Particle mass and number emissions from marine engines preparing for the upcoming sulphur cap limits

Lehtoranta Kati, Aakko-Saksa Päivi, Murtonen Timo, Vesala Hannu, Ntziachristos Leonidas, Karjalainen Panu, Rönkkö Topi, Kuittinen Niina, Alanen Jenni

TAMPERE UNIVERSITY OF TECHNOLOGY

Content

- Introduction
- Experimental
  - Engines, ships, fuels, emissions measurements
- Results
- Conclusions
- Acknowledgements

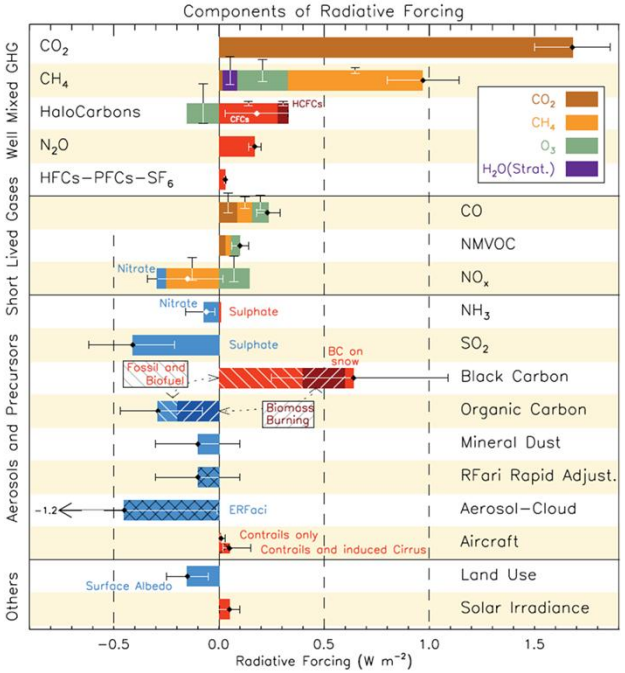
Introduction

- **Emissions from ships** can be a significant source of air pollution in coastal areas and port cities - 70% of ship emissions occur within 400km of coastlines.
- The International Maritime Organization (IMO) – regulations for emissions of NO_x and SO_x
- **Sulphur**, Global: 3.5 % S -> year 2020 0.5% S, SECA: 0.1 % S. Either low sulphur fuels or scrubbers.
- The strictest limit for **NO_x**, Tier III, NECA – increases the use of catalysts (SCR's)

https://www.marinetraffic.com/

Introduction

- No **PM** emission limits by IMO, yet.
- However:
  - BC is a major contributor to the Arctic warming, which has been twice the global warming rate. Deposits of BC on snow and ice accelerate melting by reducing the reflectivity of snow and ice. IMO limit for BC from ships is anticipated
  - Recently, Sofiev et al. 2018 ‘Cleaner fuels provide public health benefits with climate tradeoff’ – lower S fuels reduce cooling from ship aerosols - low-sulphur marine fuels will still account for 250k deaths and 6,4M childhood asthma cases annually
  - Emission limits (EU) for engines used in inland waterway vessels, also PM & PN (2020)

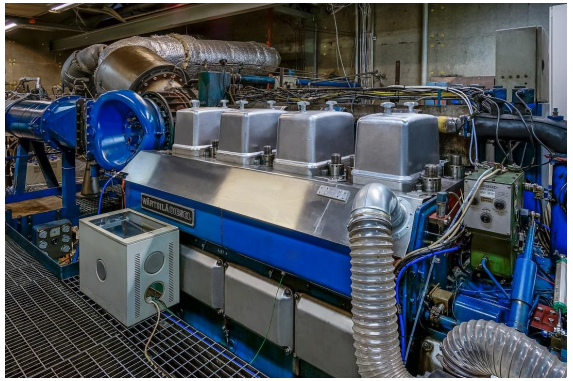


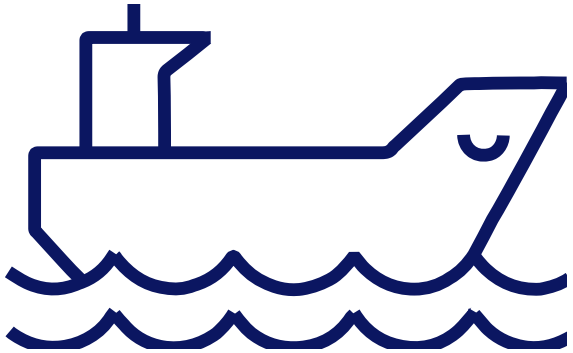
Experimental

- **Engine and ship**

  - Laboratory marine engine: Wärtsilä Vasa 4R32, a four cylinder medium-speed diesel engine modified to run with natural gas in dual fuel (DF) mode, maximum power 1400 kW.

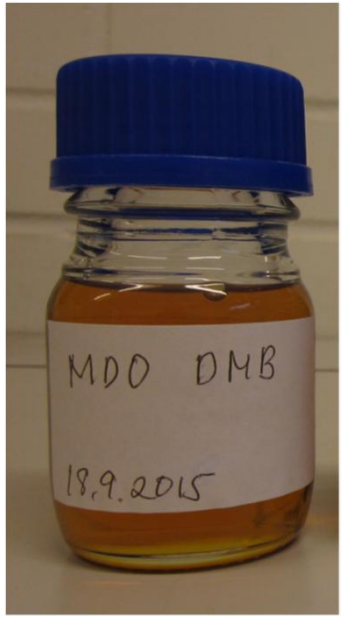
  - Ship 1: Modern cruising ship, E1 equipped with a hybrid scrubber, E2 with a selective catalyst reduction catalyst and a hybrid scrubber.



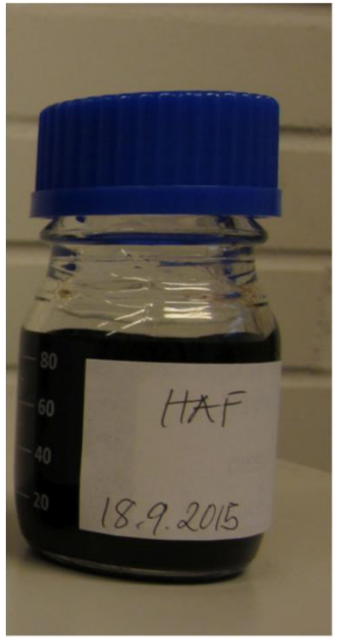


Experimental

- **Fuels**
  - Heavy fuel oil, HFO
    - HFO 1 < 1% S
  - Marine diesel oil, MDO
    - < 0,1% S
  - Marine gas oil, MGO
    - < 0,001 % S (road diesel)
  - Natural Gas, NG
    - < 0,0001% S
    - + With NG in DF mode – MGO was utilized as a pilot fuel



Marine diesel oil



Heavy fuel oil

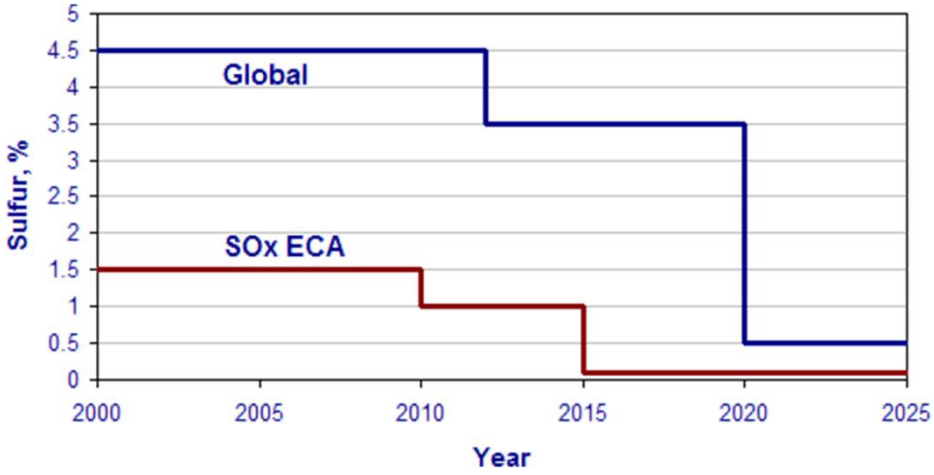
Measurements

- PM was measured following the standard ISO 8178-1:2006. PM filter T 42-52 ºC. Dilution ratio of 10 and sampling times of 5-30 min were used.
- PN standard originates from the PMP (Particle Measurement Programme) and consider non-volatile particles with a diameter greater than 23 nm.
- + PM further analysed for EC/OC, anions (sulphates), metals
- + Gaseous emissions NO_x, CO, CO_2, HC, SO_2, H_20

Results

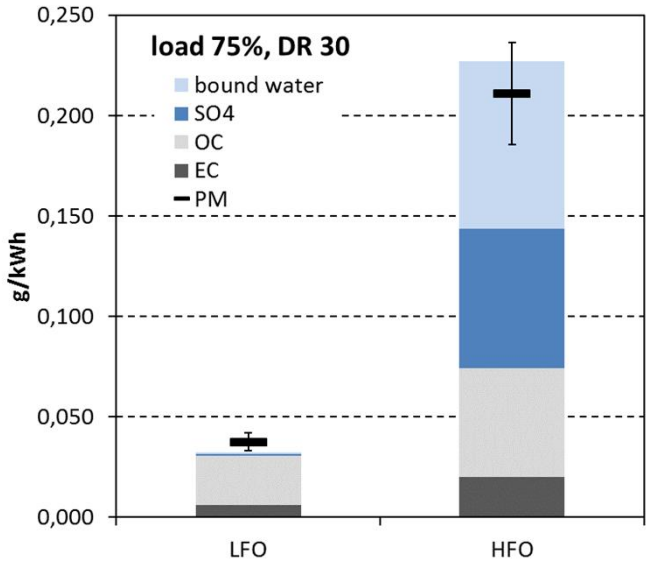
1. From HFO to fuels fulfilling SECA

2. From HFO to scrubbers fulfilling SECA



Source: Dieselnet

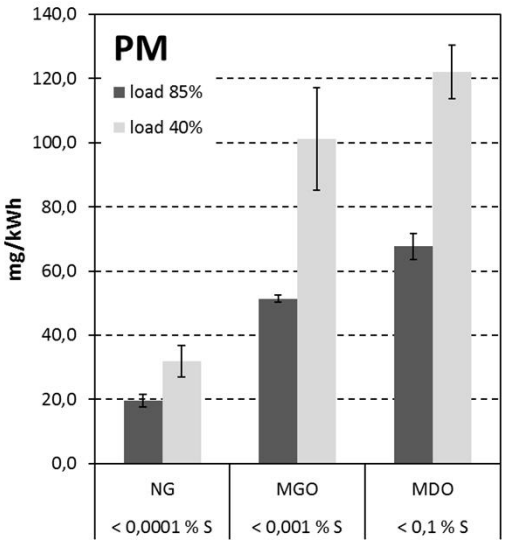
From HFO to fuels fulfilling SECA

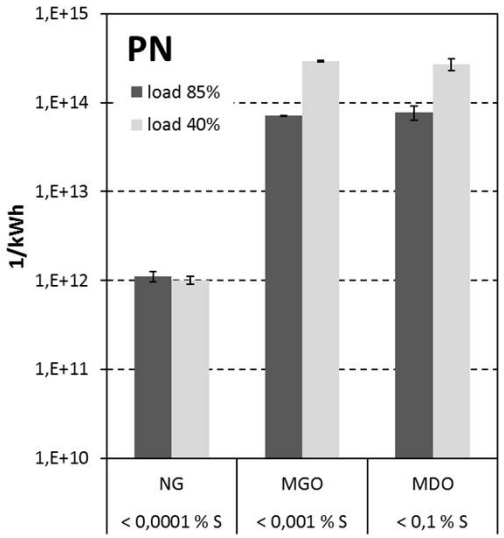


Ntziachristos et al. Fuel 2016

- From earlier studies: Decreasing fuel sulphur level will decrease the PM also
- This was also expected by IMO when setting the S limits
- However, the particle composition depends also on other specifications of the fuel than the sulphur level…

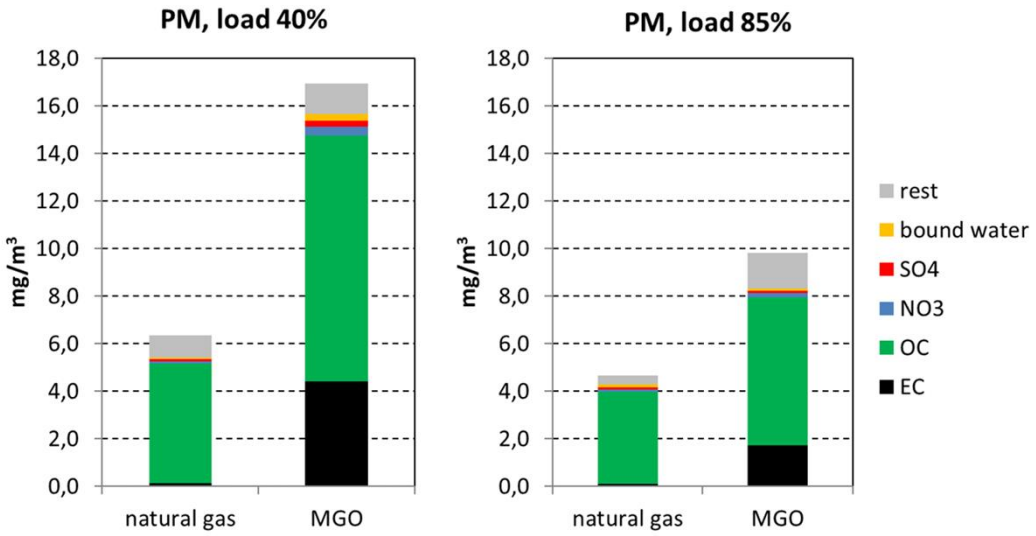
From HFO to fuels fulfilling SECA





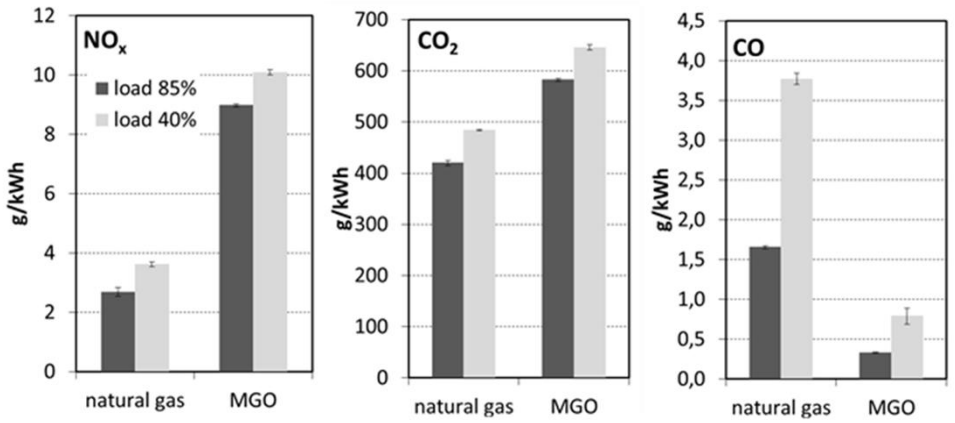
- Decreasing fuel sulphur level decreases the PM also.
- However, the effect on PN is not so clear.
- Natural gas produces the lowest PM & PN.

PM composition (MGO & NG fuels)



- The **organic carbon** was found to be the main component in all cases studied while the **elemental carbon** was practically found only when utilizing MGO and not with the natural gas use

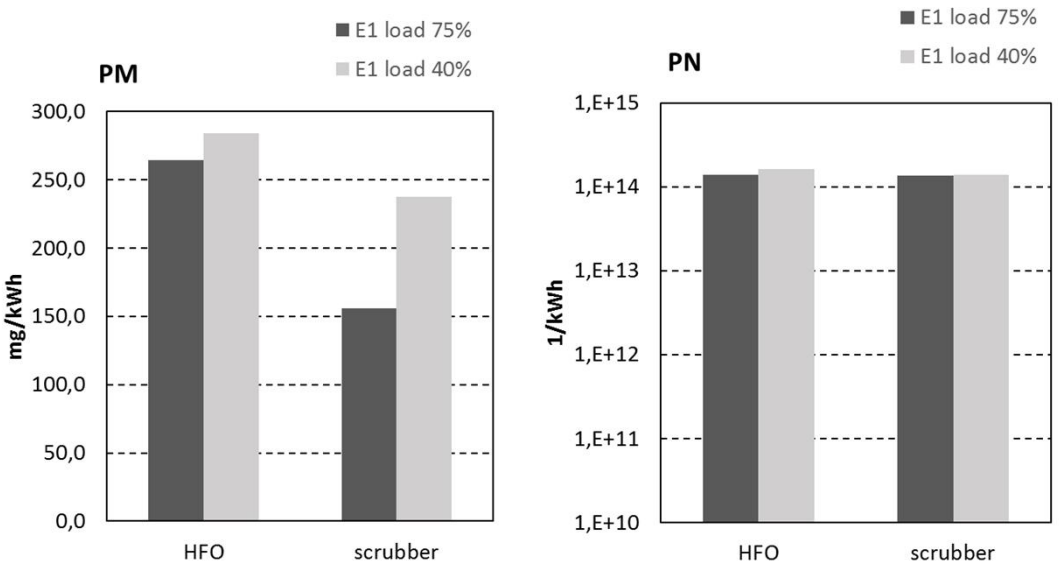
Gaseous emissions – NG fuel



	load %	CH_4 g/kWh	C_2H_6 g/kWh	C_3H_8 g/kWh
Natural gas	85	5,6	0,24	0,05
	40	13,8	0,62	0,05
		*THC g/kWh		
MGO	85	0,37		
	40	0,53		

- No **SO_2**
- Lower levels of **NO_x** were measured with natural gas compared to the diesel fuel only.
- Since the natural gas is mainly composed of methane it has a higher H/C ratio compared to diesel. This results to lower **CO_2** emissions.
- However the **CO** and **HC** emissions were higher with the natural gas use compared to MGO use.

From HFO to scrubbers fulfilling SECA



- PM clearly decreased over the scrubber
- However, there is practically no effect on PN.

Conclusions

- The main conclusion from present study is that the **fuel change** to lower sulphur level fuels or to usage of scrubbers in combination with higher sulphur level fuels can have a significant **decreasing effect on the PM**, but **the effect on PN is not straightforward**.
- While in some conditions, a **PN decrease was seen** in the other condition **no PN decrease was observed** although the PM was clearly decreased. This should be taken into consideration when discussing the **health effect of particles**, especially. Further, studies on particle size & volatility would give more information about particle emissions health and atmospheric implications.
- The PM decrease was **not only due to the decrease of sulphates**. In present study, decreases in organics and elemental carbon were also seen due to fuel change to NG or utilization of a scrubber.
- **Natural gas** is a flexible and cost-effective way to support the decarbonisation of transport and to tackle air quality. The **low levels of PM and PN** measured in present study support the usage of NG, as well. However, there is a challenge with **methane slip**, which needs to be solved in order not to compromise the climate benefit gained from the CO_2 decrease.

Acknowledgements

HERE project

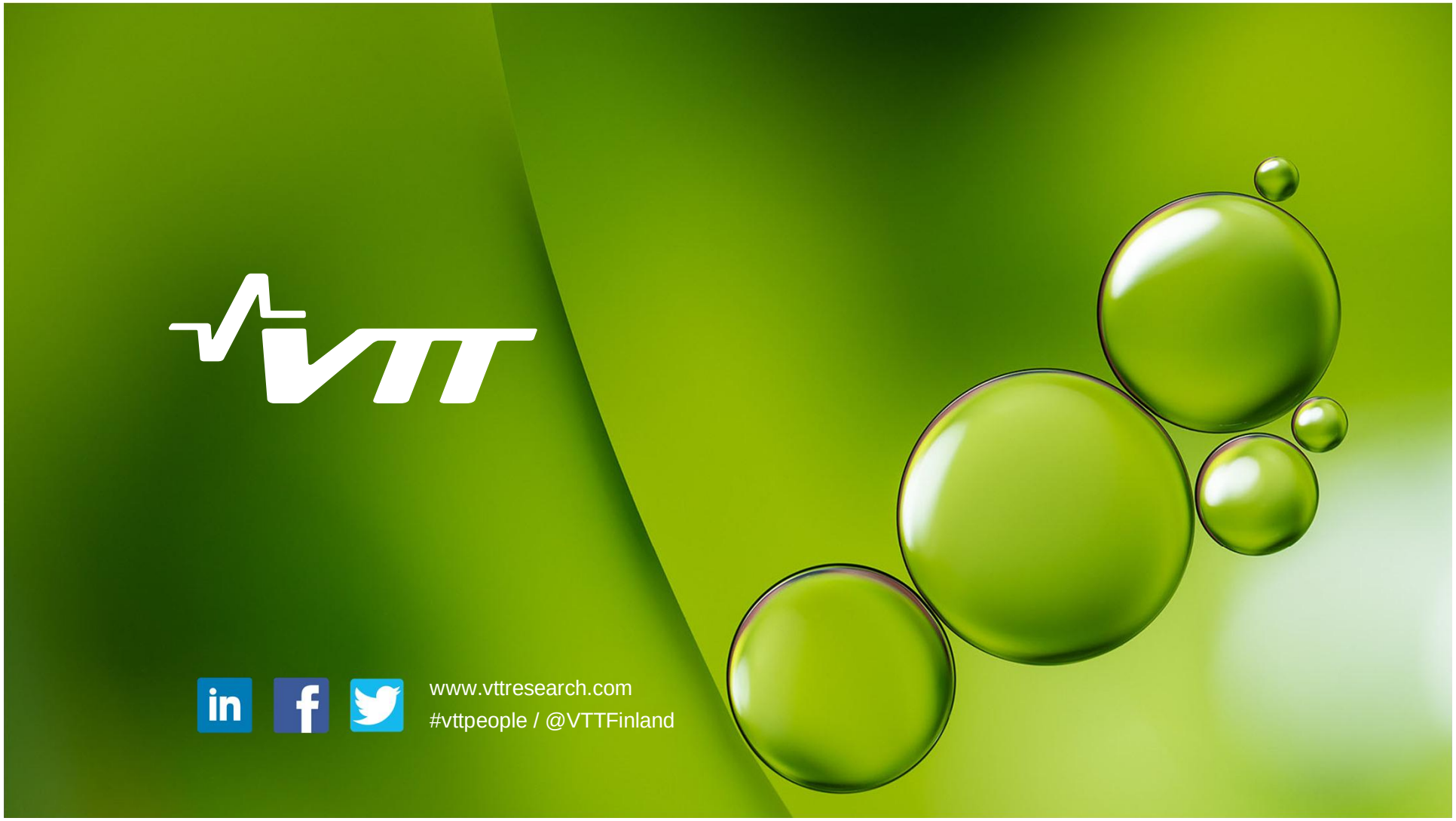
SEA-EFFECTS BC project

Hercules-2 project

Funding from Business Finland

Funding from EU

Funding from several Finnish companies


www.vttresearch.com
#vttpeople / @VTTFinland