Future Fuels for Shipping; Emissions and Socio-Economic Benefits

Erik Fridell

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SVENSKA MILJÖINSTITUTET

Research and consultancy by
IVL Swedish Environmental Research Institute

- around 230 employees
- engineers, economists, social scientists, geoscientists, chemists, biologists, agriculturalists, communicators etc.

Independent

- owned by a foundation (SIVL) in which both the Government and commercial life are represented on the Board

Accredited laboratories

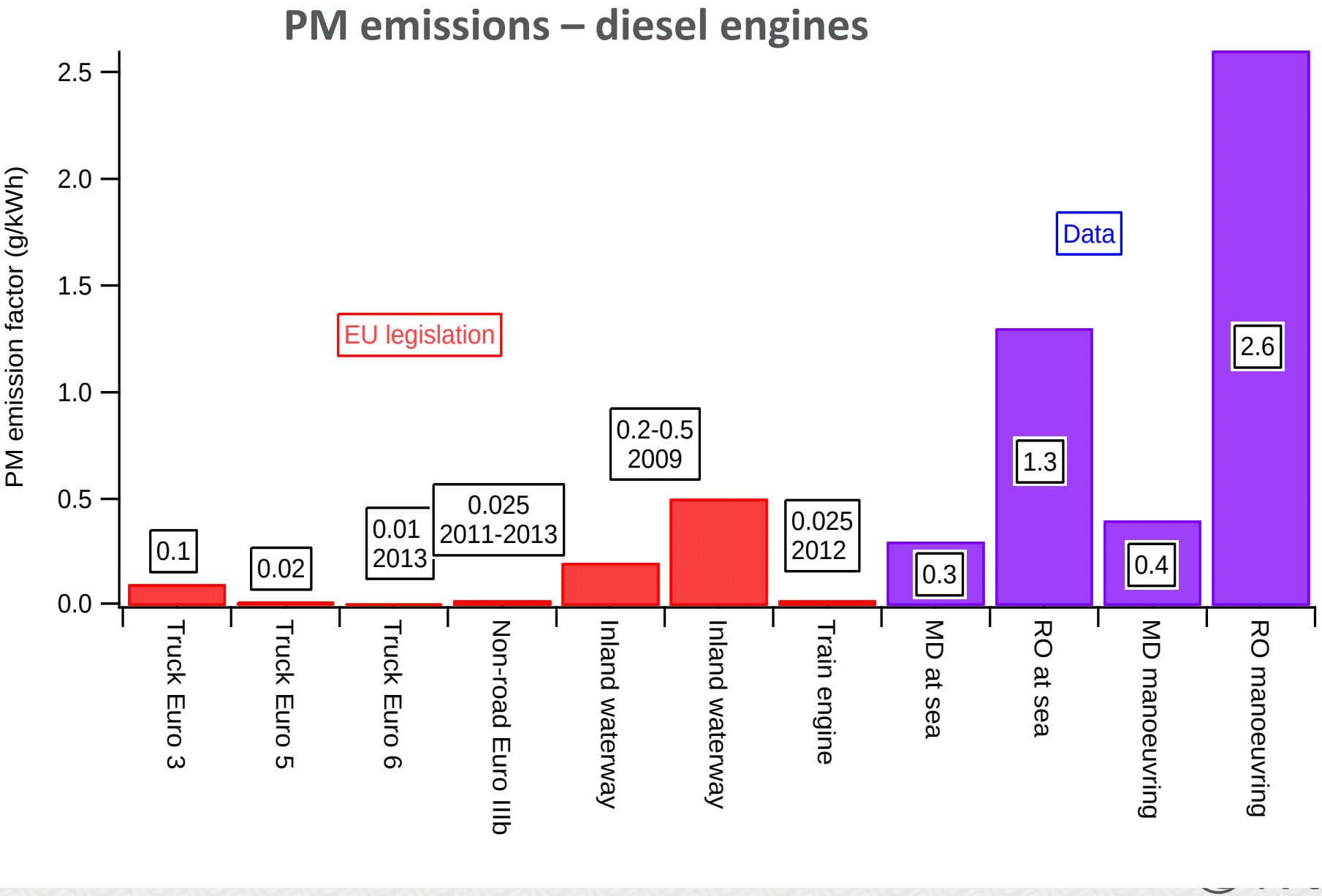
More than 40 years' experience

– In continuous development since 1966

– **Marine emissions measurements since 1989**

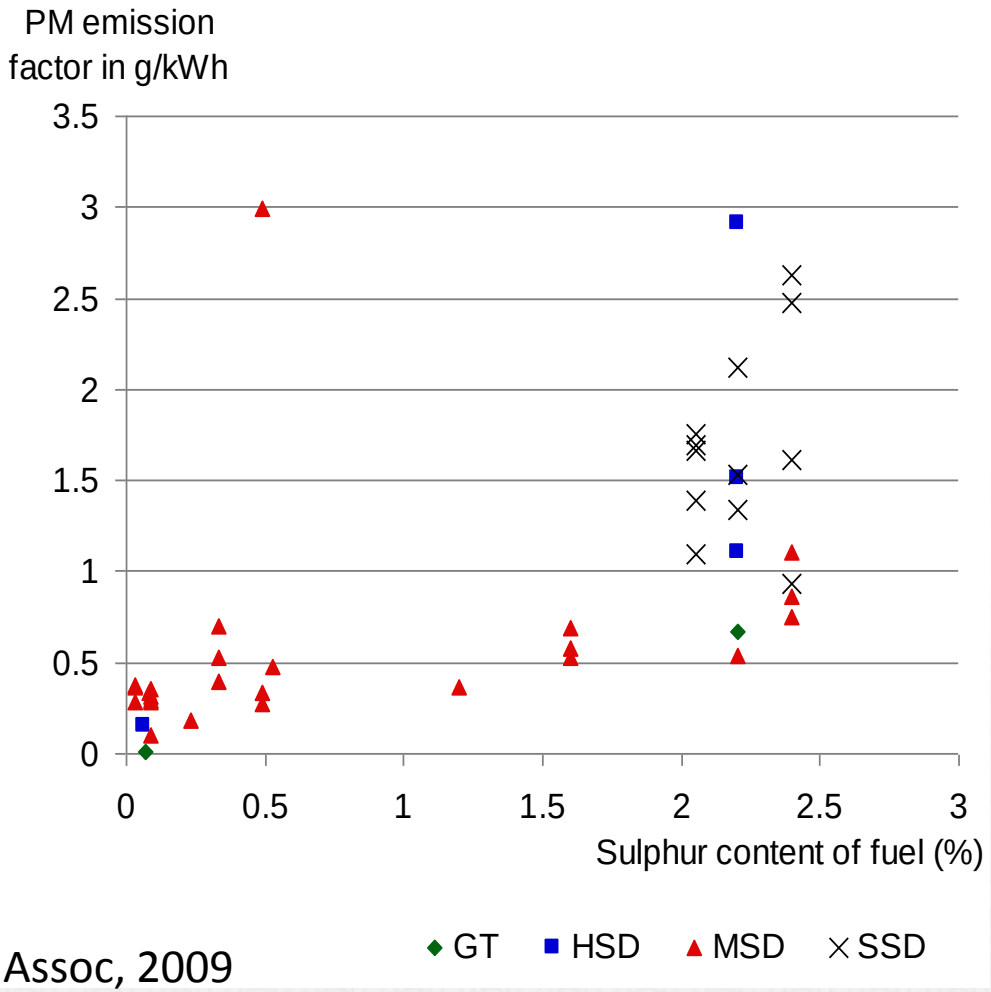
IVL work on shipping

- Onboard measurements for NO_X certificates and research (mostly PM)
- Emission factors, inventories, emission reporting including prognoses
- Dispersion modeling and atmospheric chemistry
- Cost-benefit analyses for abatement equipment, fuel
- External cost modeling
- Life-cycle assessments
- Research on abatement methods
- Teaching and development of educational material (NMU, KnowME)


PM emissions – diesel engines
PM emission factor (g/kWh)
2.5
2.0
1.5
1.0
0.5
0.0
EU legislation
Data
0.1
0.02
0.01
2013
0.025
2011-2013
0.2-0.5
2009
0.025
2012
0.3
1.3
0.4
2.6
Truck Euro 3
Truck Euro 5
Truck Euro 6
Non-road Euro IIIb
Inland waterway
Inland waterway
Train engine
MD at sea
RO at sea
MD manoeuvring
RO manoeuvring

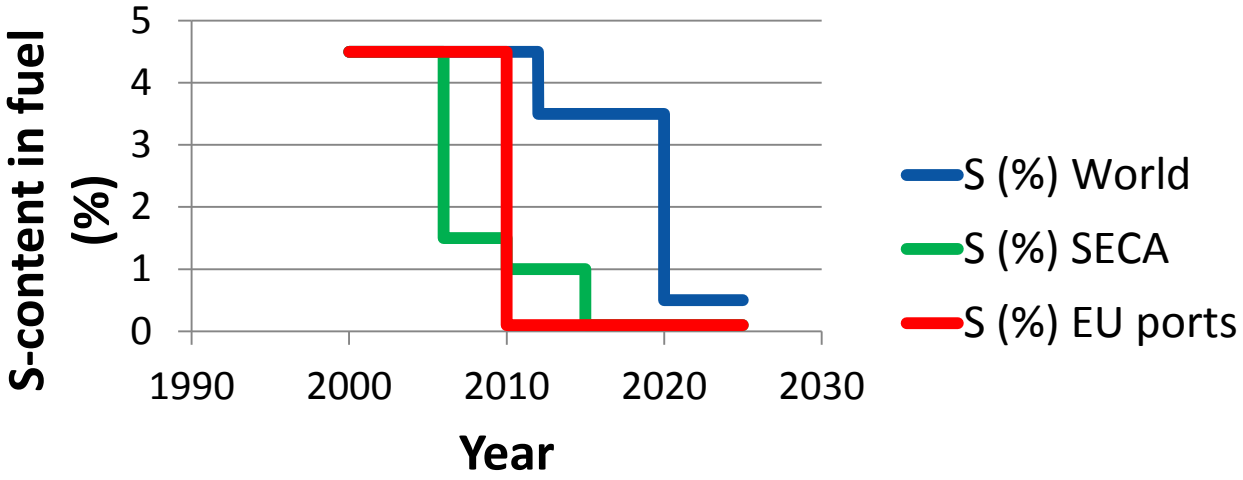
Sulphur in fuel => Particle emission

PM formation vs fuel sulphur



Winnes and Fridell, J. Air & Waste Man Assoc, 2009

Regulations, sulphur



How to comply?

- Low-sulphur fuel
- Scrubbers
- LNG

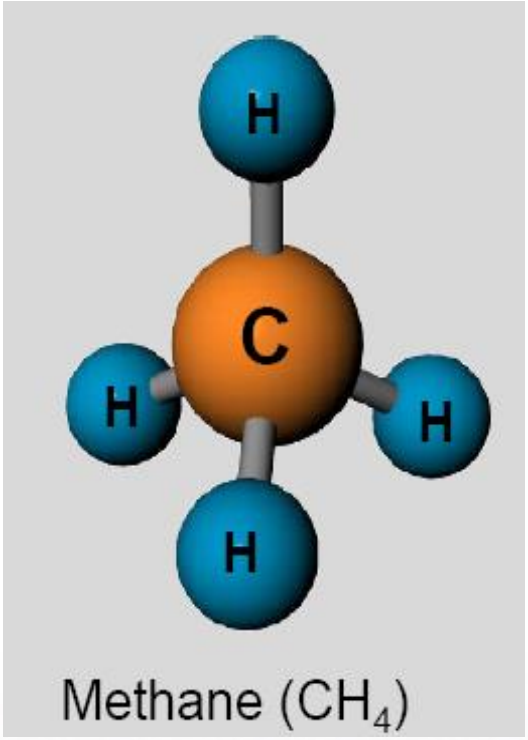
LNG (liquified natural gas)

Natural gas cooled to 127 K and liquified (600 times lower volume)

LNG transport ships use the evaporating gas as fuel

Engines can use biogas

Lower emissions: CO_2 down 25%, NO_X down 85%, SO_2 and Particles very low



Methane (CH_4)

- Size of fuel tanks
- NOx emissions (Tier IV?)
- Methane slip, CO_2
- Supply

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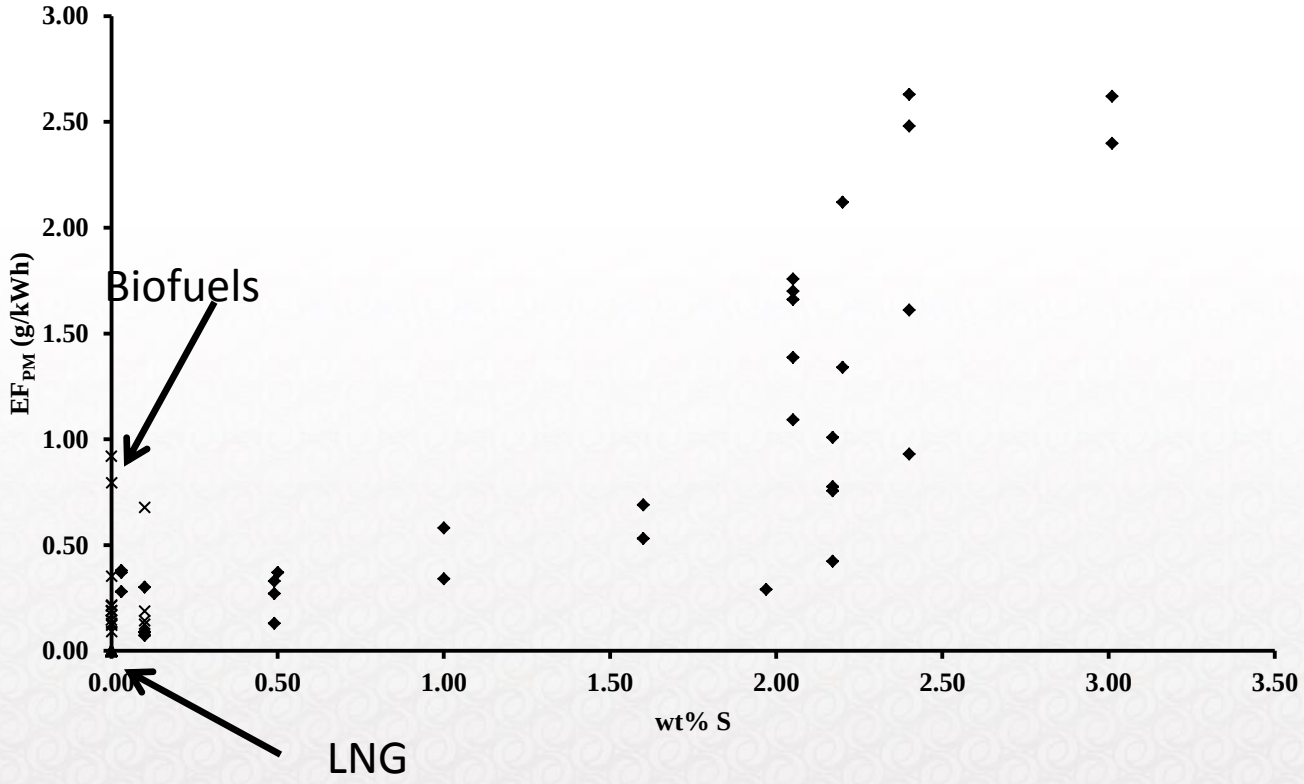
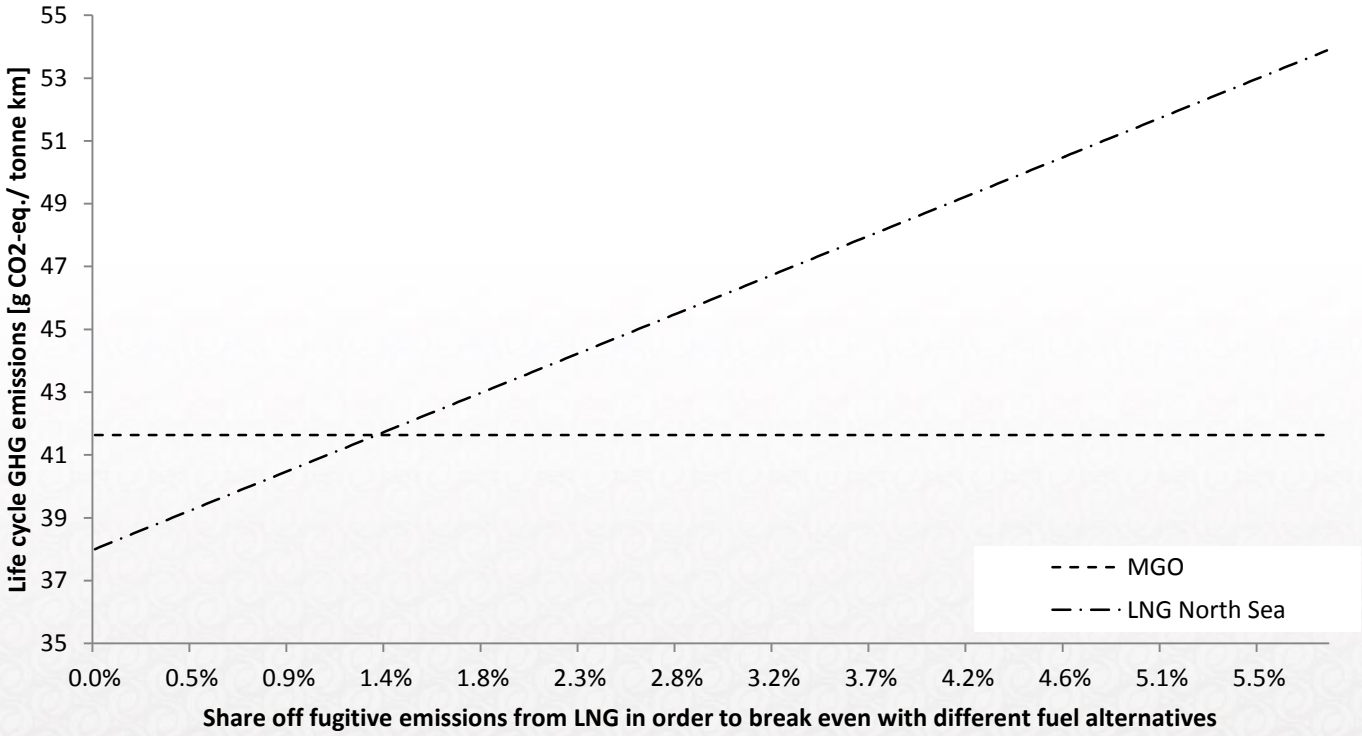


Anderson, Salo and Fridell, Env. Sci Tech 2015

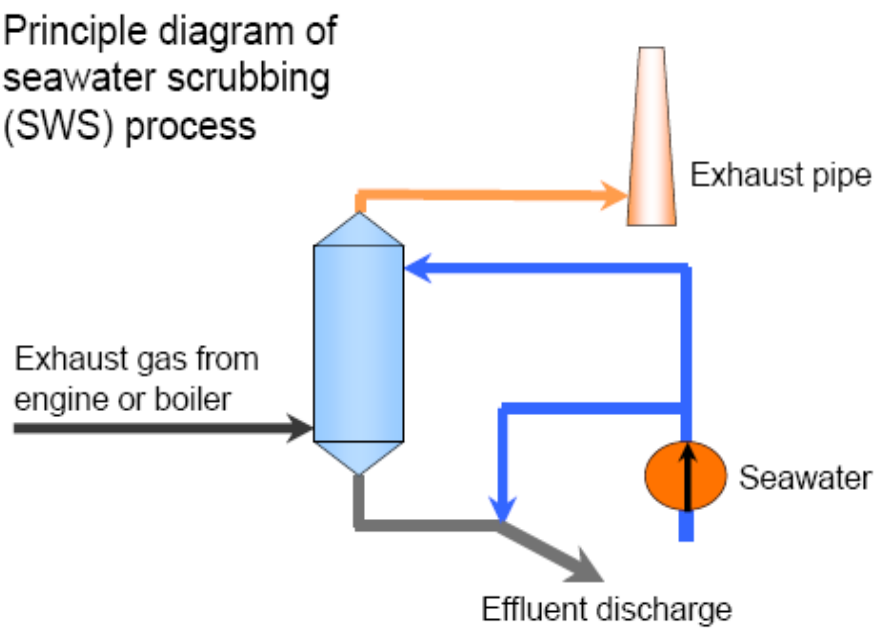
Methane -slip



Selma Bengtsson et al, 2010

Scrubbers

Sulphur removal from exhaust gas

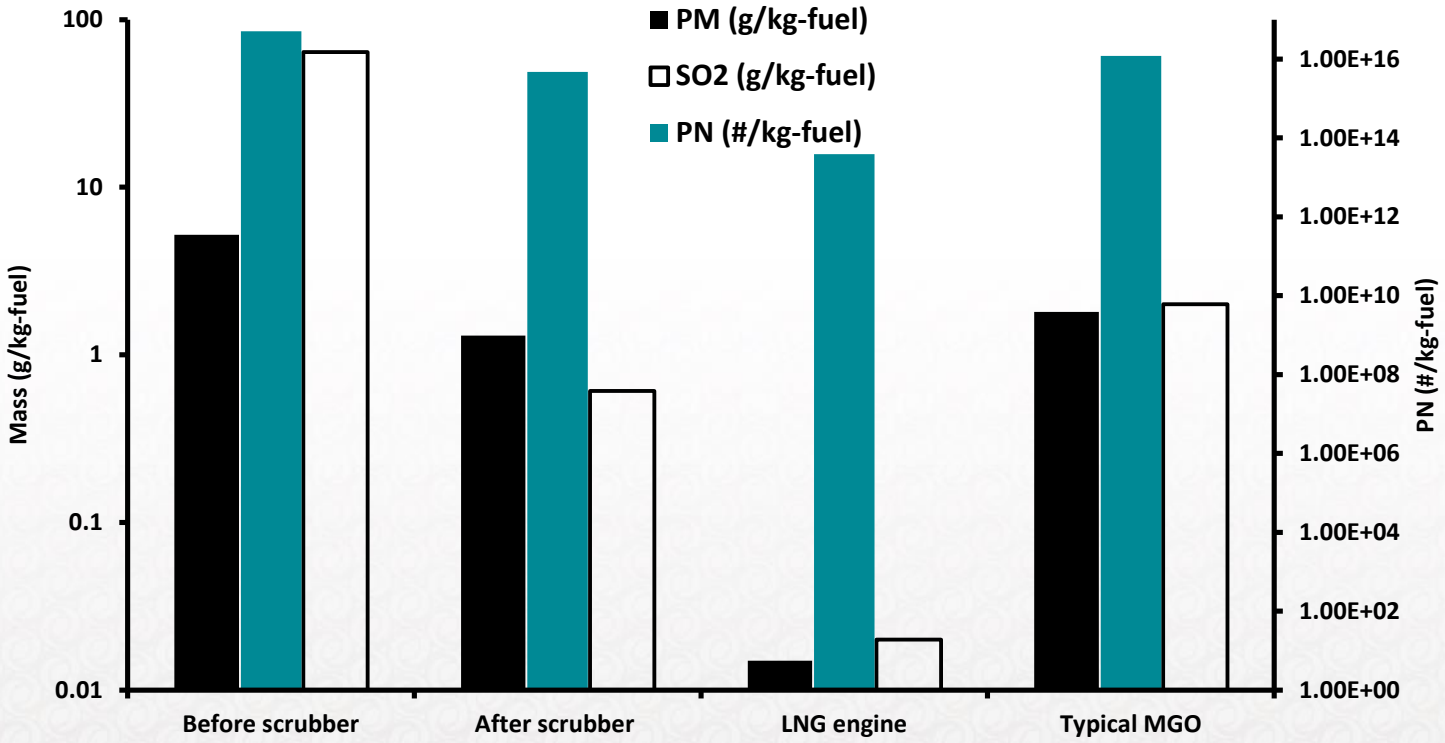


- The exhaust is brought in contact with scrubber water (bubbling, or mist).
- SO_2 reacts with salt and form ions.
- The water is treated and returned to sea
- Can be open with seawater or closed loop with freshwater and NaOH
- Established technology on land

SO_2 (gas) + H_2O + ½O_2 ==> SO_4^{2-} + $2H^+$

HCO_3^- + H^+ ==> CO_2 + H_2O

Emission factors for particle mass, particle number and SO_2 for an LNG ship and a ship with scrubber compared with typical values for MGO



Fridell and Salo, J Eng Maritime Env 2016

JUP 0.8

Estimating the socio-economic benefits of reducing emissions from shipping – ZVT case studies

Stefan Åström & Erik Fridell
IVL Swedish Environmental Research Institute

Why did we perform these calculations?

- European emissions of air pollutants are recognised to cause negative environmental and health impacts
- Within the ZVT network there are initiatives to build and use ships with lower emissions and lower health impacts than required by legislation
- These ships are more difficult to finance, EVEN though they are beneficial for society
- To use a common metric (money) often facilitates discussions and can make the costs for reducing emissions comparable with the benefits

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How did we perform the calculations?

- Three case studies:
  - Case study 1 – BalticSO2lution vs. Reference ship
  - Case study 2 –LNG-Conv. vs. Reference ship
  - Case study 3 – Pilot Methanol vs. Reference ship
- Emission calculations: Emission = emission factor*fuel use
- Emission dispersion from sea regions to countries
- Calculations of human health impacts & crop impacts
- Monetisation of human health impacts & crop impacts & climate change impacts

Emission calculations - method

- Traffic and fuel consumption assessed by shipowner
- Emission factors from literature
- Calculations for
  - Nitrogen oxides
  - Particulate matter
  - Sulphur oxides
  - Greenhouse gases as CO2-equivalents (CO2, methane, nitrous oxide)

Results - emissions

Case study 1: BalticSO2lution vs. Reference ship (1&2)

Emissions

	Baltic SO2lution	Reference ship 1	Reference ship 2	
CO_{2eq}	7	12	8	kton
SO_2	1	7	5	ton
NO_X	43	278	199	ton
$PM_{2.5}$	1	9	6	ton
Fuel use	113	161	113	TJ
SECA compatible?	yes	yes	yes	
NECA compatible?	yes	NO	NO	

Emission reduction

	low	high	
CO_{2eq}	1	5	kton
SO_2	4	7	ton
NO_X	156	235	ton
$PM_{2.5}$	5	7	ton

We assumed 65% of emissions in the Baltic Sea

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Emission dispersion and impact

- Emission dispersion from the Baltic sea and the North Sea (+ English Channel) over Europe were simulated by using the GAINS model
- The GAINS model is used to calculate population exposure to fine particulate matter in air caused by human activities
- The ARP model is used to calculate human health impacts
- Knowledge on human health impacts gathered from epidemiological studies that have identified relationships between human health and concentrations of fine particulate matter
- Crop impacts are assessed from earlier studies on ozone damages on crops

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Monetization of human health-, crop-, and climate change impacts

- The ARP model then monetize these impacts
- Monetized values are based on peer-reviewed economic literature
- Crop impacts are valued using market prices for crop
- Climate change impacts are monetized using literature values on prices for CO_2
- Economic value of CO_2

Range	Value	Unit	Reference
Low	6.7	€/ton CO_2	EU ETS market price, November 2014
Mid	24	€/ton CO_2	Stern 2006, 450-550 ppm world ($30 / ton CO2)
High	70	€/ton CO_2	Stern 2006, BAU world ($85 / ton CO2)

Results – Socioeconomic benefits

Case study 1: BalticSO2lution vs. Reference ship (1&2)

Monetized annual benefits – central estimate (low & high)

	BalticSO2lution vs. Reference ship 1	**BalticSO2lution vs. Reference ship 2**	
Human Health	1092 (511-2550)	724 (339-1691)	thousand €
Crop damages	25	17	thousand €
Climate change	110 (31-320)	25 (7-72)	thousand €
TOTAL	**1227** (567-2896)	**765** (362-1780)	thousand €

Discussion

Of direct concern for our study

- Impacts are sensitive to where emission reductions take place
  - Larger human health impacts from North sea shipping than Baltic sea shipping
  - Our calculations are based on average values for entire sea regions
- Monetized impacts on acidification, eutrophication, biodiversity not considered
- Impacts on work safety, water , employment not considered

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Thank You!

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