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Lowering laboratory and real driving particle emissions of direct injection spark ignition engines with n-butanol and isobutanol blends.

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Overview of the study

2013 / EURO 6 Ford Focus car with EcoBoost DISI engine

Gasoline, E15, 25% n-butanol, 25% isobutanol

Chassis dynamometer - NEDC, WLTP, Artemis, US06
HC, CO, NO, NO2, PM, PN (PMP), PN (EEPS),
Unregulated: FTIR, PAH, genotoxicity (DNA adducts, ...)

55-km real driving loop - size distribution (onboard EEPS)

Issues adressed in this study

Particle emissions from DISI engines:

- **emissions from production / in-use engines**
- **effects of driving cycle / off-cycle emissions**
- **particles smaller than 23 nm**
- **volatile nanoparticles**

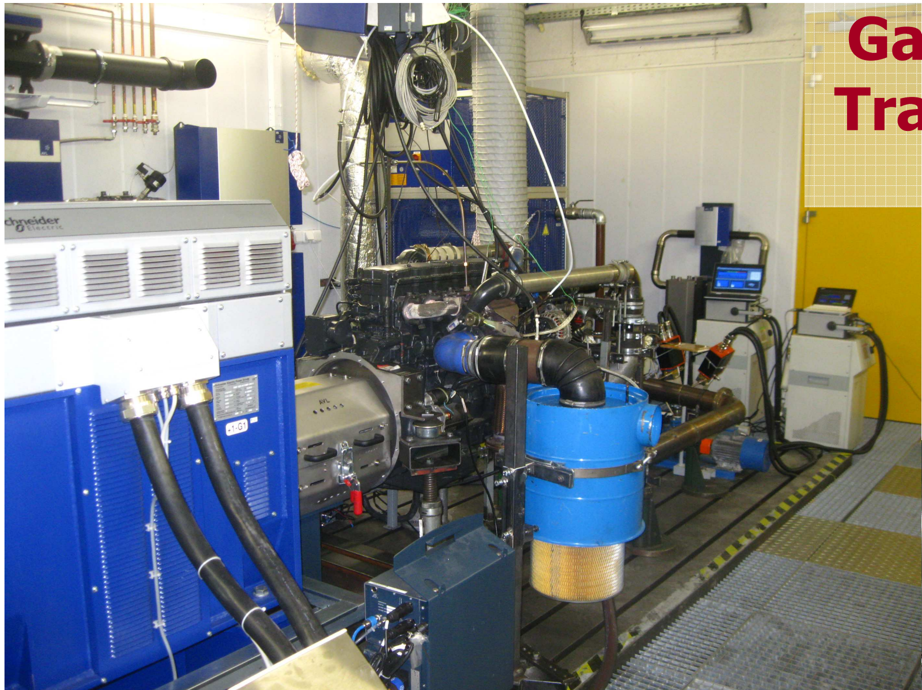
Real driving emissions and their measurement

WLTP vs. NEDC, Artemis, US06, ..., real driving

Effect of renewable alcohol fuels on particle emissions

Butanol as a potential alternative to ethanol

Project BIOTOX – Mechanisms of Toxicity of Particles from Biofuels
PM measurement and sampling using high-volume samplers



Gasoline MPI and direct injection, diesel, Traditional and alternative fuels (ethanol, butanol, biodiesel, NExBTL, blends)

Real driving emissions measurement
Portable on-board monitoring systems (PEMS)

Cars, buses, trucks, tractors, loaders, mowers, small airplanes, mopeds, ferries, locomotives, construction machinery

"Research PEMS": On-board FTIR (gaseous compounds), EEPS (size distributions), CPC (particle counts)

Student projects: E85, n-butanol, isobutanol in unmodified gasoline engines in Škoda cars

On-board FTIR

~ 30 kg

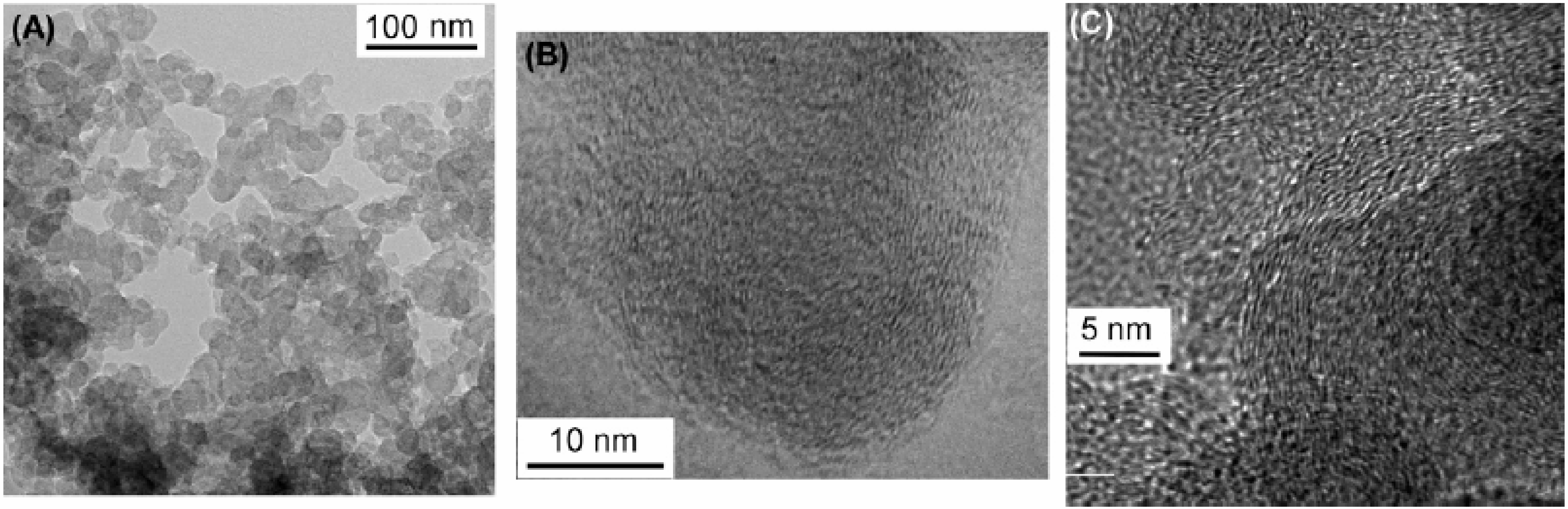
~ 300-400 W

3 hours on

26 kg of batteries

(Diesel) ICE exhaust particulate matter

- **Small particles (units to hundreds of nm) formed by incomplete combustion of fuel and engine lubricating oil and wear metals**
- **Complex mixture of compounds, many known to be carcinogenic**
- **More premature deaths (> 400 K per year in EU) than traffic accidents (< 40 K per year)**
- **One of the most pressing urban environmental problems**

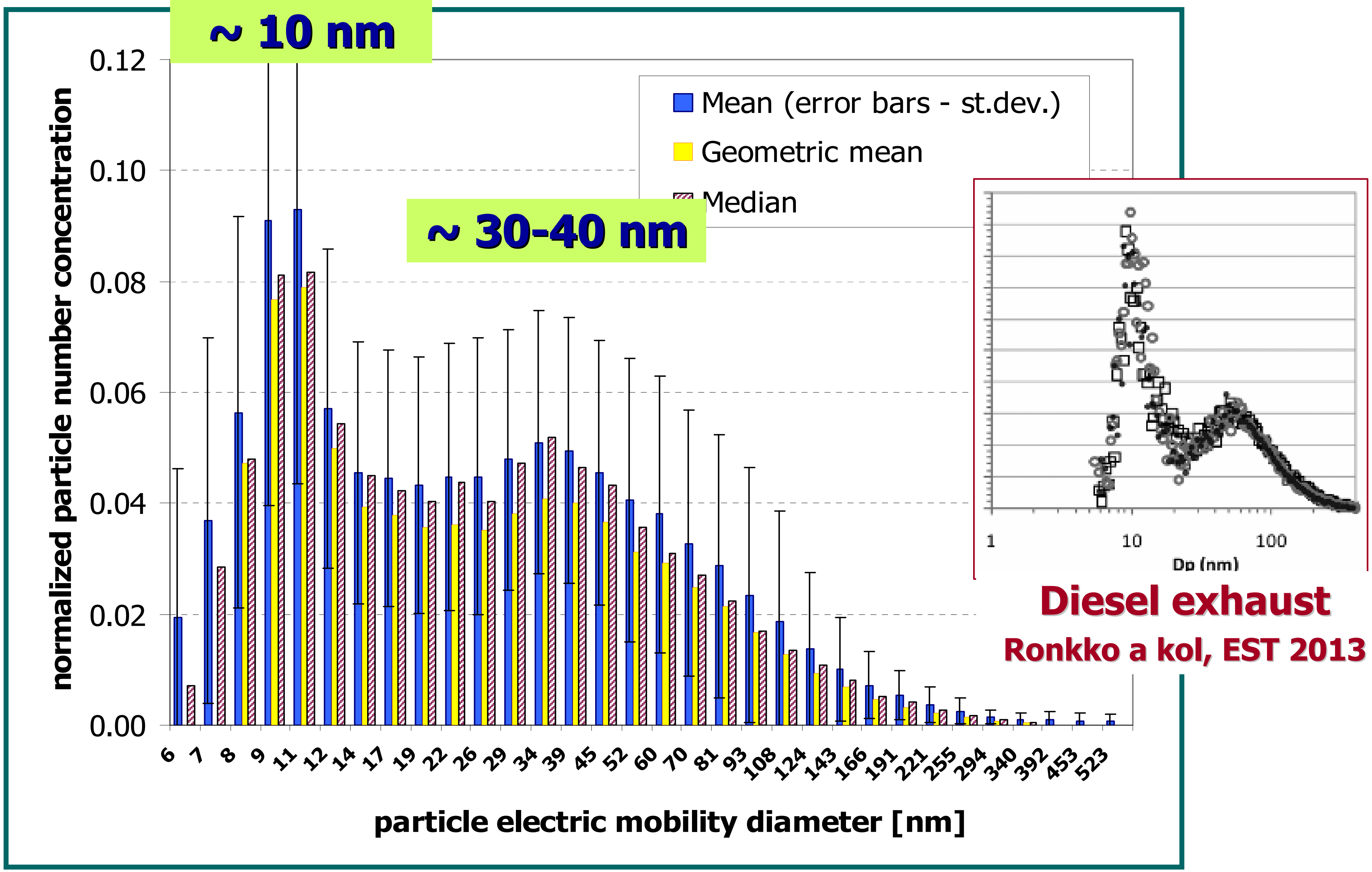


Liati A., Dimopoulos P.E., Combustion and Flame 157 (2010) 1658–1670.

Spořilov – ambient concentrations of 5-100 nm particles (thousands per cm3) – March 26, 2014

Roadside & neighborhood ambient PM

Spořilov, February 2014, average of 40 locations, typical concentrations 10^4-10^5 particles/cm³ (max. 10^6/cm³)



Diesel exhaust

Ronkko a kol, EST 2013

Vojtíšek a kol., NanoCon 2014

Is diesel PM becoming more of a question of public policy rather than technology?

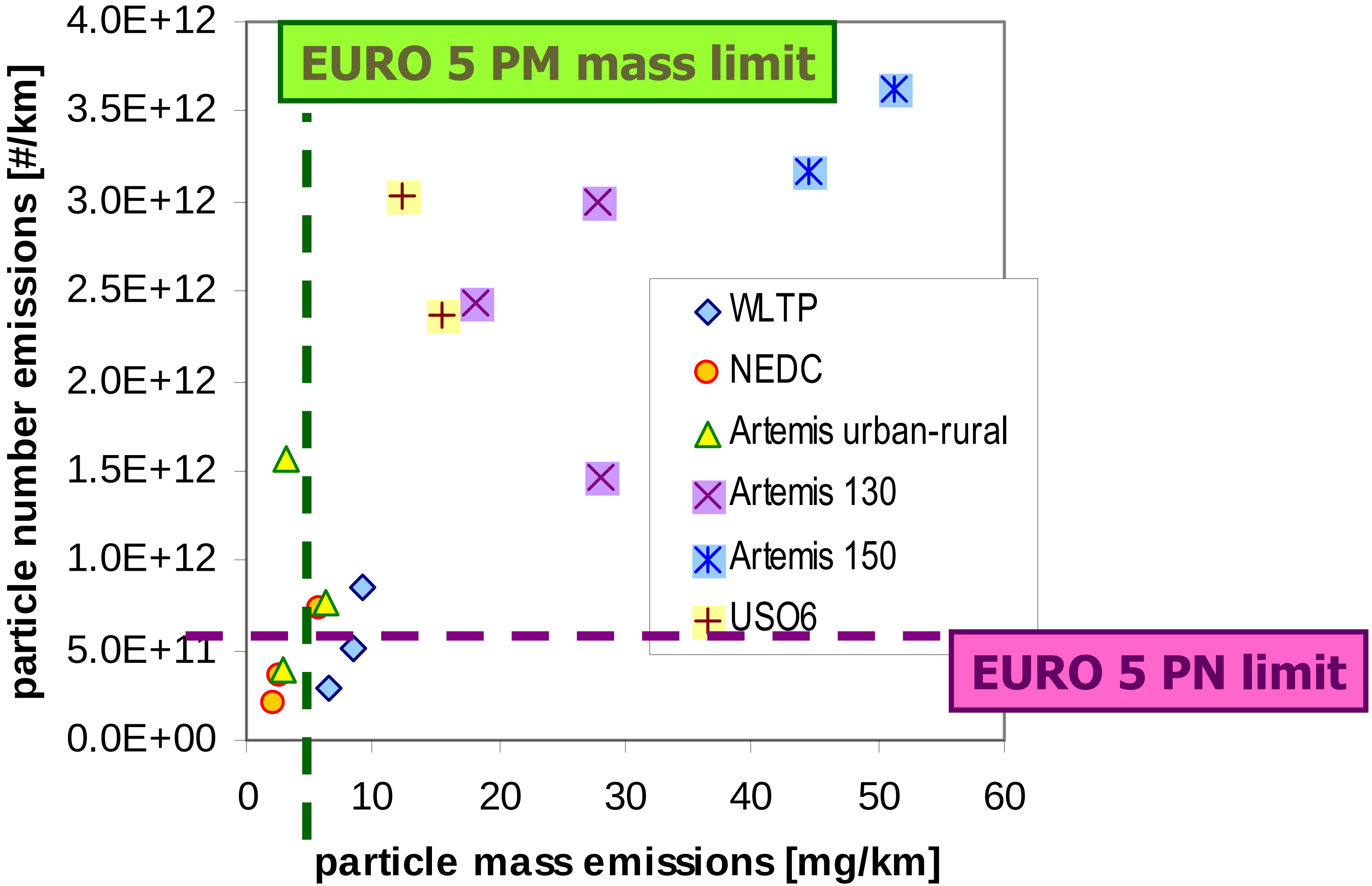
With DPF

Euro 5 with no DPF
(Prague, CZ)

Gasoline engine PM:
Number vs. Mass limits by driving cycle

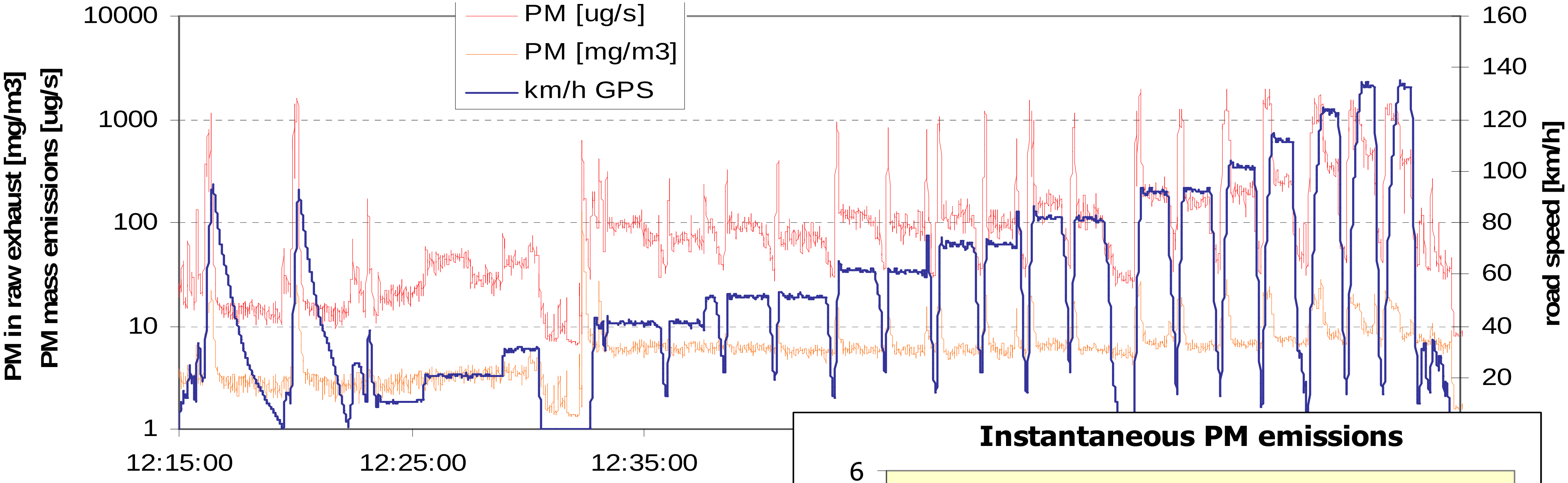
WLTP is "not as lame as NEDC", but does it cover the problem – enrichment at high load (prohibited by EPA)**?**

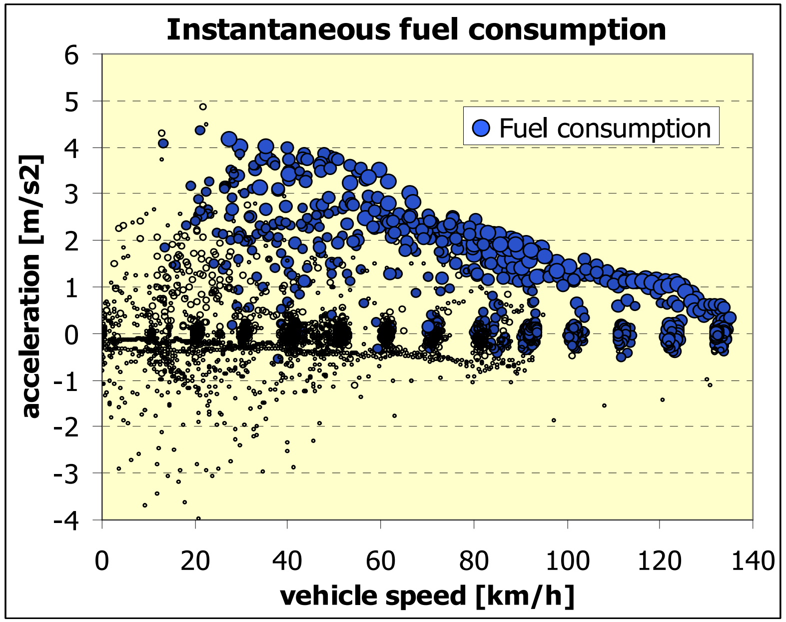
US06 and Artemis motorway cycles as a supplement?

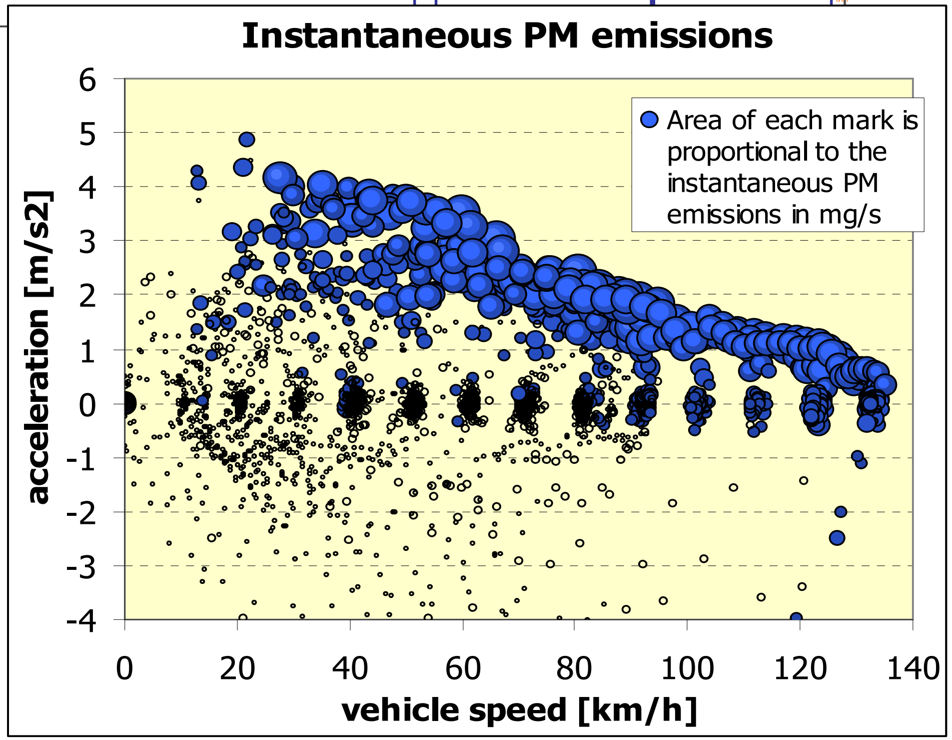


Gasoline engine real-driving PM emissions

Gasoline engine on-road PM emissions – steady speed vs. full-power acceleration



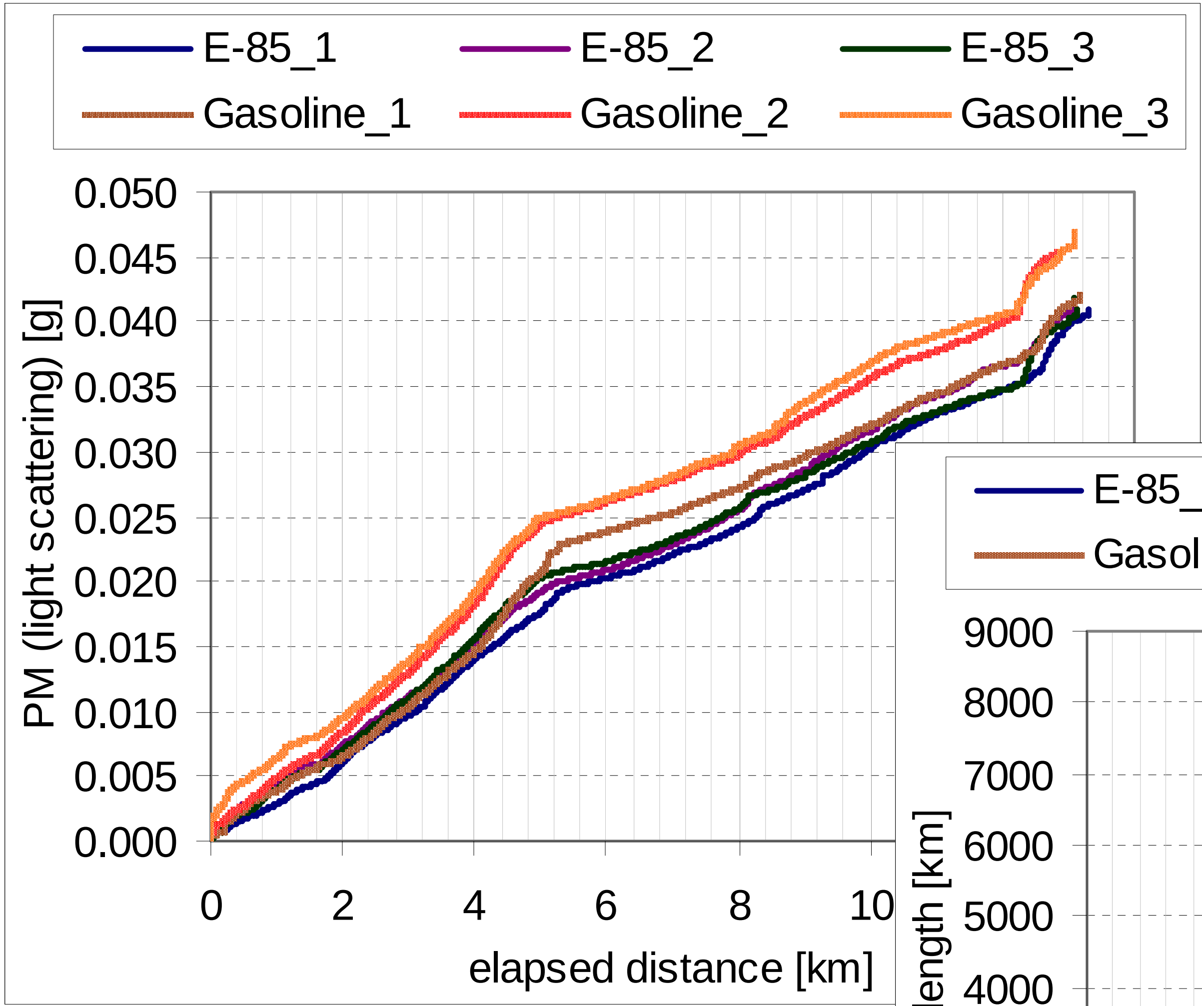


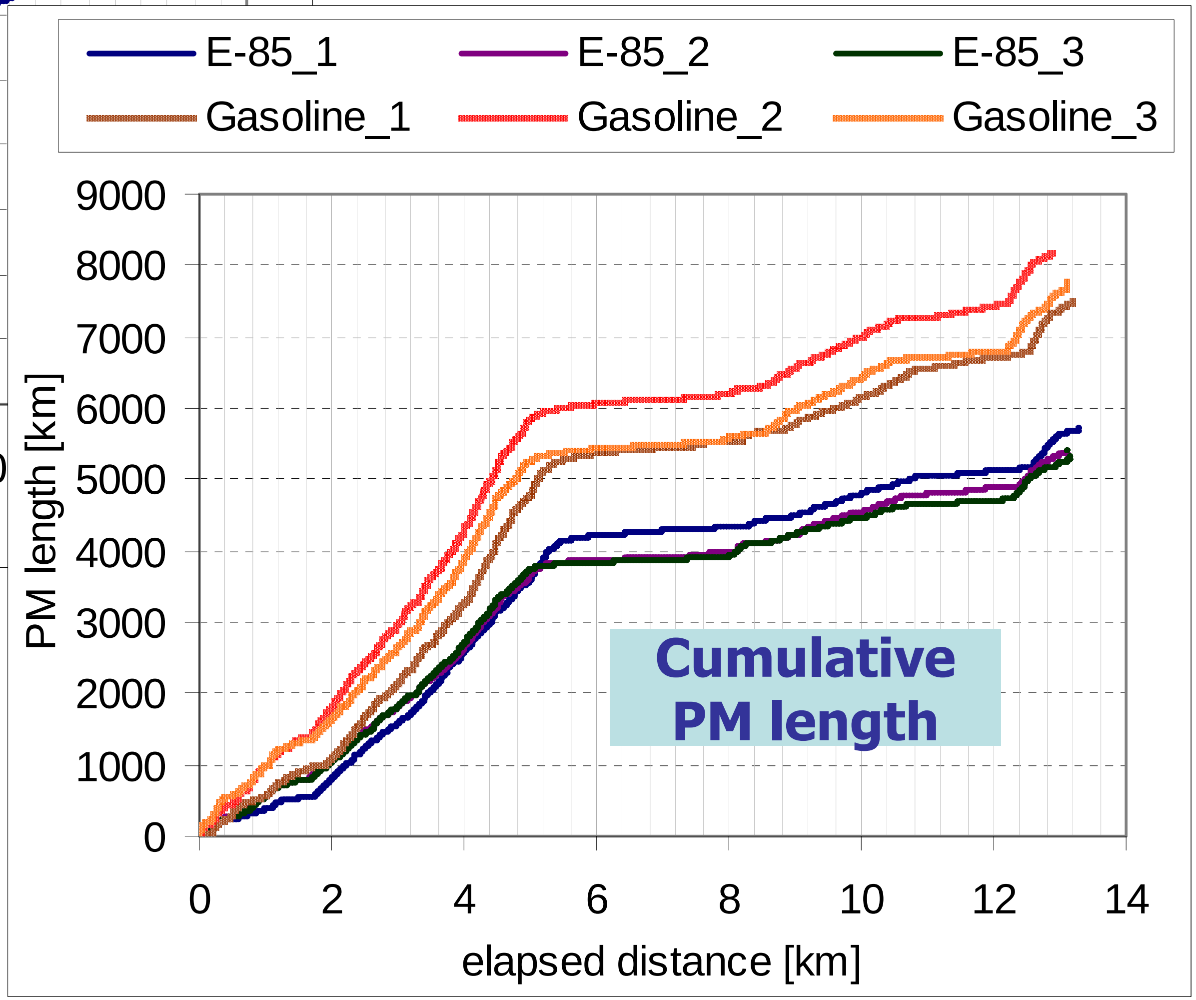


Effects of E85 on real driving emissions in an ordinary car

14 km test route

(SAE 2013-24-0102)





Škoda Felicia passenger car, Euro 3 1.4-liter MPI SI engine
3 runs on gasoline
3 runs on E85

Laboratory tests

Vehicle:

2013 Ford Focus, Euro 6
EcoBoost 1.0-liter engine
Direct ignition gasoline

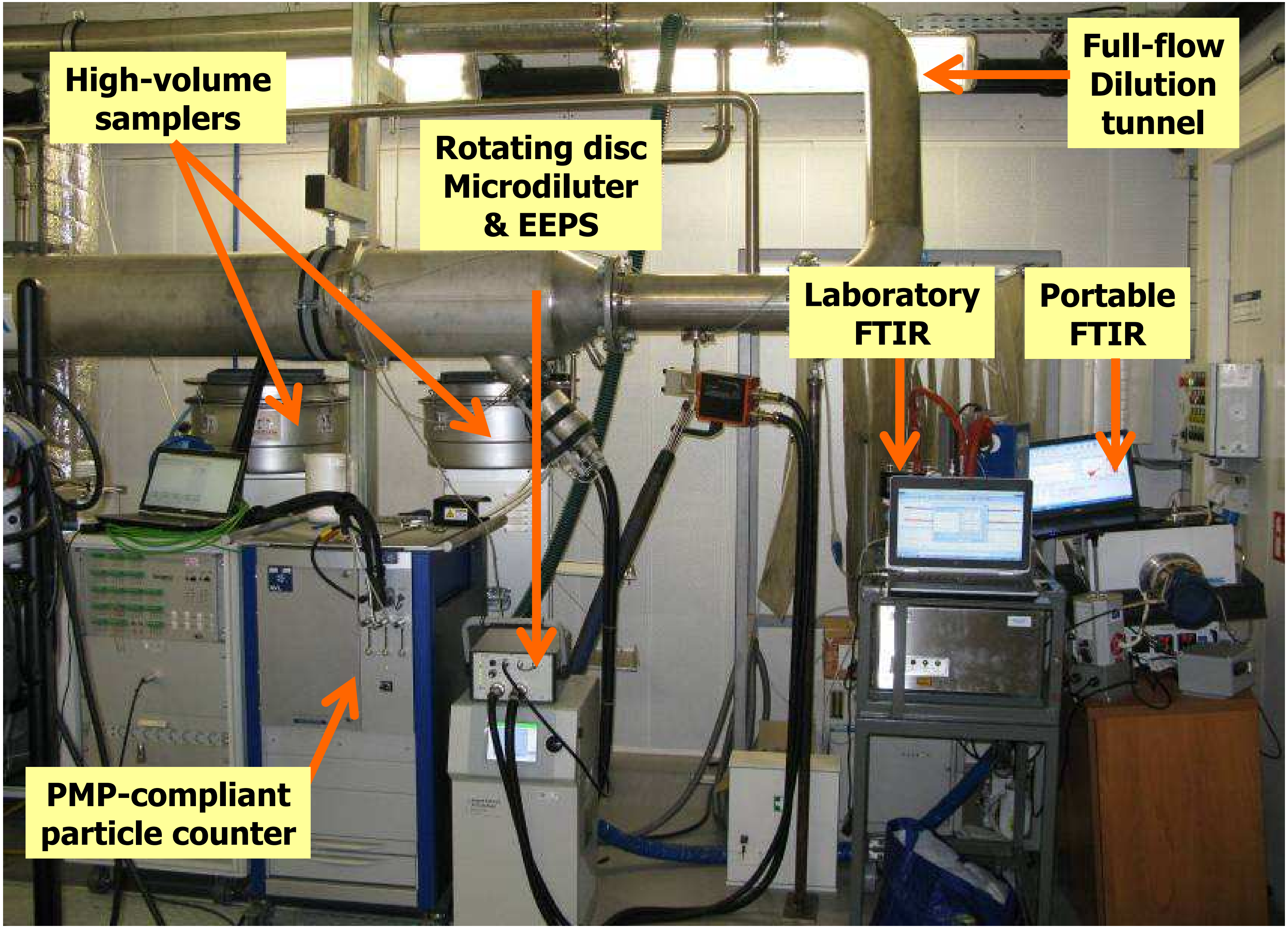
Fuels:

Gasoline (no ethanol),
E15 (15% ethanol)
25% n-butanol
25% isobutanol

Cycles:

Fuel change & adaptation,
WLTP preconditioning,
WLTP cold, WLTP hot,
4 x Artemis

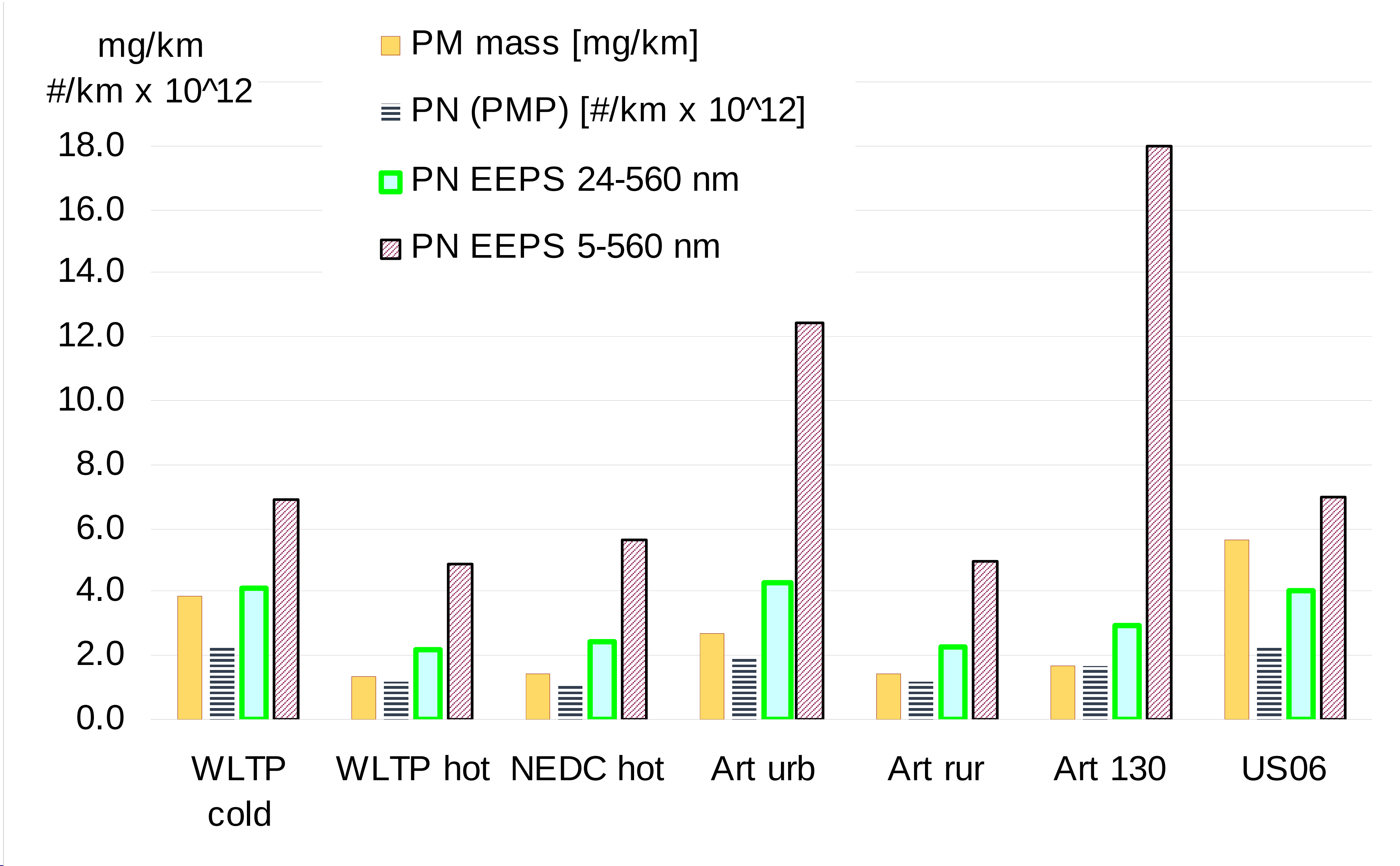
Dilution tunnel instrumentation



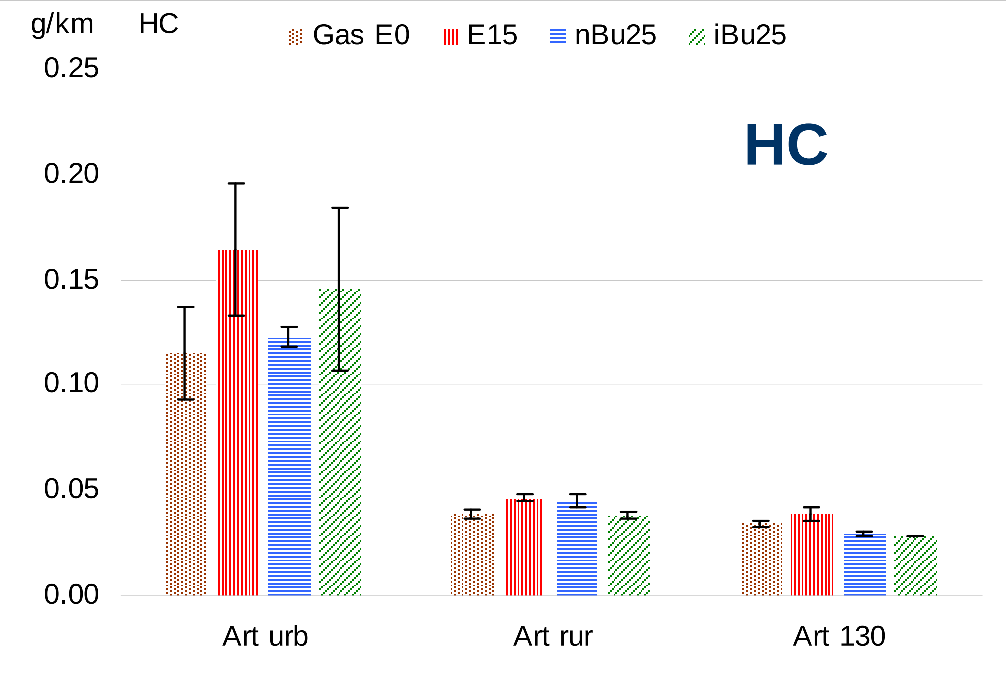
Effect of cycle & effect of "PN" definition:

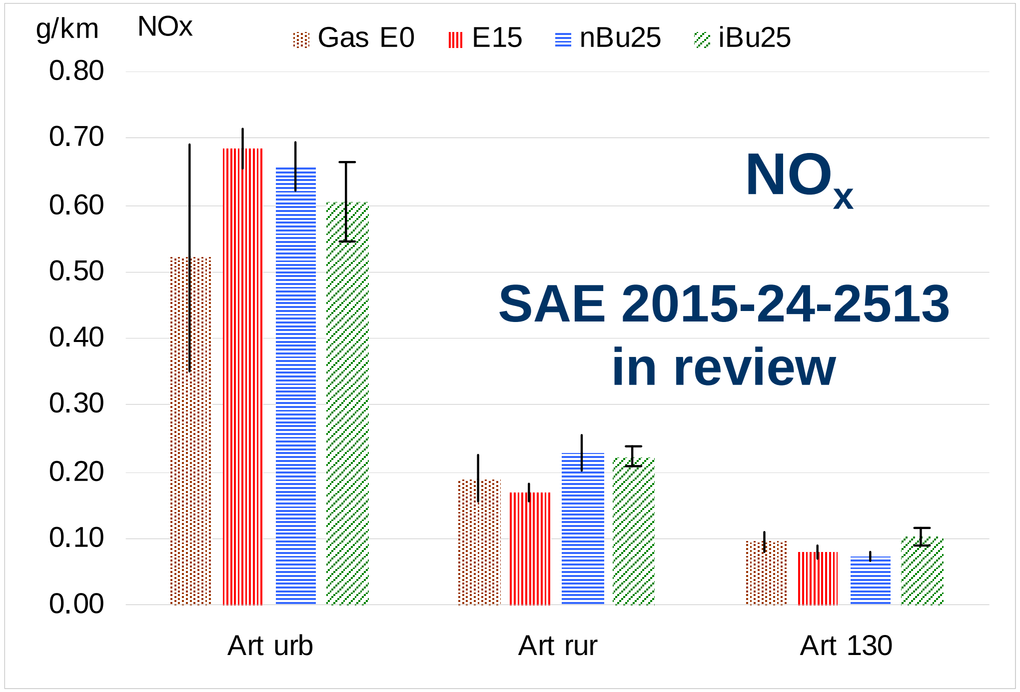
PN (PMP), PN (EEPS 5-560 nm), PN (EEPS 23-560 nm)

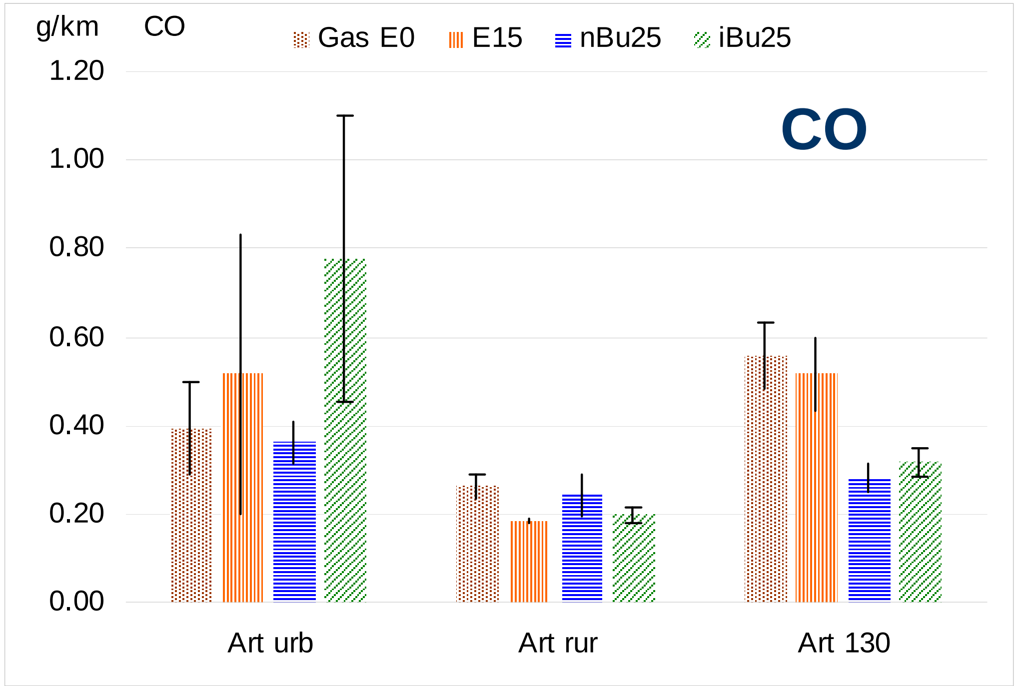
Gasoline, PM is gravimetric on TX40HI20-WW Emfab filters

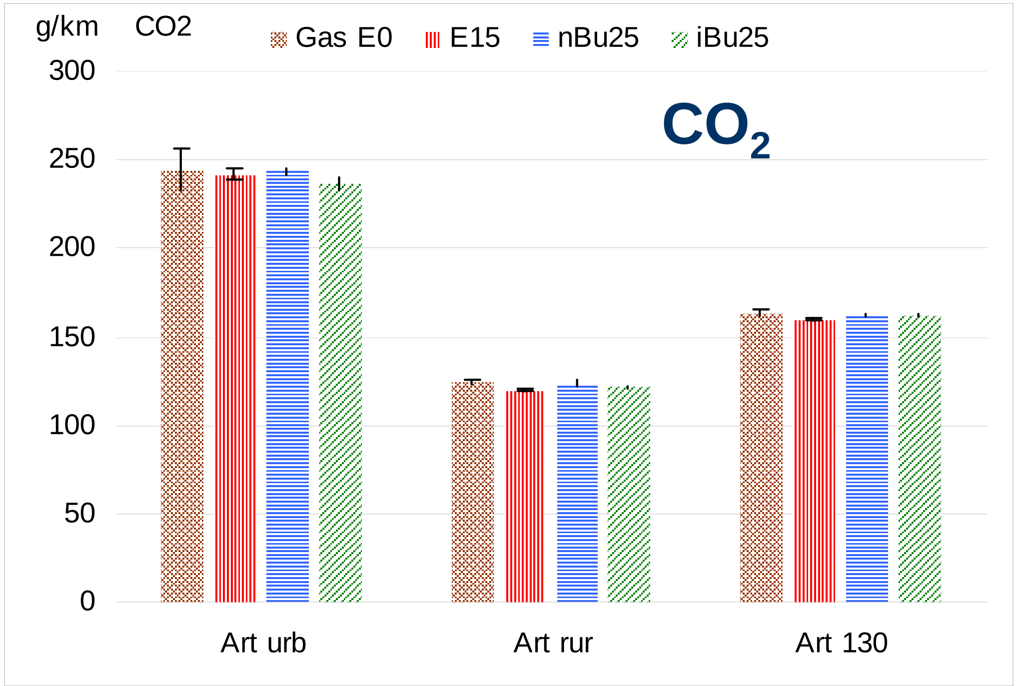


Fuel effect on HC, CO, NOx, CO2: 4 runs of Artemis cycle

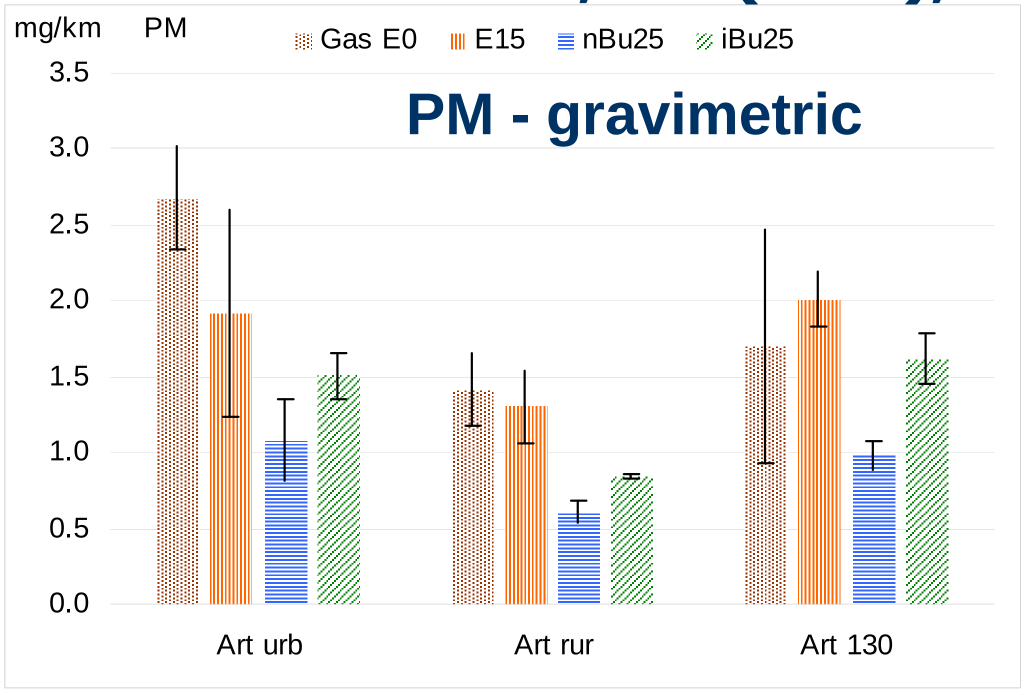


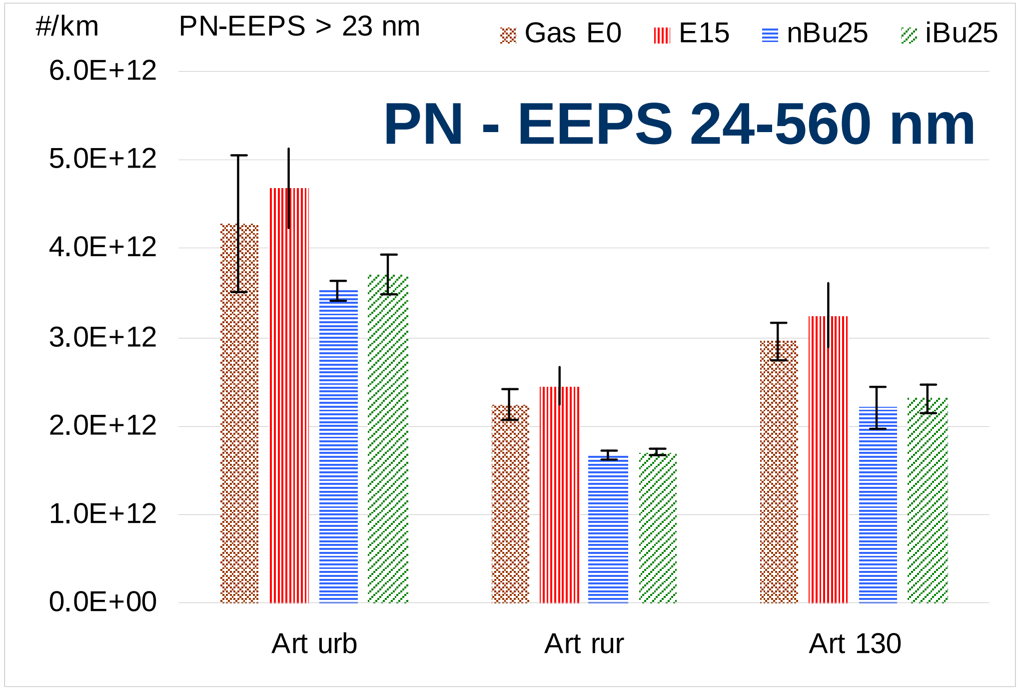


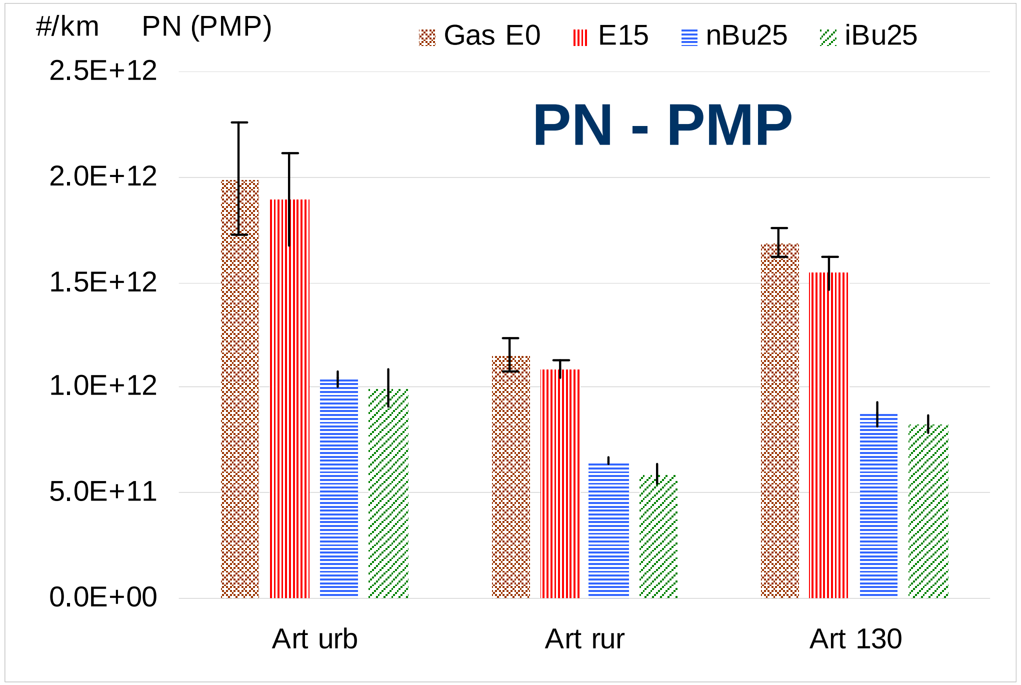


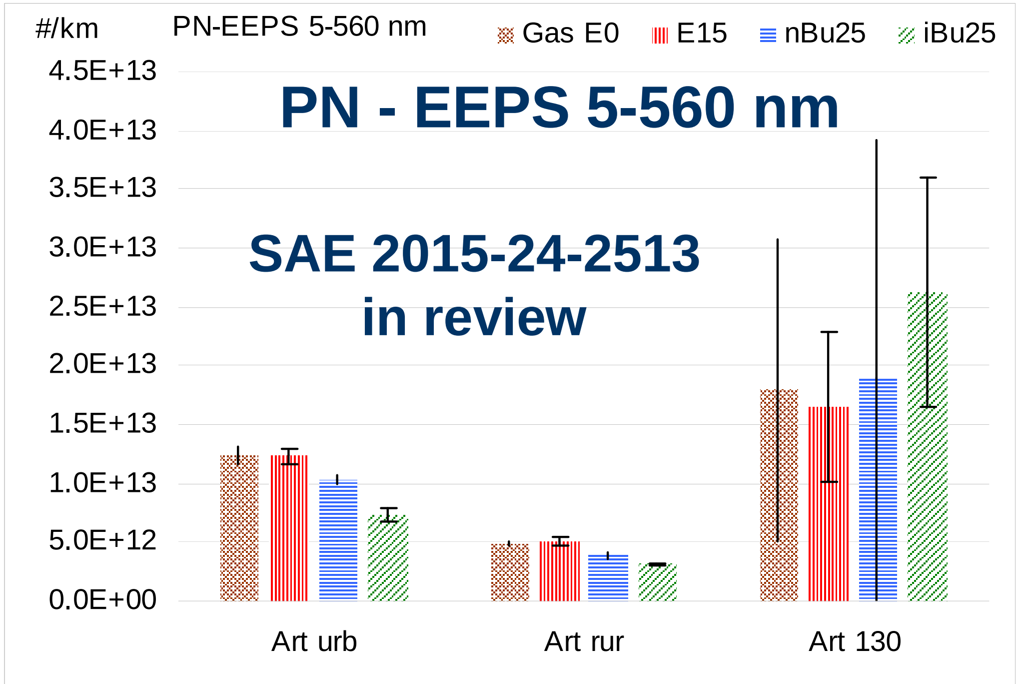


Fuel effect on PM, PN (PMP), PN (EEPS, 24-560 and 5-560 nm)





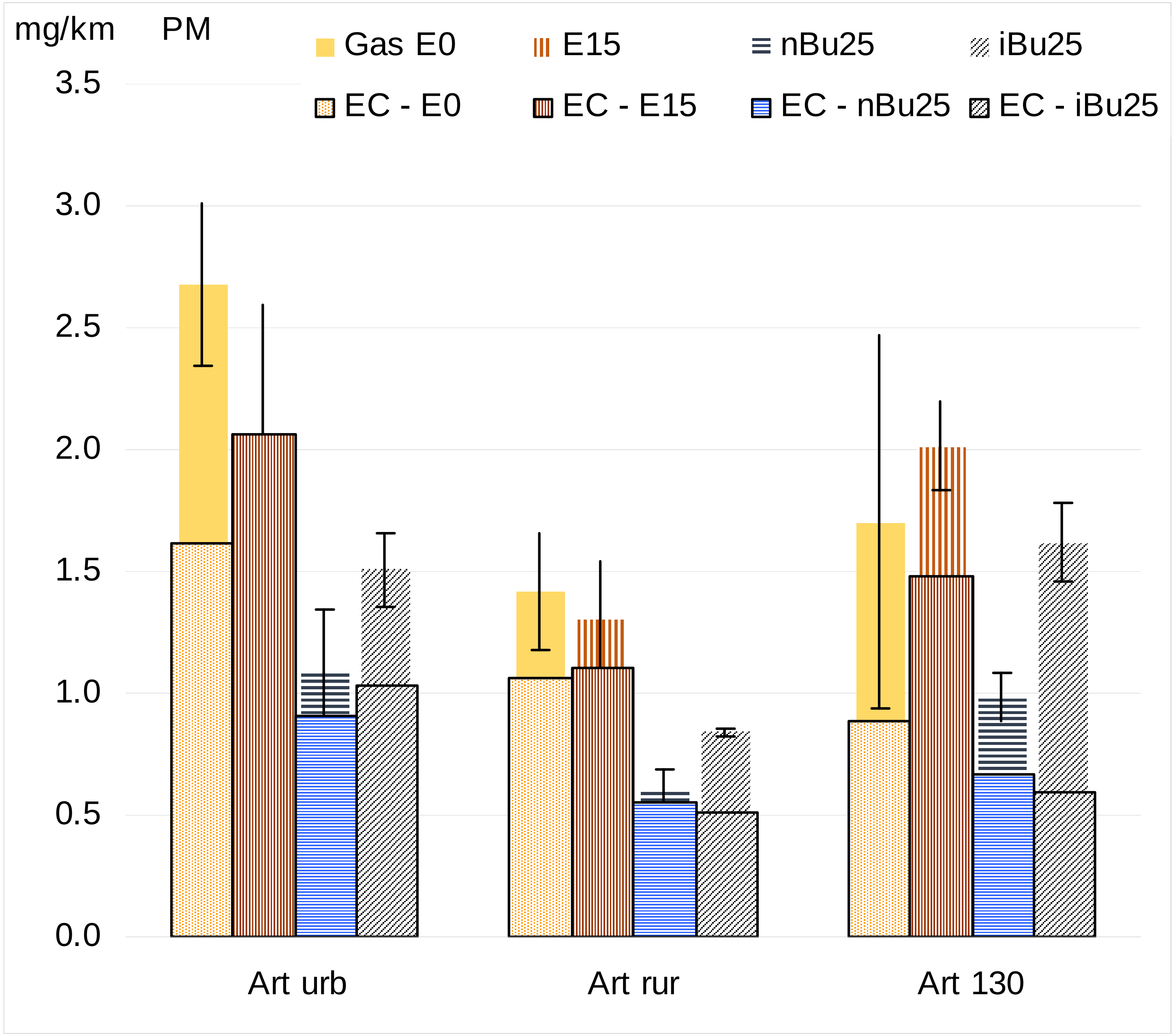




Fuel effect on PM mass – gravimetric and EC
Artemis cycle (4 runs on each fuel)

Gravimetric:
TX40HI20-WW Filters

EC:
Quartz fiber filter
EC/OC split: EUSAAR 2 protocol



"Non-volatile" component of PM and PN

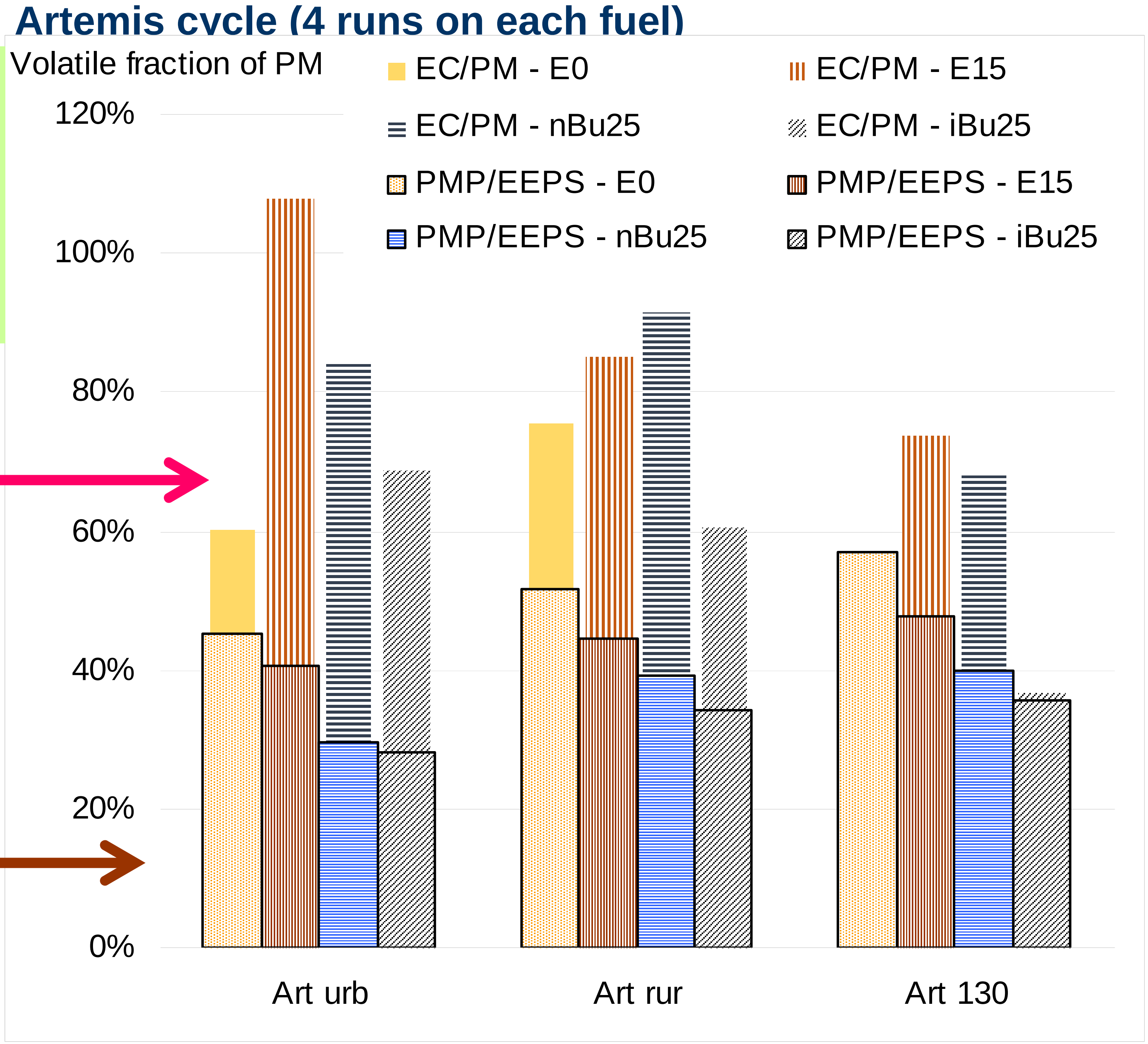
Are solid particles mostly larger, and volatiles smaller ???

Or artefact ???

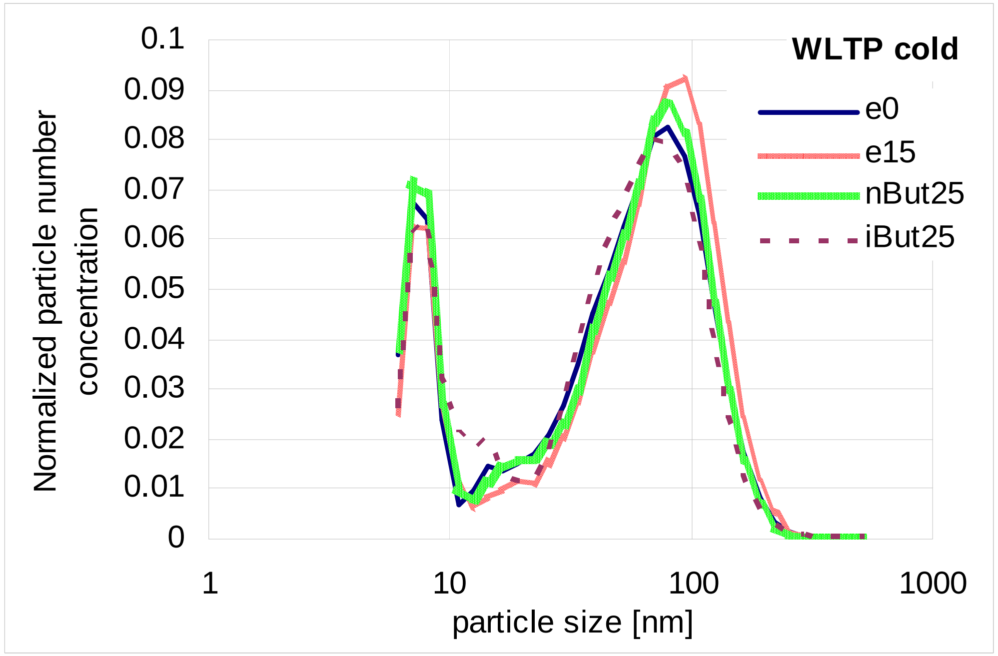
"Solid PM" fraction:
EC (from EC/OC)
----
total PM mass

"Solid PN" fraction:
PN-PMP

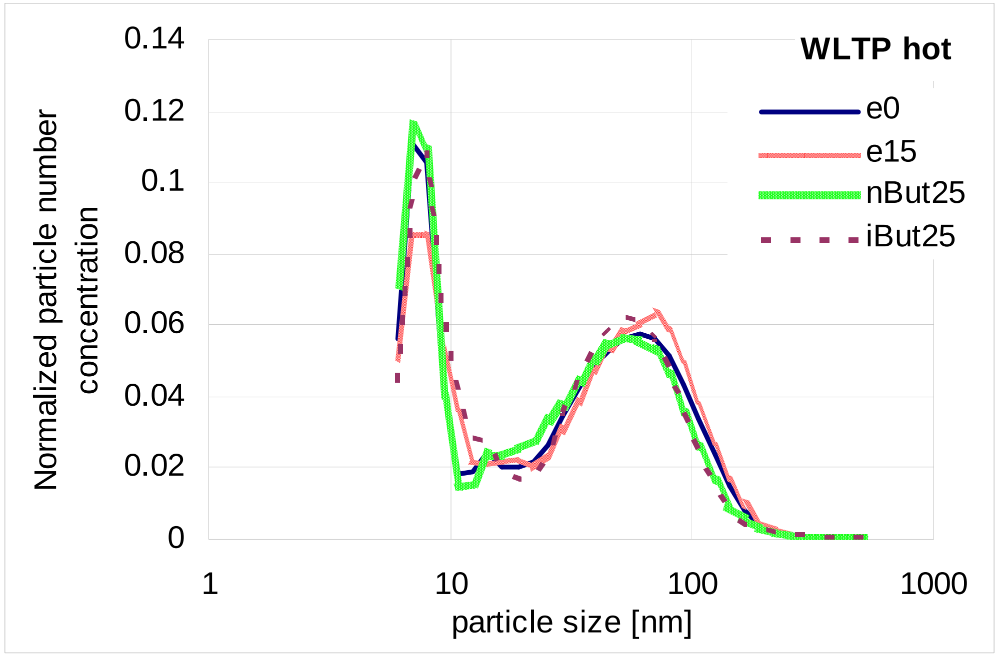
EEPS 24-560 nm
no volatile removal

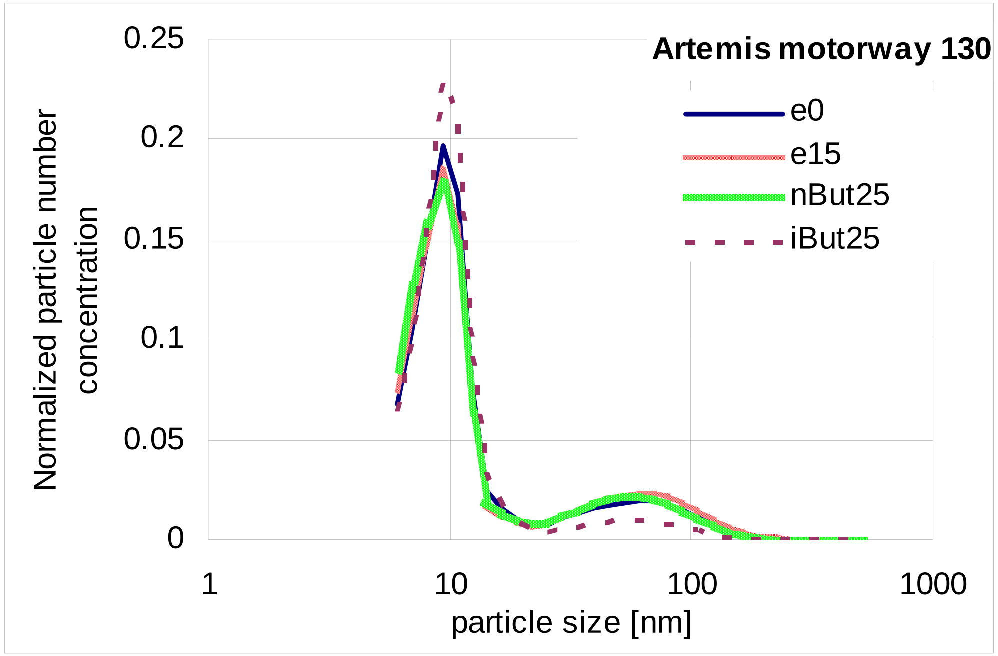


Effects of fuel on *normalized* size distribution

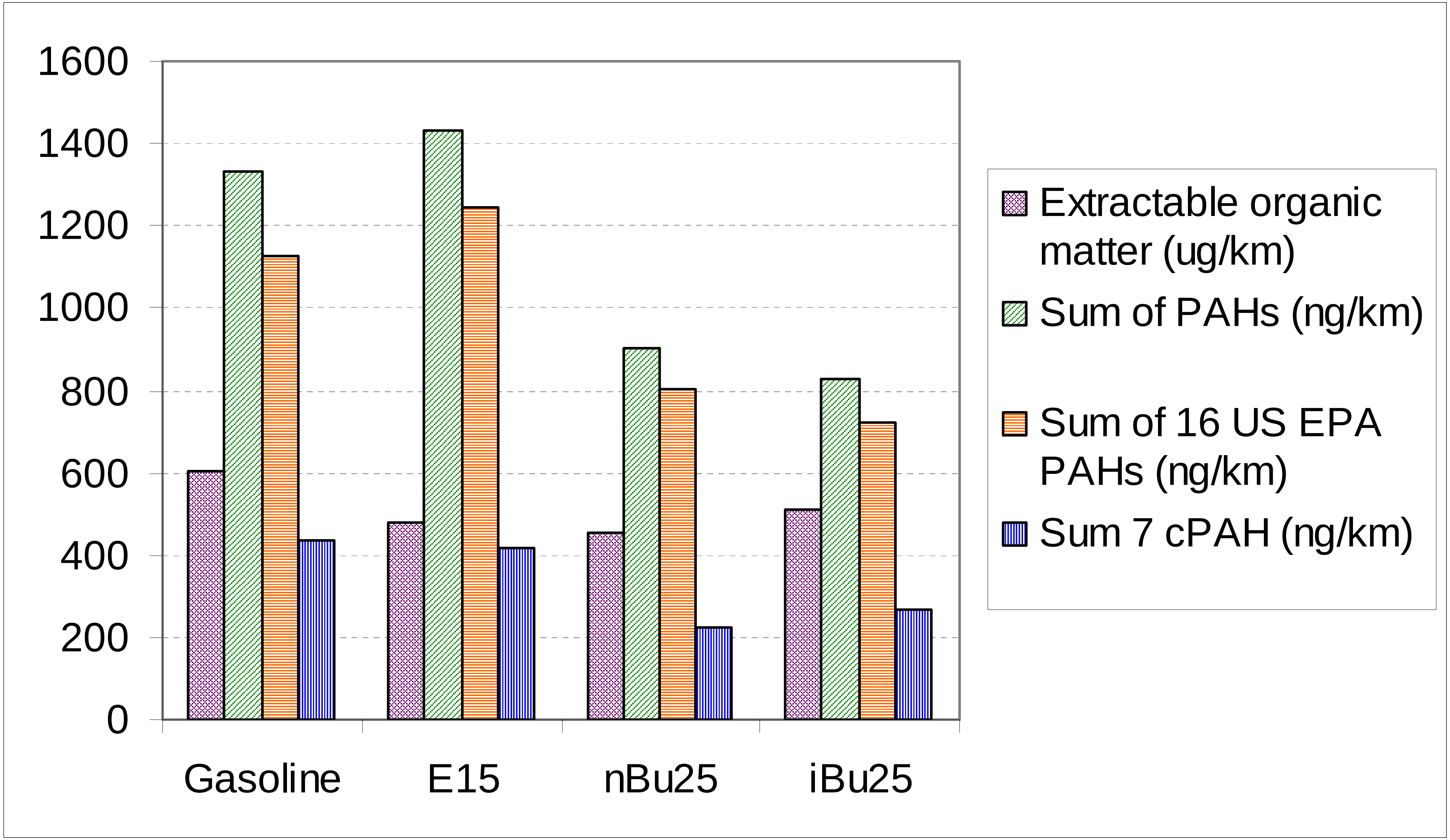


Normalized size distributions mostly similar among fuels





Effects of fuel on polyaromatic hydrocarbons (PAH)
Artemis cycle, all parts, all runs



Effects of fuel on polyaromatic hydrocarbons (PAH)

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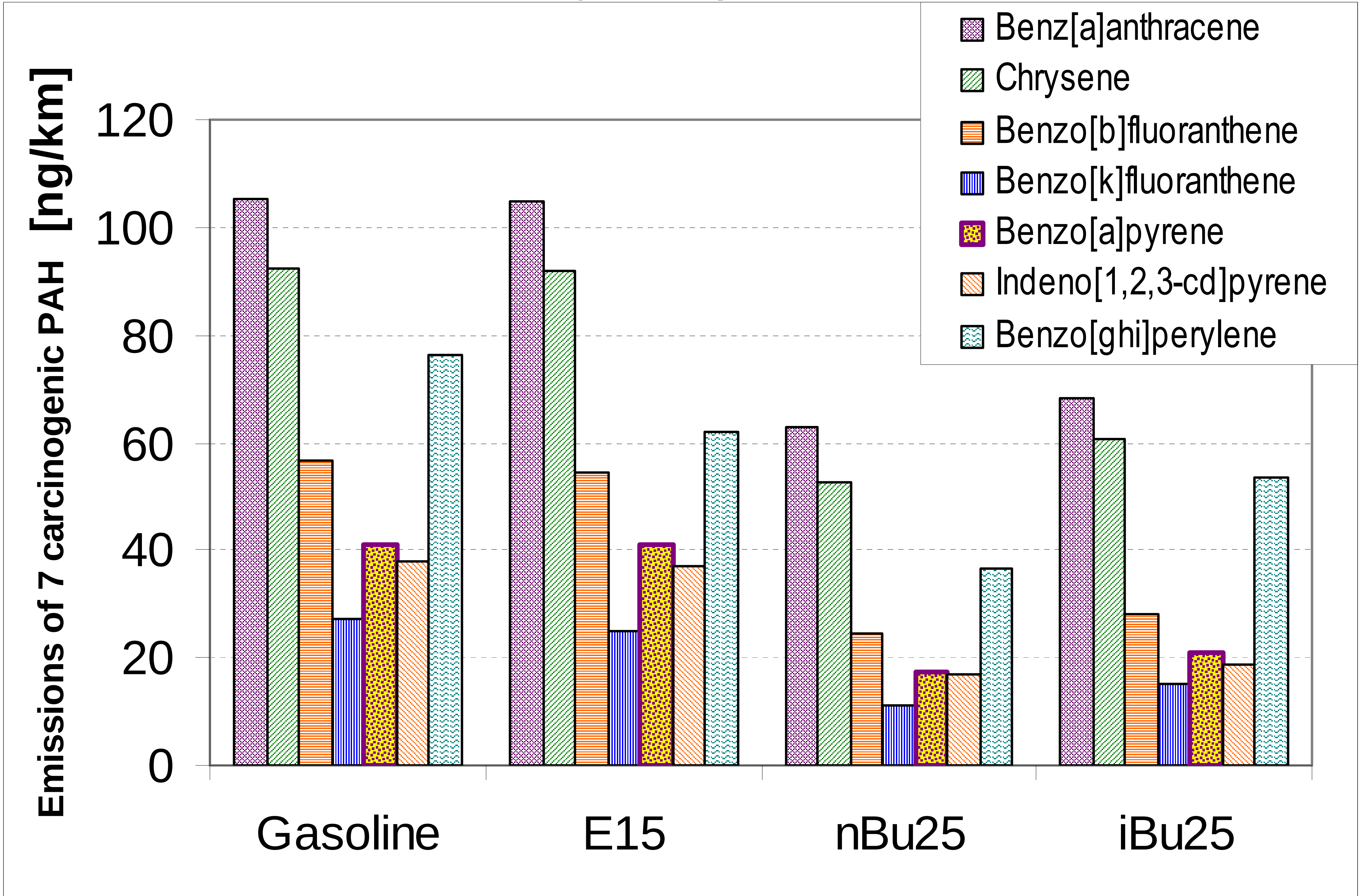
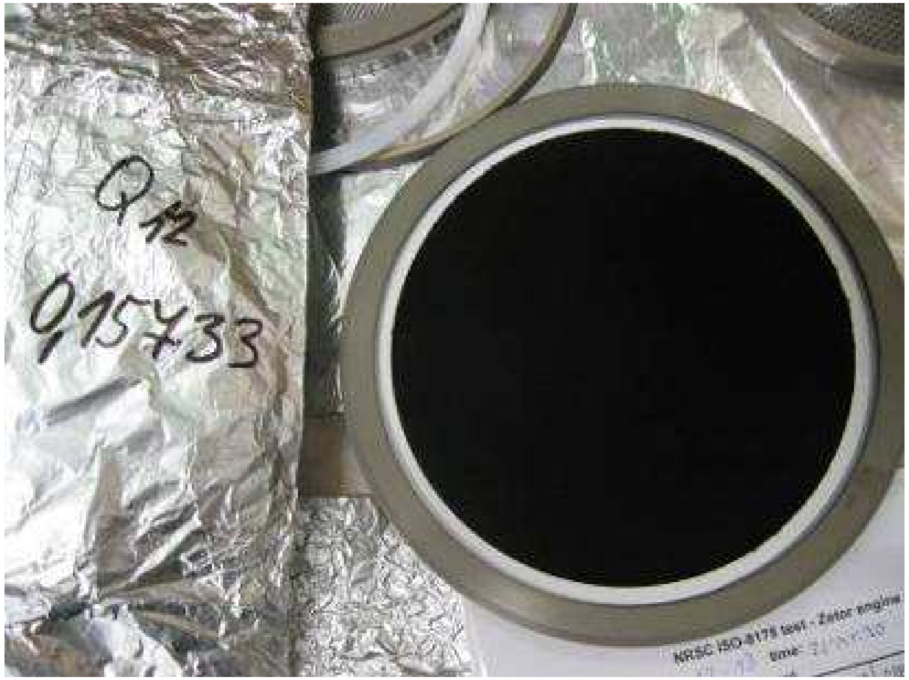
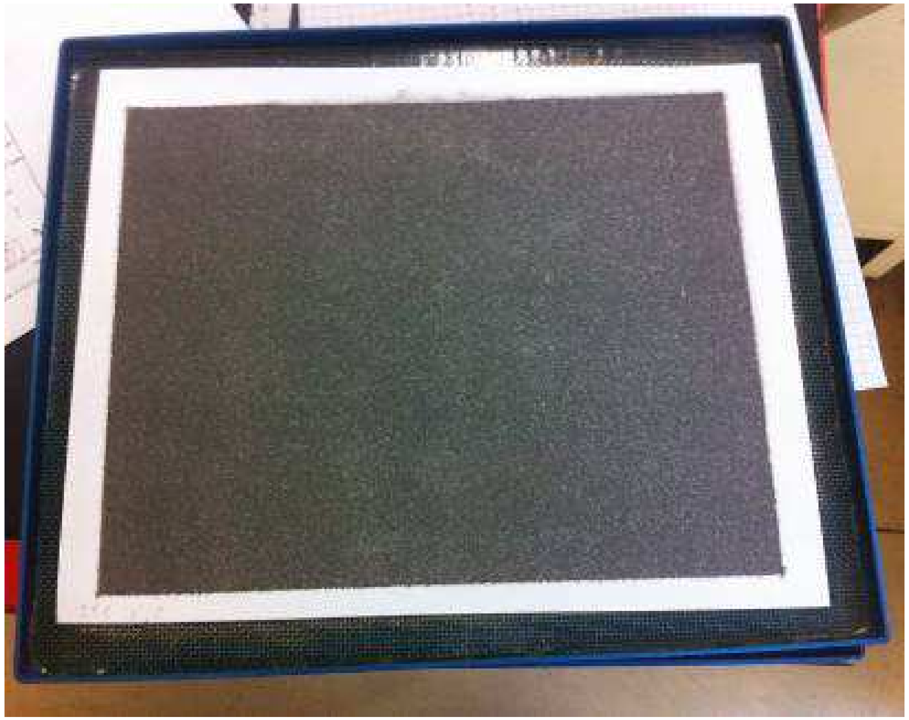
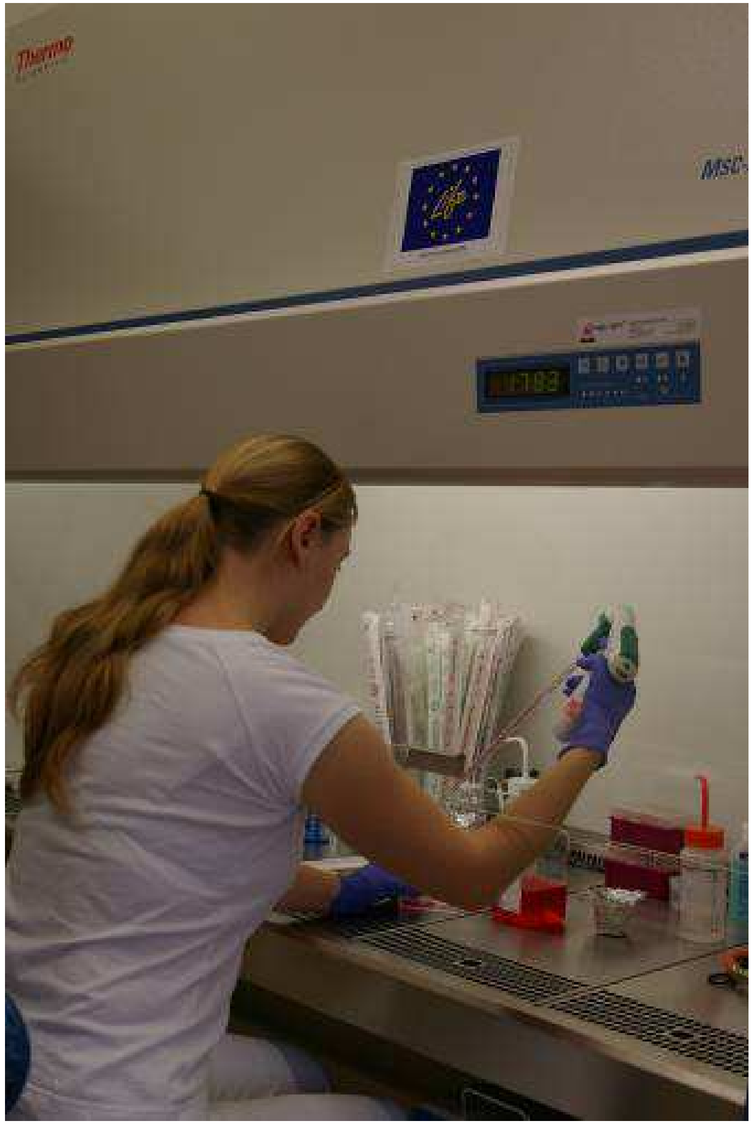


Toxicity assays: Ongoing, will report later



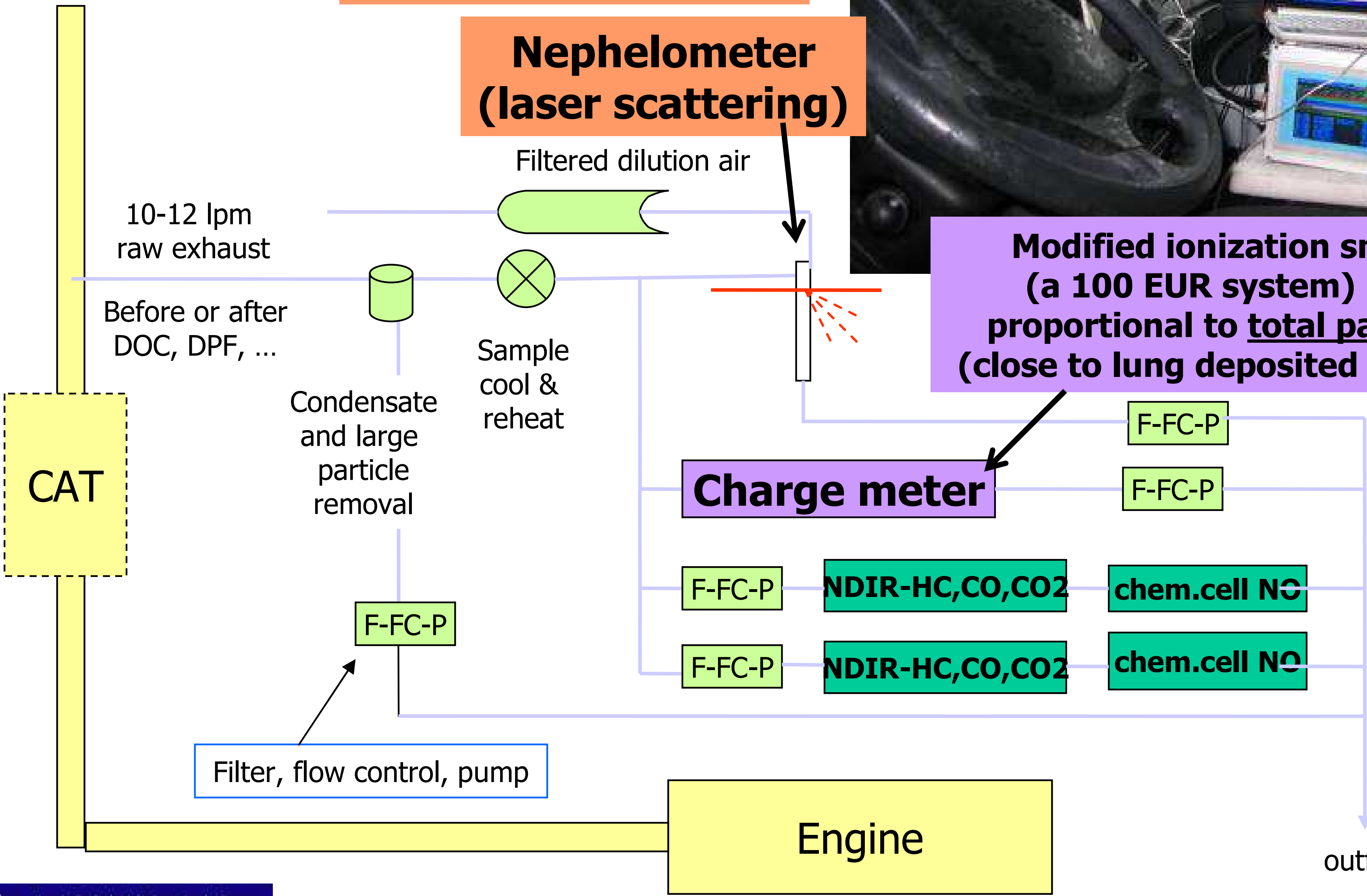




On-board instrumentation – EEPS, mini-PEMS, batteries

Rotating disc microdiluter, (150 C, DR 300:1) sampling from the tailpipe -> -> EEPS (5-560 nm, 1 Hz)

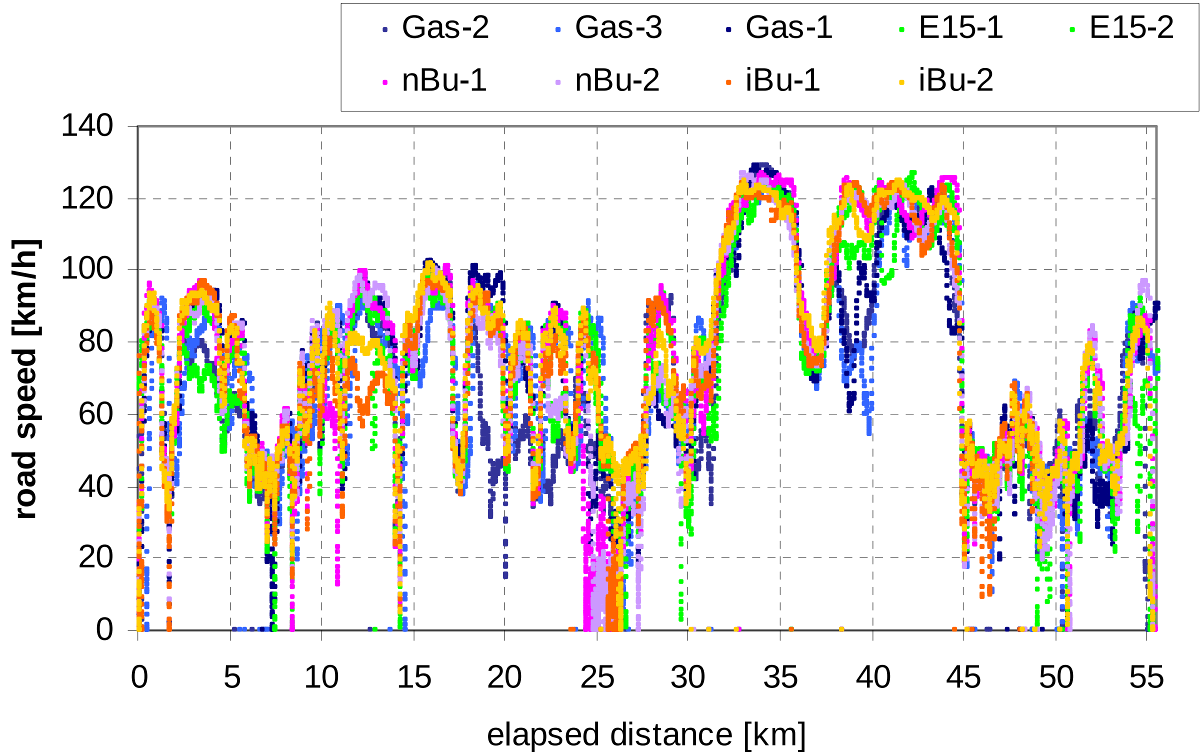
On-board monitoring system “Mini-PEMS” (13 kg)

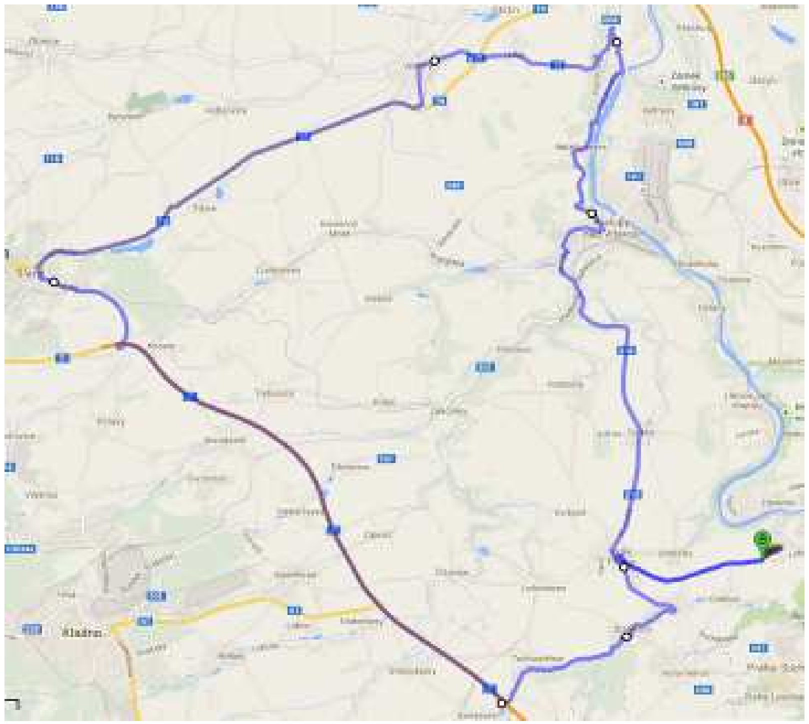


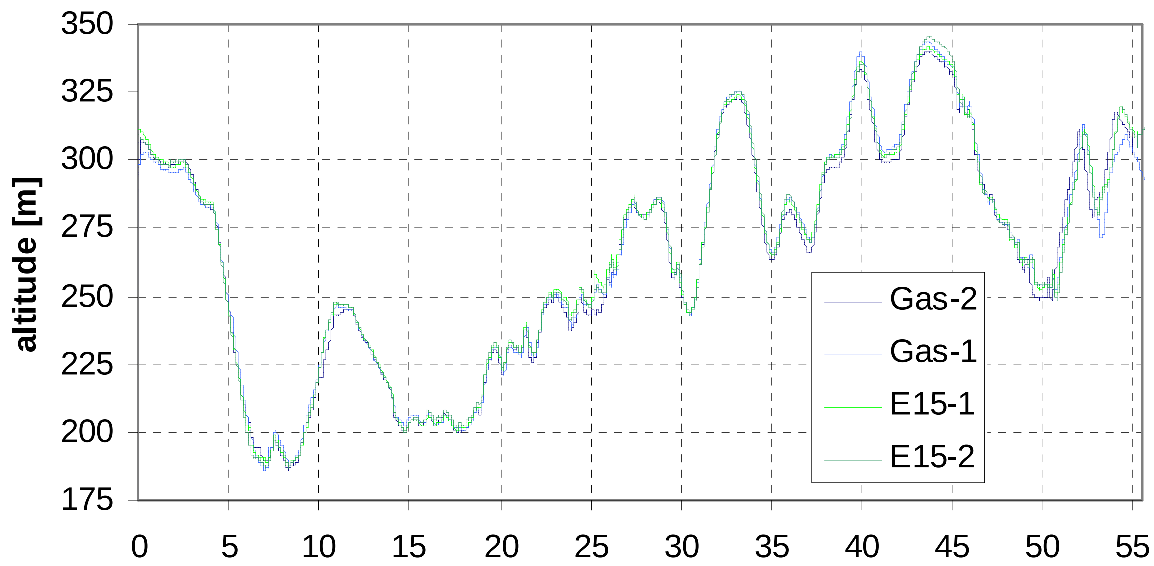
Test route

55 km, 1-hour
2 times on each fuel

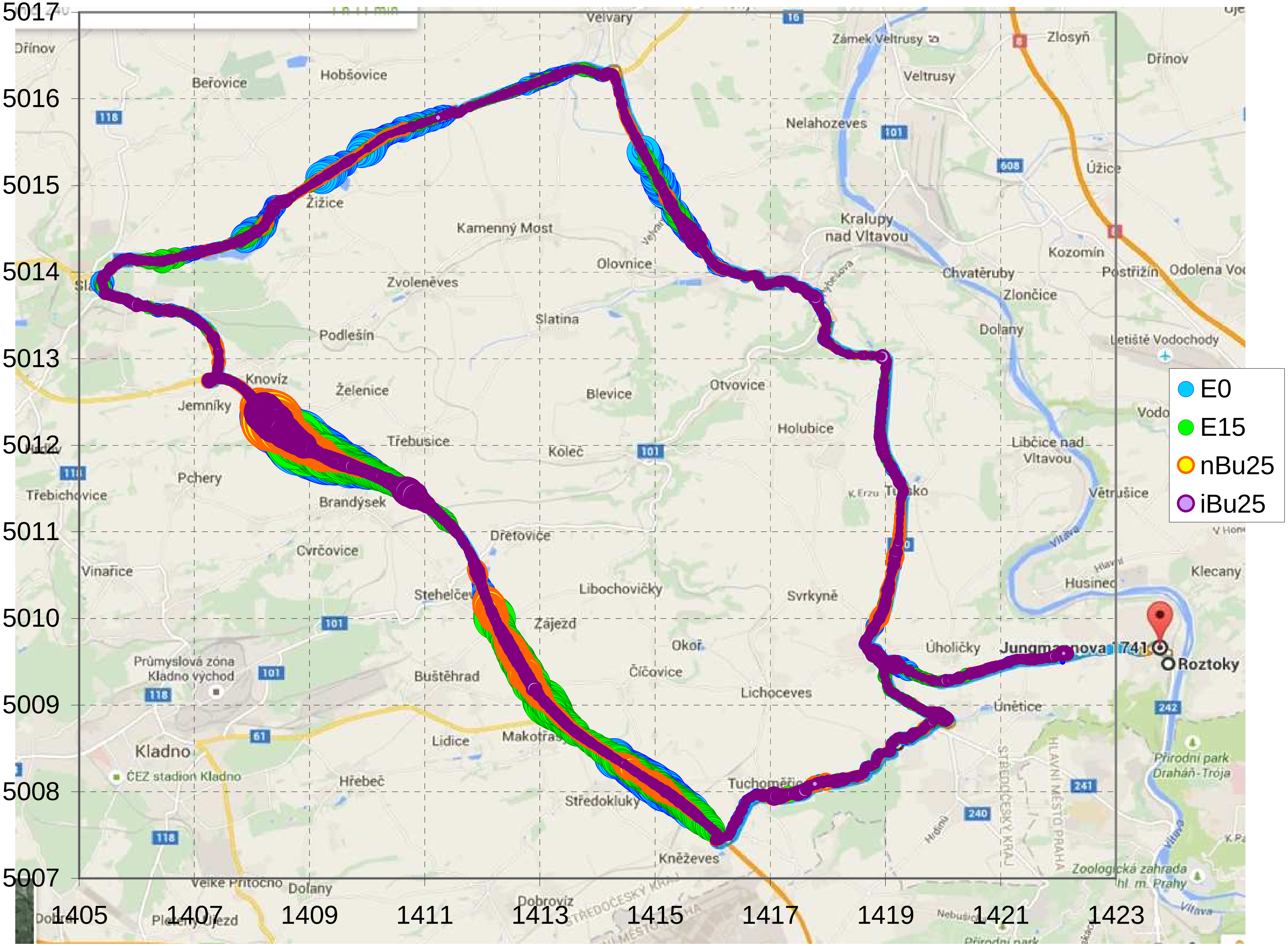
Preconditioning:
(Artemis or 1 run) + 6 km



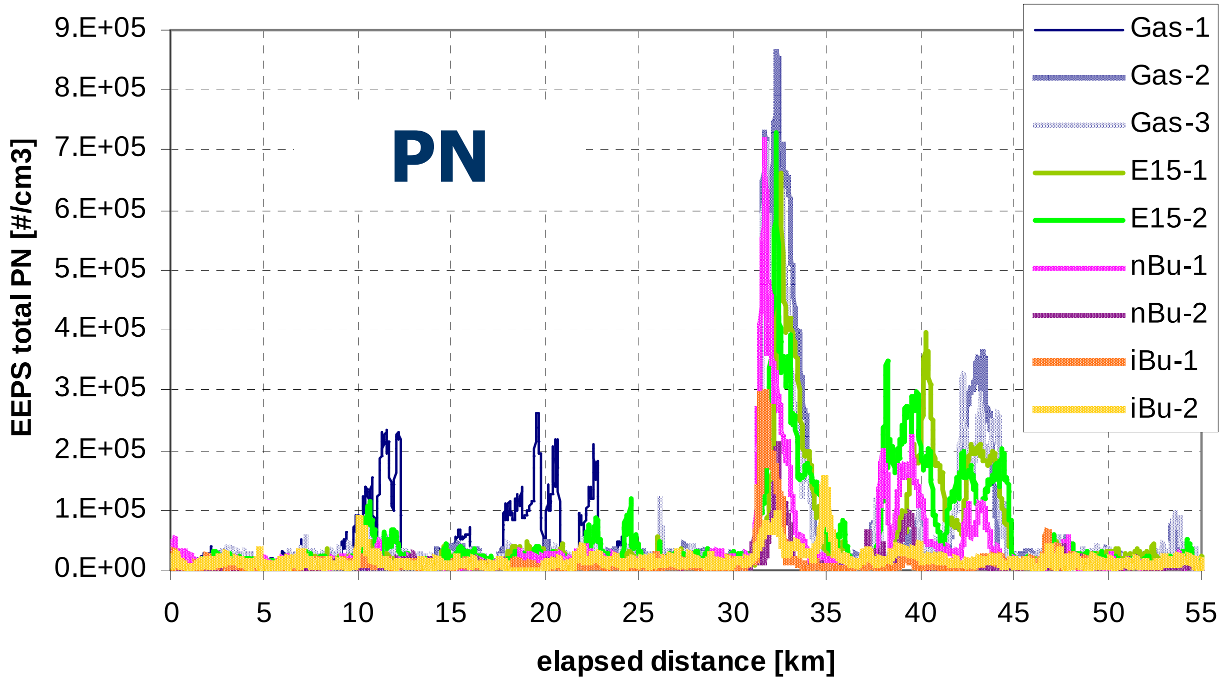


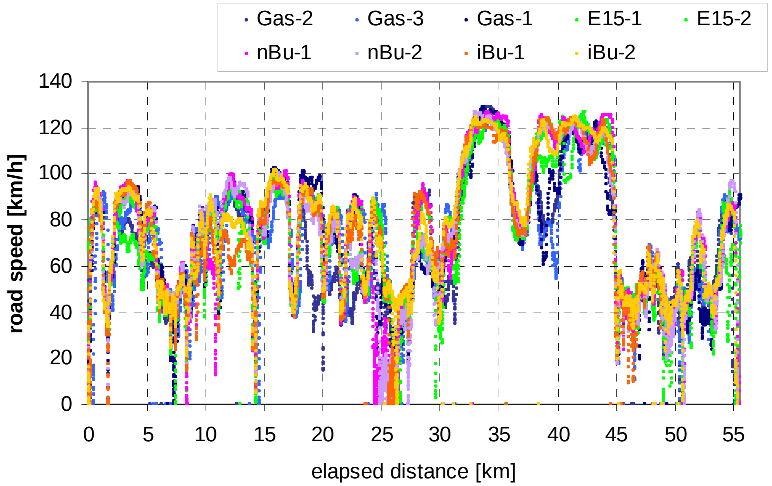


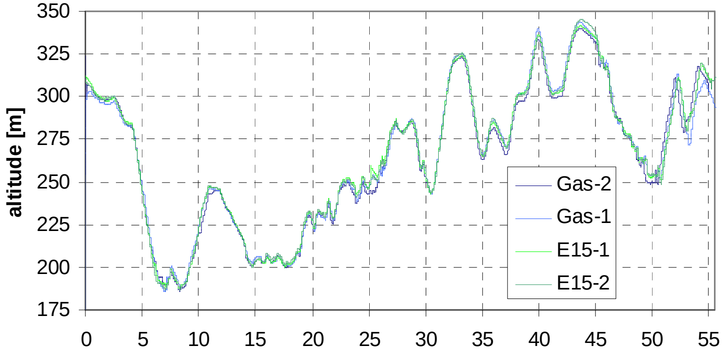
Instantaneous PN emissions along the test route

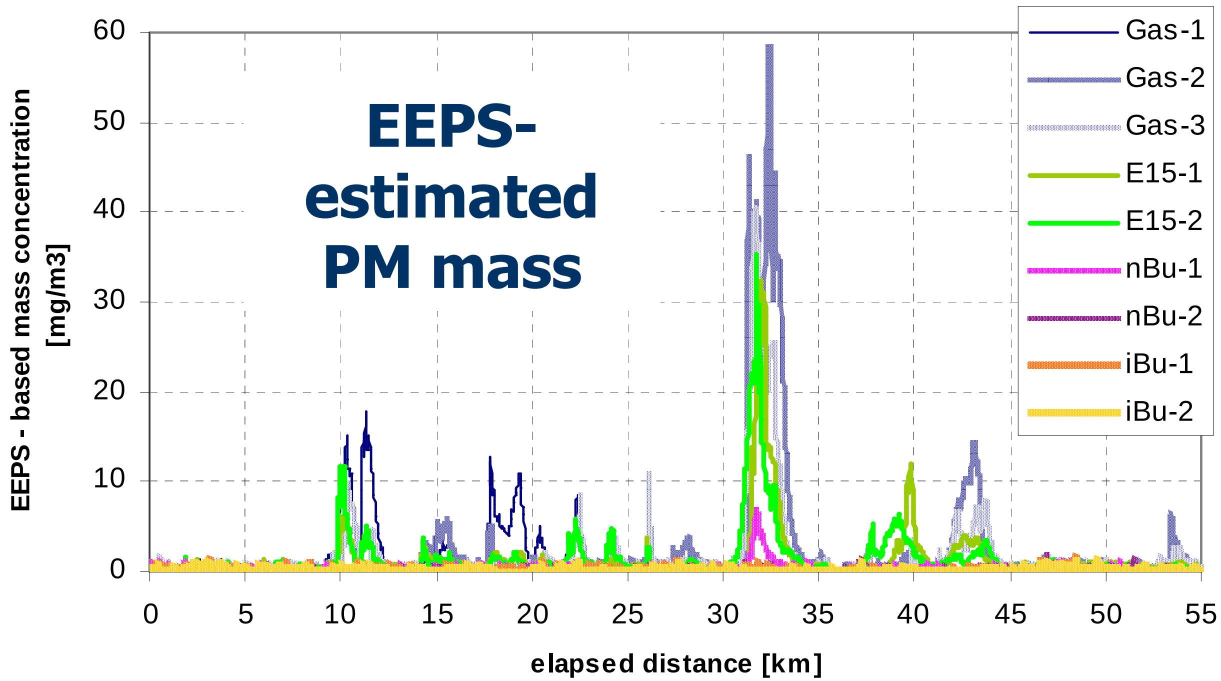


Instantaneous emissions

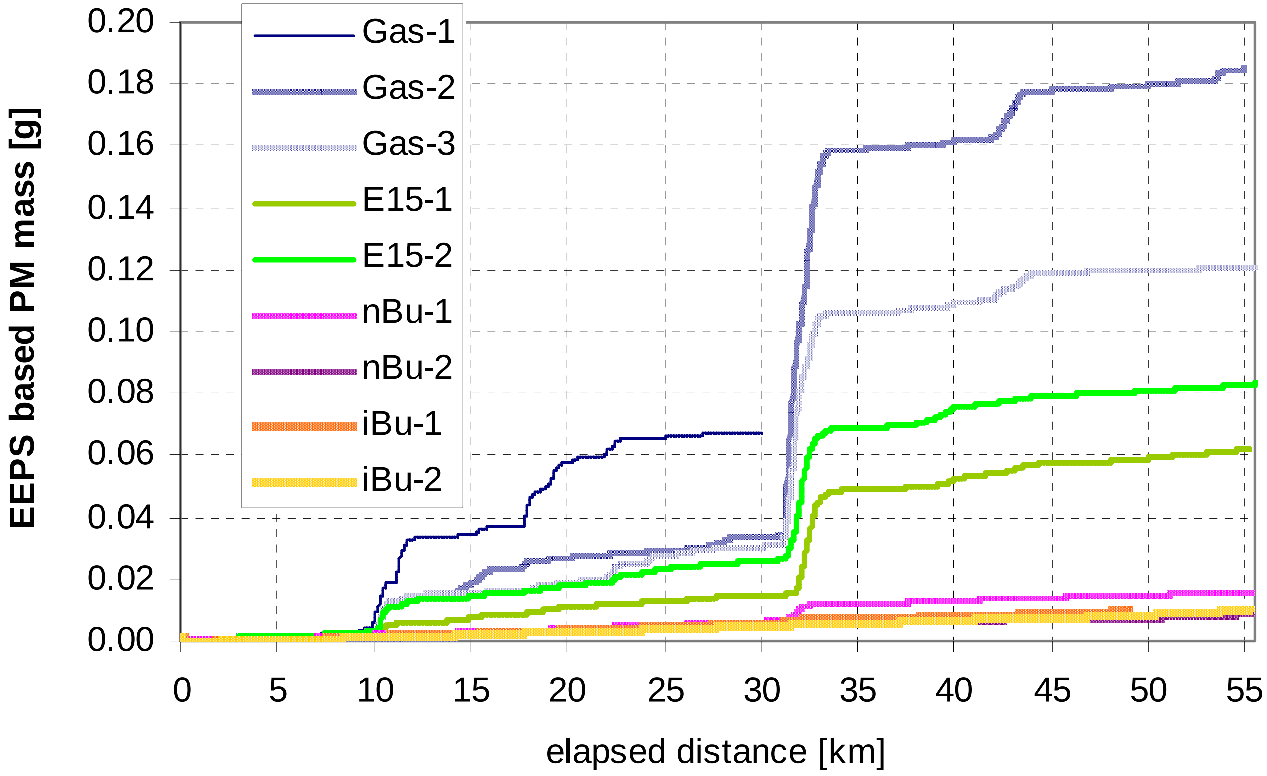


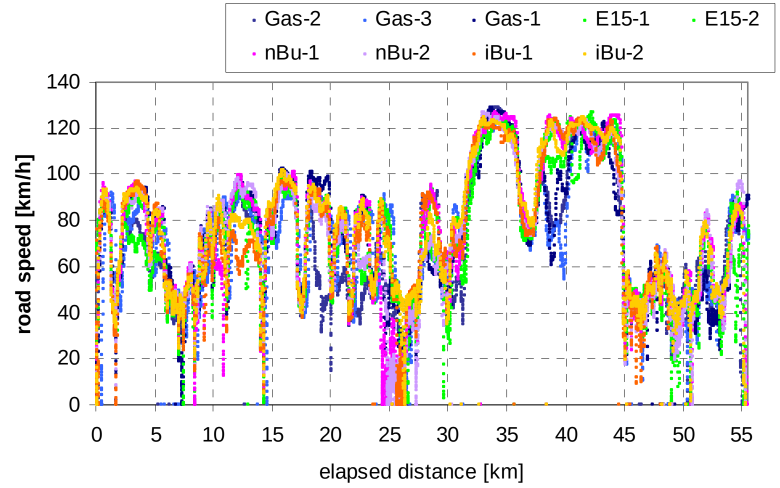


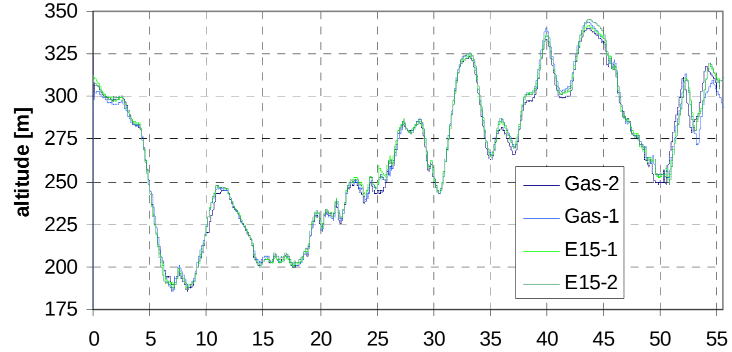


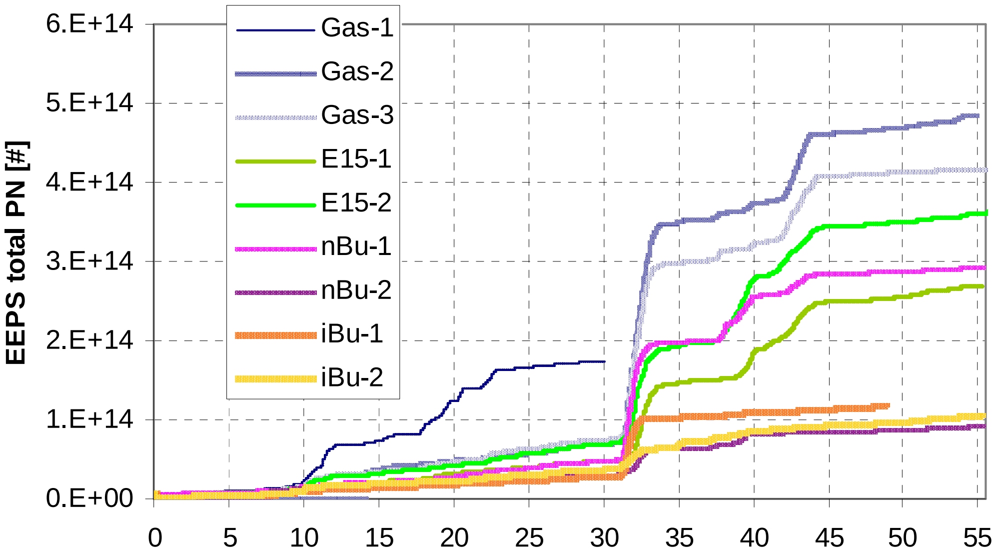


Cumulative emissions

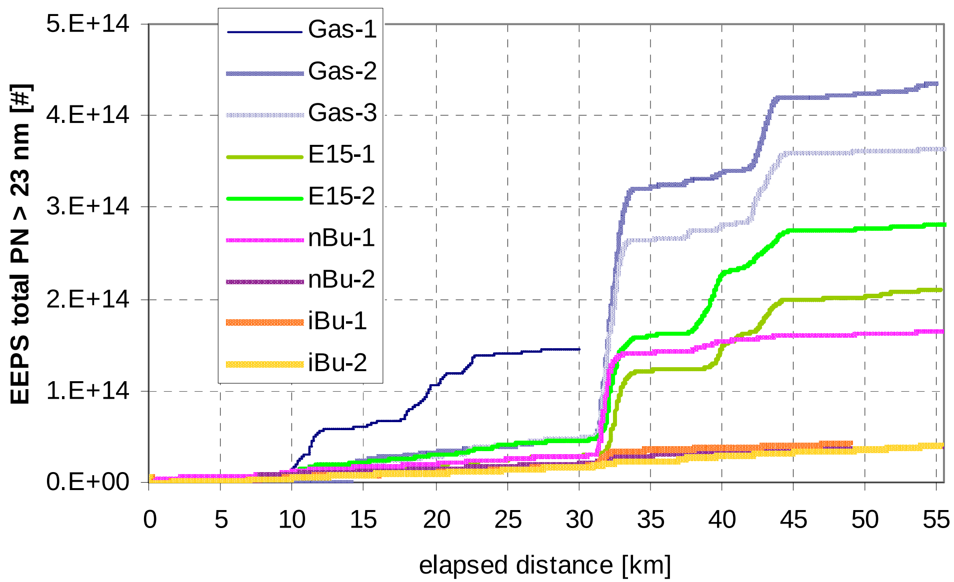






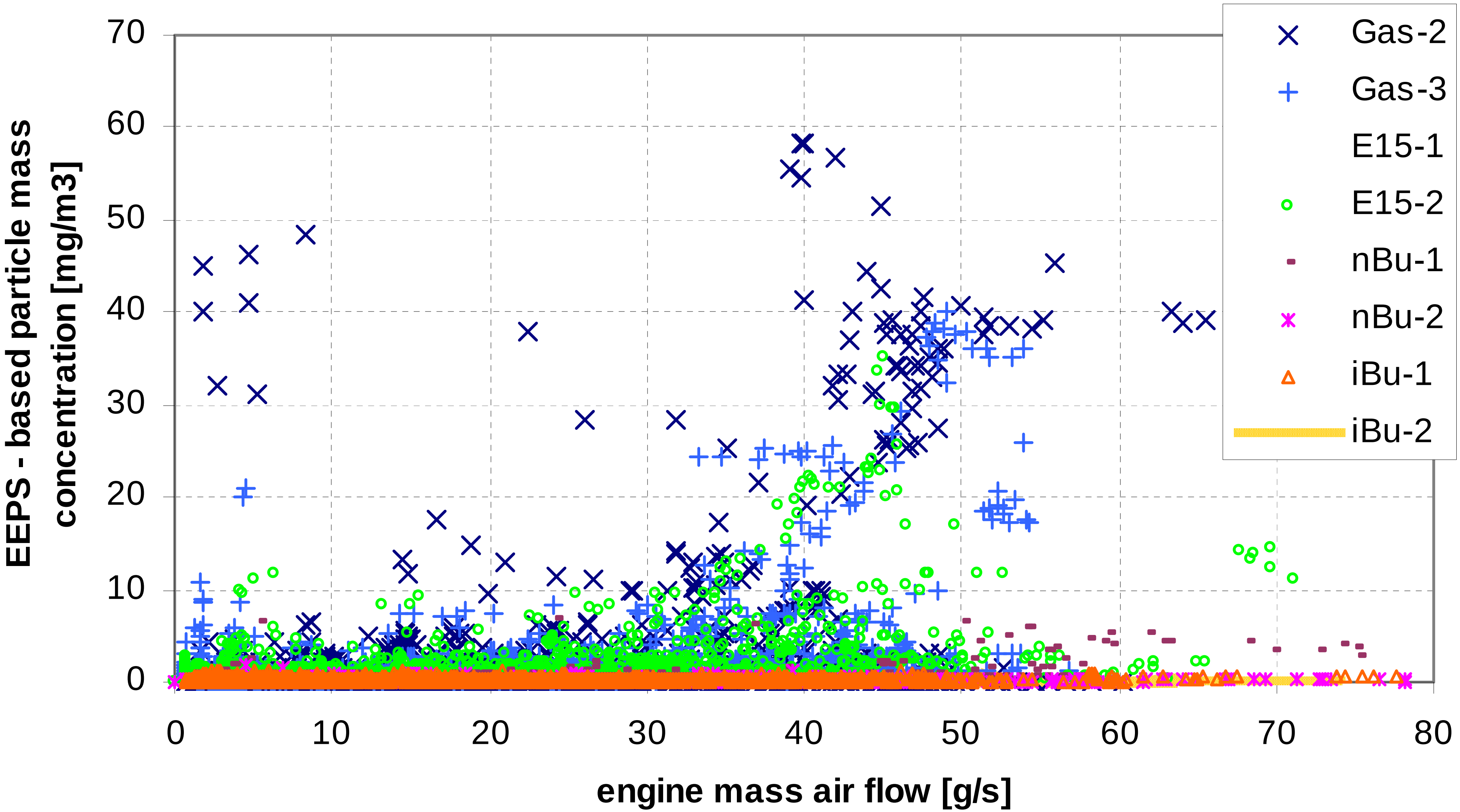


elapsed distance [km]



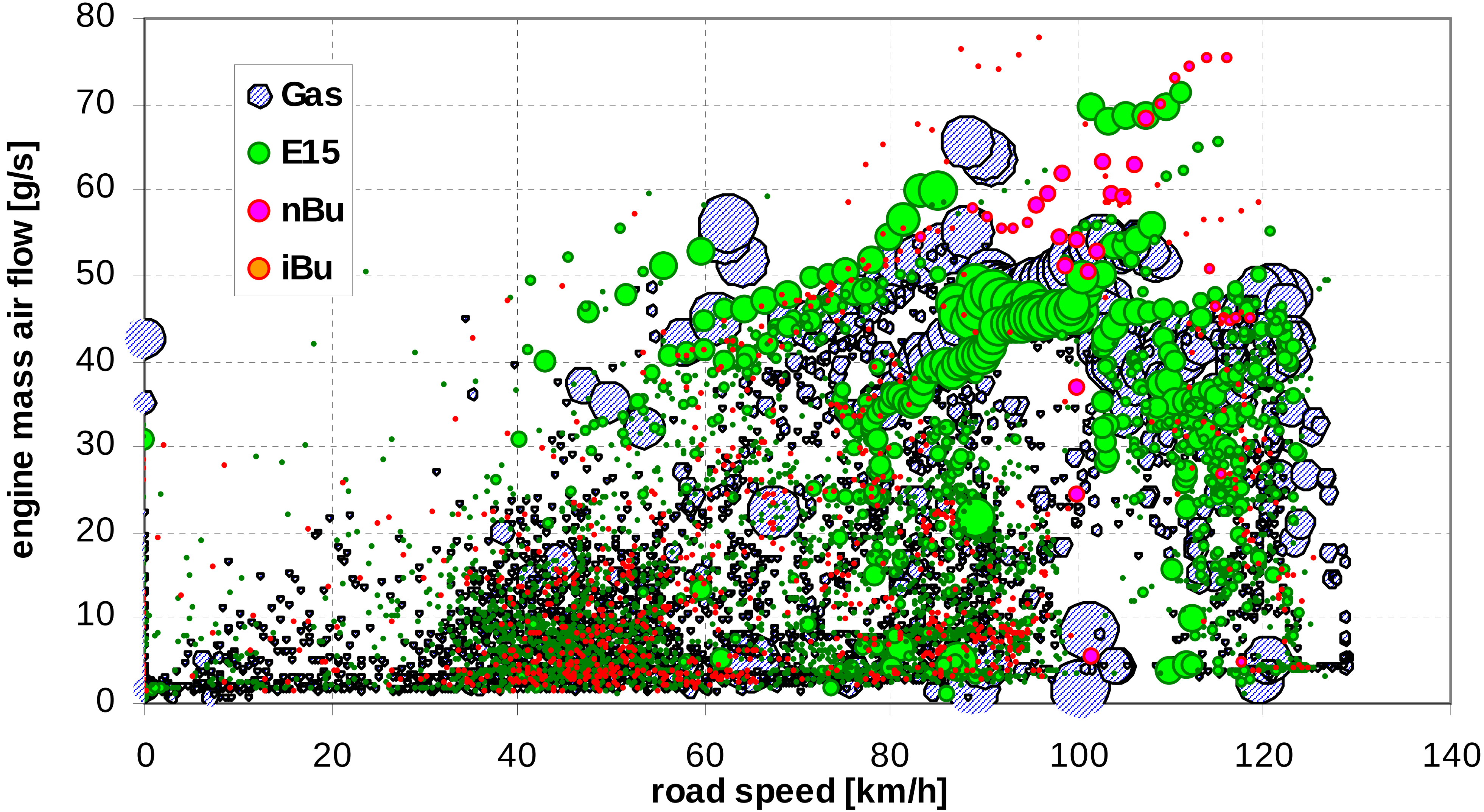
PN as a function of engine power

Mass air flow used as a surrogate of fuel flow (stoichiometric operation), fuel flow as a surrogate of engine power



PN as a function of road speed and engine power

PN emissions are dominated by full-power accelerations – notably for gasoline, less for E15, and much less for both butanols.



Summary

Particle emissions from DISI engines

- emissions from production / in-use engines -- MEASURED
- effects of driving cycle / off-cycle emissions – investigated & found
- particles smaller than 23 nm – found, about half of 5-560 nm total count
- volatile nanoparticles – found, large part of total PN
- non-regulated compounds – PAH measured, toxicity tests ongoing

Real driving emissions and their measurement

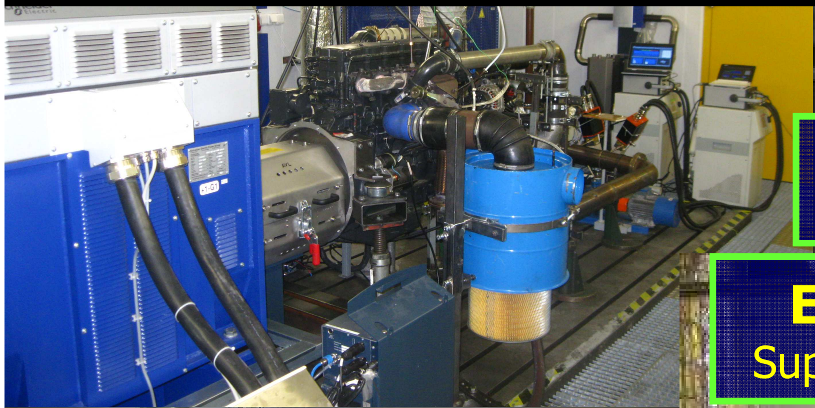
– onboard mini-PEMS and EEPS (onboard FTIR to be done later)

– PM and PN emissions dominated by high power operation

Effect of butanol on particle emissions

While E15 did not produce consistent PN or PM reduction, both 25% n-butanol and 25% isobutanol reduced elemental carbon (EC), particle number emissions per PMP, and 7 US EPA priority carcinogenic polyaromatic hydrocarbons by roughly one half, with no increase in NOx or other demonstrated problem.

Warning: This engine may produce nanoparticles that are harmful when inhaled.



Thank you !

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EU LIFE+ program, project MEDETOX - Innovative Methods of Monitoring of Diesel Engine Exhaust Toxicity in Real Urban Traffic (LIFE10 ENV/CZ/651)

Czech Science Foundation project BIOTOX (13-0148S): Mechanisms of toxicity of particles from biofuels