POPs and heavy metal emissions from marine diesel engines – Nordic program

Päivi Aakko-Saksa, VTT

TFEIP meeting

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Nordic programme on developing air pollutant emission inventories, especially POP and heavy metal emissions

Participants/project group:

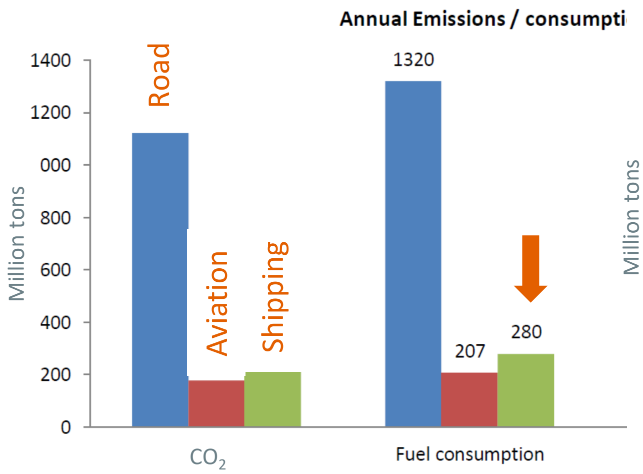
- Ole-Kenneth Nielsen, Denmark
- Tomas Gustafsson, Sweden
- Britta Hoem, Norway
- Vanda Hellsing, Iceland
- Kristina Saarinen, Finland; EF work: Päivi Aakko-Saksa, VTT

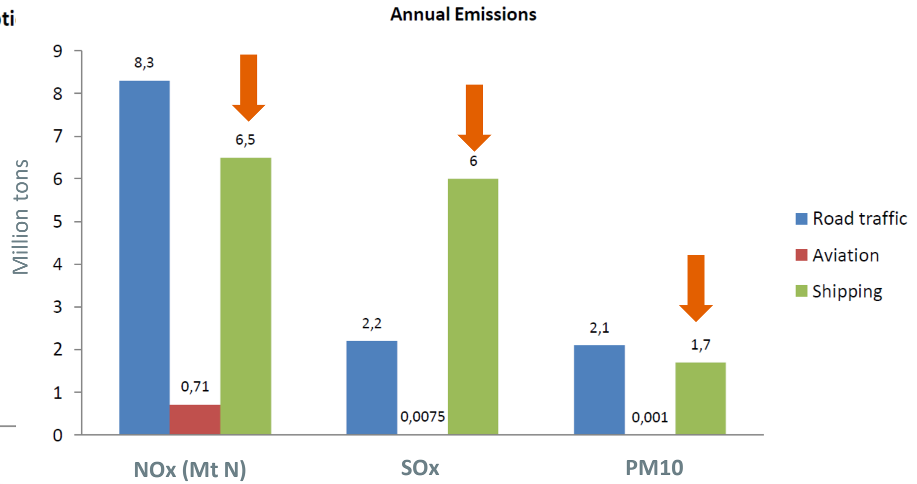
Contents

- Ship emissions
- Fuels and emission control devices
- POP and HM emissions
- Conclusions

Shipping emissions are substantial

Shipping represents globally approximately **9% of SO_x, 18-30% of NO_x** and **8-13% of diesel black carbon** (*Winther 2014, Azzara 2015*).





Global warming

Energy security

Acidification

Health effects

Eutrophication

Environmental effects

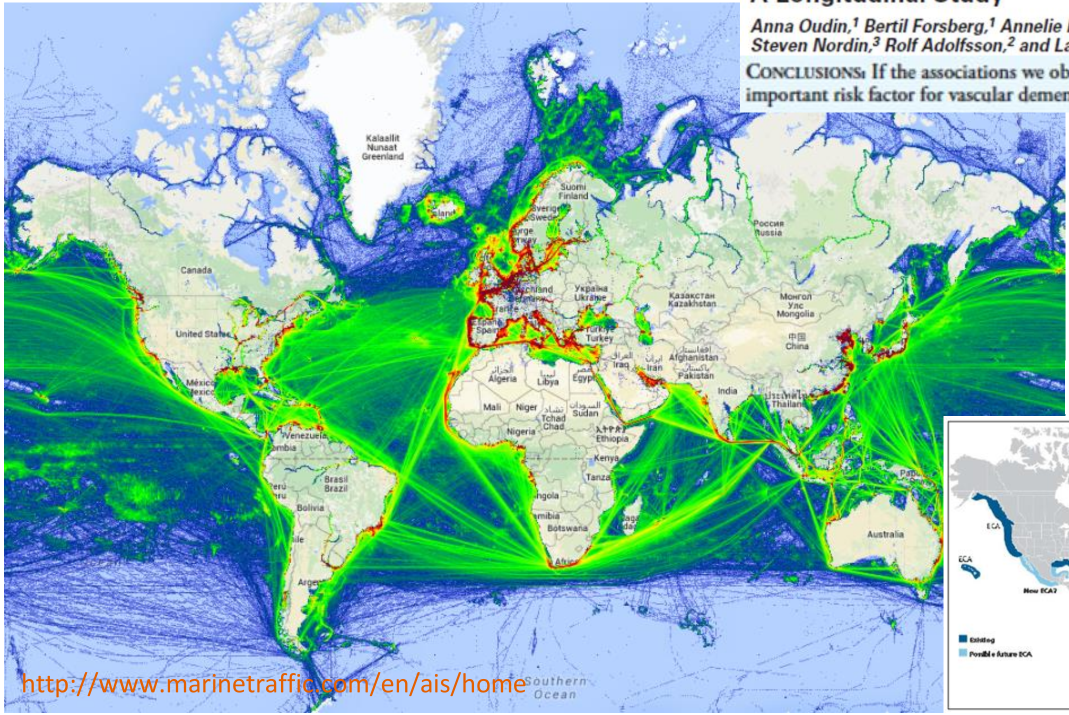
Ref. Eyring et al. 2005 in Fagerlund and Ramne 2013.

Ships travel close to coast where dense population lives

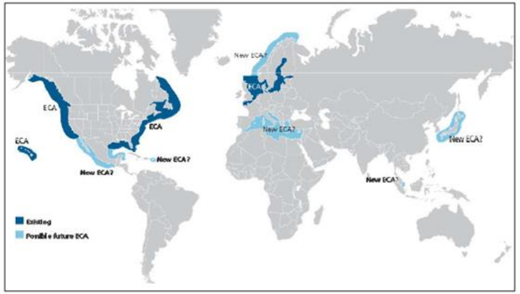
Traffic-Related Air Pollution and Dementia Incidence in Northern Sweden: A Longitudinal Study

Anna Oudin,[1] Bertil Forsberg,[1] Annelie Nordin Adolfsson,[2] Nina Lind,[3] Lars Modig,[1] Maria Nordin,[3] Steven Nordin,[3] Rolf Adolfsson,[2] and Lars-Göran Nilsson[4,5]

CONCLUSIONS: If the associations we observed are causal, then air pollution from traffic might be an important risk factor for vascular dementia and Alzheimer's disease.



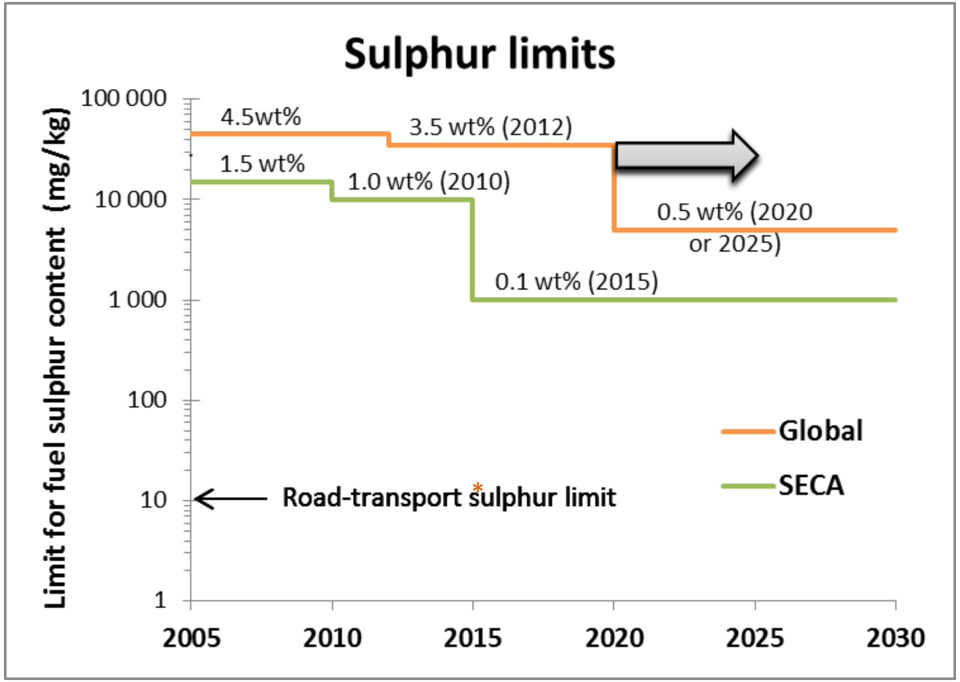
Existing and possible ECAs



IMO limits NO_x and SO_x (Marpol Annex VI)

Tighter limits in the **emission control areas (ECAs)**

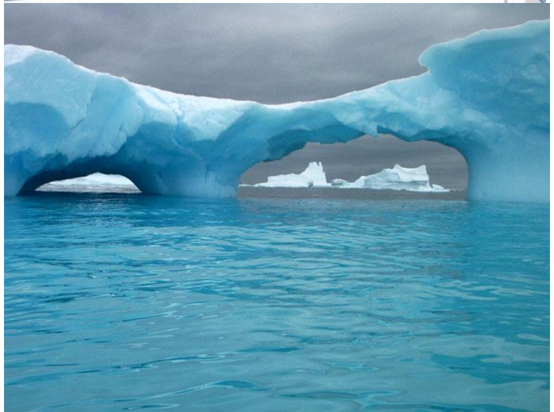
- **SO_x** the SECA of Baltic sea, North sea and English channel (since 2015).
- Global **fuel sulphur** limit 0.5 %S in 2020 or 2025
- Tier III **NO_x limits** for new builds in NECAs from 2016 (Tier II 2011 and Tier I 2000).



*) In many countries and regions

New emission limits anticipated

- The ship emissions anticipated to be regulated in the near future: **particulate matter (PM), particle number (PN) and black carbon (BC) and methane.**
- Black carbon (BC) warms the climate being the second strongest human climate forcing emission, surpassed only by CO_2 (Bond et al. 2013). Particularly important in the Arctic as deposits on snow and ice reduce the reflectivity.
- Furthermore, IMO's global 0.5% fuel sulphur content regulation in 2020 will reduce cooling feature (SO_x emission) of ship exhaust, while warming feature (BC emission) remains. (Sofiev et al. 2018),



Exhaust gas treatment

- SO_x scrubbers
- Selective Catalytic Reduction (SCR)
- Diesel oxidation catalysts
- Developing: PM reducing technologies e.g. particulate filters

Engine technology

- Size, speed, load
- Injection
- Low BC tuning & SCR
- EGR
- Hybrids/alternative powertrains

EMISSION CONTROL

Fuel technologies

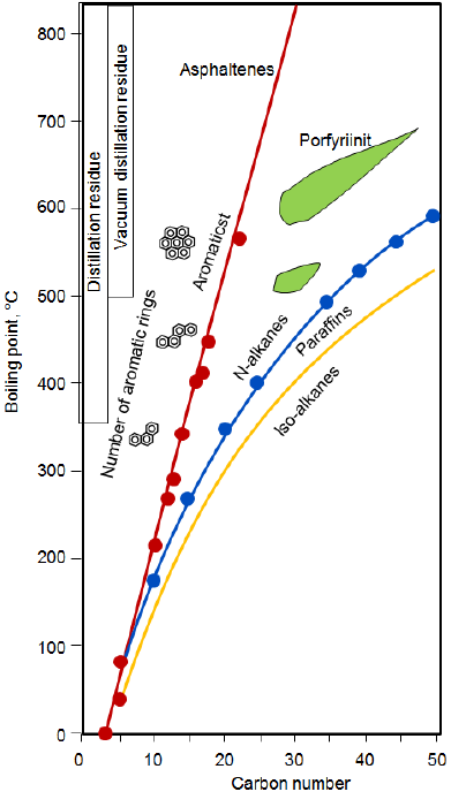
- Fossil distillate fuels, LNG, methanol
- Renewable fuels
  - Distillate-type fuels (e.g. HVO)
  - Vegetable oils and animal fats
  - Renewable methane (LNG-type)
  - Renewable methanol
  - Pyrolysis oil
  - Electro-fuels based on green hydrogen

(Fuel additives, e.g. WiFE)

Marine fuels in the Arctic and globally

Ship type (present)	Container ships, bulk carriers, oil tankers	Ferries, cruisers, RoRo, RoPax, passenger	Fishing vessels	
Engine type (present)	Mainly slow speed diesel (SSD), 2-stroke	Mainly medium speed diesel (MSD), 4-stroke	Mainly high-speed diesel (HSD)	**Total**
Marine fuel in the Arctic (geogr.)	Residual 1.63 mt Distillate 0.08 mt	Residual 0.63 mt Distillate 0.63 mt	Mainly distillates 2.4 mt	**5.4 mt (Winther 2017)**
Marine fuel in the Arctic (Polar code)	0.202 mt	0.045 mt	0.114 mt (other 0.075 mt)	**0.44 mt (Comer 2017)**
Marine fuel globally	**Residual 181 mt** Distillate 12 mt LNG 0.03 mt	Residual 26 mt Distillate 21 mt LNG 2.3 mt	Residual 0.5 mt Distillate 14 mt LNG 0 mt	**266.3 mt ~10% of transport fuels (Comer 2017)**
Comment on BC control using present fuels	Mainly residual fuels today → Challenging to reduce BC without fuel switch.	Appr. 50% of fuels distillates → PF option relevant. Also fuel switching needed.	Mostly distillates used → PF feasible. Also other options available.	

Marine fuels today are mostly a kind of heavy aromatic ”refinery residue”



From heavy residues to lighter liquids or gases

Photo: Koponen

Photo: Koponen

Photo: Piimäkorpi

Photo: Piimäkorpi

Marine fuels

Marine fuels in ISO 8217

- **Residual fuels** e.g., RMA, RMB) classified by viscosities (e.g., 10, 30, 80, 180, 380, 700).
- **Distillate fuels**
  - **DMA,** called marine gas oil, MGO, free from residual fuel. Category 1 (< 5 L/cylinder) engines.
  - **DMB,** marine diesel oil, MDO, traces of residual fuel. Category 2 (5-30 L/cyl) and 3 (≥ 30 L/cyl) engines.
- **Hybrid fuels** (<0.10%S) some fuel properties resemble residual fuels (Wright 2016).

Note: <0.1%S residual fuel may contain PAHs, heavy metals

Renewables (can technically replace their fossil counterparts)

- **Renewable liquid diesel-type fuels**
  - HVO, GTL, BTL, XTL
  - Vegetable oils and fats (FA) and their methyl esters (FAME)
- **Renewable methane**: similar to **LNG**.
- **Renewable methanol** e.g. retrofitting diesel engines.
- **Renewable hydrogen**.

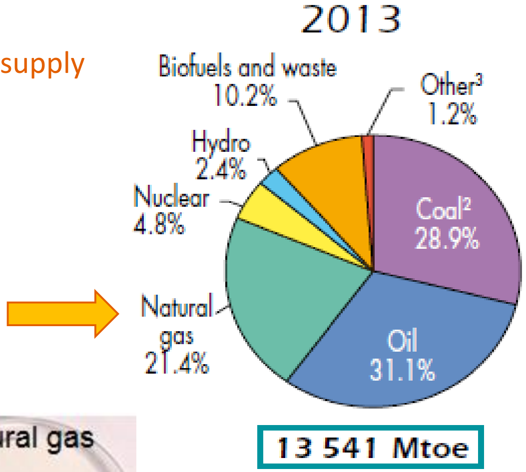
Note: renewable fuels typically don't have impurities, except some biofuels

LNG/renewable methane

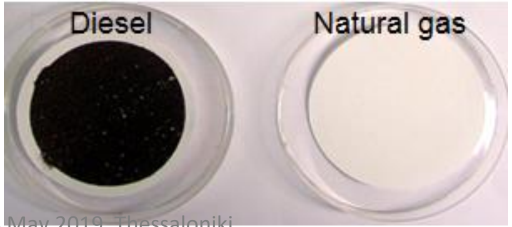
- Natural gas is available in **large-scale at low price, however, gas engines** and **new fuel infrastructure needed**.
- Dual fuel engine offers diesel as back-up fuel. LNG tank space = **4.2 x diesel tank space. LNG at -162 °C.**
- LNG gas burns with **clean, non-sooting flame**.
- Biomethane or renewable/synthetic methane offer low GHG emissions.

Photo: Courtesy of the Finnish Border Guard.

Total primary energy supply



Ref. IEA World Energy Statistics 2015.



Renewable fuels and methanol

- Marine biofuel from **oils and fats** already used, e.g. by Finnish Meriaura shipping company in EcoCoaster^{TM} . Generally, lower soot than when using diesel, but not much studied in shipping.
- **Paraffinic fuels** can be e.g. fossil GTL or renewable e.g. BTL, HVO. Generally, lower soot and NOx than with diesel in HD studies (not much studied in marine engines).
- **Methanol** (fossil or renewable) is used in otto engines (M85). Methanol is clean-burning, concerns on e.g. safety. Wärtsilä methanol-diesel retrofit used in Sweden by Stena line. Seven tankers use methanol in the MAN engines.

Burning of conventional diesel (left) and paraffinic diesel (right). Ref. ASFE

Pictures below: Marine Propulsion News, Stena Line

MERIAURA

VGMarine ECOFUEL™

MAN demonstrated the ME-LGI engine for the shipowners in 20

Selective Catalytic Reduction (SCR), commercial

- SCR is designed for NOx reduction. Study “FI-2”.

Diesel Oxidation Catalysts (DOC) not many in shipping

- DOCs are common in automotive diesel engines removing organic species in exhaust (also in PM). Study “FI-4”.

Particulate filters, not feasible for marine engines using challenging marine fuels

- Automotive DPFs not suitable when using marine fuels having high fuel sulphur and metals contents clogging filter pores. Also other technical concerns (filter size, back-pressure, regeneration, removal of ash, reliability and durability). Feasible for ships using clean distillate fuels.

Refs: Johansen, K. (2015), Køcks, M. et al. (2017), CIMAC (2012), Corbett et al. (2010), Mayer et al. (2011)

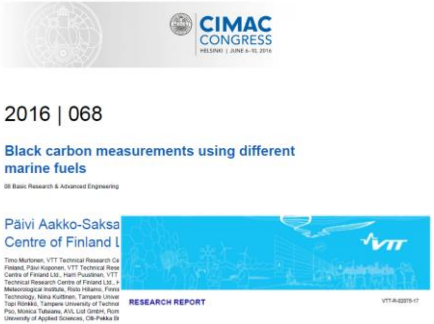
NMR results

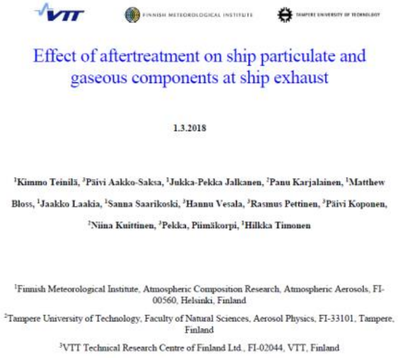
- Evaluation of data
- Results

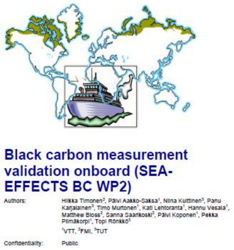
Recent ship emission measurement projects

- SEA-EFFECTS BC: laboratory (FI-1, WP1) and on-board measurements (FI-2, WP2) http://www.vtt.fi/sites/sea-effects
- EnviSuM: on-board measurements (FI-3) https://blogit.utu.fi/envisum/wp-content/uploads/sites/66/2018/06/EnviSumWP2ReportFMI.pdf

Measurements by VTT Technical Research Centre of Finland, Finnish Meteorological Institute (FMI), Tampere University (TAU)







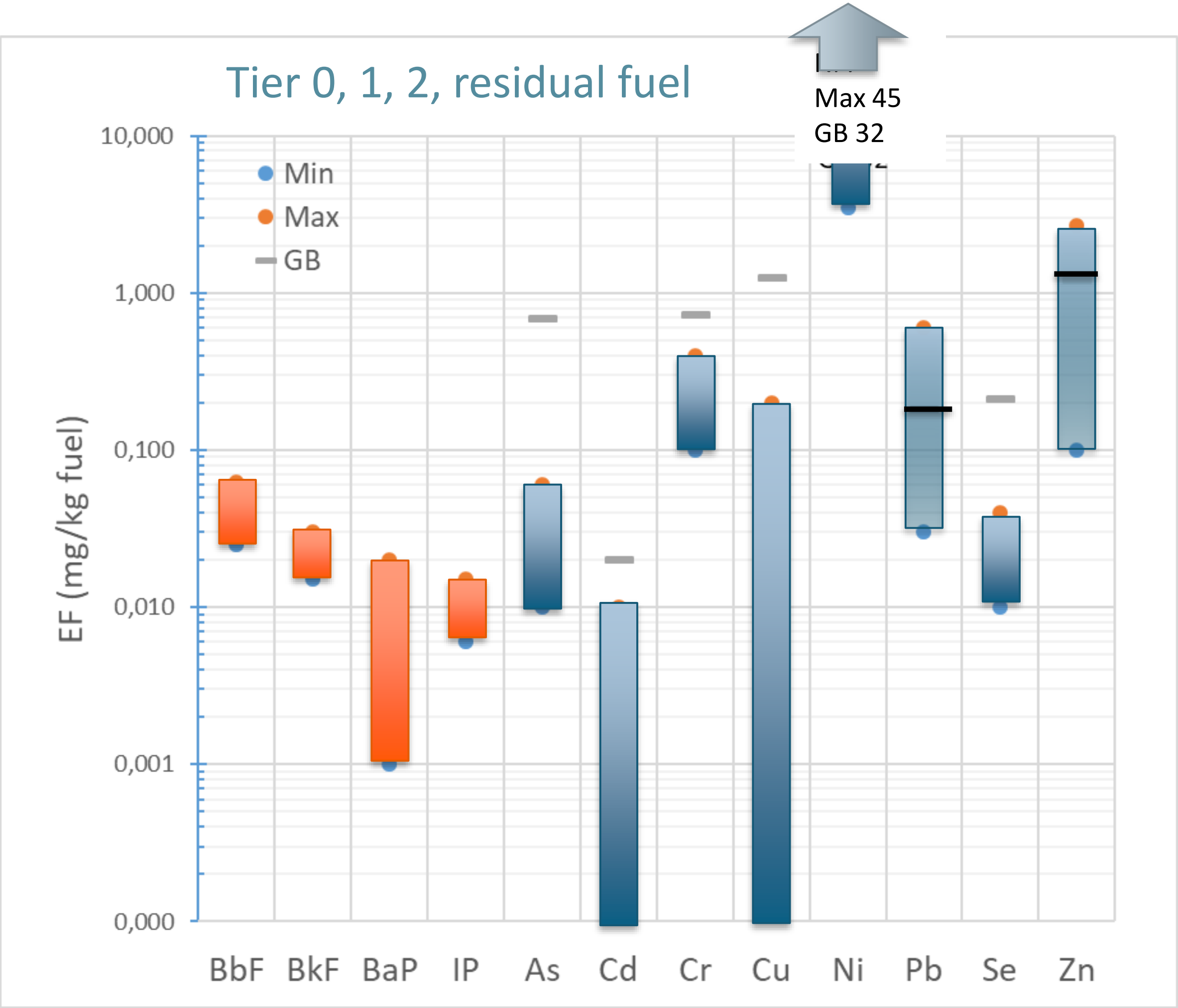
Interreg Baltic Sea Region
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Evaluation of data

Data evaluated for medium-speed (MSD) and slow-speed (SSD) diesel engines >1 MW. Three recent measurement campaigns in Finland with POP and HM measurements:

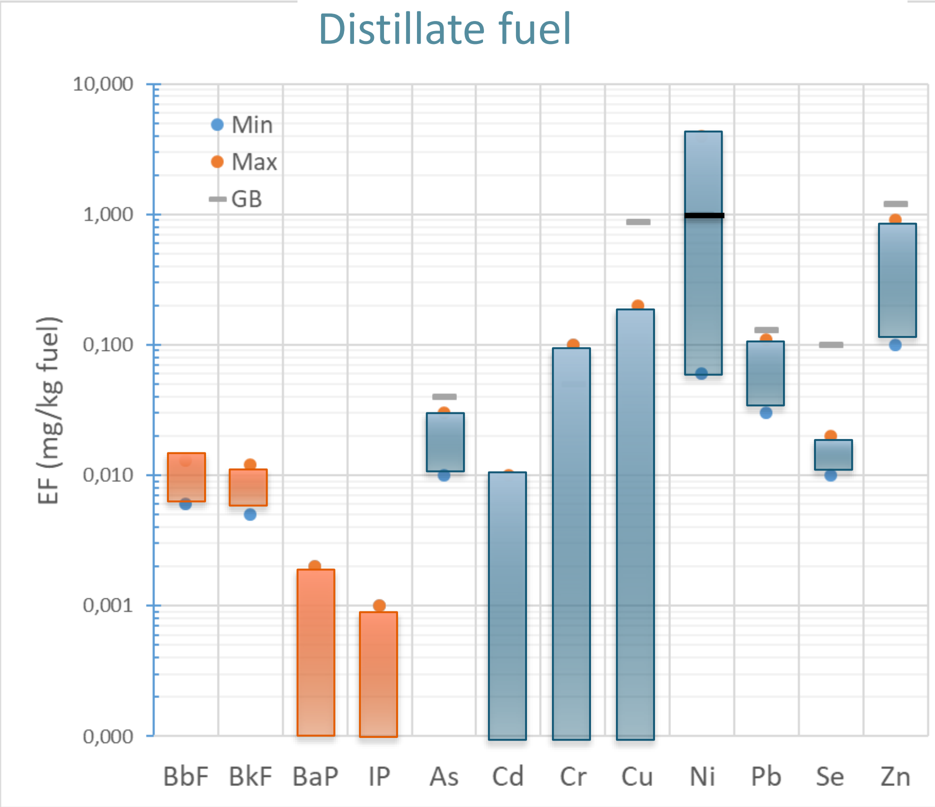
- **Laboratory testbed marine engine (MSD 1.6 MW);** at two engine loads (25% and 75%); using four fuels: bunker fuel (HFO), low-sulphur bunker fuel (0.5%S), distillate fuel MDO-DMB and a biofuel blend (Bio30). Ref. Aakko-Saksa et al. (2016, 2017):
- **On-board a modern cruise vessel, two engines**; bunker fuel (HFO 0.65%S) and limitedly MGO fuel; MSD 9.6 MW engine, before and after SOx scrubber and SCR; MSD 14.4 MW engine, before and after SOx scrubber. Ref. Timonen et al. (2017):
- **On-board a passenger ship (RoPax);** MSD 4-S engines, each 10.4 MW, diesel oxidation catalyst (DOC) and scrubber (ECO-DeSOx); using bunker fuel (HFO 1.9%S) and MGO during shorter period. Teinilä et al. (2018)

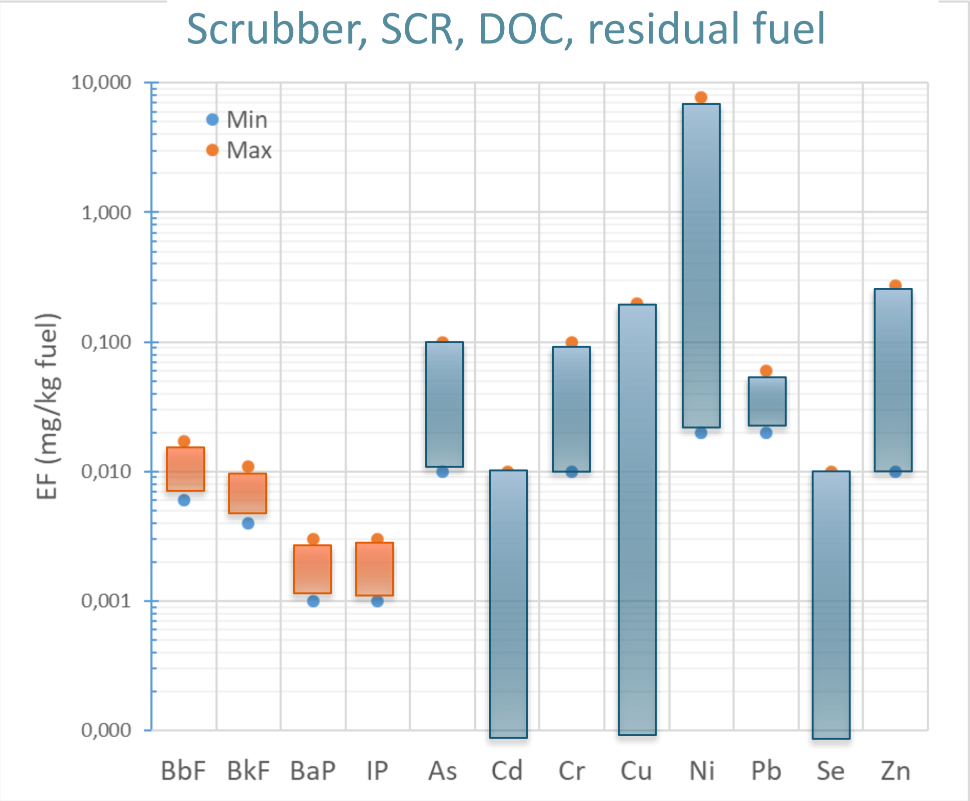
Comparison with the data presented in the Guidebook 2016 and in literature (e.g. Agrawal et al., 2008; Celo, Dabek-Zlotorzynska, & McCurdy, 2015; Fridell & Salo, 2016).



Ref. measurement campaigns FI-1, FI2-, FI-3 and Guidebook

Aakko-Saksa, TFEIP meeting 13 May 2019, Thessaloniki





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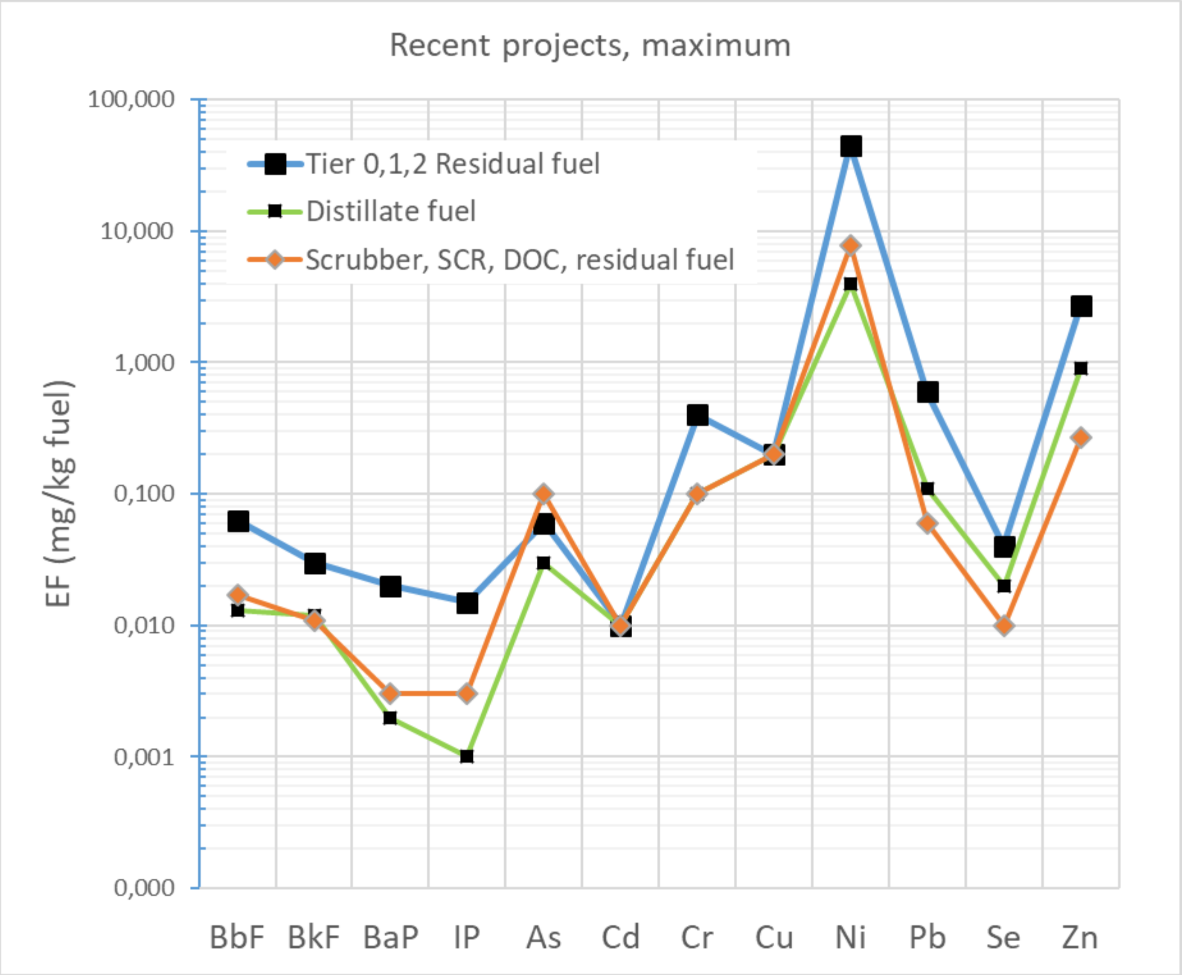

Ref. measurement campaigns FI-1, FI2-, FI-3 and Guidebook

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	Tier 0, 1, 2, Recent data [a, b, c] (old[e]) (mg/kg fuel)	Bunker fuel Guidebook[d] (mg/kg fuel)	Distillate or biofuel Recent data [a, b, c] (old[e]) (mg/kg fuel)	Guidebook[d] (mg/kg fuel)	Tier 1, 2 SOx scrubber, SCR or DOC [b, c] * (mg/kg fuel)
BbF	0.025-0.063 (0.004-0.06)	No data	0.006-0.013	No data	0.006-0.017
BkF	0.015-0.030 (0.005-0.07)	No data	0.005-0.012	No data	0.004-0.011
BaP	0.001-0.020 (0.005-1.8)	No data	0.002	No data	0.001-0.003
IP	0.006-0.015 (0.01-0.3)	No data	0.001	No data	0.001-0.003
As	**<0.01-0.06** (<0.01-0.05)	0.68	<0.01-0.03 (0.01)	0.04	<0.01-0.1
Cd	<0.01 (0.001-0.05)	0.02	<0.01 (0)	0.01	<0.01
Cr	<0.1; 0.4 (0.01-0.19)	0.72	<0.1; 0.1	0.05	<0.01; 0.1
Cu	**<0.2** (0.02-0.55)	1.25	**<0.2** (0.04)	0.88	<0.2
Ni	3.5-45 (12-48)	32	0.06; 0.2-4 (1)	1	<0.02-7.8
Pb	0.03-0.6 (0.03-0.3)	0.18	0.03-0.11 (0.01)	0.13	0.02-0.06
Se	**<0.01-0.04** (0.01-<0.05)	0.21	**<0.01-0.02** (0.001)	0.1	<0.01
Zn	<0.1-2.7 (0.5-3.5)	1.2	<0.1-0.9 (0.95)	1.2	<0.01-0.27

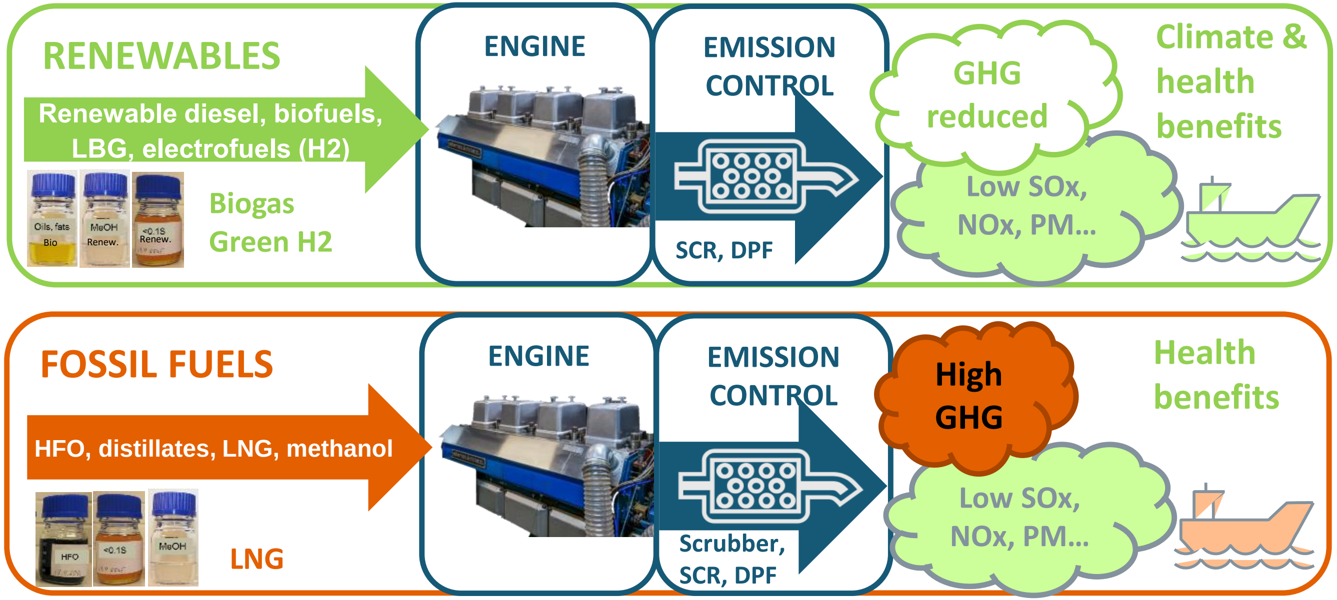
[a] Aakko-Saksa et al. (2016, 2017) [b] Timonen et al. 2018 [c] Teinilä et al 2018 [d] Guidebook (2016)
[e] (Agrawal et al., 2008; Celo, Dabek-Zlotorzynska, & McCurdy, 2015; Fridell & Salo, 2014)
*) Exhaust gas treatment devices depending on ship (SO_X scrubber, SCR or DOC).

Conclusions

- PAH EFs were evaluated from recent marine engine measurements
  - bunker “residual” fuel
  - distillate fuels
  - ships equipped with emission control devices using residual fuels
- PAH EFs for marine engines are not in the Guidebook.

- The HM EFs evaluated from recent programs were in most cases well in-line with the Guidebook. However, slightly lower EFs for As, Cu and Se than in Guidebook.

How to meet emission regulations and GHG reduction targets?



Renewable, clean fuels?
Exhaust treatment technologies?
Availability?
Affordability?

Note: Some emission control devices may set requirements for cleanliness of fuel

Fuel cells, batteries in the future

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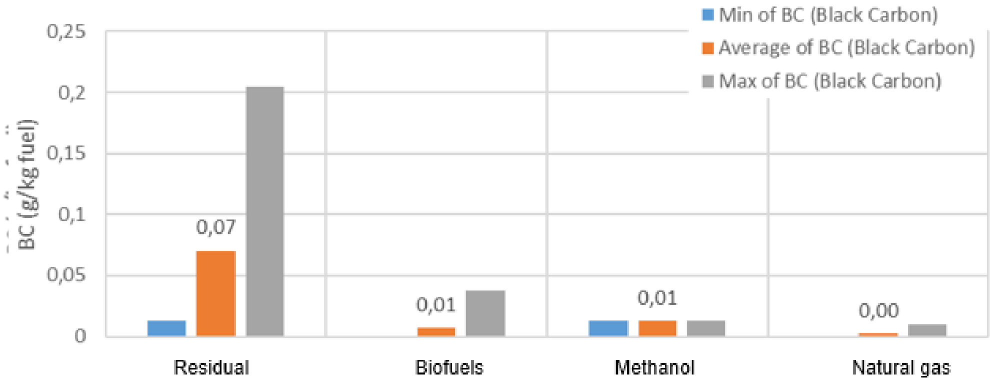
Ship emissions review in INTENS project


RESEARCH REPORT VTT-R-00335-19

Ship emissions in the future - review

Authors: Päivi Aakko-Saksa, Kati Lehtoranta

Confidentiality: Public



INTENS project website:
http://intens.vtt.fi/index.htm

INTENS

Black carbon (BC) emissions from marine engines (MSD and SSD). Engine loads >50% MCR. Example from a report of INTENS project.

Thank you

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paivi.aakko-saksa@vtt.fi