Nanoparticle emissions from LNG and other low sulfur marine fuels

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Why consider particle emissions from ships?

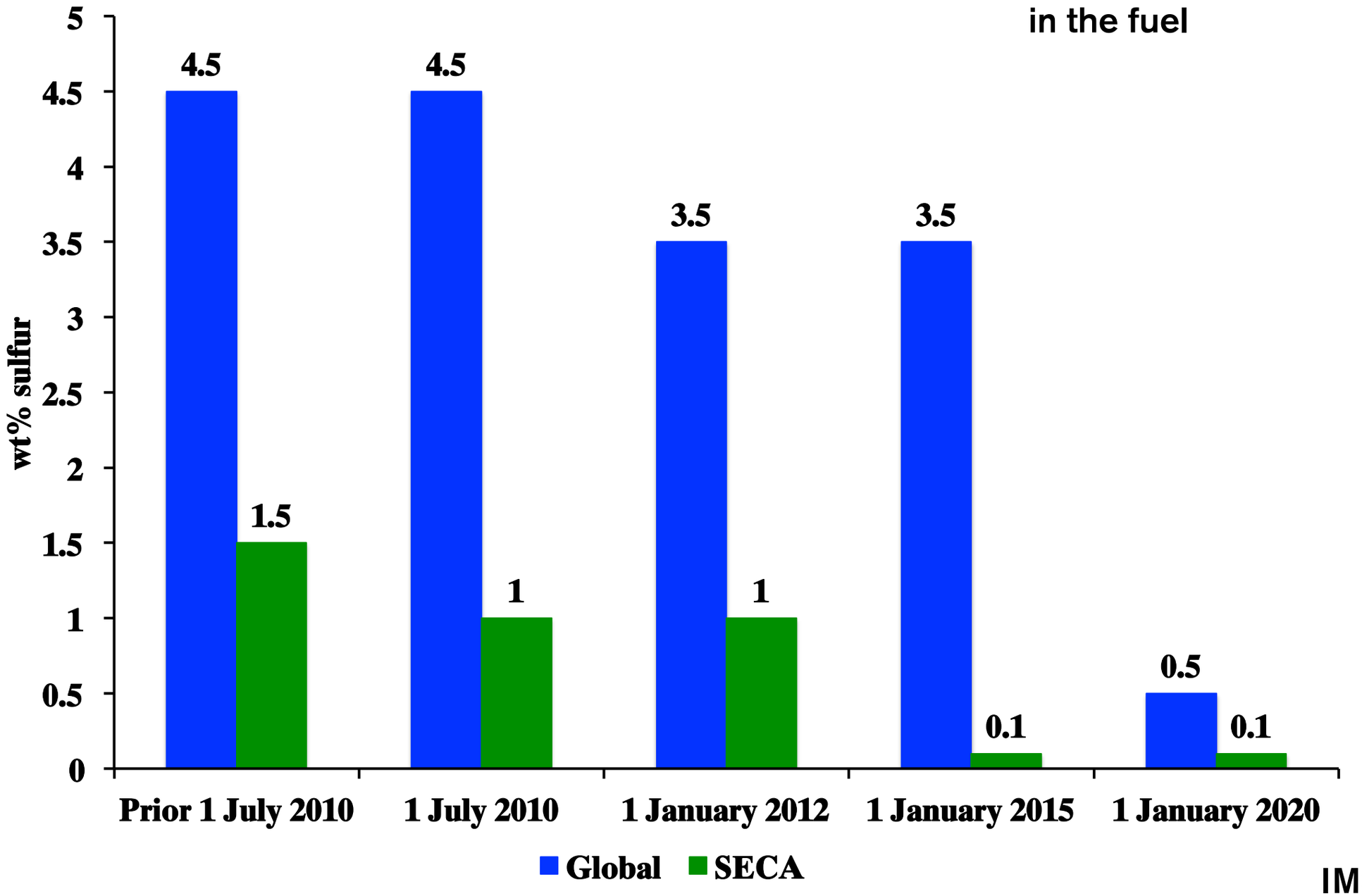
- Emissions of primary particles from shipping (1.7 Tg) are within same magnitude as for road traffic (2.1 Tg) annually (Eyring, 2005, Journal of Geophysical Research, vol 110)
- 15-25% of global PM2.5 emissions are from shipping (EEA technical report, 4/2013)
- Cause approx. 60 000 deaths from lung cancer and cardiovascular diseases annually and globally (Corbett et al., 2007, Env. Sci. & Tech. vol 41)
- Not yet directly regulated
- Ongoing discussions within International Maritime Organization about regulation of emissions of black carbon
- Consist of black carbon, sulfate, organic carbon, elemental carbon, ash, particulate nitrate and inorganic substances and metals (Moldanová et al., 2009, Atm. Env. Vol 43; Lack et al., 2009, Journal of Geophysical Research, vol 114)

Indirectly regulation of particles

- Indirectly regulated through regulation of sulfur content in marine fuels (Regulation 14 in MARPOL Annex VI, International Maritime Organization (IMO))
- Reduction of particles was the driving force
- Global limits and limits in designated sulfur emission control areas (SECAs)

Limitations of fuel sulphur content

Note: The shipping sector still discuss % sulfur in the fuel



IMO, 2013,
MARPOL Annex VI

Limitations of fuel sulfur content

Force ship owners to use….

- Abatement technologies (scrubbers)
- Low sulfur marine fuels
- Alternative fuels (for example liquefied natural gas (LNG), methanol)

To comply with the regulation of sulfur content in SECAs

Focus on particle emission from:

- Low sulfur marine fuels
- Alternative fuels, here LNG

Focus on number of particles emitted and the sizes and emissions from ship operations

Experimental

Two different studies

1. Measurements on test-bed engine, Chalmers*

- Marine diesel engine with installed power of 81 kW
- Heavy fuel oil (HFO) with 0.1% sulfur content
- Marine diesel oil (MDO) with 0.5% sulfur content
- Swedish environmental class 1 diesel (MK1) with <3 ppm sulfur content as reference fuel

2. Onboard measurements

- Dual-fuel engine with installed power of 7600 kW/engine
- Liquefied natural gas (LNG)
- Marine gas oil (MGO) with 0.05% sulfur content as pilot fuel

*** Anderson et al., 2015, Characterization of particles from a marine engine operating at low loads, Atmospheric Environment, vol. 101, pages 65-71**

Experimental

Particle measurements

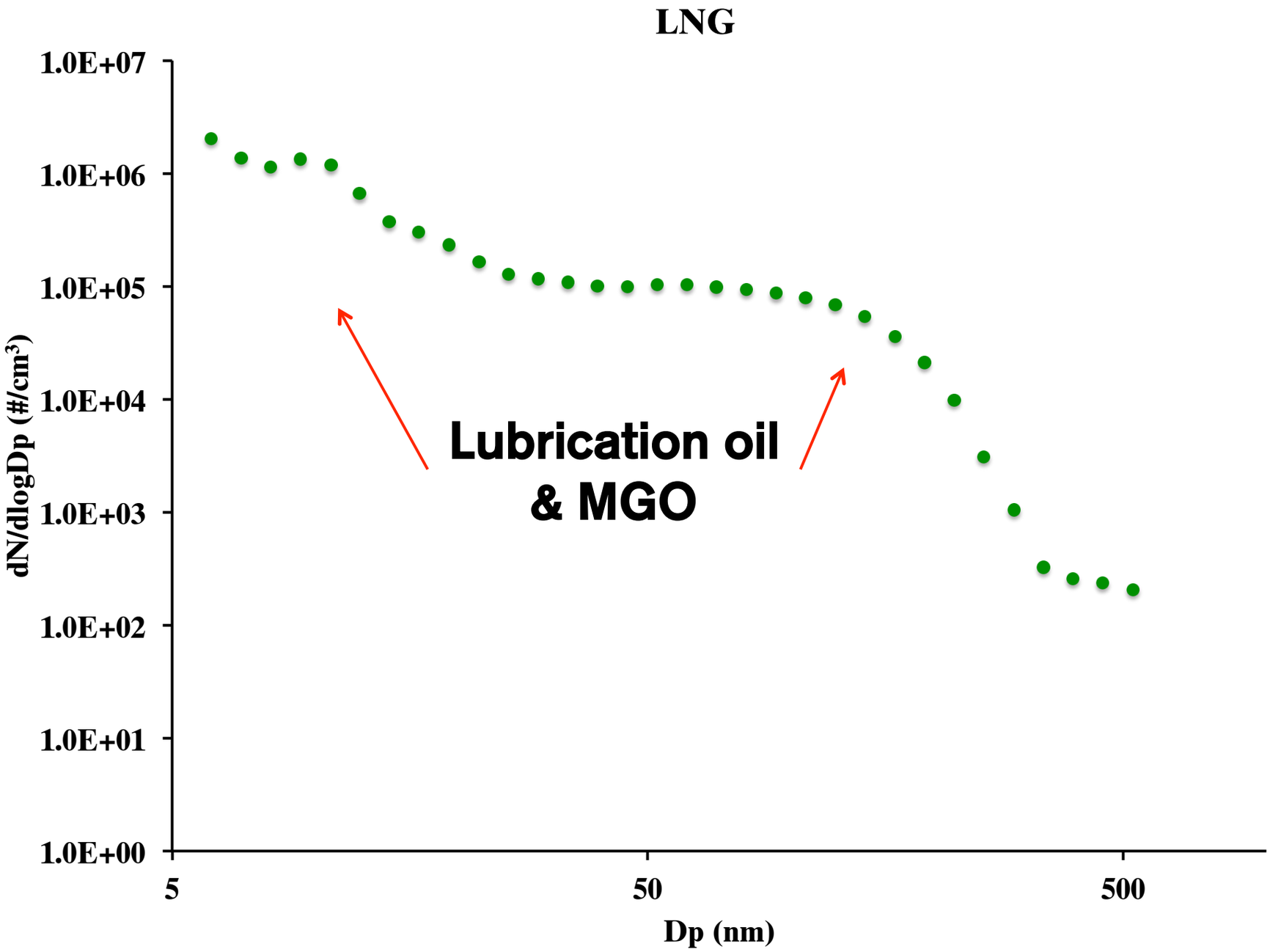
- Engine Exhaust Particle Sizer (EEPS, Model 3090 TSI Inc.)
  5.6-560 nm (number, mass and size distribution)
- Dust monitor (Grimm Model 1.108)
  300 nm to 20 µm (number and mass)
  - Thermodenuder heated to 300°C
    Non-volatile (solid) fraction of the emission

- **Dilution with Fine Particle Sampler (FPS)**

Gaseous emissions

- CO_2, CO, O_2, NO_X, SO_2 and Total hydrocarbons (THC)

Results: Sizes of particles



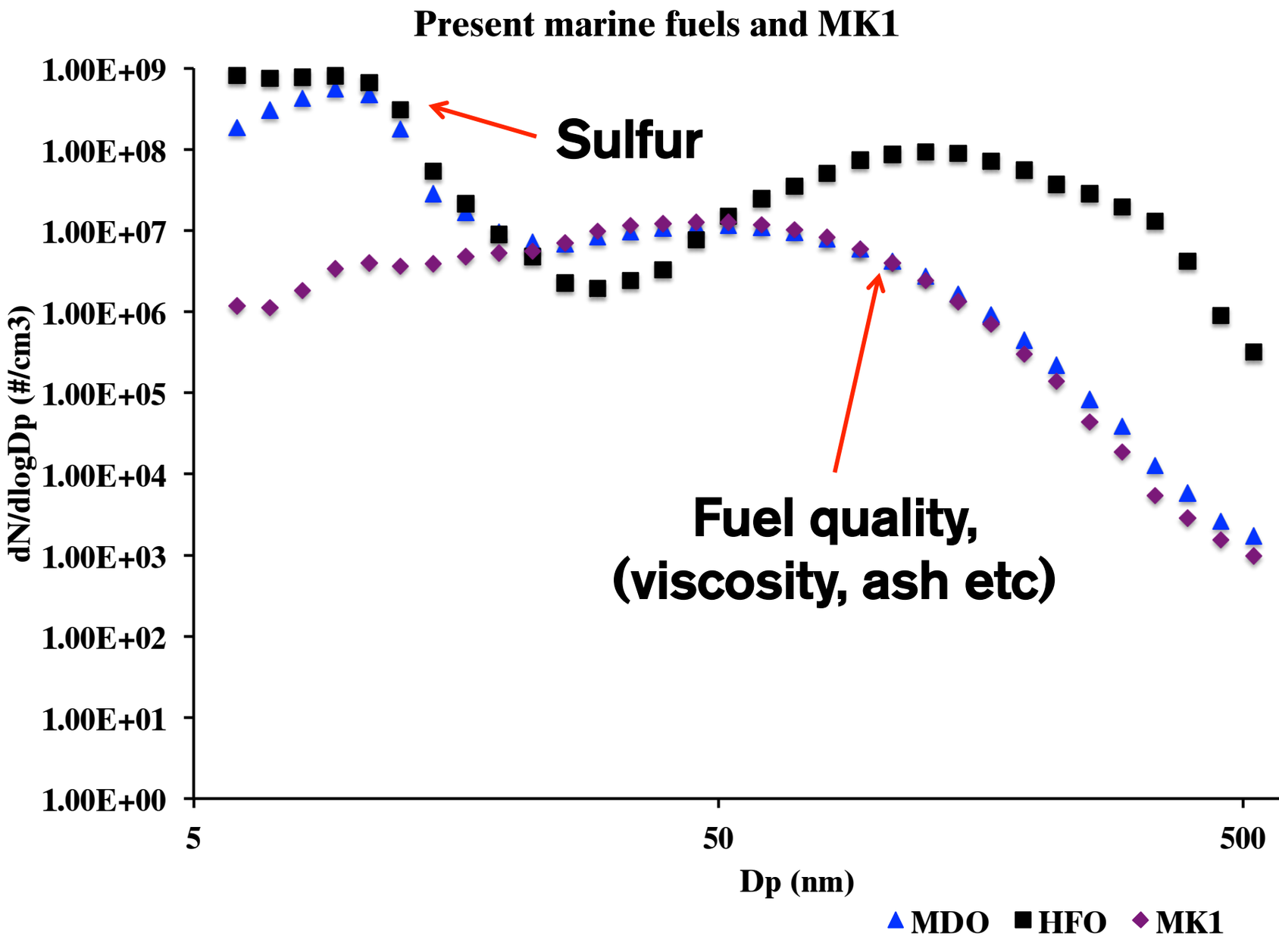
<u>Nanoparticles (<50 nm after Hinds, 1999)</u>
Dominate; 88-96% of total particle number. Volatile and non-volatile character

<u>Diameter >50 nm</u>
Non-volatile character.

<u>Origin of particles</u>
Lubrication oil and pilot fuel (marine gas oil, MGO)

Note: logarithmic scales on x- and y-axis

Results: Sizes of particles



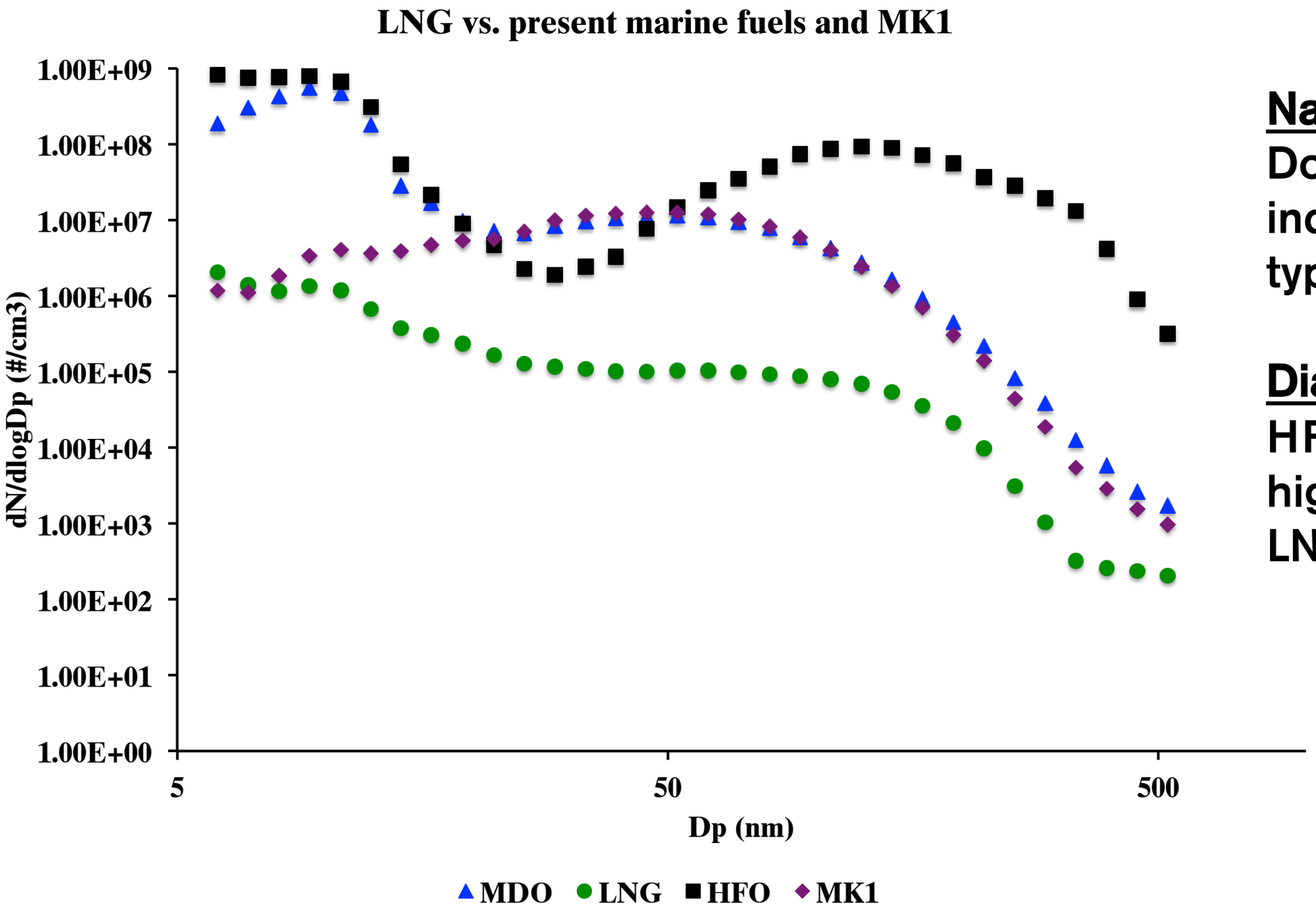
Nanoparticles
Dominate;
94% for MDO, 85% for HFO of total particle number.
Both of non-volatile (solid) and volatile character.

Diameter >50 nm
HFO considerably higher than MDO.
Non-volatile (solid) particles.

Origin of particles
Fuel and lubrication oil

Note: logarithmic scales on x- and y-axis
HFO: heavy fuel oil; MDO: marine diesel oil;
MK1: Swedish environmental class 1 diesel

Results: Sizes of particles

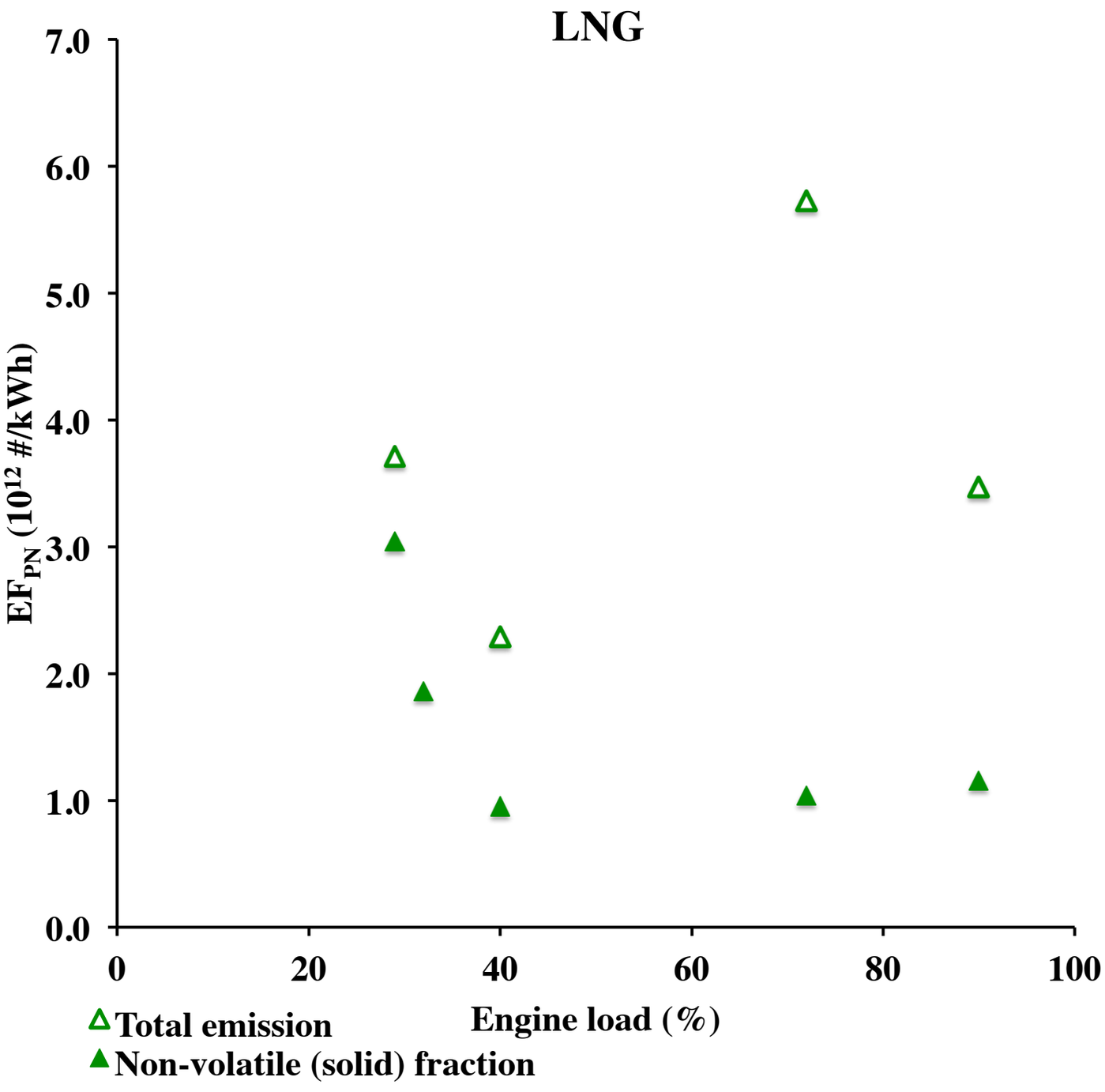


Nanoparticles
Dominate independently of fuel type.

Diameter >50 nm
HFO considerably higher than MDO and LNG.

Note: logarithmic scales on x- and y-axis
HFO: heavy fuel oil; MDO: marine diesel oil

Results: Number of particles



Trend

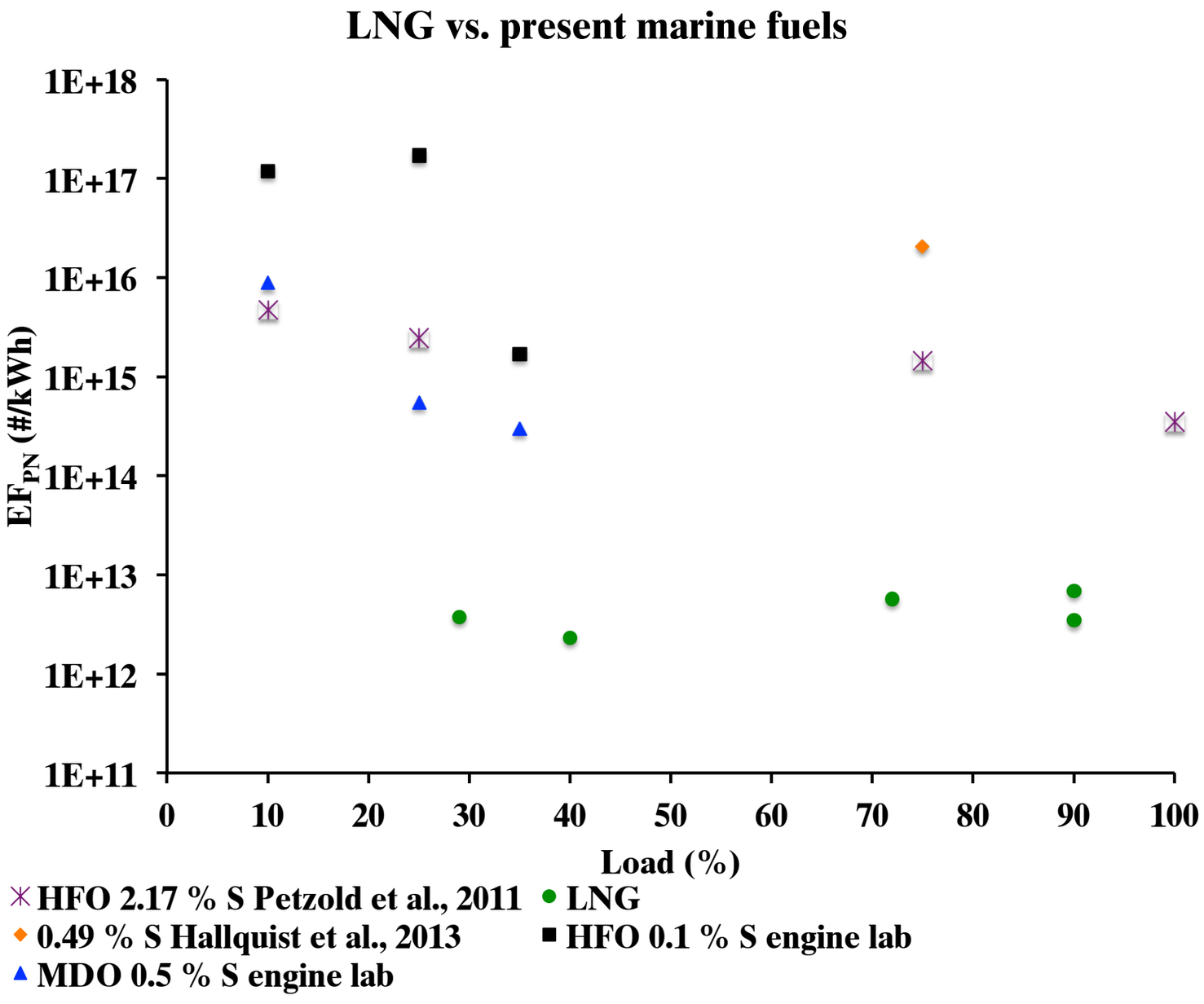
Emissions of non-volatile particles increase with reduced engine load.

Why?

Higher amount of pilot fuel used

Important to consider when operating in ports and coastal areas

Results: Number of particles



Highest emissions of particles related to number (PN) for HFO.

Significant reduction in emissions of particles for LNG, compared to present marine fuels

Note: logarithmic scales on x- and y-axis
HFO: heavy fuel oil; MDO: marine diesel oil

Concluding remarks

These studies show that

A change from low-quality fuels (heavy fuel oil) to high-quality fuels (marine diesel oil or marine gas oil) or alternative fuels (here LNG) is a step in the right direction towards more sustainable shipping in aspect of air quality

- But, there are still particle emissions to consider

Both sulfur content and fuel quality should be considered in evaluation and in future legislation of particle emissions from ships

- Sulfur content impact emissions of nanoparticles
- Fuel quality impact emissions of particles with Dp>50 nm

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Thank you for your attention!

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