Particle emissions from marine Diesel engines operating on biofuels

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Background

The use of bio fuels for power generation or propulsion gains increasing importance in the framework of CO_2 reductions and the use of energy from renewable sources. The knowledge on emission characteristics of various bio fuels however is very limited. In order to add new knowledge to this field, the German project **BIO***clean* was set up.

Objectives

The project investigates the emission of CO_2, NO_x, hydrocarbon compounds, SO_2, H_2SO_4 and particulate matter for different fuel types. The simultaneous consideration of climate-active trace species like NO_x, particulates and sulphur-containing particle precursors on one hand and of the most important climate-active exhaust constituent CO_2 on the other hand allows for the investigation of trade-off effects of CO_2 emissions reduction and possible increased emissions of other climate-active trace constituents. Accompanying model studies investigate the global reduction potential for both applications of large medium-speed Diesel engines in ship propulsion and power generation. These studies will form the basis for decisions on reasonable applications of bio fuels. A first estimate of the expected reduction in CO_2 equivalent emissions by a replacement of fossil fuels with fuels from renewable sources will be provided.

The consortium considers the quantification of all key climate-active exhaust constituents as a very important task not only for fossil fuels but also for fuels from renewable sources. The evaluation of the climate impact of bio fuels requires precise knowledge on the differences in emission characteristics between conventional and bio fuels. As a whole, the project will provide decision guidance and guidance on technological realisation for a world-wide use of CO_2 neutral fuels in the investigated applications of large Diesel engines.

Experimental Approach

In the course of **BIO***clean* particle emissions from marine diesel engines were characterised in terms of microphysical properties, chemical composition and emission factors with respect to particle number, black carbon mass and total mass. Measurements were performed using bio fuels based on soy bean oil, sunflower oil, palm oil and waste grease, and on heavy fuel oil as a fossil fuel reference case. Engine operation conditions ranged from 10% engine load to 100% engine load. The studies followed the structure of previous work investigating the particle emissions from fossil fuel use in medium speed marine engines (Kasper et al., 2007; Petzold et al., 2004, 2008).

The aerosol instrumentation consisted of a set of condensation particle counters (CPC), partially equipped with diffusion screens for various particle size ranges, one differential

mobility analyser (DMA) and multi-angle absorption photometer (MAAP). A subset of CPCs was connected to a thermodenuder for separating volatile and non-volatile particles. An optical particle counter was used for the fast measurement of particles in the size range from 250 nm to 1 µm. In summary, the particle size range of the instruments spanned from approx. 5 nm to 1 µm in diameter. Volatility analyses provided information on the aerosol mixing state for several particle size ranges. Particle filter samples for subsequent analysis of particle mass and chemical composition was conducted with an AVL Smart Sampler unit. The black carbon mass concentration was measured by optical means using the MAAP, and by the analysis of filter samples.

Results

First results indicate a significant difference between fossil fuels and bio fuels in the emission of carbon-containing combustion particles. In the combustion particle size range from 30 nm to 200 nm, fossil fuel use causes particle emissions which are two orders of magnitude higher by number than related emissions from bio fuels, see Figure 1. Also the black carbon emission is significantly reduced compared to fossil fuel combustion. In contrast, particle emissions in terms of number do not differ significantly between fossil fuel and bio fuels.

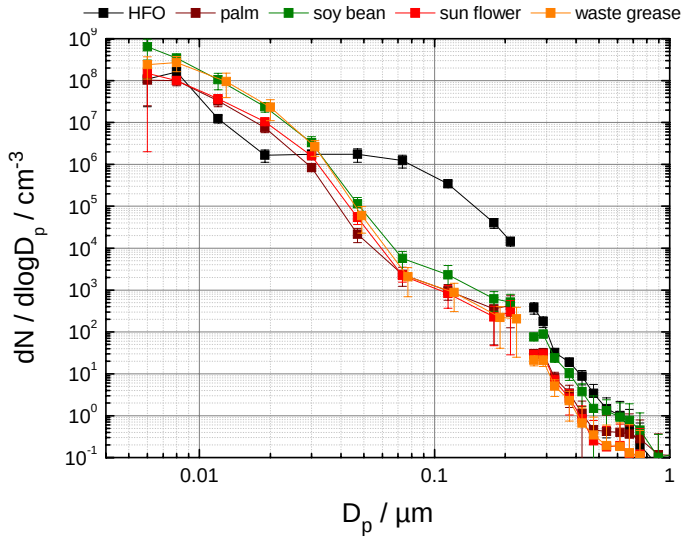


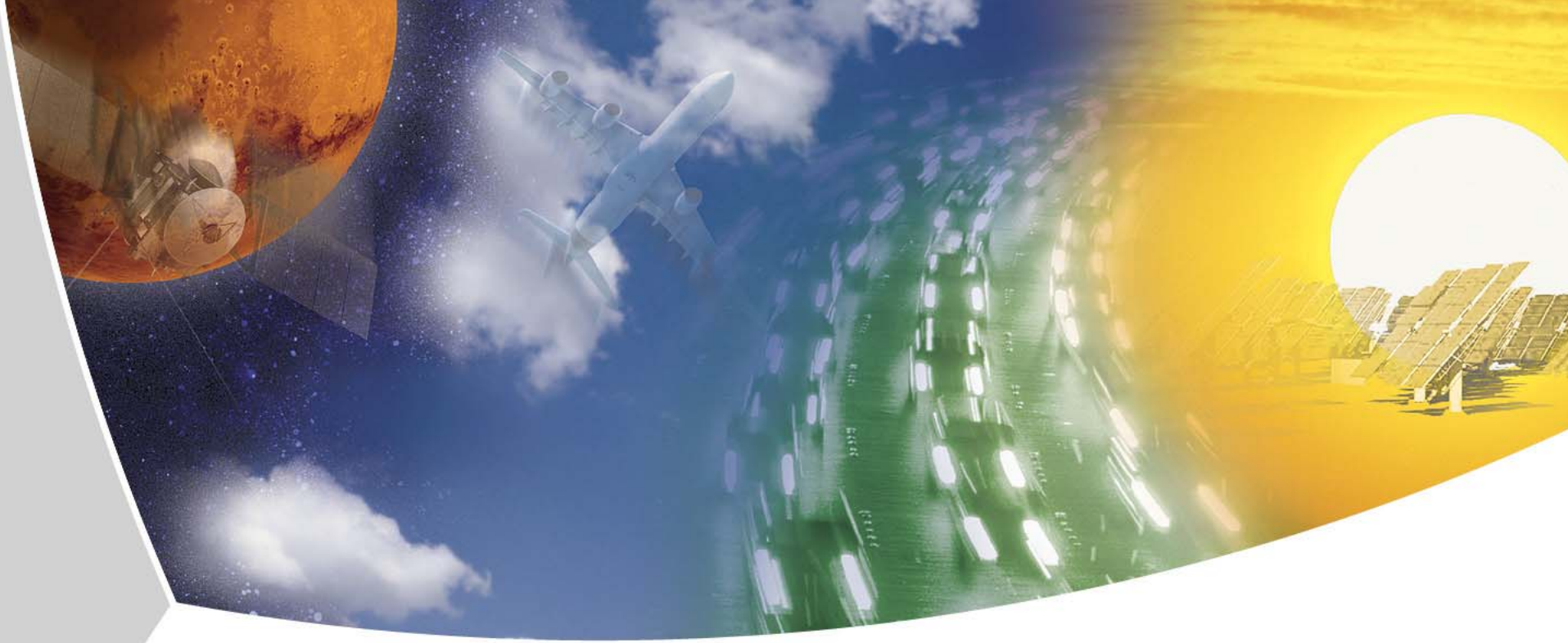
Figure 1: Number size distribution of particles emitted from a marine Diesel engine operating on different bio fuels and on heavy fuel oil (HFO) as a reference case.

References

Kasper, A., Aufdenblatten, S., Forss, A., Mohr, M., and Burtscher, H.: Particulate emissions from a low-speed marine diesel engine, Aerosol Sci Technol, 41, 24-32, 2007.

Petzold, A., Feldpausch, Ph., Fritzsche, L., Minikin, A., Lauer, P., Kurok, C. and Bauer, H.: Particle emissions from ship engines, J. Aerosol Sci., Abstracts of the European Aerosol Conference, S1095-S1096¸ 2004.

Petzold, A., J. Hasselbach, P. Lauer, R. Baumann, K. Franke, C. Gurk, H. Schlager, and E. Weingartner: Experimental studies on particle emissions from cruising ship, their characteristic properties, transformation and atmospheric lifetime in the marine boundary layer, Atmos. Chem. Phys., 8, 2387–2403, 2008.



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BIOclean
alternative fuels in shipping

klimazwei
Risiken mindern · Chancen nutzen

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MAN Diesel SE

OBJECTIVES

Medium-speed marine Diesel engines are in worldwide use for power generation and in shipping.

Like any other combustion source, marine Diesel engines emit CO_2, CO, NO_x, CH_4, Hydrocarbons, SO_x and particulate matter which all can impact global climate.

The emission characteristics of gaseous and particulate climate-active constituents from medium-speed marine Diesel engines are not well known.

BIO*clean* investigates gaseous and particulate emissions from medium-speed marine Diesel engines for conventional heavy fuel oil (HFO) and for four different biofuels.

Technical assessment studies investigate the influence of biofuel usage on the engines in terms of degradation and corrosion.

Modelling studies assess the potential CO_2 reduction when replacing conventional fuel by biofuels.

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Fuel	Properties	Fuel specs.
Palm oil	Large availability on the global market, very good fuel properties, critical production conditions.	2.83 kg CO_2 / kg fuel 0.651 kg CO_2 / kWh C: 77.30 wt-% S: 0.10 wt-% O: 11.50 wt-%
Soy beans	Potential technical problems from unsaturated fatty acids, energy plant production competes with food plant production.	2.86 kg CO_2 / kg fuel 0.660 kg CO_2 / kWh C: 78.10 wt-% S: 0.10 wt-% O: 10.5 wt-%
Sunflower oil	Biofuel from regional markets.	2.87 kg CO_2 / kg fuel 0.655 kg CO_2 / kWh C: 78.30 wt-% S: 0.10 wt-% O: 10.5 wt-%
Waste edible fat	Waste products from food production, only of regional interest.	2.82 kg CO_2 / kg fuel 0.651 kg CO_2 / kWh C: 77.00 wt-% S: 0.10 wt-% O: 11.6 wt-%
Heavy Fuel Oil	Conventional reference fuel.	3.19 kg CO_2 / kg fuel 0.660 kg CO_2 / kWh C: 86.94 wt-% S: 2.17 wt-% O: 0.02 wt-%

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TEST PROGRAMME

Engine load conditions for each fuel

100% - 75% - 25% - 10%

Measured properties

Gaseous emissions (CO_2, CO, NO_x, Formaldehyde)

Particle number (total and nonvolatile, D > 5 nm)

Particle Size (5 nm - 5 µm)

Total Aerosol Mass (Gravimetry)

Black Carbon Mass (Optical absorption)

Aerosol chemical composition (filter analyses)

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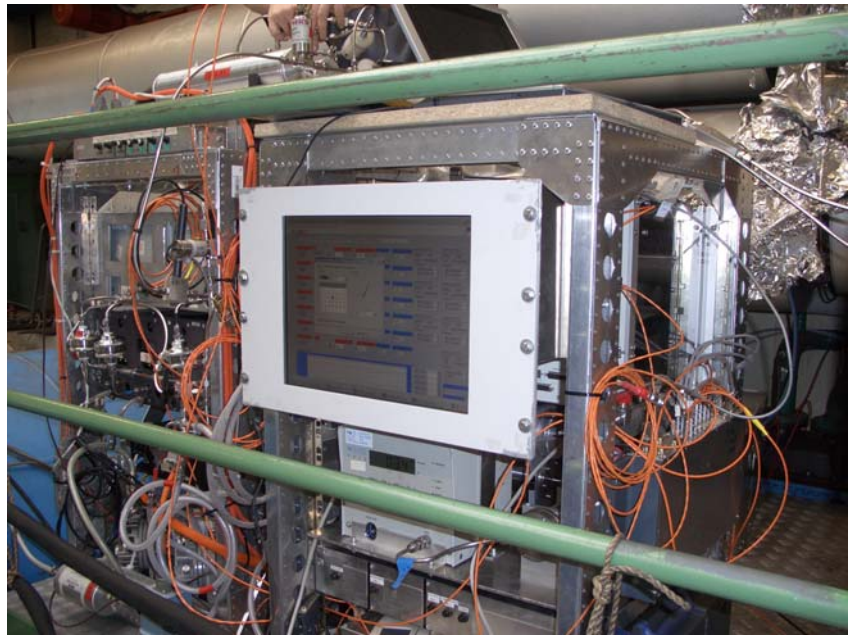
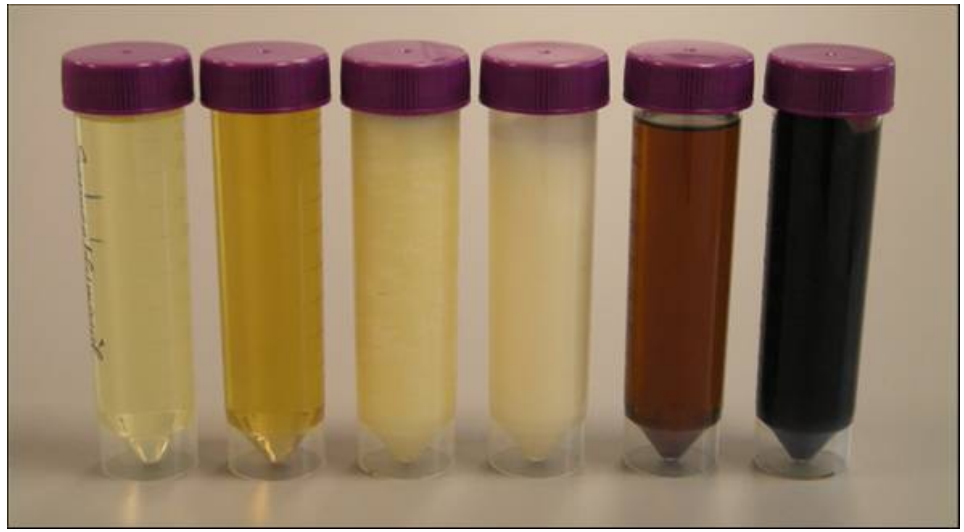
Single cylinder test engine



Equipment



Fuel samples

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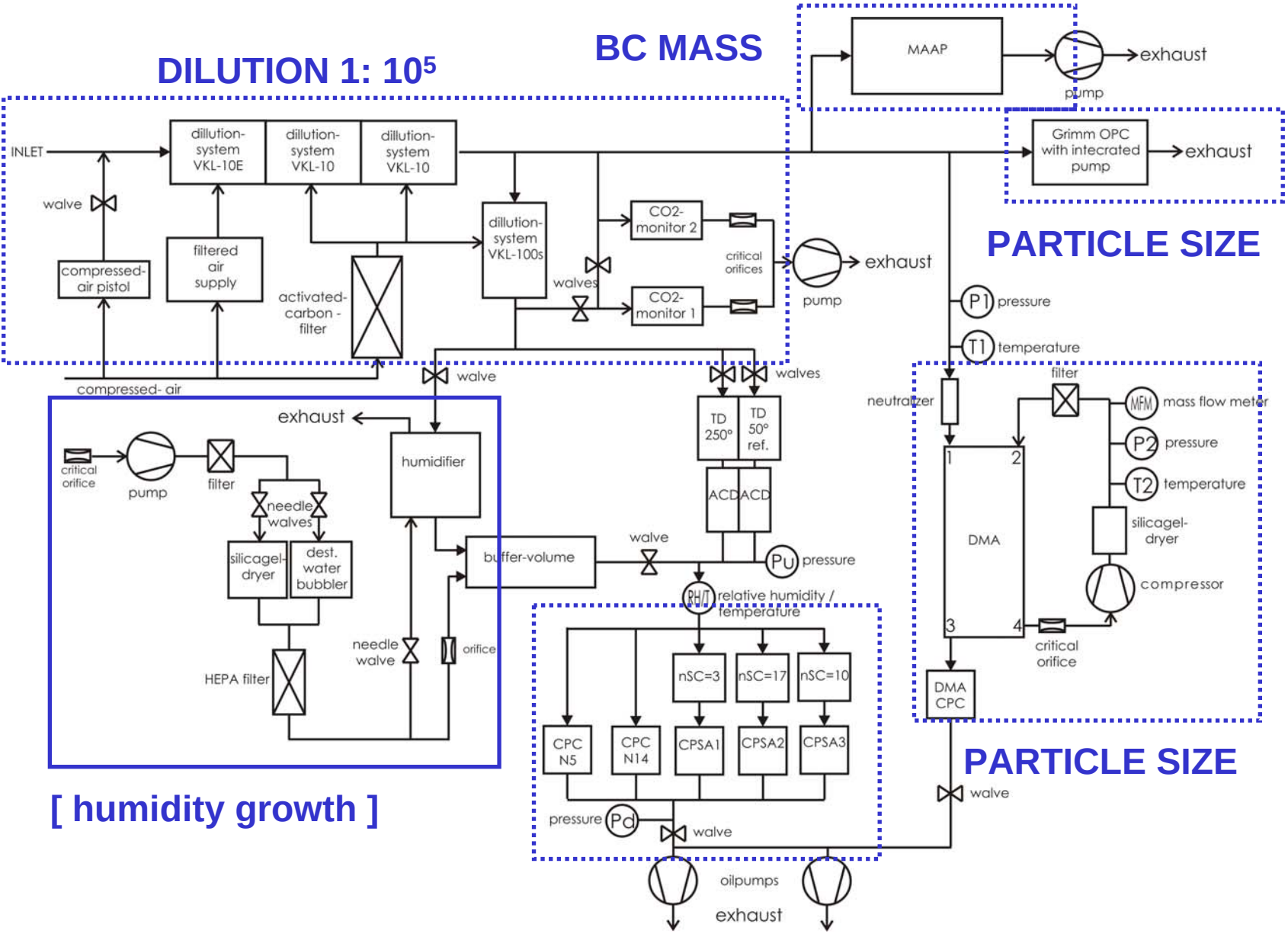
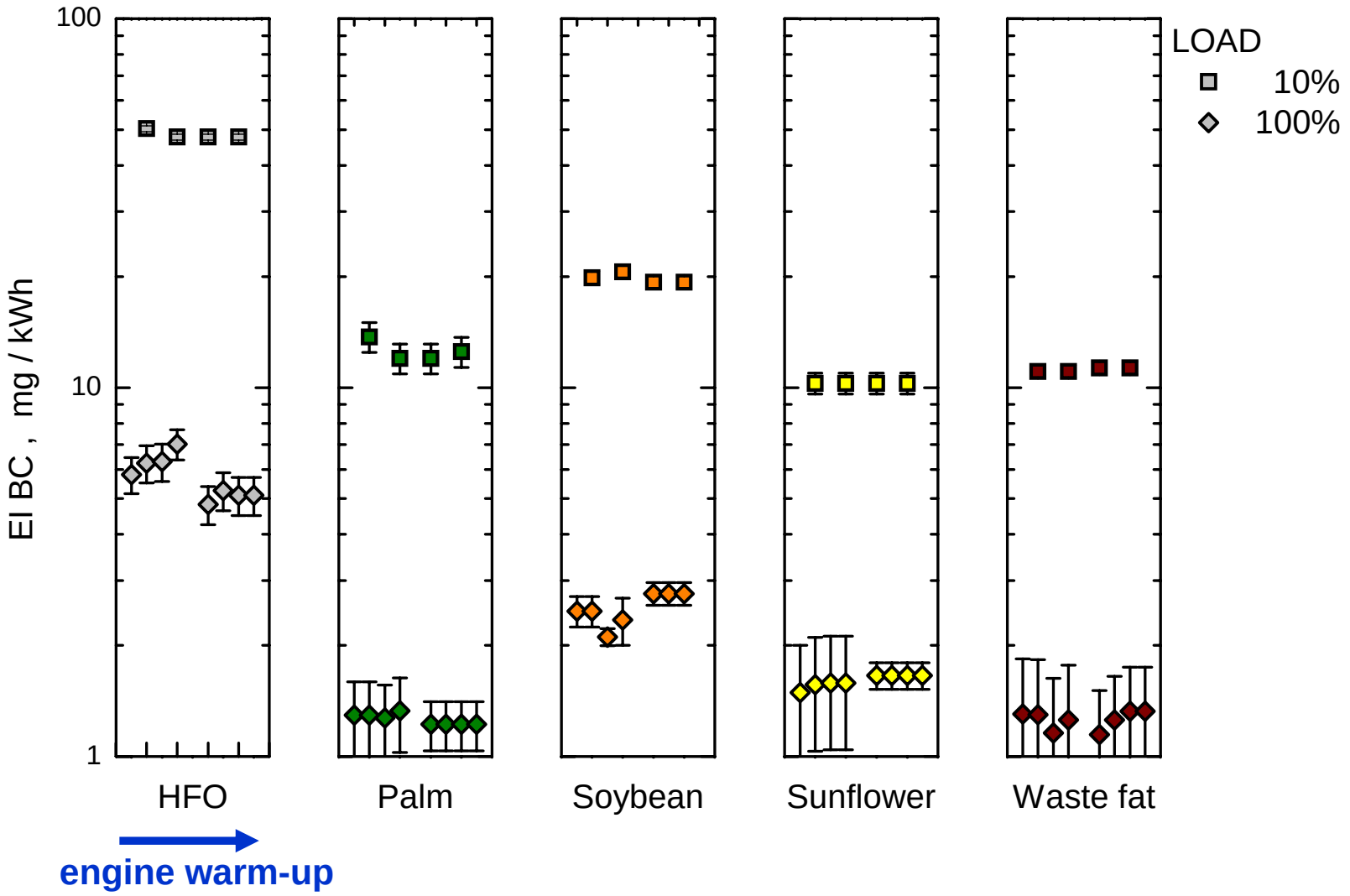
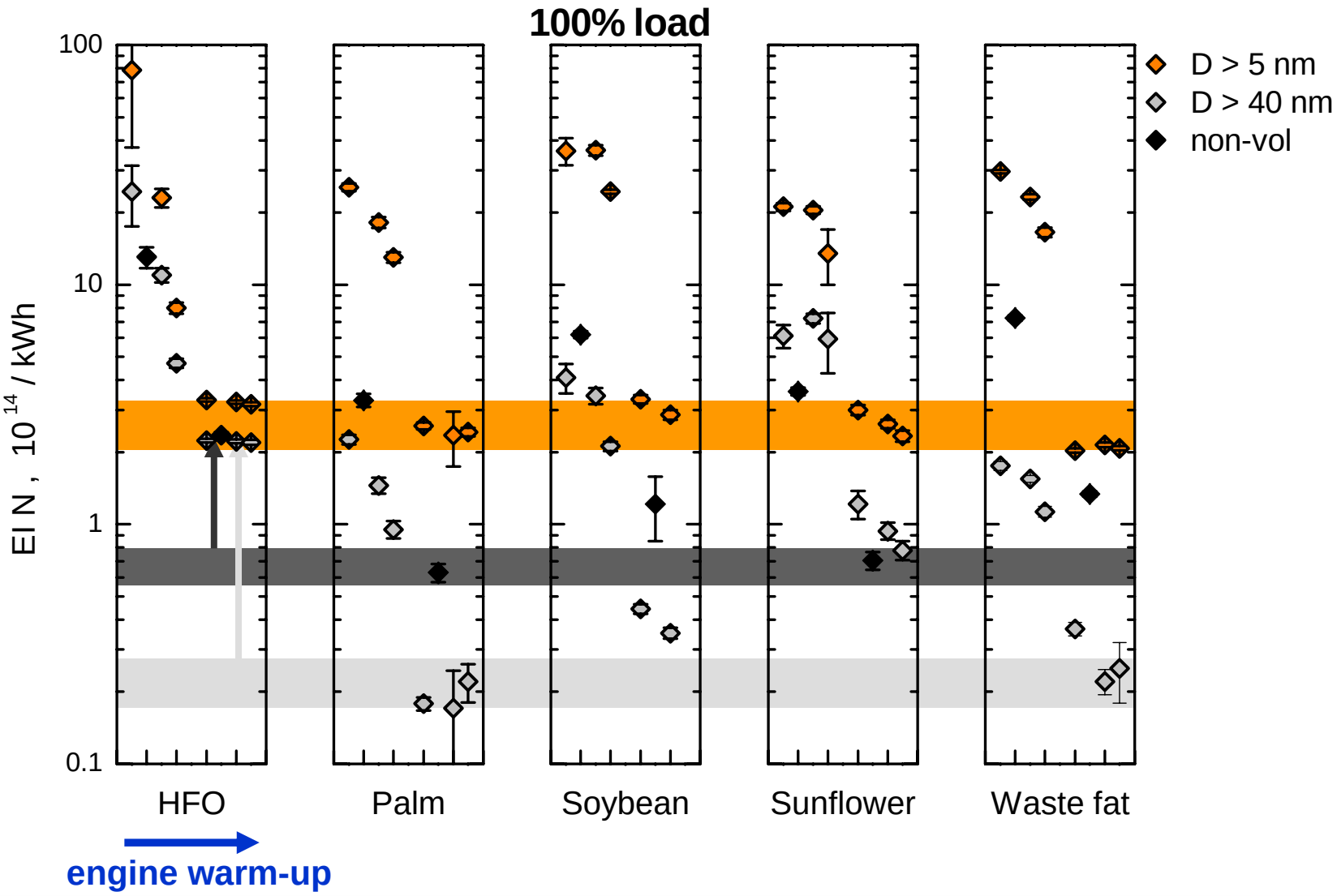

DILUTION 1: 10^5
BC MASS
MAAP
pump
exhaust
INLET
dillution-system VKL-10E
dillution-system VKL-10
dillution-system VKL-10
Grimm OPC with intecrated pump
exhaust
walve
compressed-air pistol
filtered air supply
activated-carbon - filter
dillution-system VKL-100s
walves
CO2-monitor 2
CO2-monitor 1
critical orifices
pump
exhaust
PARTICLE SIZE
P1 pressure
T1 temperature
compressed- air
walve
walves
neutralizer
filter
MFM mass flow meter
P2 pressure
T2 temperature
silicagel-dryer
compressor
DMA
critical orifice
DMA CPC
exhaust
critical orifice
pump
filter
humidifier
needle walves
silicagel-dryer
dest. water bubbler
buffer-volume
walve
TD 250°
TD 50° ref.
ACD
ACD
Pu pressure
RH/T relative humidity / temperature
needle walve
orifice
HEPA filter
[humidity growth]
nSC=3
nSC=17
nSC=10
CPC N5
CPC N14
CPSA1
CPSA2
CPSA3
pressure Pd
walve
oilpumps
exhaust
PARTICLE NUMBER DENSITY

RESULTS - BC Mass



RESULTS - Particle Number



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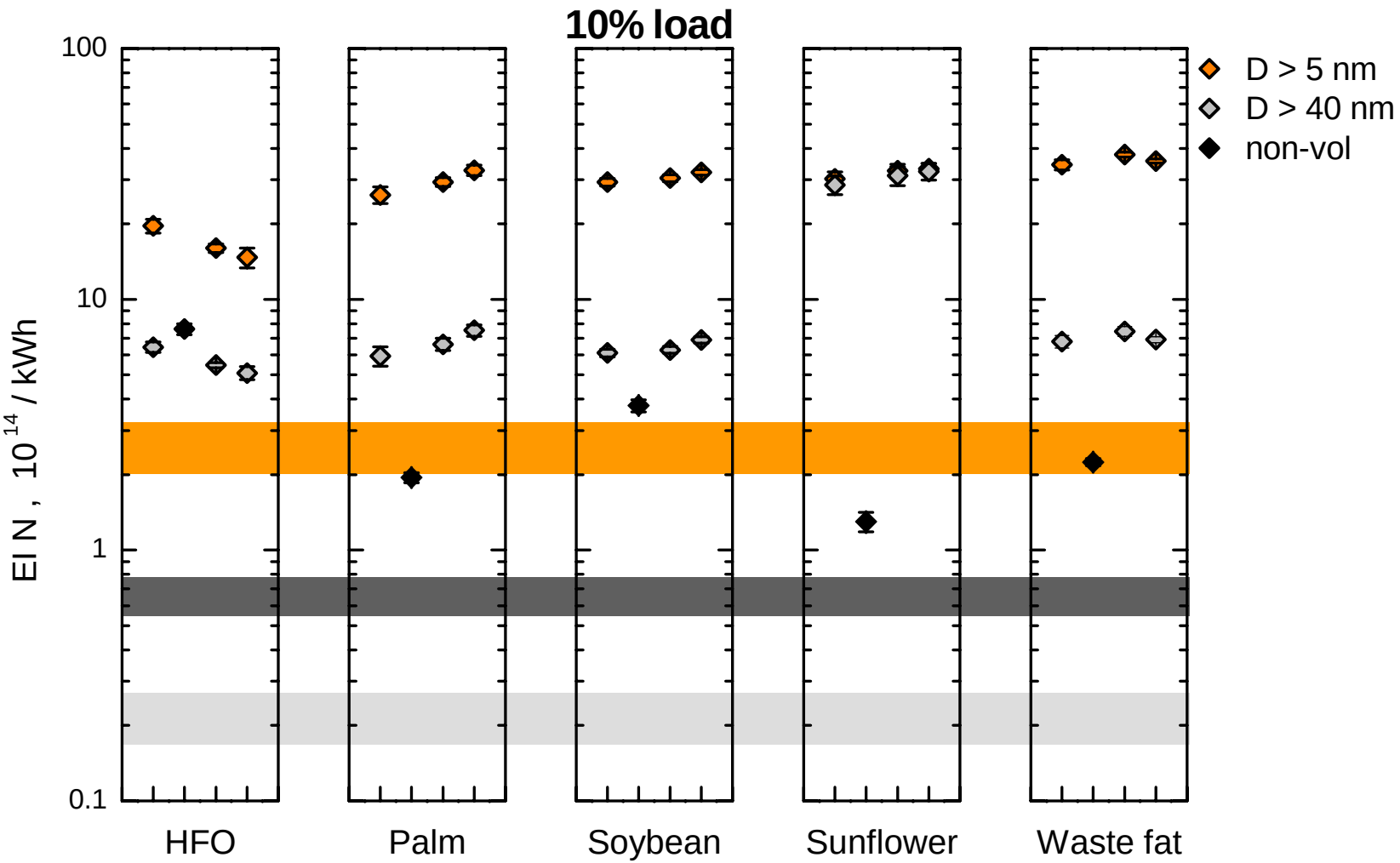
RESULTS - Particle Number



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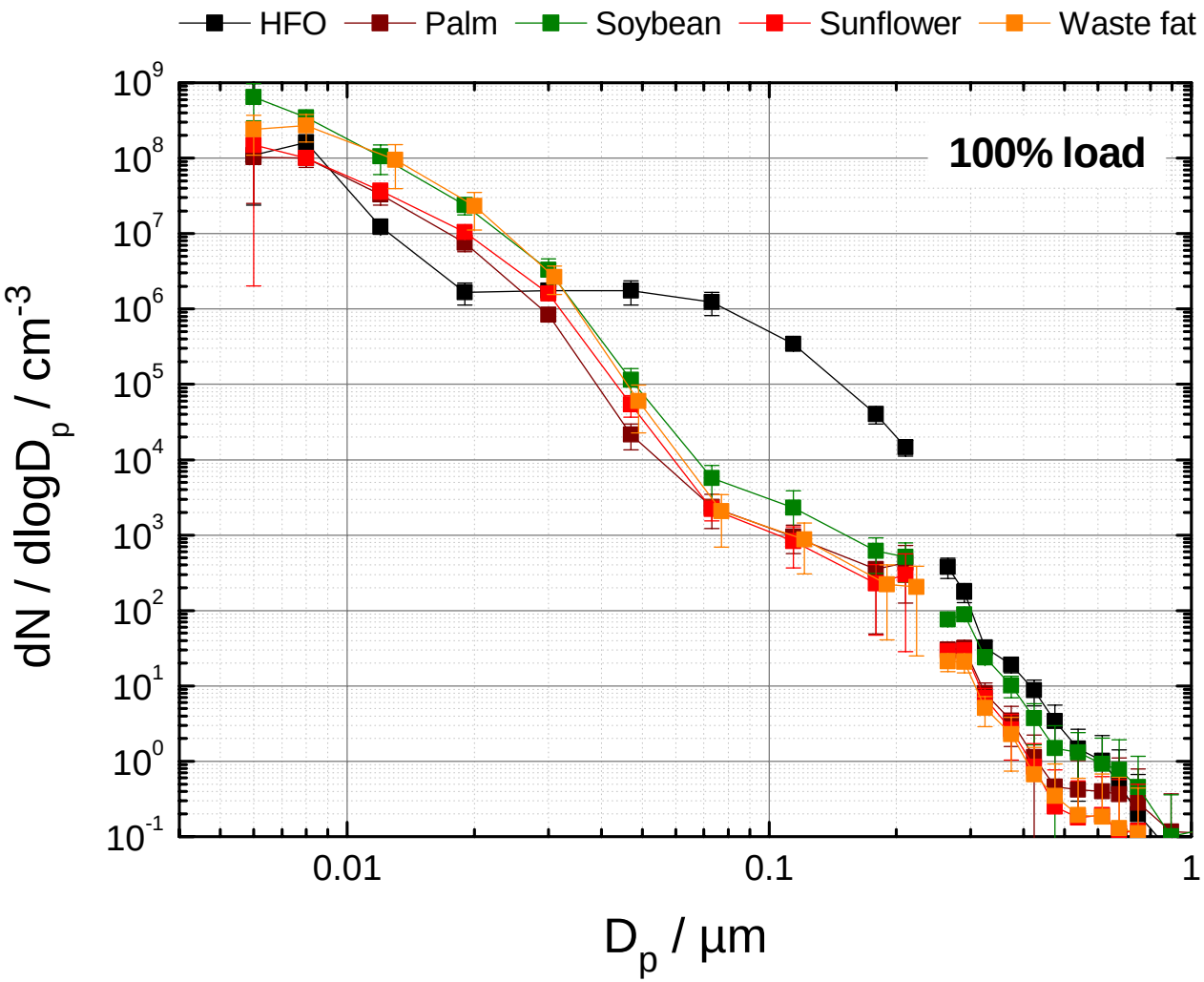
RESULTS - Particle Size



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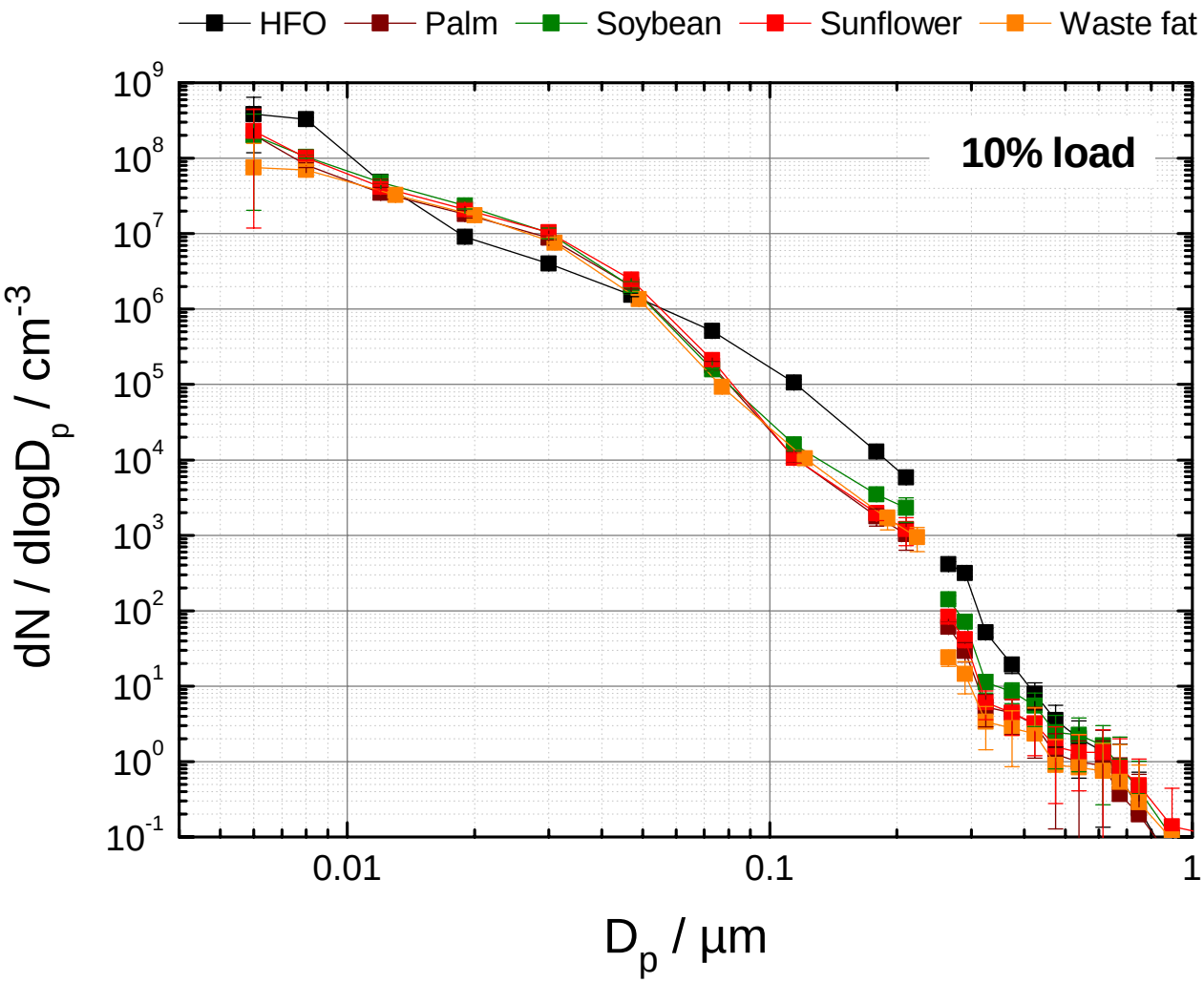
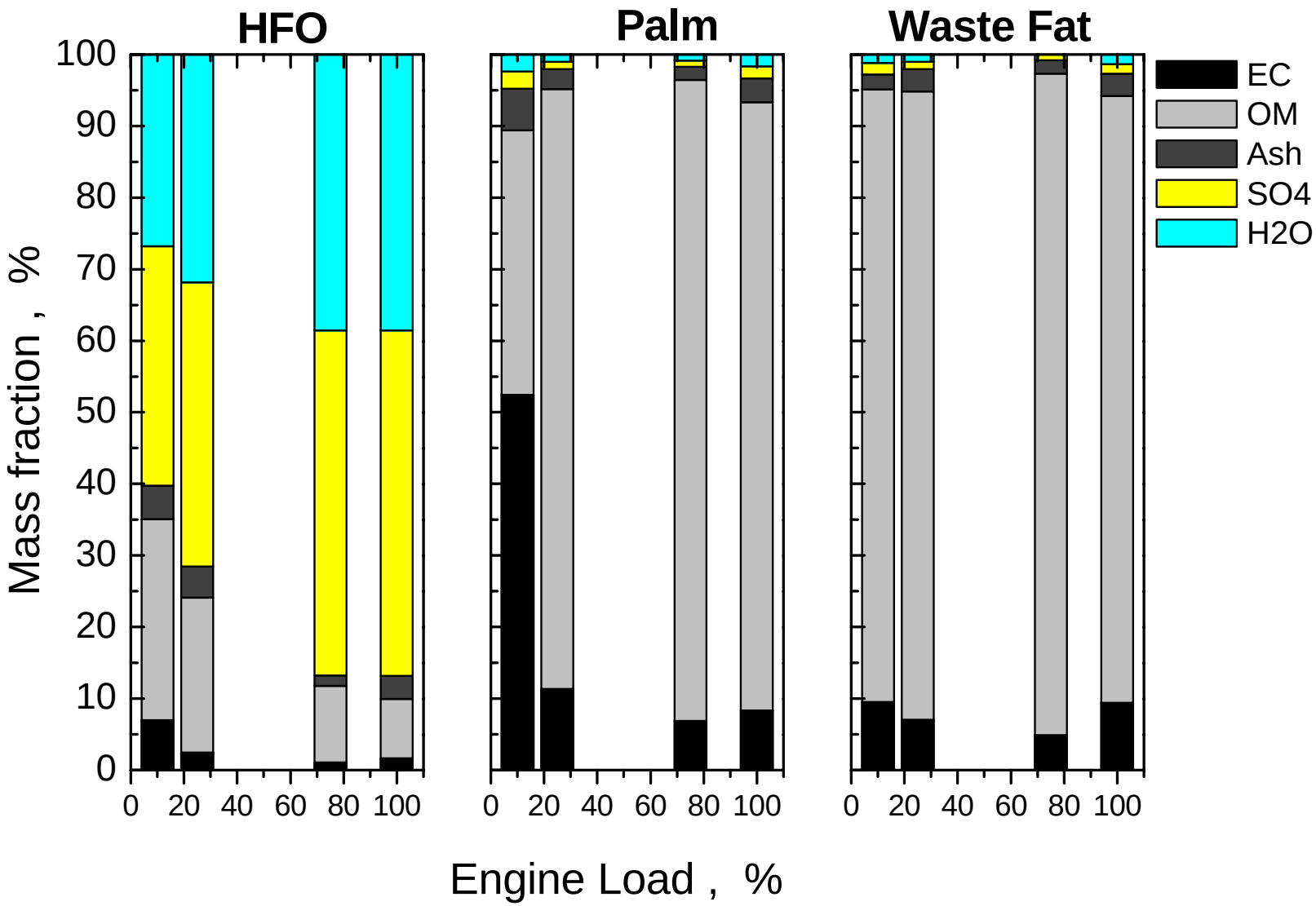
RESULTS - Particle Size



RESULTS - Chemical Composition



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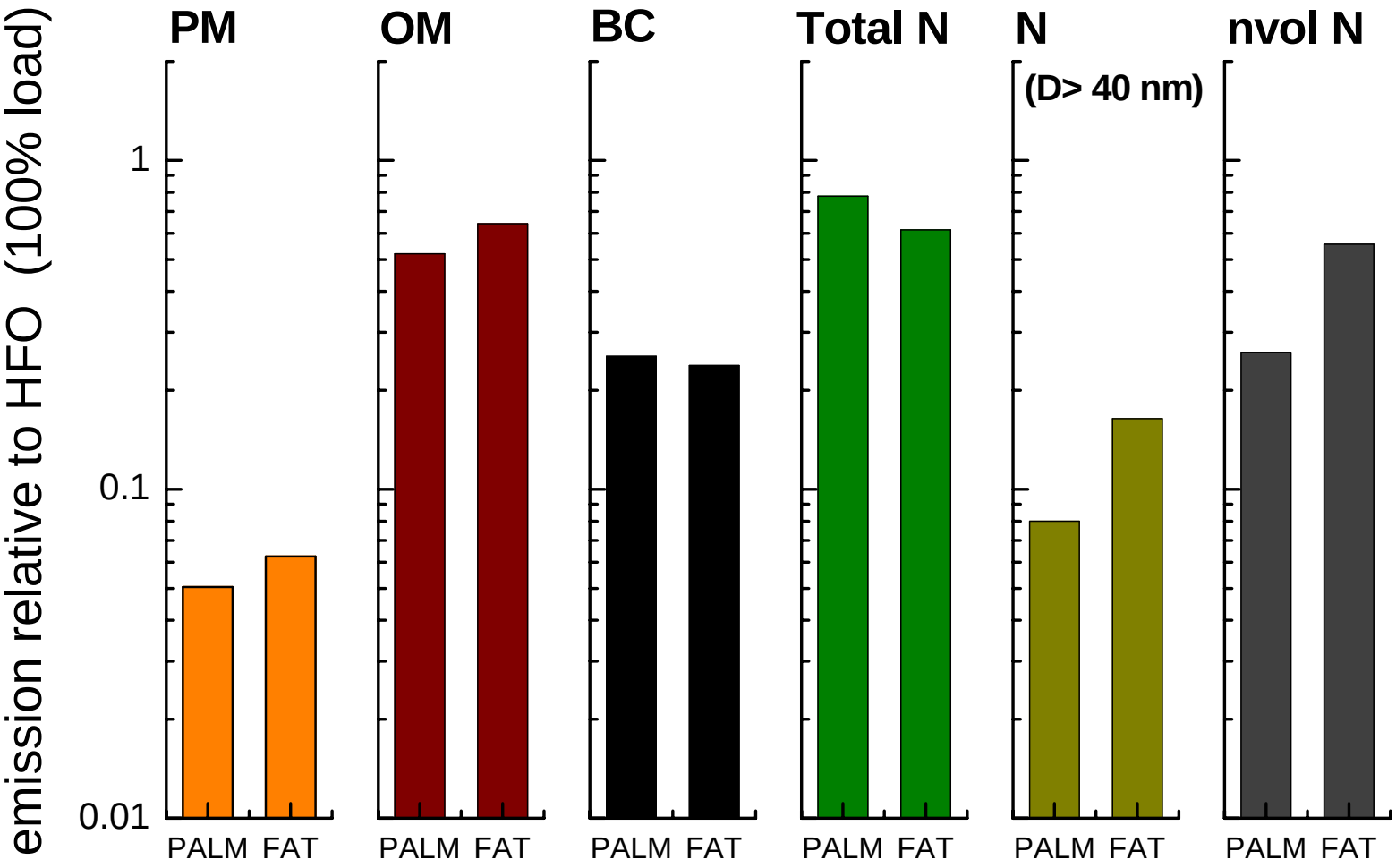
RESULTS - Emission Factors



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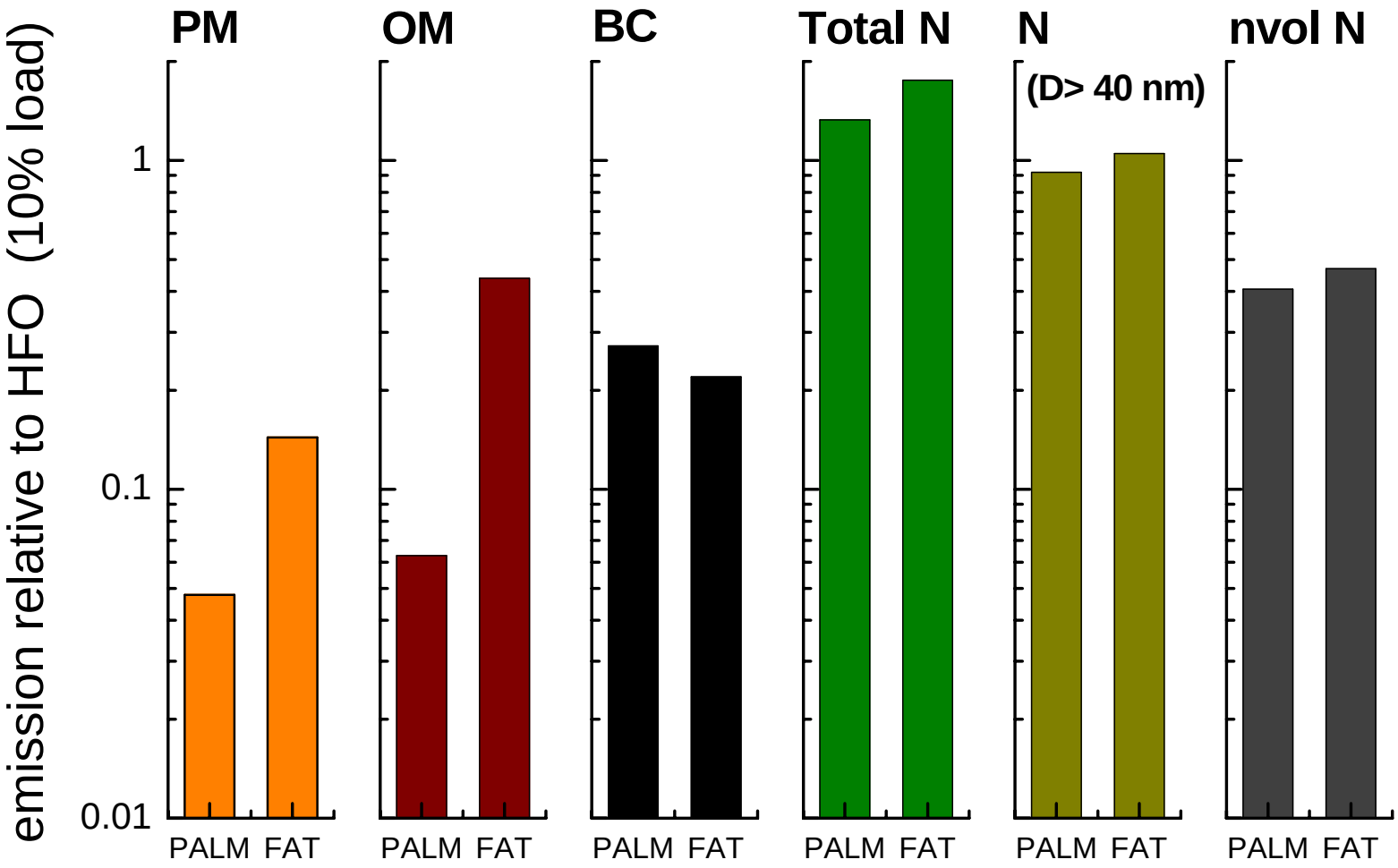
RESULTS - Emission Factors



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SUMMARY

The investigated set of biofuels demonstrated good combustion properties in the single-cylinder four-stroke test engine.

The optical inspection of engine components did not show a significant increase in engine degradation and corrosion for biofuel use.

Emission properties

Energy content per mass:	HFO	40.4 MJ kg^{-1}
	Biofuels (av.)	37.3 MJ kg -1
CO_2 emissions	HFO	675 g CO_2 kWh^{-1}
	Biofuels (av.)	655 g CO2 kWh -1
Particle mass	5 - 15% of HFO.	
Black Carbon	< 30% of HFO.	
Organic Matter at 100% load	50 - 70% of HFO.	
Particle number	≅ HFO.	

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CONCLUSIONS - NEXT STEPS

Biofuels offer an option for power generation using fuels from renewable sources with palm oil and waste edible fat showing the best emission properties of the investigated set of fuels.

With a global perspective, palm oil and soy bean oil are the potential candidates for biofuels from renewable sources.

BUT

Palm oil cannot claim to be CO_2 neutral because of severe environmental damages during production.

Soy bean production shows a problematic competition between energy and food use.

NEXT STEPS

Assessment of the climate impact of emissions.

Fuel life cycle analysis.

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PEACE
LOVE
FLOWER
POWER