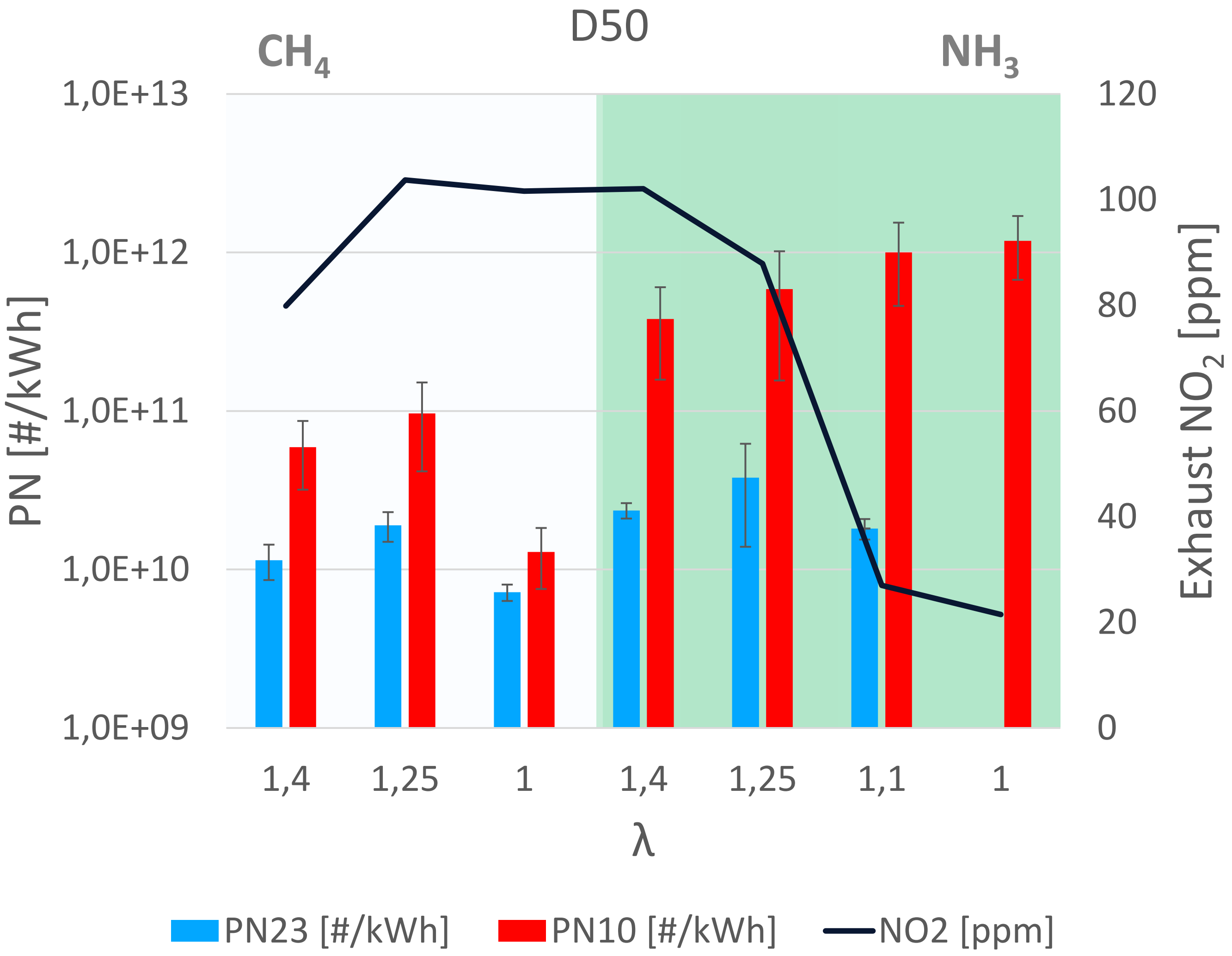


Engine specifications	
Engine type	1-cyl CFR SI 4-stroke
Displacement volume	611 cm^3
Bore	82.78 mm
Stroke	114.3 mm
Compression ratio	4.5 – 15
Intake pressure	0.5 - 1.5 bar absolute

Fuels tested separately:

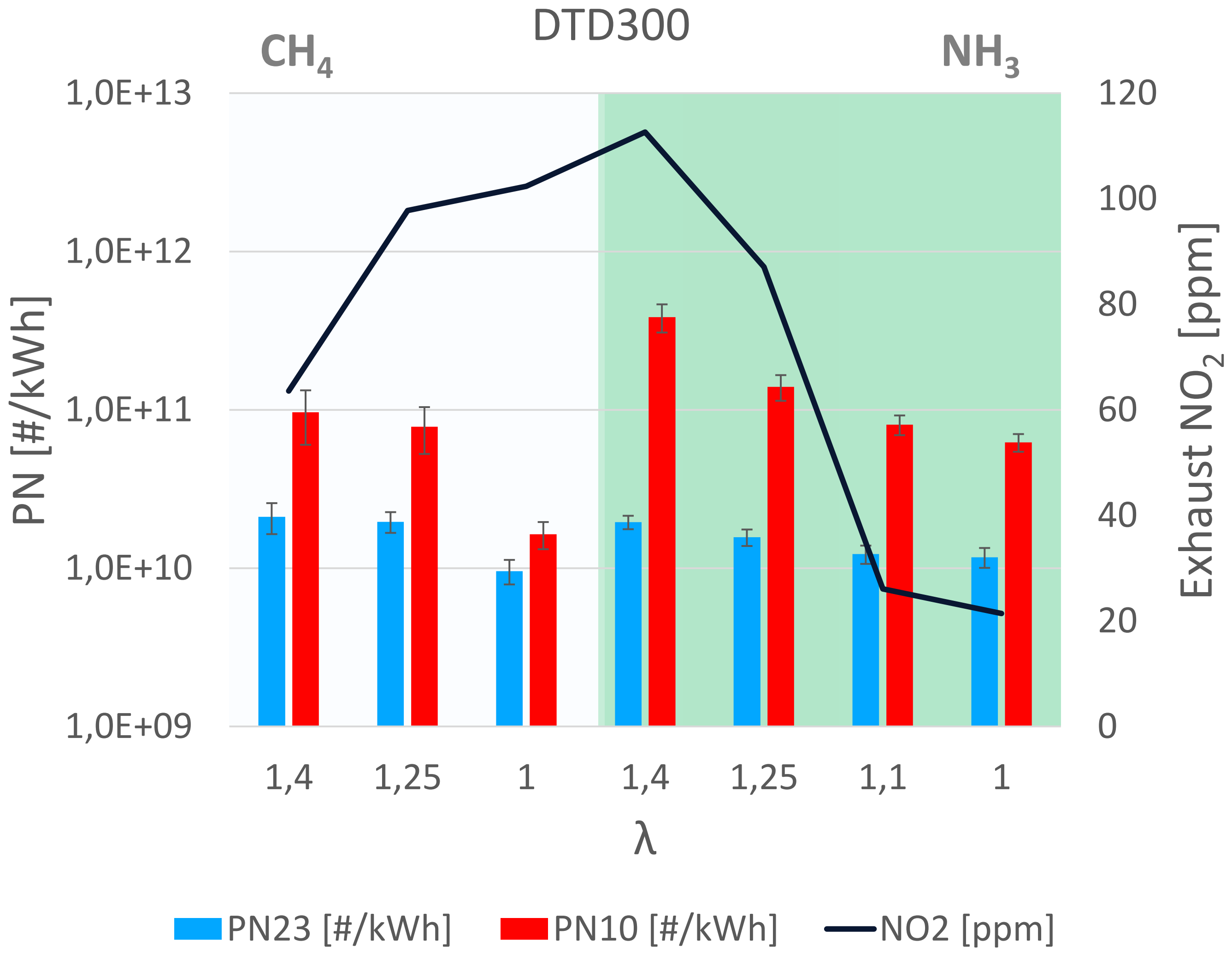
- CH_4 (reference)
- NH_3

Does homogeneous NH_3 combustion form particles?



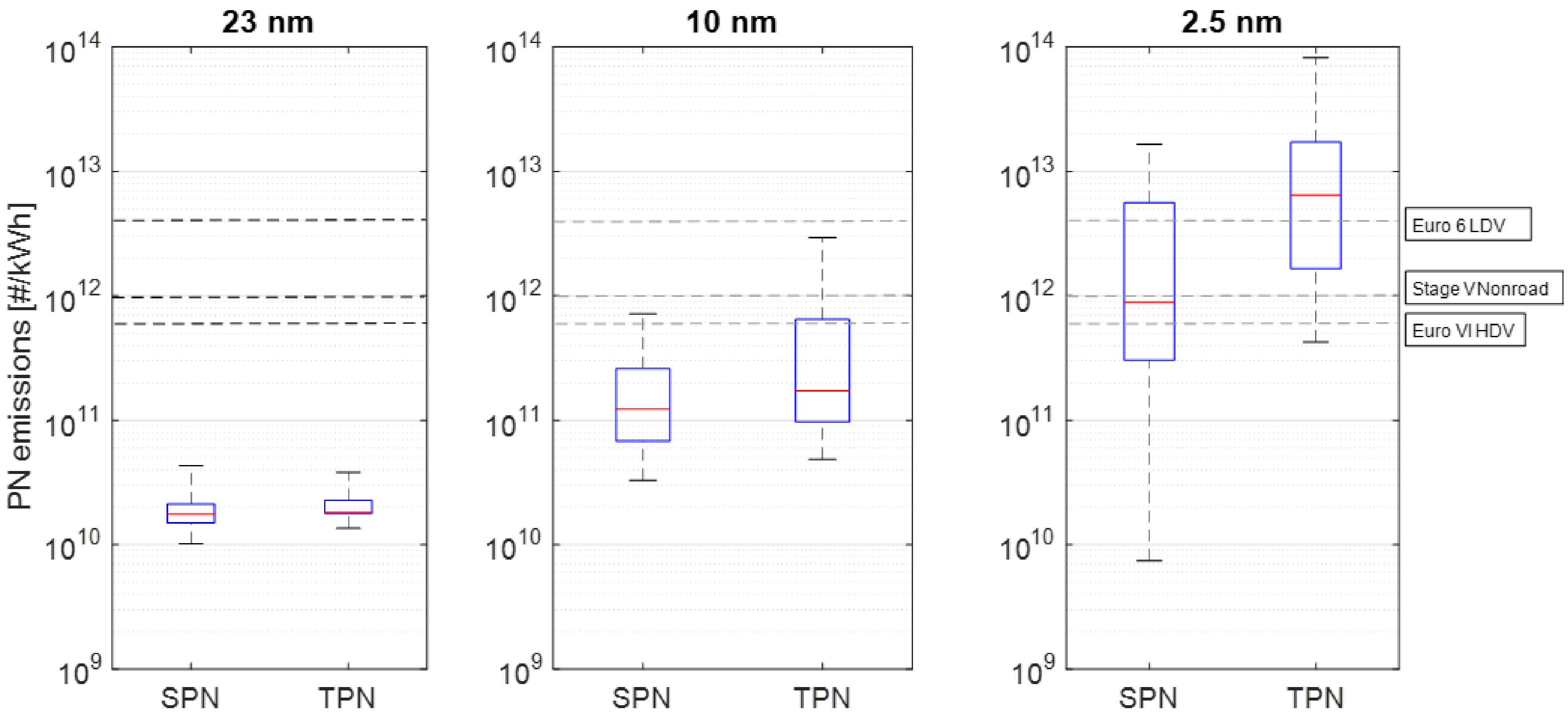
- TPN_{23} of NH_3 higher than CH_4 combustion
- TPN_{10} from NH_3 far exceed those from CH_4
- NH_3 TPN_{10} emissions show inverse correlation with λ

Does homogeneous NH_3 combustion form solid particles?



- SPN_{23} of CH_4 and NH_3 combustion are at similar levels
- NH_3 SPN_{10} still higher than CH_4
- NH_3 SPN10 & SPN23 emissions seem to correlate with λ

What is the level of NH_3 particle emissions?



- S/TPN_{23} consistently below of ‘23 nm Stage V limit’, regardless of sampling configuration
- SPN_{10} below ‘23 nm Stage V limit’; some exceedance TPN_{10}

Some highlights of NH_3 EATS development

From lab testing/modeling:

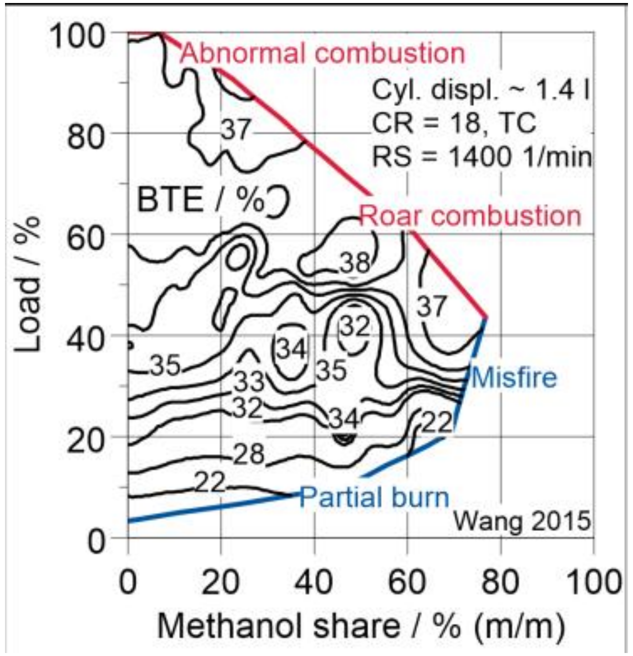
- New chemical reaction schemes are necessary to describe the SCR reactivity in ammonia engine exhaust.
- Good sulfur tolerance of Fe-SCR at $T>300^oC$.
- deN_2O catalyst materials for $T<400^oC$ not yet identified.
- NH3 has the potential to form new (non-C) particles

From simulated marine engine exhaust:

- Potential of 70-90% GHG emissions reduction with Tier III compliant NO_x possible if engine is tuned for low NH_3, low N_2O and high NO_x.

Methanol combustion emission challenges

- LP vs HP approach
- Pilot quantity
- Low cetane number (CN = 3)
- Low NOx but PN and HCHO may be issues



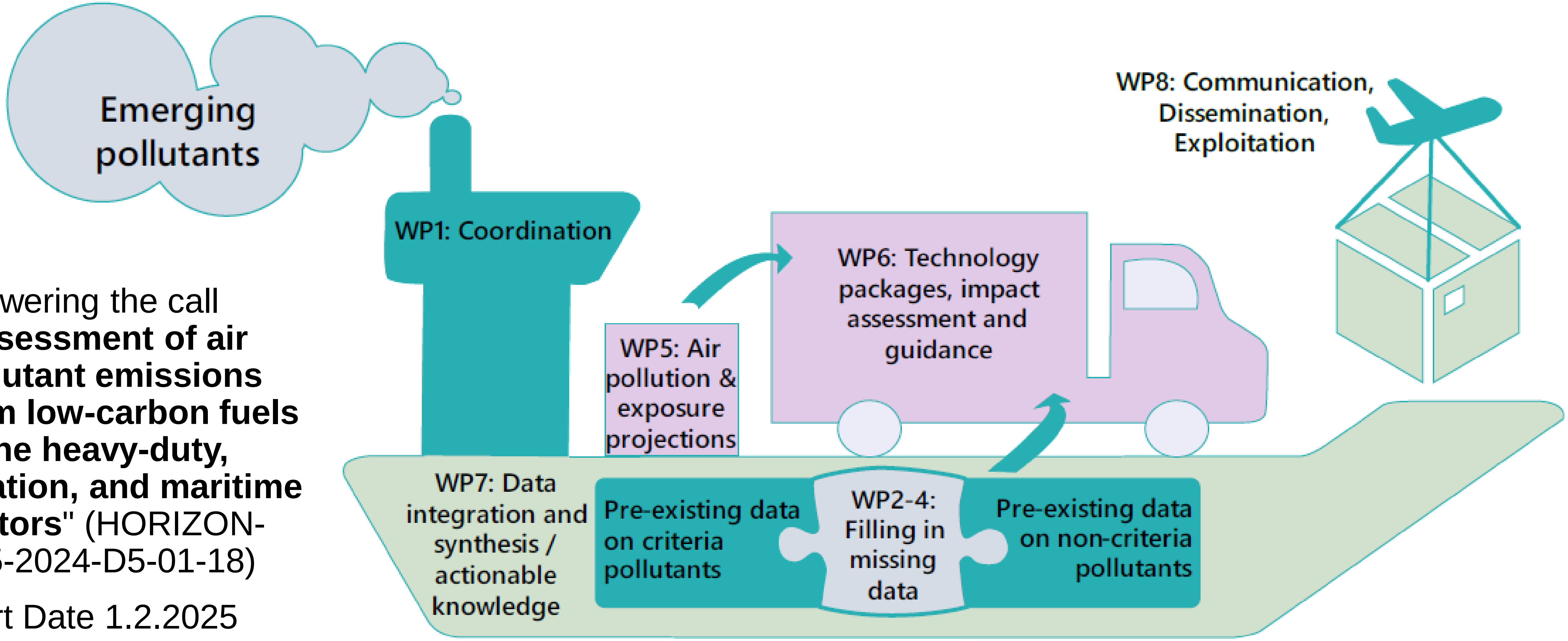
Engine Load	Methanol Share	Effect	Cause
Low	Low	Poor Combustion Reduced BTE	Evaporative Cooling & Lean Methanol-Air Mixture
Increased	Increased	Misfire Roar Combustion	1) In methanol rich atmosphere diesel is not compressed to ignite. 2) Misfire leads to an unburned charge. 3) In the following cycle, a highly reactive premixed mixture is formed by the unburned diesel, methanol in the residual gas and injected fuel.
Increased	Decreased	Reliable Diesel Ignition	Long ignition delay period leads to fast conversion of the premixed methanol mixture.
Full	Decreased	Abnormal Combustion	Premixed methanol autoignition before diesel injection.

REALCHEM

REALCHEM: Real-world emission Experiments and comprehensive Assessment of Low-carbon fuels: towards Clean Hard-to-Electrify traffic Modes

- Produce scientific data on the characteristics of emissions from low-carbon fuels in the Hard-to-Electrify transport modes
- Understand the effect of introducing low-carbon fuels to the developing technology matrix on human health, climate, and the environment
- Help technology developers and users to understand the emission formation and reduce the harmful pollution from engines using low-carbon fuels

REALCHEM project structural overview



Answering the call "**Assessment of air pollutant emissions from low-carbon fuels in the heavy-duty, aviation, and maritime sectors**" (HORIZON-CL5-2024-D5-01-18)

Start Date 1.2.2025

THANK YOU

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