Ship Emissions and Health

Johannes Passig[1,2], Sebastian Öder[1,2], Julian Schade[1], Hendryk Czech[1,2], Thorsten Steibel[1,2], Ralf Zimmermann[1,2]

[1]University of Rostock, Germany
[2]Comprehensive Molecular Analytics, Helmholtz Zentrum München, Germany

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photonion

Motivation – Ship Emissions

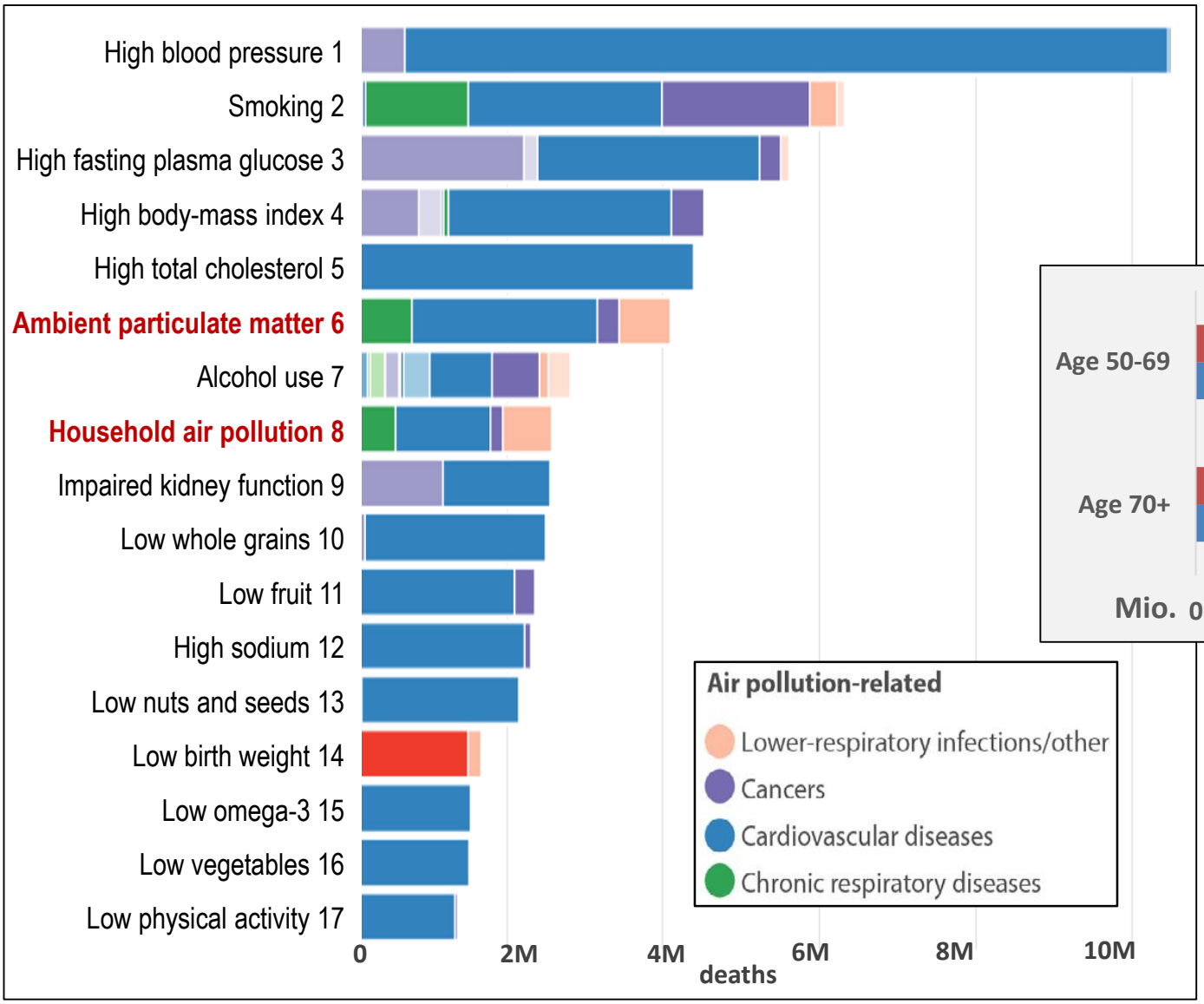
In the middle ages

OSTSEITE RATHAUS 1584

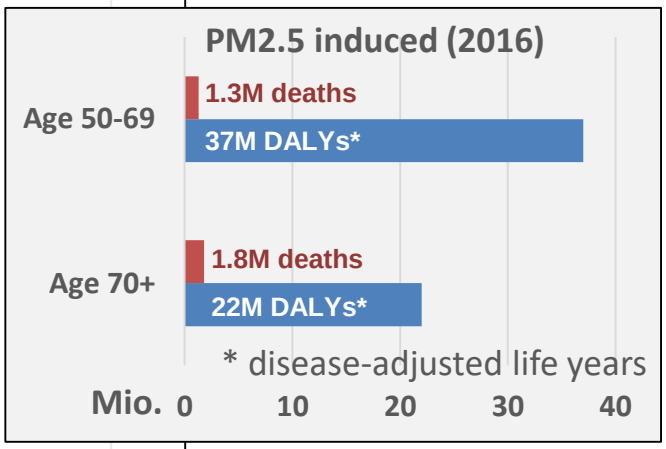
Detail of the
'Vicke-Schorler-Rolle',
V. Schorler, Rostock, 1578

Air Pollution is Among the Top-10 Causes of Death

Suspect Candidates



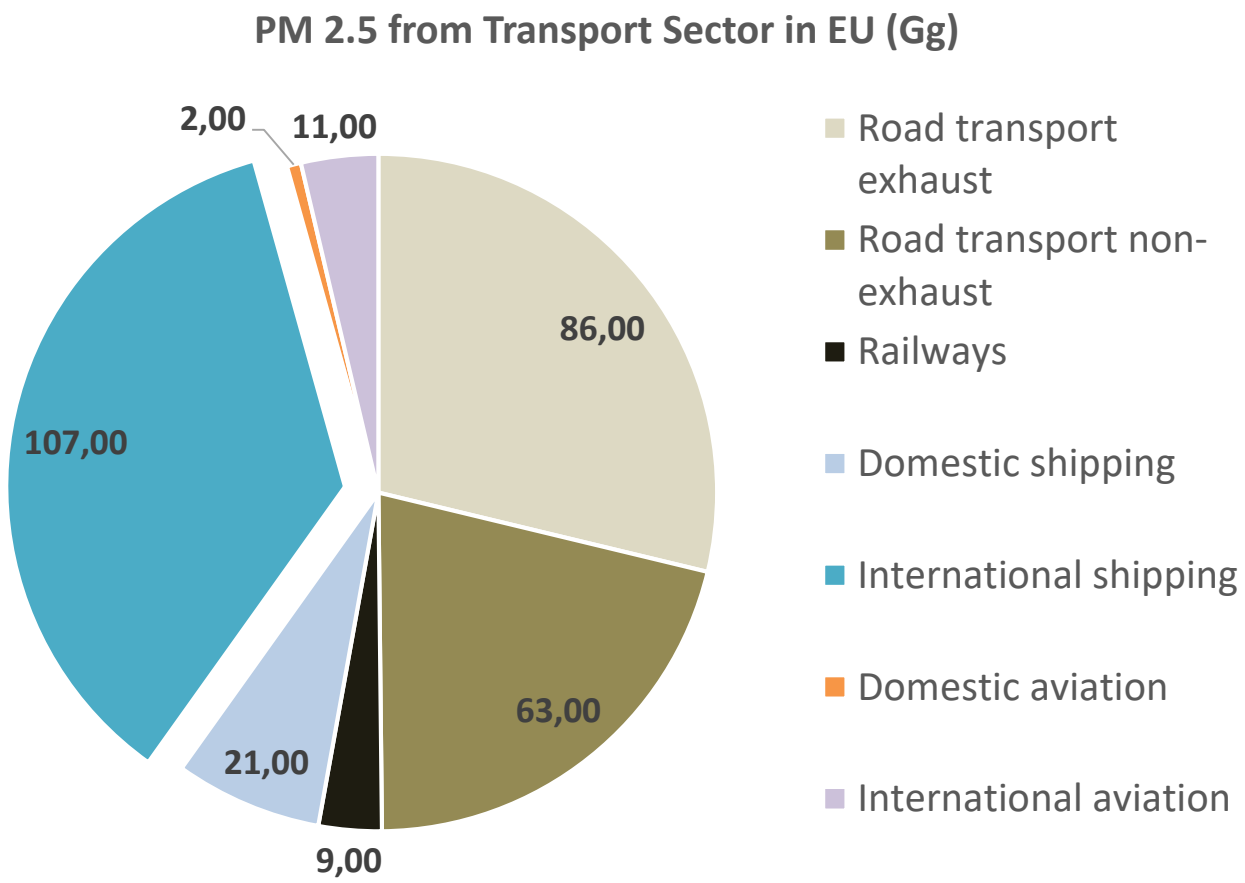
acute, short-term effects kill the most people (not the young and healthy ones)



source: Health Effects Institute. State of Global Air 2018. Report. Boston, MA

Motivation – Ship Emissions

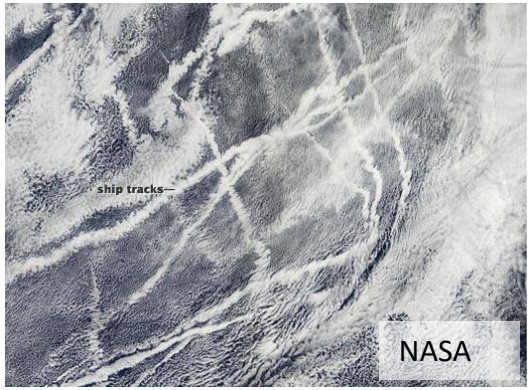
Impact on Health and Climate



data source: European Environment Agency, 2019

Motivation – Ship Emissions

Impact on Health and Climate



Ship Emissions

- 400,000 premature deaths from lung cancer and cardiovascular disease
  14 million childhood asthma cases annually
  Sofiev, M. et al. *Nat. Commun.* **9**, 406, (2018)
- comparable amount as land-based emissions
  Eyring V, et al. J. Geophys. Res-Atmos. **110**:D17305 (2005)
- strong climate impact
  Eyring, V. et al. *Atmos. Environ.* **44**, 4735–4771, (2010).
- if running on bunker fuels, large emissions of sulfur, metals, organics
  Streibel et al., Environ. Sci. Pollut. Res. Int. **24**(12) (2017)

further reading:

Corbett, J. J. et al. Mortality from ship emissions: a global assessment. *Environ. Sci. Technol.* **41**, 8512 (2007).

Liu, H. et al. Health and climate impacts of ocean-going vessels in East Asia. *Nat. Clim. Change* **6**, 1037–1041(2016).

Viana, M. et al. Impact of maritime transport emissions on coastal air quality in Europe. *Atmos. Environ.* **90**, 96-105, (2014).

Jalkanen, J. P. et al. A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area. *Atmos. Chem. Phys.* **9**, 9209–9223 (2009).

Eyring, V. et al. Multi-model simulations of the impact of international shipping on atmospheric chemistry and climate in 2000 and 2030. *Atmos. Chem. Phys.* **7**, 757–780 (2007).

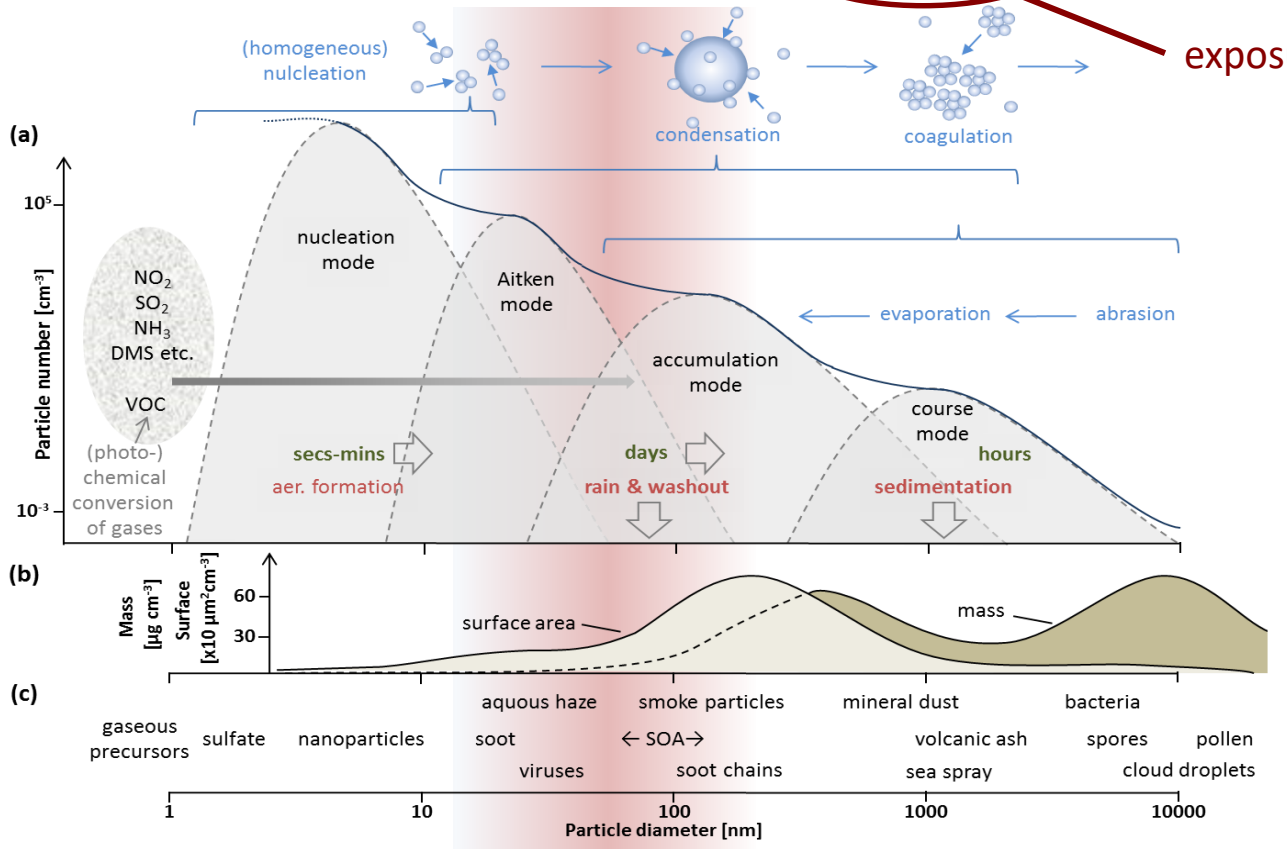
Lack, D. & Corbett, J. Black carbon from ships: a review of the effects of ship speed, fuel quality and exhaust gas scrubbing. *Atmos. Chem. Phys.* **12**, 3985–4000 (2012).

Ship Emissions

Gas Phase / Particle Phase

	gas phase	particulate phase
Substances	CO_2, NO_X, SO_2, volatile organics etc.	Elemental/Organic carbon (EC/OC), Metals, Sulphate
Lifetime	minutes	days
Travel Distance	0-1 km	10…1000 km

exposure!

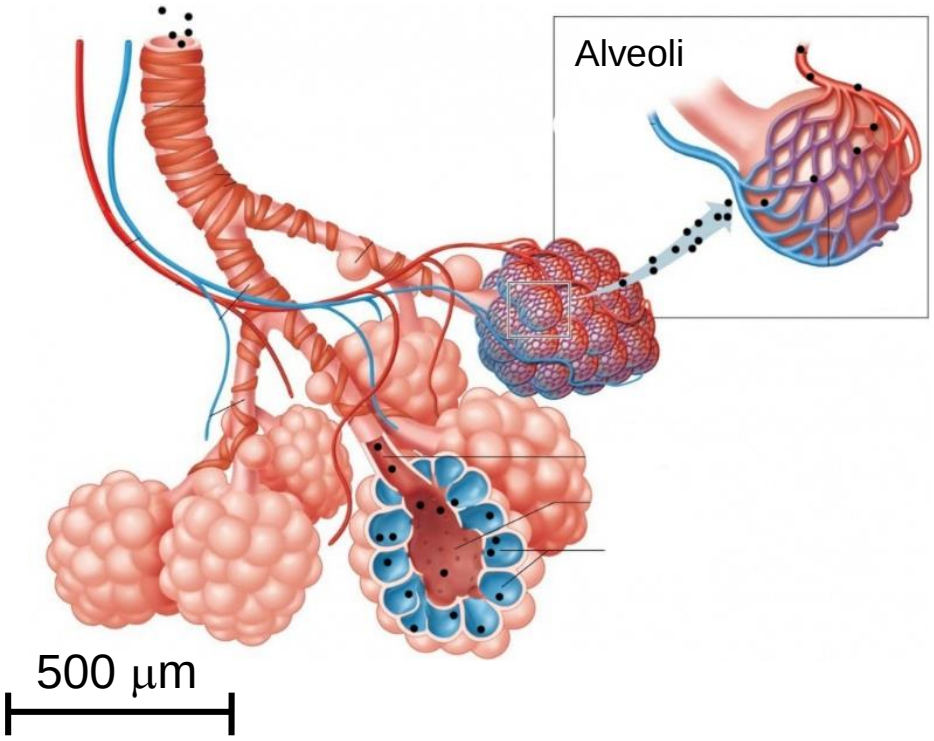


diesel/ship emission particles

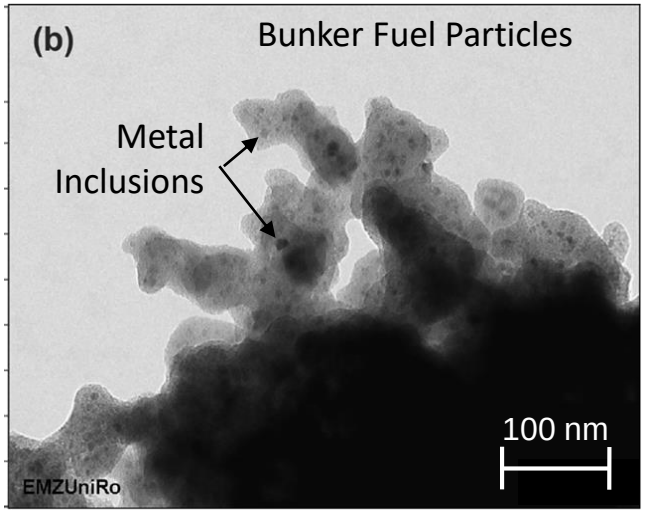
modified from:

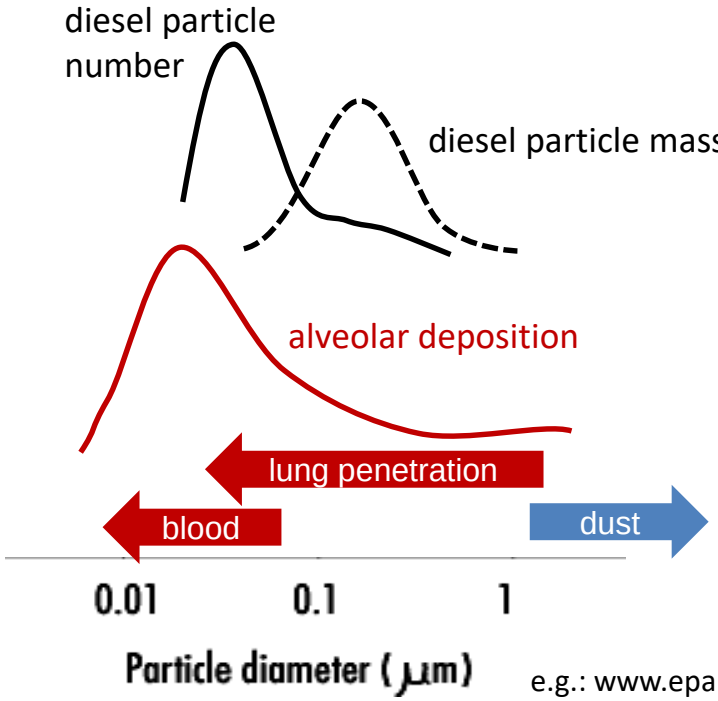
Buseck, P. R.; Adachi, K. (2008), *Elements* 4 (6), pp. 389–394.

Ship Emissions
Particle Morphology



Passig et al., submitted 2019

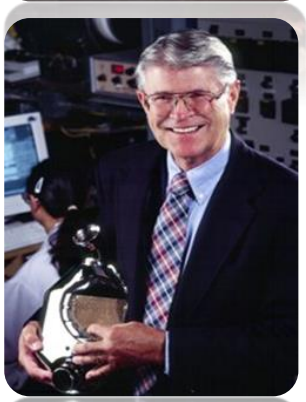




e.g.: www.epa.gov

Soot and Health: An Old Story

But a late Start of Action



- 1775: Percival Pott proves the correlation between cancer and soot at chimney sweeps scrotum
- 1928: Lawther proves correlation between traffic in London/Wales and lung cancer
- 1936: first assumption in the German journal “DUST” correlates diseases to particles < 1 µm
- 1959: OSH Convention in Johannesburg defines the submicron fraction which penetrates bronchi and alveoli
- 1978: John J. Mooney introduces aftertreatment for the petrol engine, the three way catalyst
- 1982: CARB introduces the first limit value for Diesel PM
- 1989: WHO declares Diesel exhaust probably carcinogenic
- 1993: Dough Dockery: Mortality due to PM2.5 quantified in the Six Cities Study USA 1978-1993

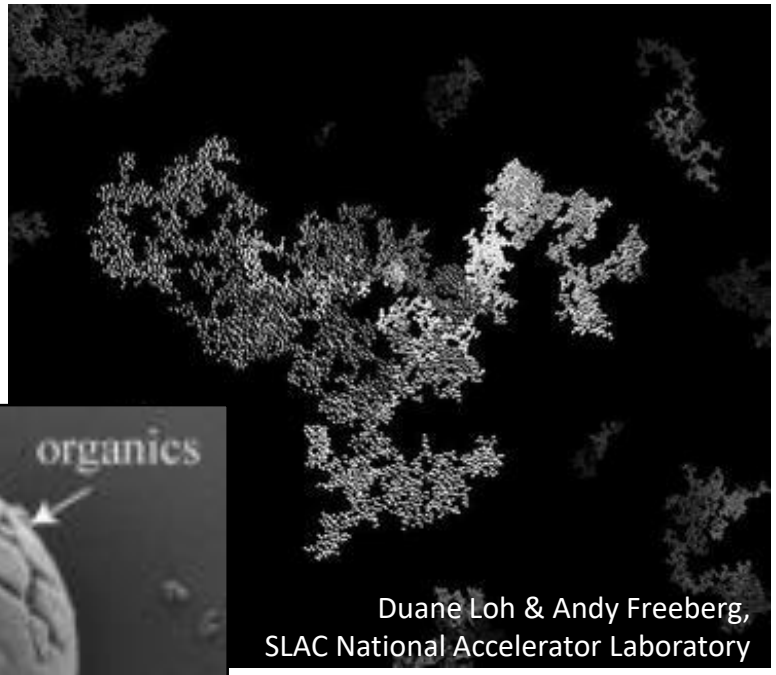
What are the Toxic Components?

Suspect Candidates

Carbon Cores ?

yes!

(deep lung penetration and inflammation)



Duane Loh & Andy Freeberg,
SLAC National Accelerator Laboratory

Organic Coatings?

sure!

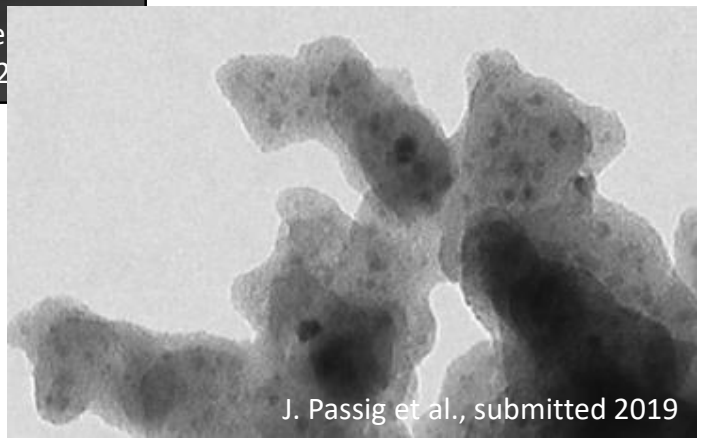
(carcinogenic PAHs)

W. Li., J. Che
Clean. Prod. 112

Metal Oxides?

of course!

(redox cycling activity)

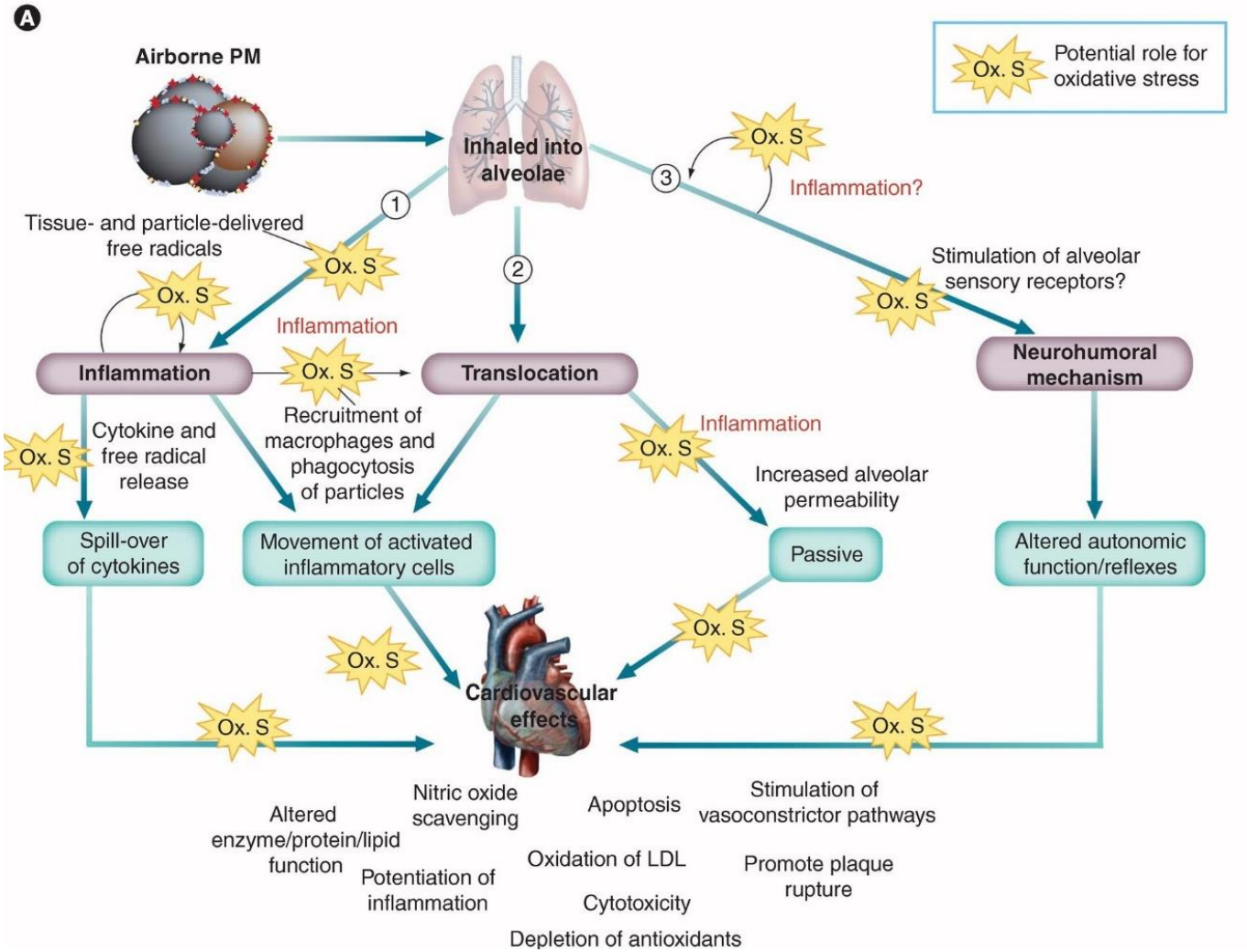


J. Passig et al., submitted 2019

Do we know the Mechanisms?

No! We are just beginning to learn.

Just an Example of the complexity of acute effects!

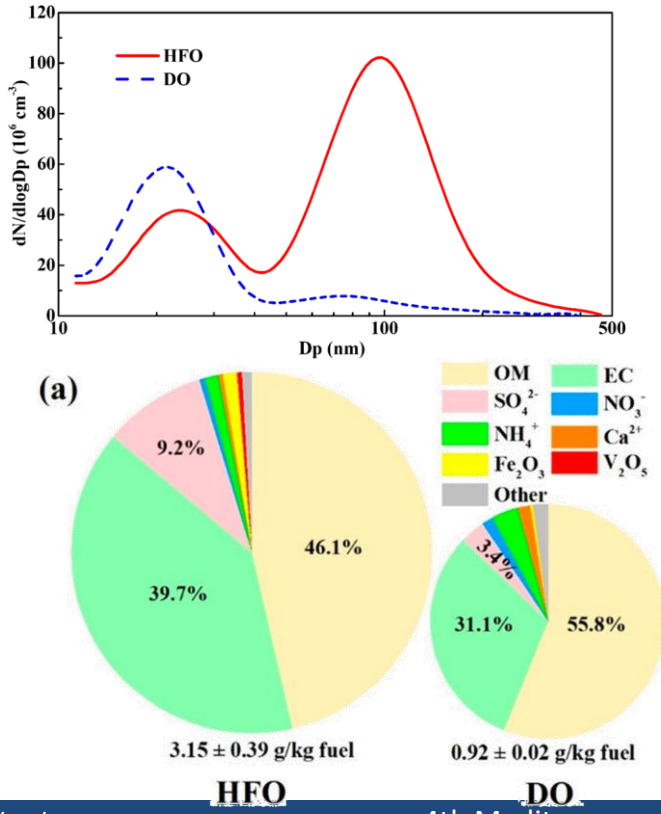


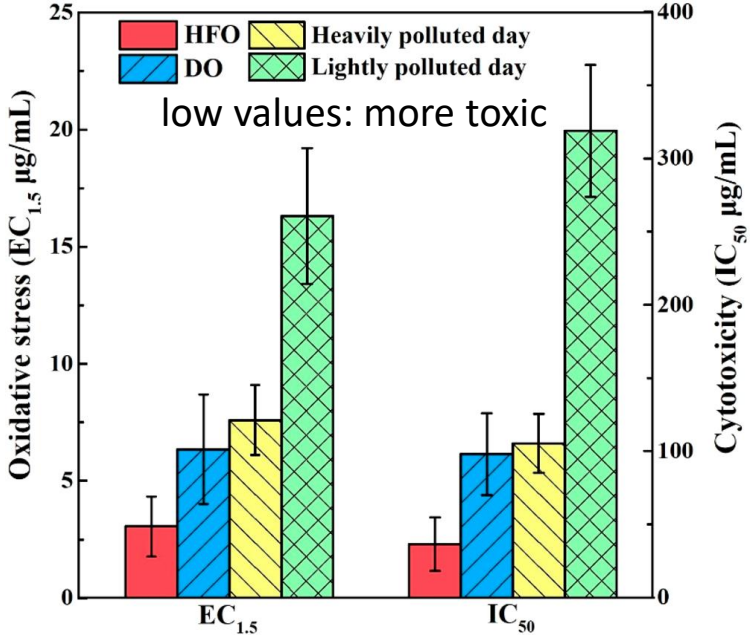
Miller MR, Shaw CA, Langrish JP. 2012, *Future Cardiology* 8(4):577-602

How to Reduce the Exposure Risks?

Role of the Fuel Type

Toxic Element	Heavy Fuel Oil („bunker fuels“)	Distillate Fuels (MDO, MGO etc.)
Soot Cores (Elemental Carbon)	↑↑	↑↑
Organic Matter and Carcinogenic PAHs	↑↑	↑
Metals	↑↑	-
Health Effects		
Acute (e.g. Inflammation)	↑↑	↑↑
Long-term (e.g. cancer, COPD, asthma)	↑↑	↑



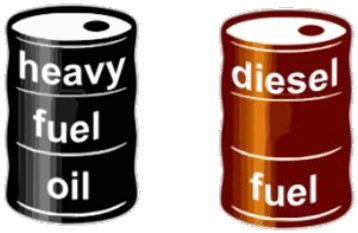


Study on a Container Ship in Shanghai, submersed Exposure of A549 lung cell lines

D. Wu et al., *Environ. Sci. Technol.* 52, 12943−12951 (2018)

Heavy Fuel Oils vs. Diesel Oil

A slightly different picture



Realistic exposure of cells in Air-Liquid-Interface

Effect	HFO	DF
Inflammation	↑	-
Oxidative Stress	↑	-
Cell homeostasis	↑	-
Response to chemicals	↑	↓↑
Cellular stress response	↑	↑
Motility	↑	↑
Endocytosis	↑	↑
Energy metabolism	-	↑
Protein synthesis	-	↓
Protein degradation	-	↑
RNA metabolism	-	↓
Chromatin modifications	-	↑

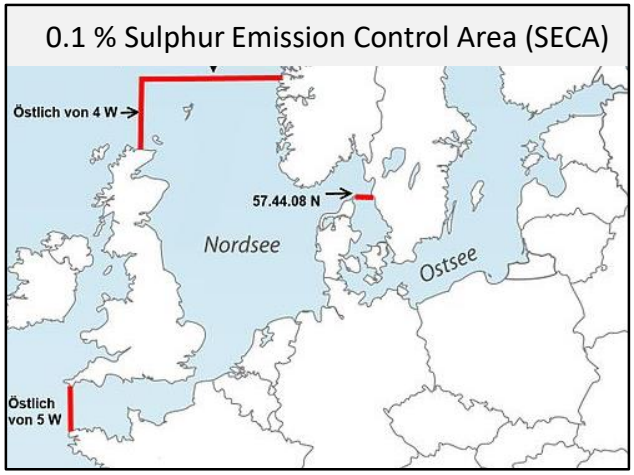
HICE › Aerosols and Health
Helmholtz Virtual Institute of Complex Molecular Systems in Environmental Health

aeroHEALTH
HELMHOLTZ
International Lab

Öder et al., *PLoS one*, 2015
Sapcariu et al., *PLoS one*, 2016
Kanashaova et al., *Anal. Bioanal. Chem*, 2016
Streibel et al. *Environ Sci. Poll. Res.*, 2017

How to Reduce the Exposure Risks?

The SECA Zones and Health



Sofiev, M. et al. *Nat. Commun.* **9**, 406, (2018) :
Global 0.5% S Cap → 30..50 % reduction in premature mortality and morbidity

But the health benefits depend on the fuel types used!

Toxic Element	Heavy Fuel Oil („bunker fuels“) → desulphurized („hybrid fuels“) <0.5% S ??	Distillate Fuels (MDO, MGO etc.) ??
Soot Cores (Elemental Carbon)	↑↑	↑↑
Organic Matter and Carcinogenic PAHs	↑↑	↑
Metals	↑↑	-
Health Effects		
Acute (e.g. Inflammation)	↑↑	↑↑
Long-term (e.g. cancer, COPD, asthma)	↑↑	↑

*L. Johansson et al., *Atmos. Environ.* 167, 403-415 (2017)

Exhaust Cleaning

The „Own Goals" of the Shipping Industry

>90% removal of sulphur

~30…50% reduction in PM 2.5

open loop systems banned in e.g. Singapore 2019!

Toxic Element	Heavy Fuel Oil („bunker fuels")		Distillate Fuels (MDO, MGO etc.)
	without cleaning	with scrubber	
Soot Cores (Elemental Carbon)	↑↑	↑	↑↑
Organic Matter and Carcinogenic PAHs	↑↑	↑	↑
Metals	↑↑	↑	-
Health Effects			
Acute (e.g. Inflammation)	↑↑	↑(↑)	↑↑
Long-term (e.g. cancer, COPD, asthma)	↑↑	↑(↑)	↑

highly recommended:
Hulda Winnes et al., Closing the Loop, report, IVL Miljöinstitut, 2019

But where is the rest?

„open loop"

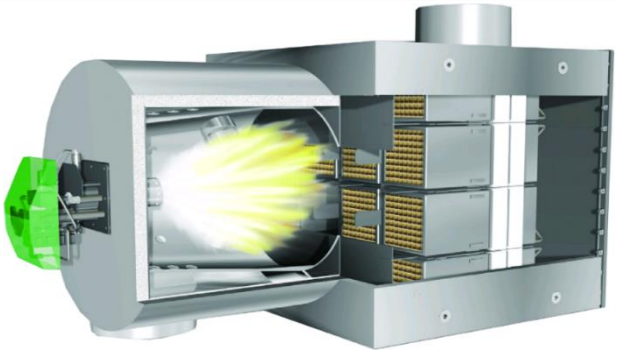
strong effects on marine life!

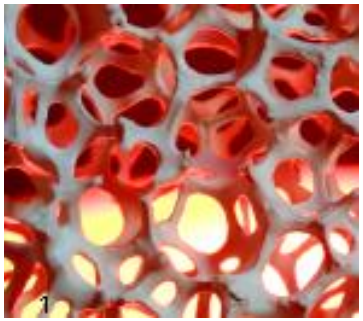
„closed loop"

requires land-based waste management

Diesel Particle Filters

The Highly Desired Technology





www.vert-dpf.eu
P. Lauer, ETH-NPC 2012

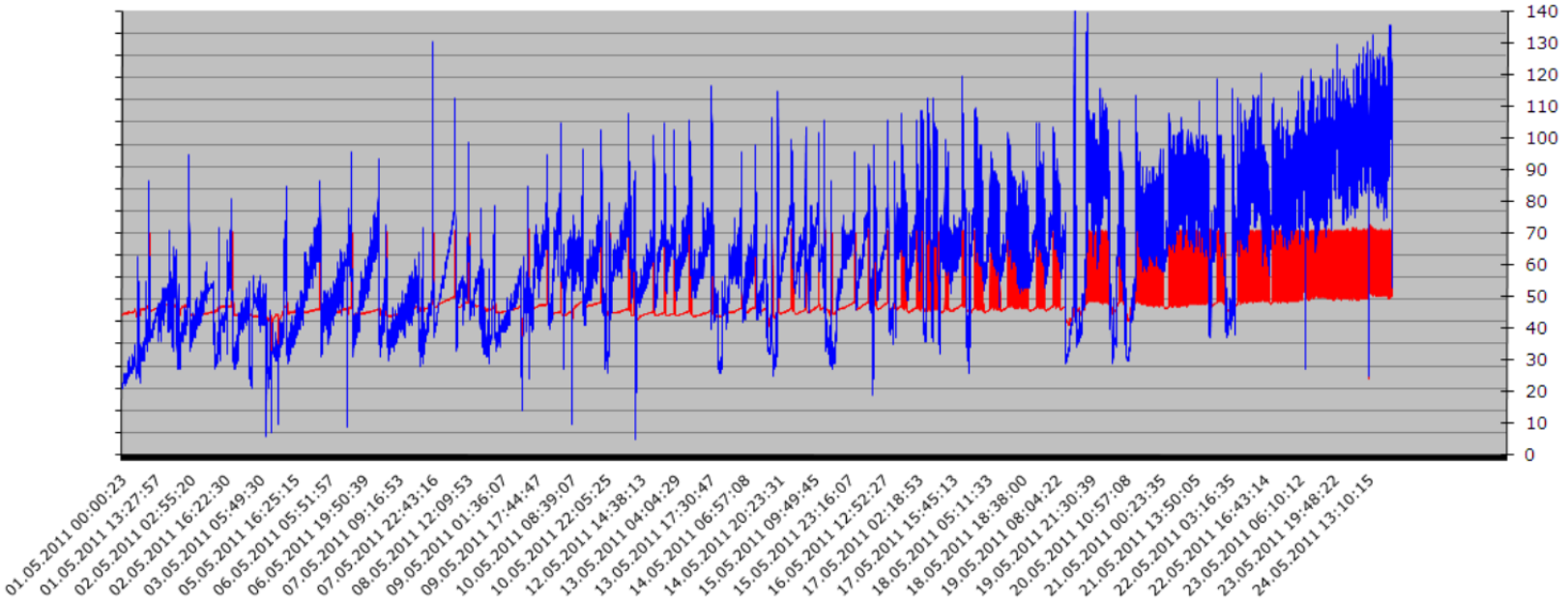
Diesel particle filters can safely remove PM2.5

Why not in ships?

→BACKPRESSURE DEVELOPMENT

Irreversible due to high ash content

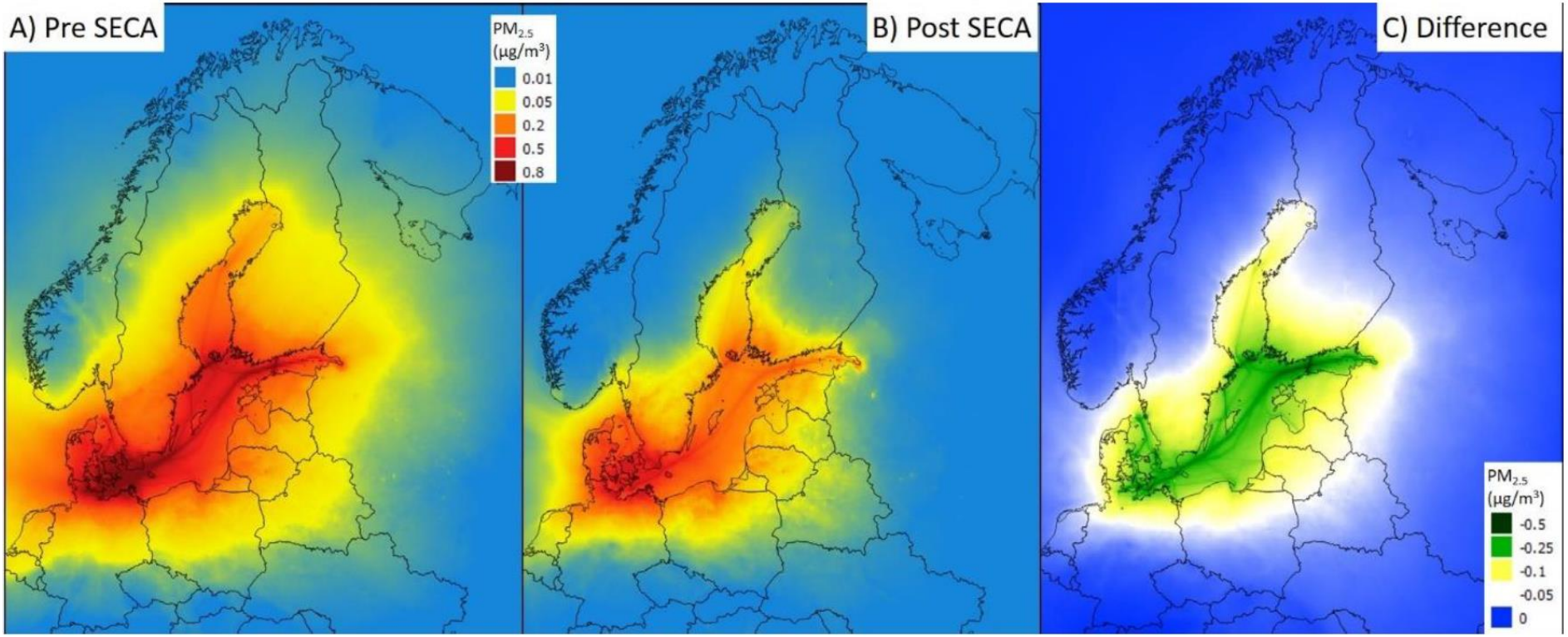
→Fuel Quality is limiting!



Lessons from SECA in Baltic Sea

A substantial difference

in the North/Baltic Sea:
- SECA-compliance >95%
- few srcubber systems
- **most ships on MDO/MGO**



L. Barregard et al., *Int. J. Environ. Res. Public Health* 16(11), 2019

PM2.5 reduction by SECA lead to
- Annual Premature Deaths : -1000 (-37%)
- non-fatal stroke and heart attacks: -1000 (-30%)
- years of life lost: 17,000–38,000 → 11,000–25,000

Implications for the Mediterranean

A 0.1 % SECA remains highly desired from the health perspective!

The 2020 GLOBAL 0.5% Cap

- High uncertainty on the fuels
- low-quality desulphurized (LSFO)-fuels will play a key role
- higher-quality MDO/MGO usage uncertain
- scrubbers uncertain

→

- small health benefits
- possible increase in carcinogenic PAHs by high-aromatic blends

A Mediterranean 0.1% SECA

- higher-quality MDO/MGO will dominate (see Baltic Sea)
- same fuel as North/Baltic → high compliance
- few scrubbers

→

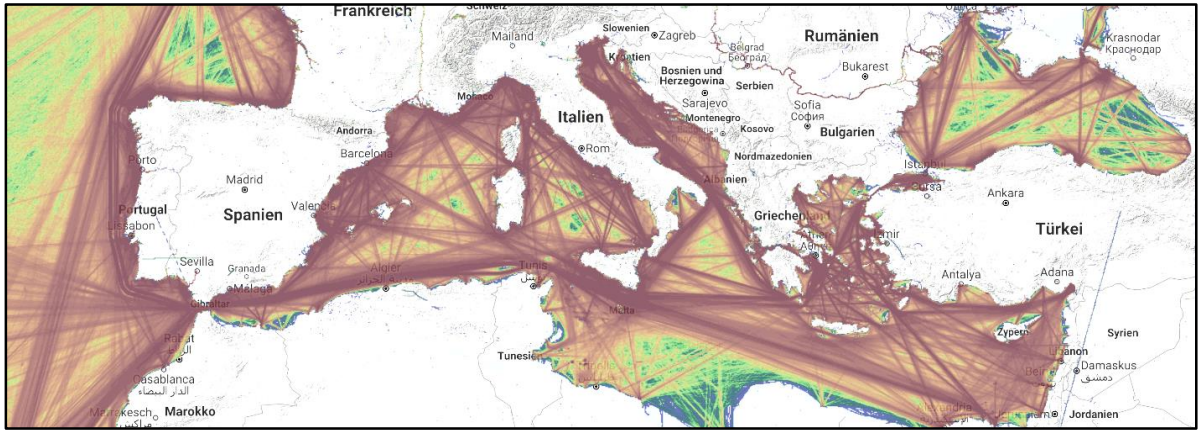
- substantial health benefits
- many 1000s reduction in mortality and morbidity
- comparable situation to North Sea/Baltic

Future Particle Filter Solutions

- more realistic for high-quality fuels
- optimum PM2.5 reduction

→

- optimum health and environ. benefits
- substantial reduction in mortality and morbidity from shipping



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Our Responsibility

Protect the Environment and Human Health

Thank You!

Your Job: Improve the policy

Our Job: Improve the scientific basis

- global and regional air pollution modelling
- epidemiology
- unraveling the health effects
- improved measurement techniques
- on-line monitoring and surveillance