Nanoparticle and secondary aerosol emissions of EURO6d-level passenger cars fueled with gasoline, diesel and natural gas: The role of exhaust after-treatment byproducts

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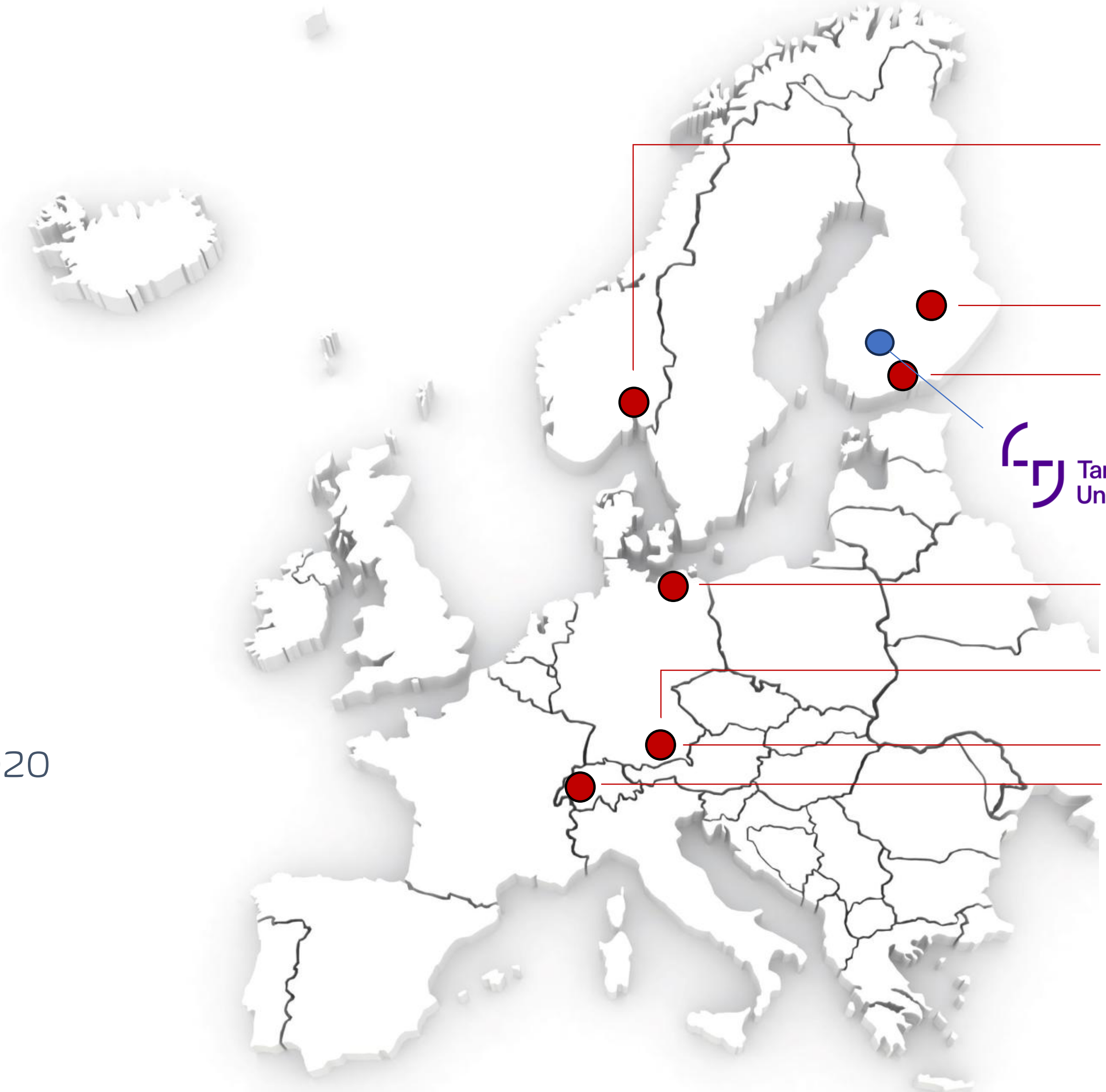
ULTRHAS

ULtrafine particles from TRansportation – Health Assessment of Sources

Duration: Sept. 2021 – Nov. 2025

Call: H2020 LC-MG-1-14-2020



Coordinator:
Johan Øvrevik

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UNIVERSITY OF EASTERN FINLAND

Finnish institute for health and welfare

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HelmholtzZentrum münchen
German Research Center for Environmental Health

Universität der Bundeswehr München

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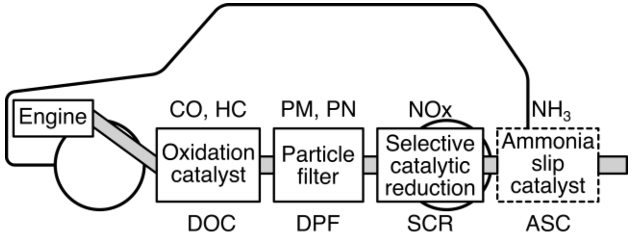
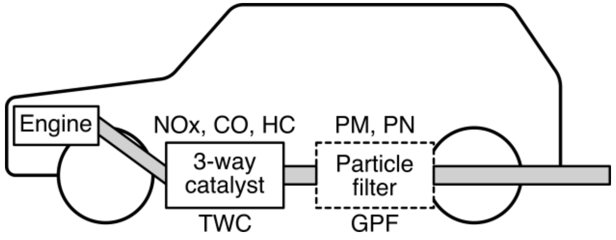
Introduction

- Euro 6d compliant vehicles:

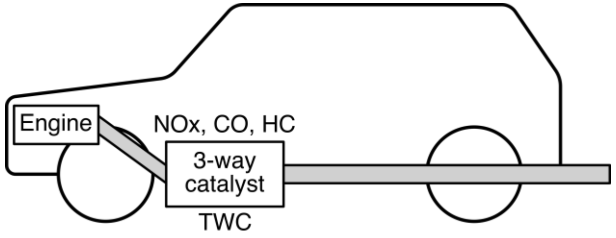
Diesel:



Gasoline:



Biogas & CNG:
(compressed natural gas)



Background:

- Diesel vehicles require extensive exhaust after-treatment to fulfill emission regulations.
- Latest EURO6d emission standard has led to the use of particle filters (GPF) also in gasoline vehicles.
- Low particle emissions (solid, D_p >23 nm) reported for CNG and biogas vehicles even when not equipped with particle filters.

Research questions:

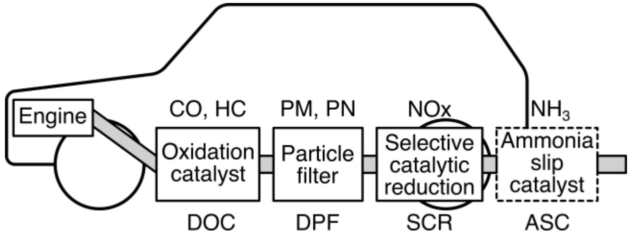
- How ultrafine particle emissions differ between different powertrains, including also particles beyond the regulation range? (down to 1 nm particles)
- What are the secondary aerosol formation potentials of the emissions?
- How gaseous emissions differ between powertrains and how they explain the measured secondary aerosol potential?

Methods

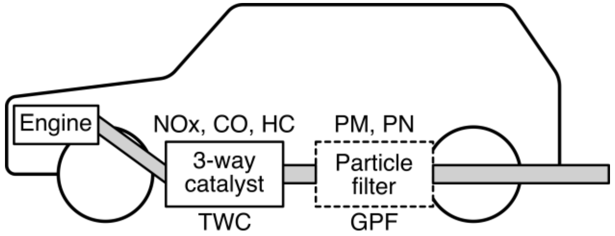
Vehicle name	Fuel	Engine displacement (L)	Model year	Mileage (km)	Emission class	After-treatment	Total number of 1-hour cycles
Gasoline	95E10 gasoline	1.0 (GDI)	2023	20 000	Euro 6d-ISC-FCM	3-way catalyst, GPF	41
CNG	Compressed natural gas	1.0	2019	50 000	Euro 6d-TEMP-EVAP-ISC	3-way catalyst	30
Diesel	Winter diesel	1.6	2019	40 000	Euro 6d-TEMP	DOC, DPF, SCR	30

- Euro 6d compliant vehicles:

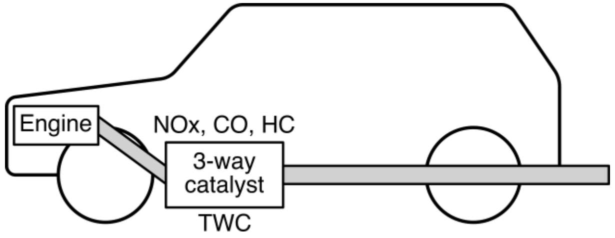
Diesel:



Gasoline:



CNG:
(compressed natural gas)



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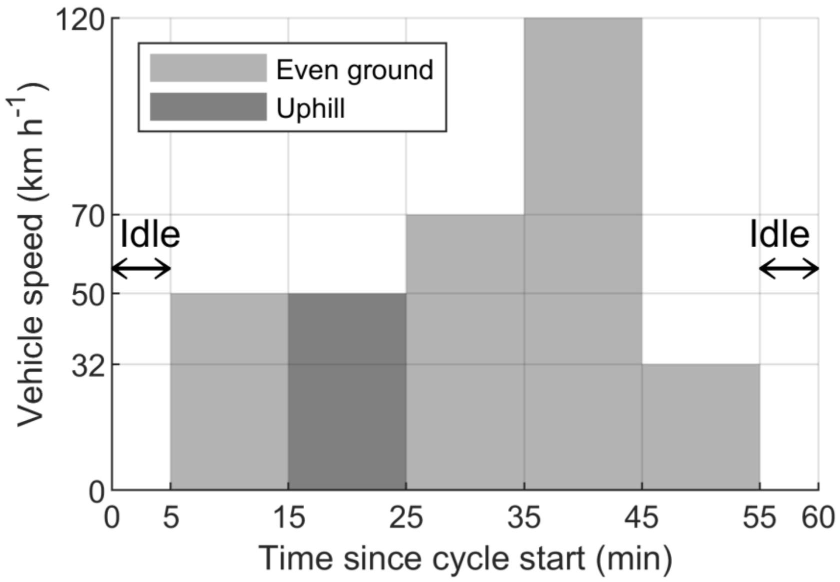
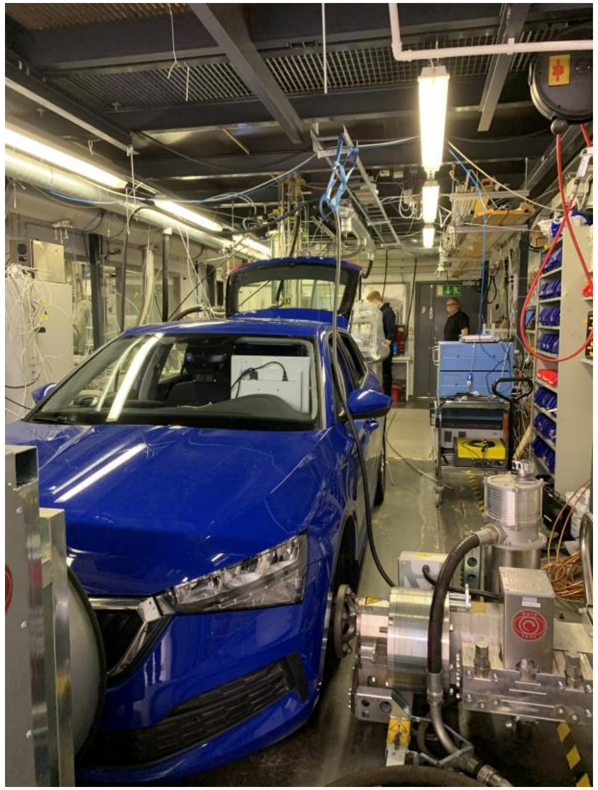
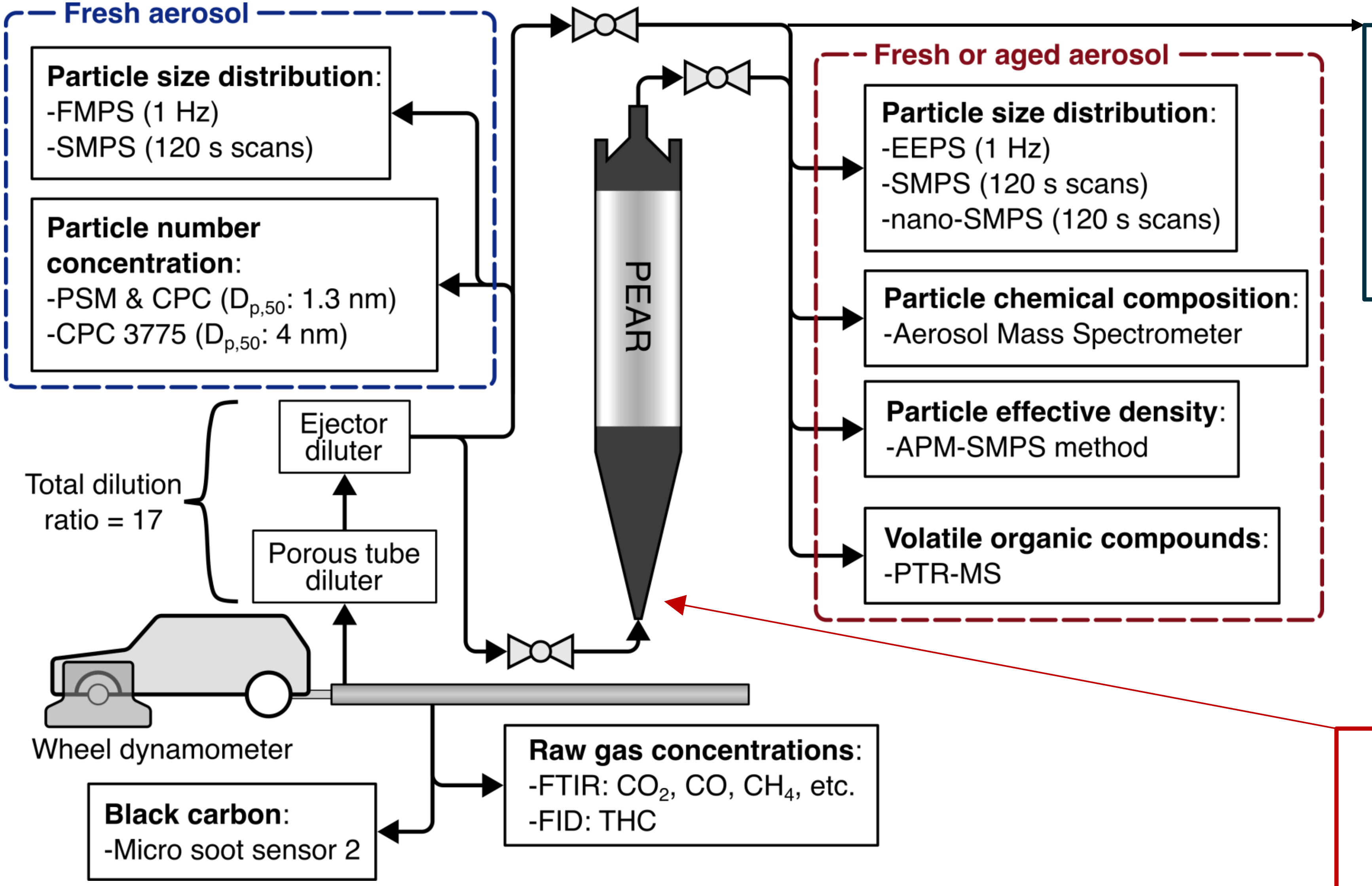
- 1 experiment consists of 4 consecutive 60 min driving cycles
- >1500 km of driving with each vehicle
- 3 DPF regenerations observed

Driving cycle:





Methods



Air-liquid cell exposure

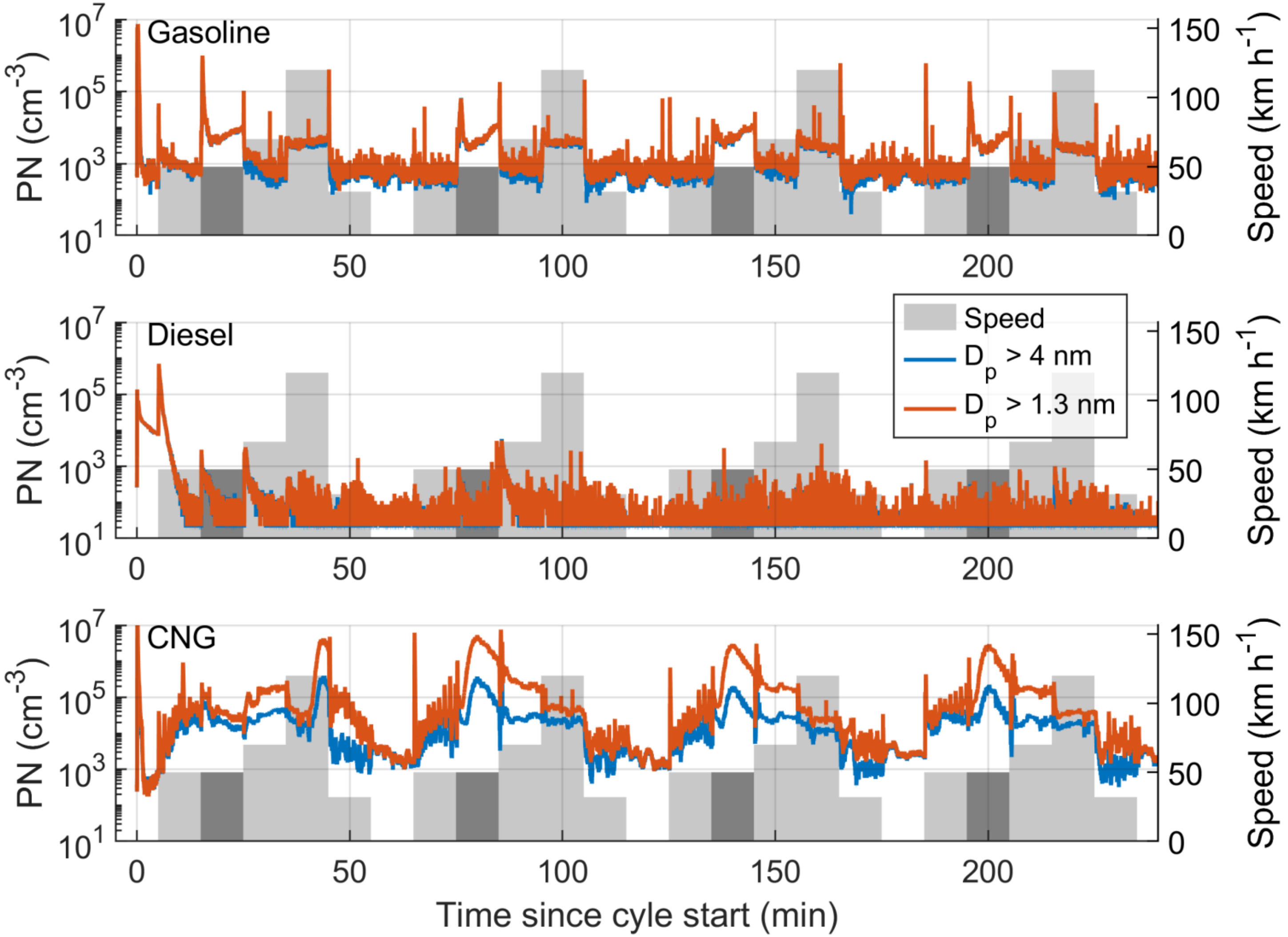
In Vivo exposure

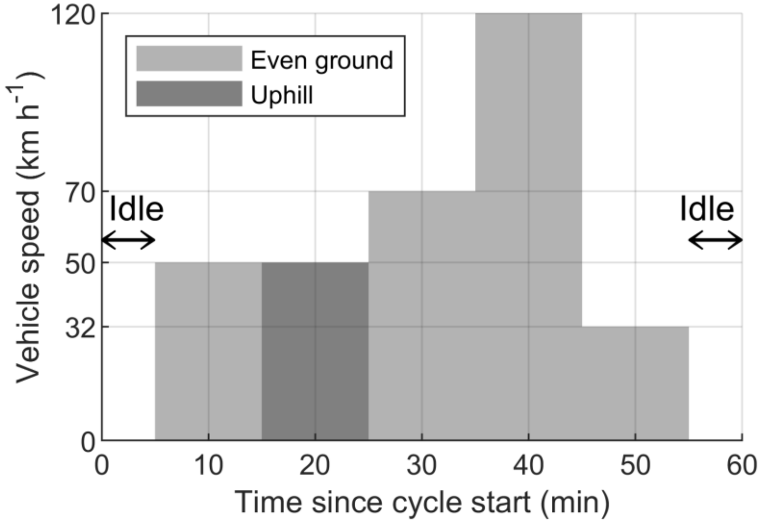
PEAR oxidation flow reactor
(Ihalainen et al., 2018, AST)

- Photochemical age 1-4 days

Results – fresh particulate emissions

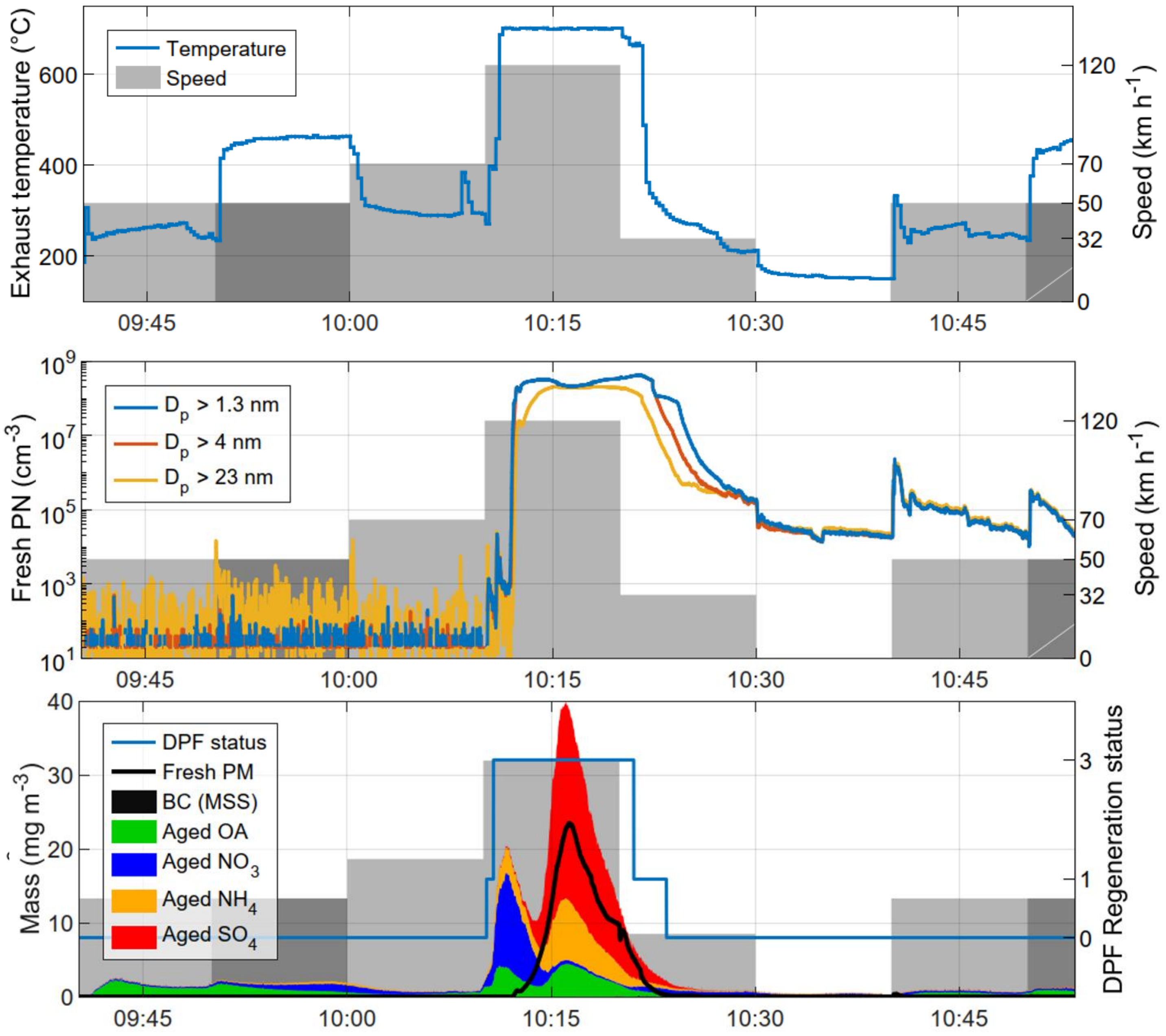
Tailpipe particle number concentrations:





Results – Diesel particulate emissions during regeneration

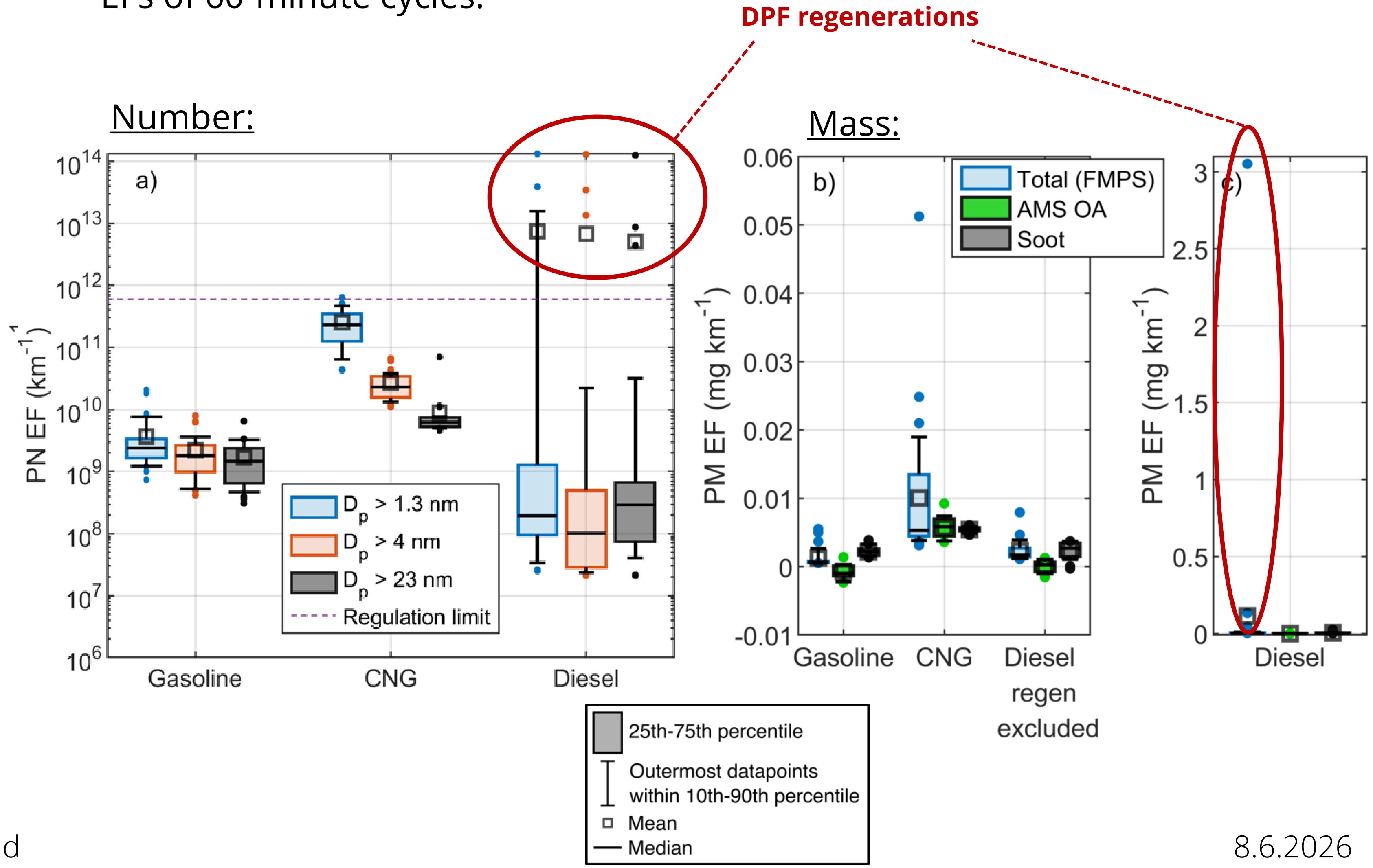
- DPF regeneration occurred roughly with the interval of 500 km
- Primary particle mass emitted during DPF regeneration: 4-152 mg



Results – fresh particulate emissions

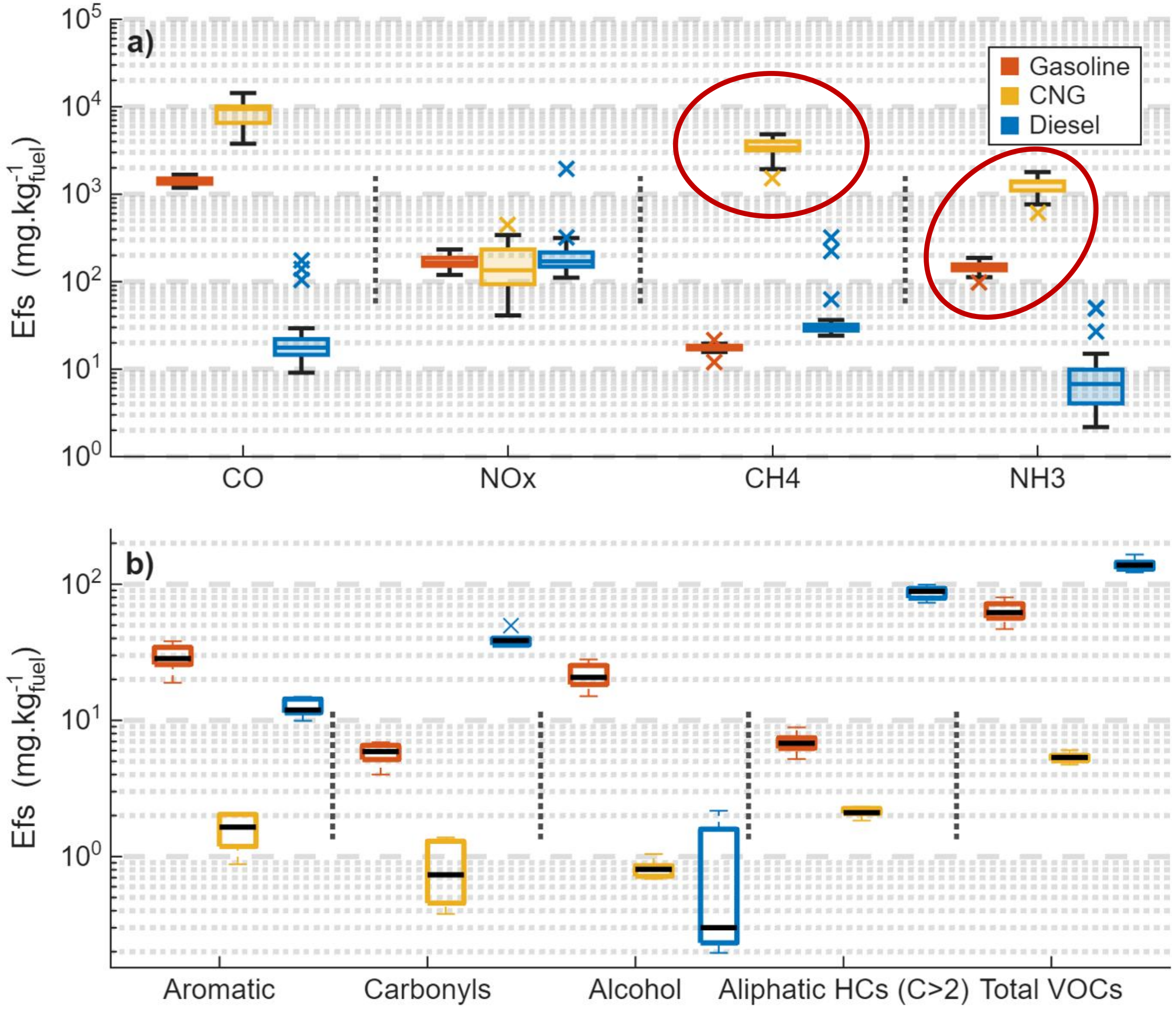
- Regulation limits:
  - 6×10^{11} #/km (PN; solid, D_p > 23 nm)
  - 4.5 mg/km (PM)
- CNG fresh emissions typically highest
- Diesel regenerations have a drastic effect on particle number emission

EFs of 60-minute cycles:



Results – fresh gas emissions

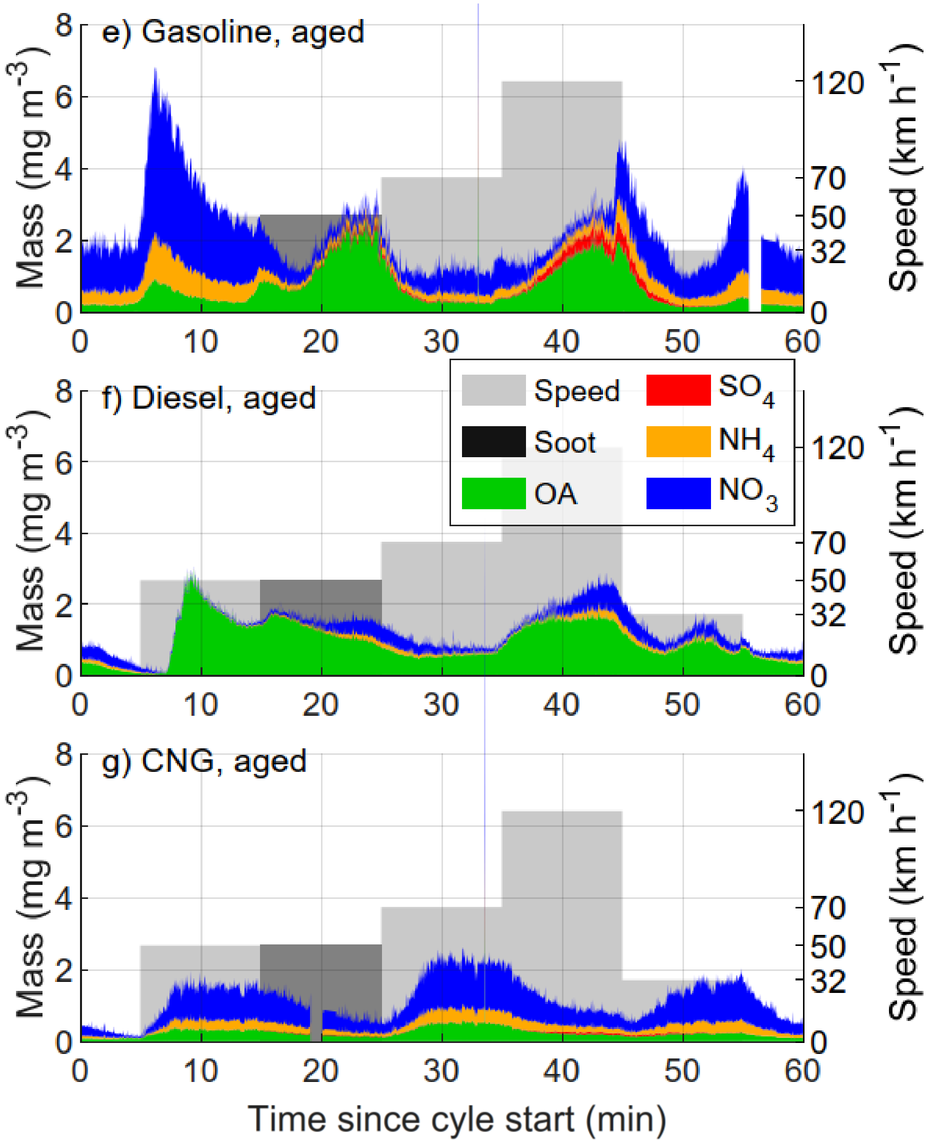
Emission factors of 60-minute cycles:



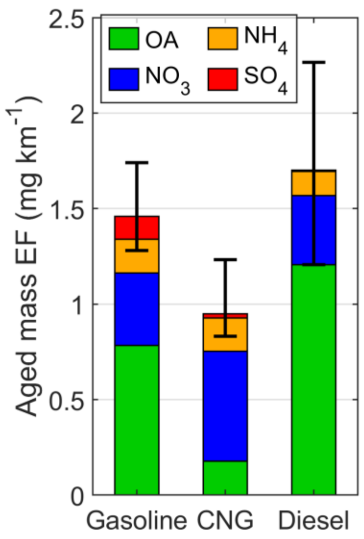
- High CH4-slip from CNG car
- High NH3 emissions from CNG and gasoline cars (formed as a byproduct in the TWC catalysts)
- Large differences in VOC compositions

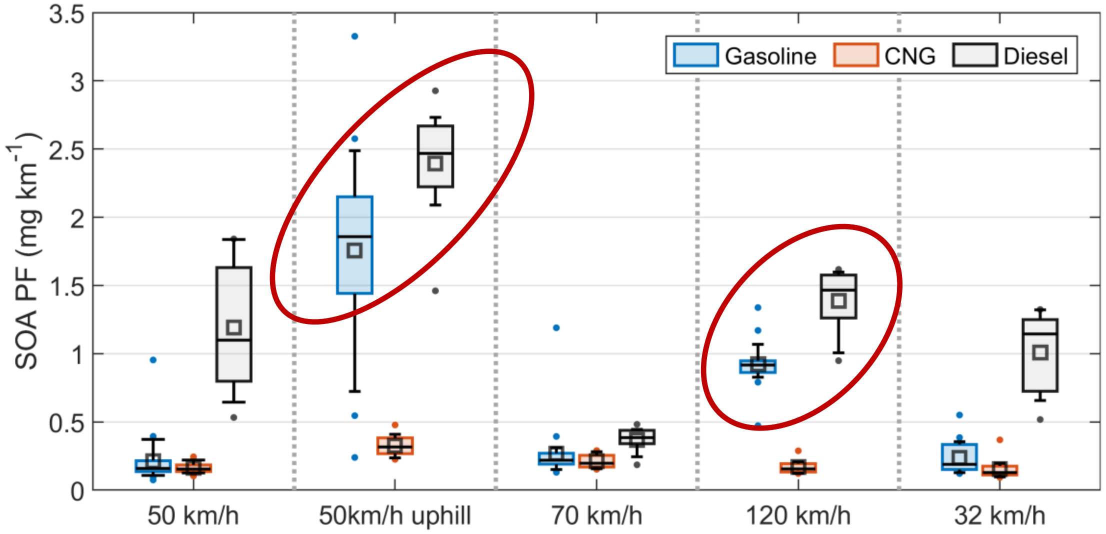
Results – secondary aerosol formation

Aged aerosol time series



Secondary aerosol and SOA emission factors



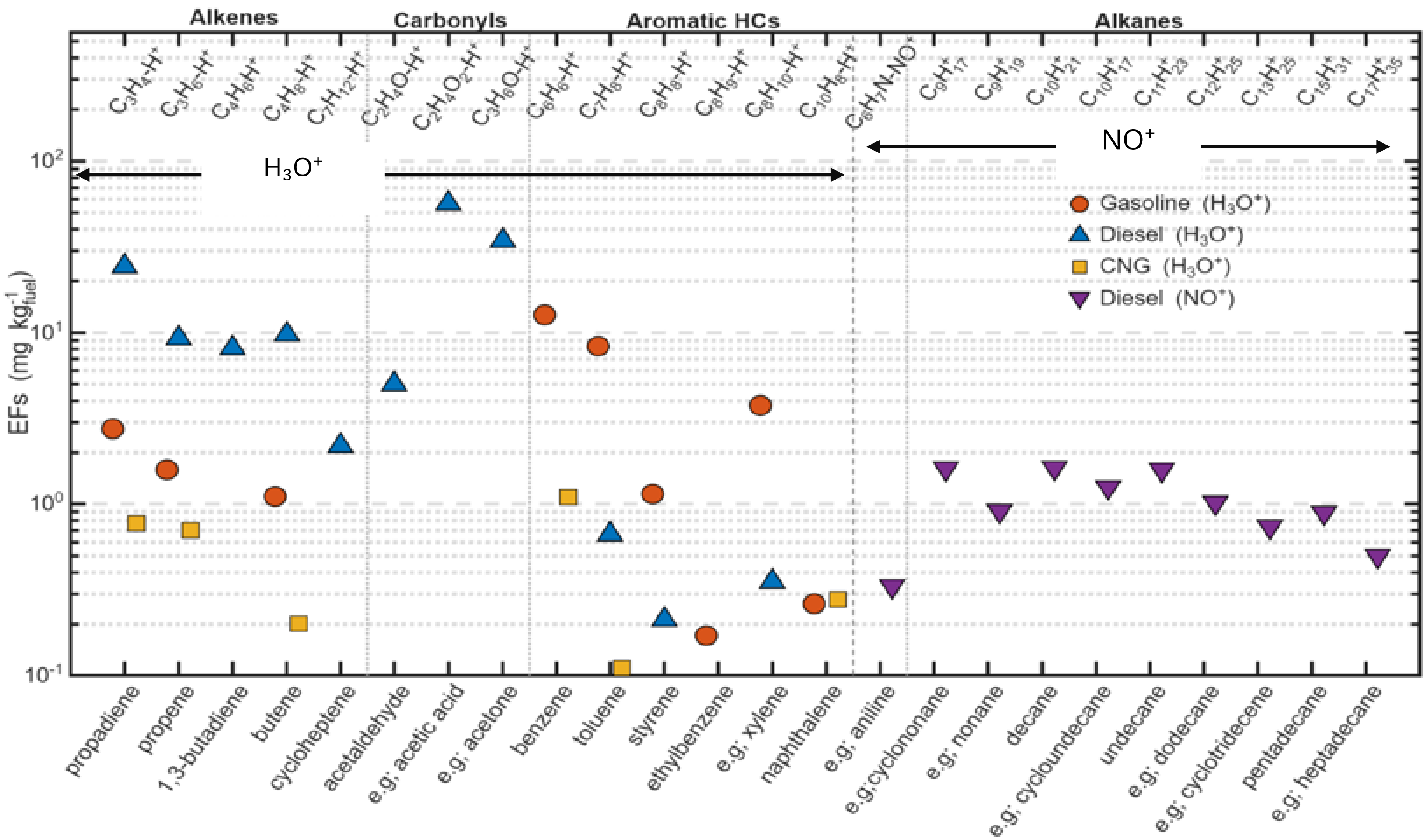


- Up to ~1000-times increase in particle mass due to aging
- Ammonium nitrate important secondary aerosol constituent with cars equipped with a 3-way catalyst (gasoline and CNG)
- Low SOA with CNG
- High SOA with gasoline and diesel at high engine loads

Results – volatile organic emissions

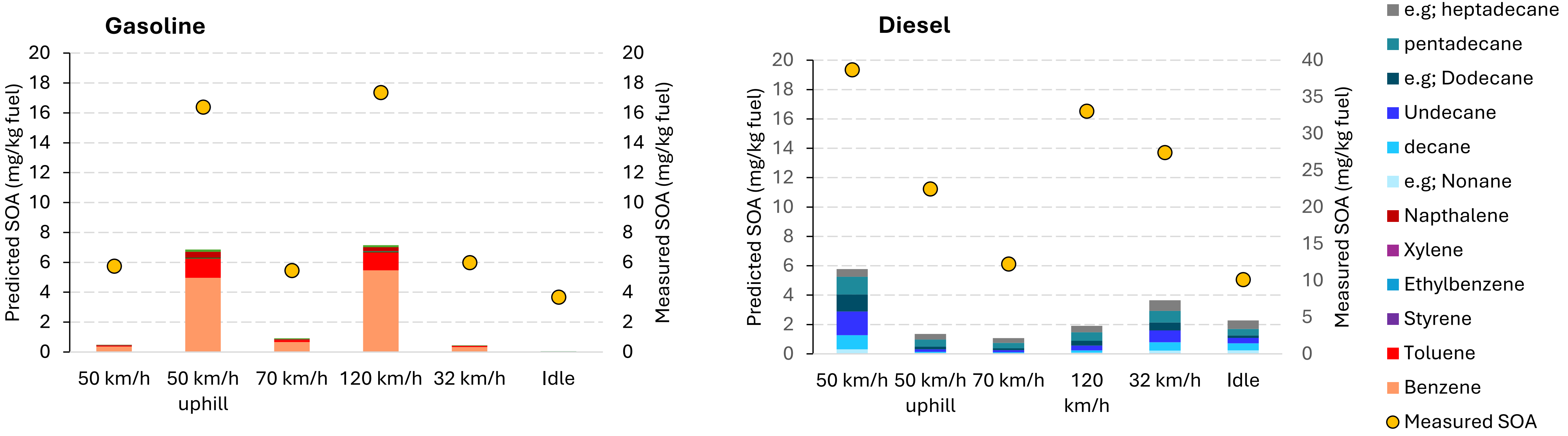
- H_3O^+ and NO^+ reagent ion modes were used in PTR to measure VOC with varying proton affinities
  - ~ 100 molecular formula assigned and quantified
- Gasoline:
  - Highest aromatic hydrocarbon emissions
- Diesel:
  - Alkenes & carbonyls
  - alkanes identified at NO^+ mode
- CNG: cleanest in terms of NMVOCs

Emission factors of VOCs



Results – secondary aerosol formation

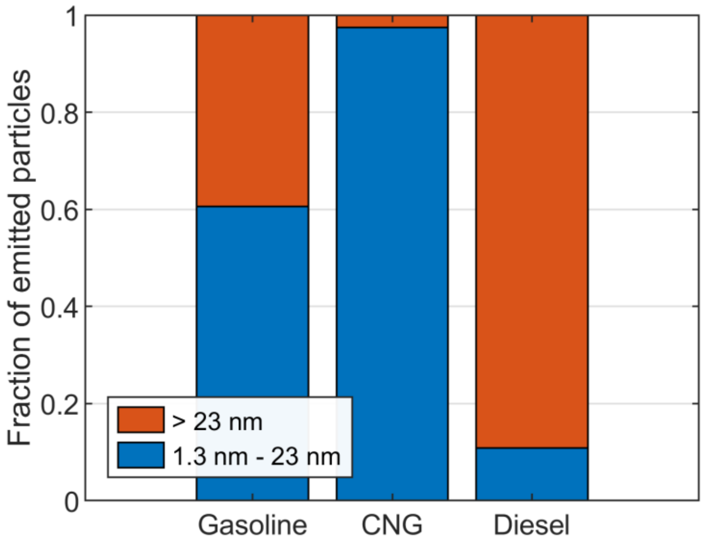
SOA predicted vs SOA measured



- Aromatic VOC:s identified as the main precursor group for SOA in gasoline and CNG
- Long-chain aliphatics the main identified SOA precursor for diesel

Conclusions

- Low primary particle emission factors on all metrics (when compared to other transportation sources)
- Large fraction of particle number emissions outside of the regulation range (<23 nm) for CNG and gasoline cars
- Byproducts from the exhaust gas after-treatment systems strongly influence emissions of EURO6 cars
  - Diesel: Considerable particle number emissions from DPF regeneration
  - CNG & gasoline: Ammonia emissions
- Secondary aerosol formation increases particle mass 2-3 orders of magnitudes for passenger cars



Thank you / Acknowledgements:

P. Simonen, A. Hartikainen, M. Ihalainen, T. Kokkola, M. Somero, P. Yli-Pirilä, G. Mustafa, H. Oikarinen, L. Ala-Hakuni, A. Mukherjee, M. Shahzaib, T. Streibel, D. Shukla, M. Rohkamp, Q. He, S. Piel, S. Jeong, U. Etzien, A. Das, L. Schwalb, T. Gröger, A. Barth, M. Sklorz, B. Gündling, M. Kalberer, B. Buchholz, A. Hupfer, T. Adam, H. Czech, T. Hohaus, M. Saraji-Bozorgzad, P. Jalava, B. Rothen-Rutishauser, O. Hänninen, S. Di Bucchianico, P. Karjalainen, J. Øvrevik, R. Zimmermann

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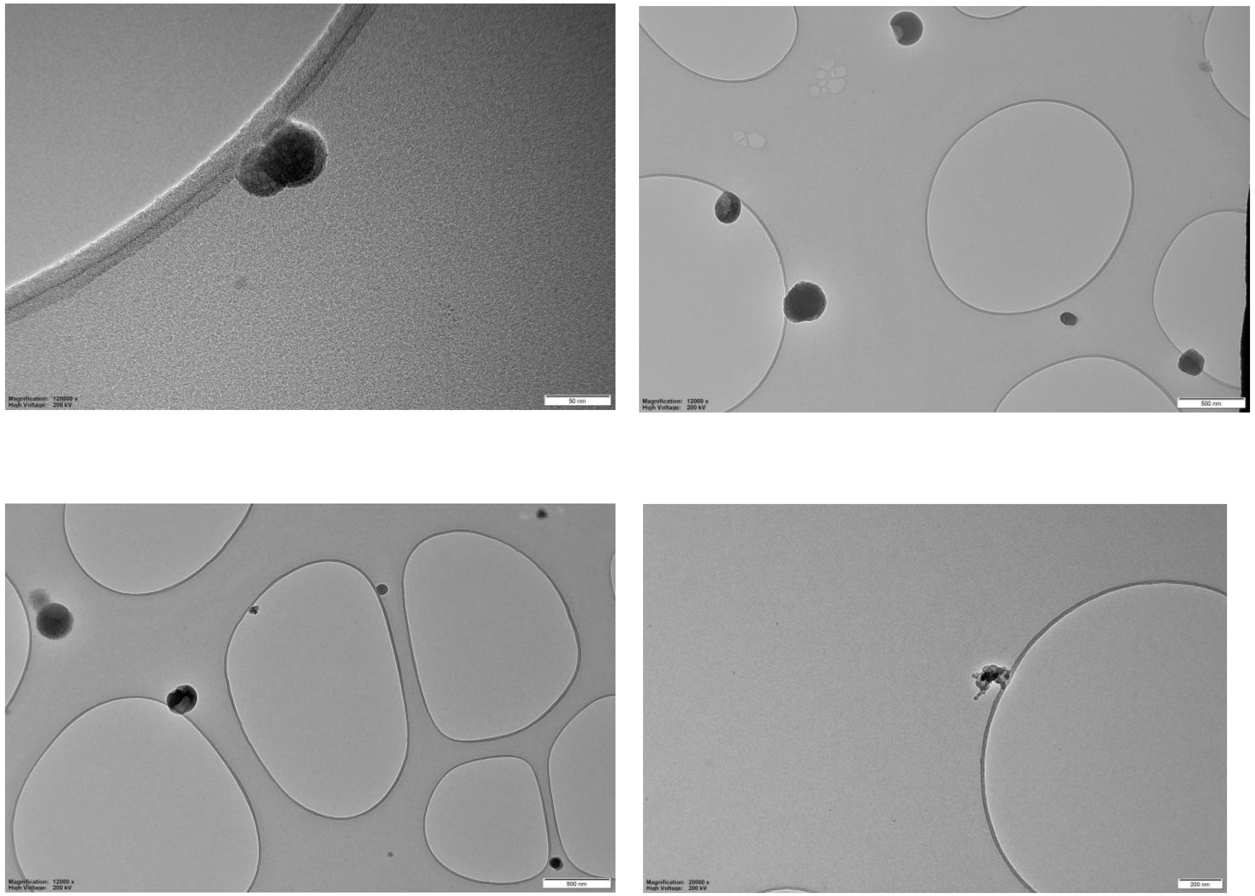
Funded by the European Union

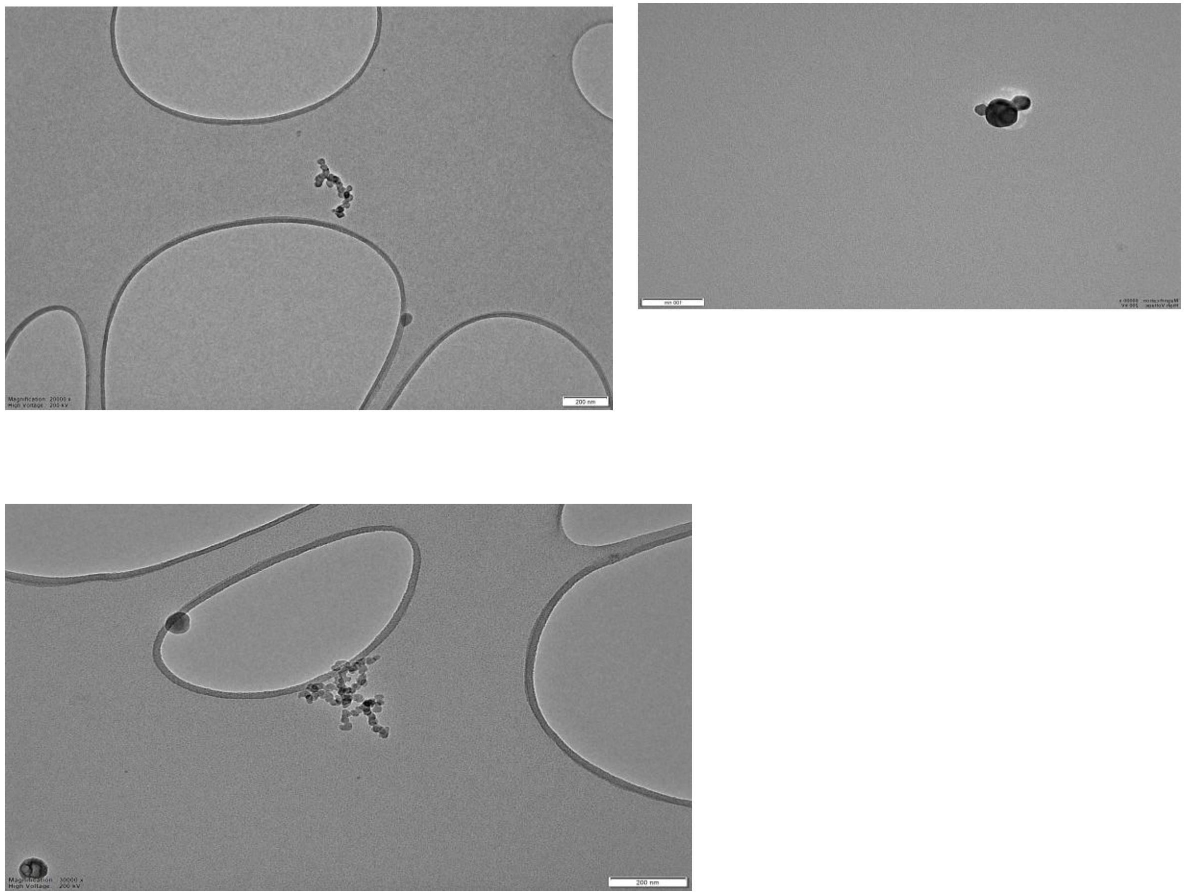
This work was supported by EU Horizon2020 project ULTRHAS (agreement 955390).

Primary particle morphologies

CNG Primary (full cycle)

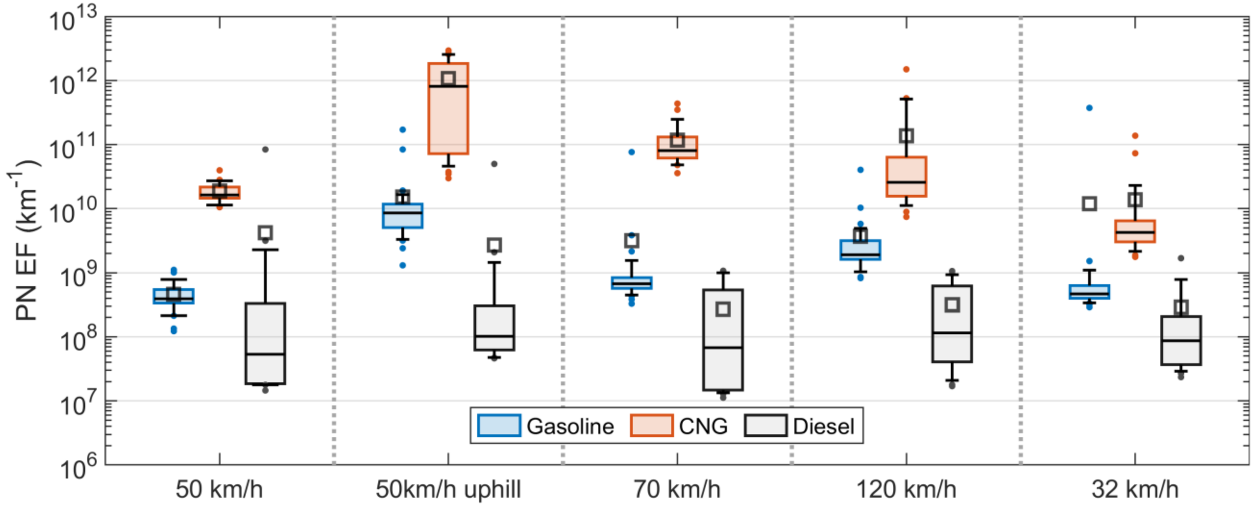


Gasoline Primary (full cycle)



Results – fresh particulate emissions

Particle number EFs for each driving phase:



CNG particle size distributions: