Emissions to Air from Shipping and Future Abatement Techniques

Erik Fridell

2011-09-09

IVL Swedish Environmental Research Institute

Erik Fridell

- Senior researcher at IVL Swedish Environmental Research Institute – an independent research institute since 1966
- Adjunct Professor at Marine Technology Chalmers University
- Member of Northern Maritime University

IVL Swedish Environmental Research Institute

erik.fridell@ivl.se

The broadest concentrated environmental expertise in Sweden

Research and consultancy work

- in the entire field of environmental issues and sustainable development

- experienced coordinators of large international projects

- **Long experience**

  - founded in 1966

- **Independent**

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

IVL Swedish Environmental Research Institute

erik.fridell@ivl.se

Opportunity for shipping

- 90% of all goods transports are by shipping.
- For most cases shipping is relatively fuel efficient
- Ease road congestion
- Possibilties to use alternative fuels

IVL Swedish Environmental Research Institute

erik.fridell@ivl.se

External costs from shipping

billion € , worldwide, 2006

Marine Pollution	
(sewage + permitted oil spills)	0.7
Air quality pollutants	184
Greenhouse gases	76
”Illegal” oil spills	44
Sum	305

Source: Maffii et al., External costs of maritime transport. (EU parlament 2007)

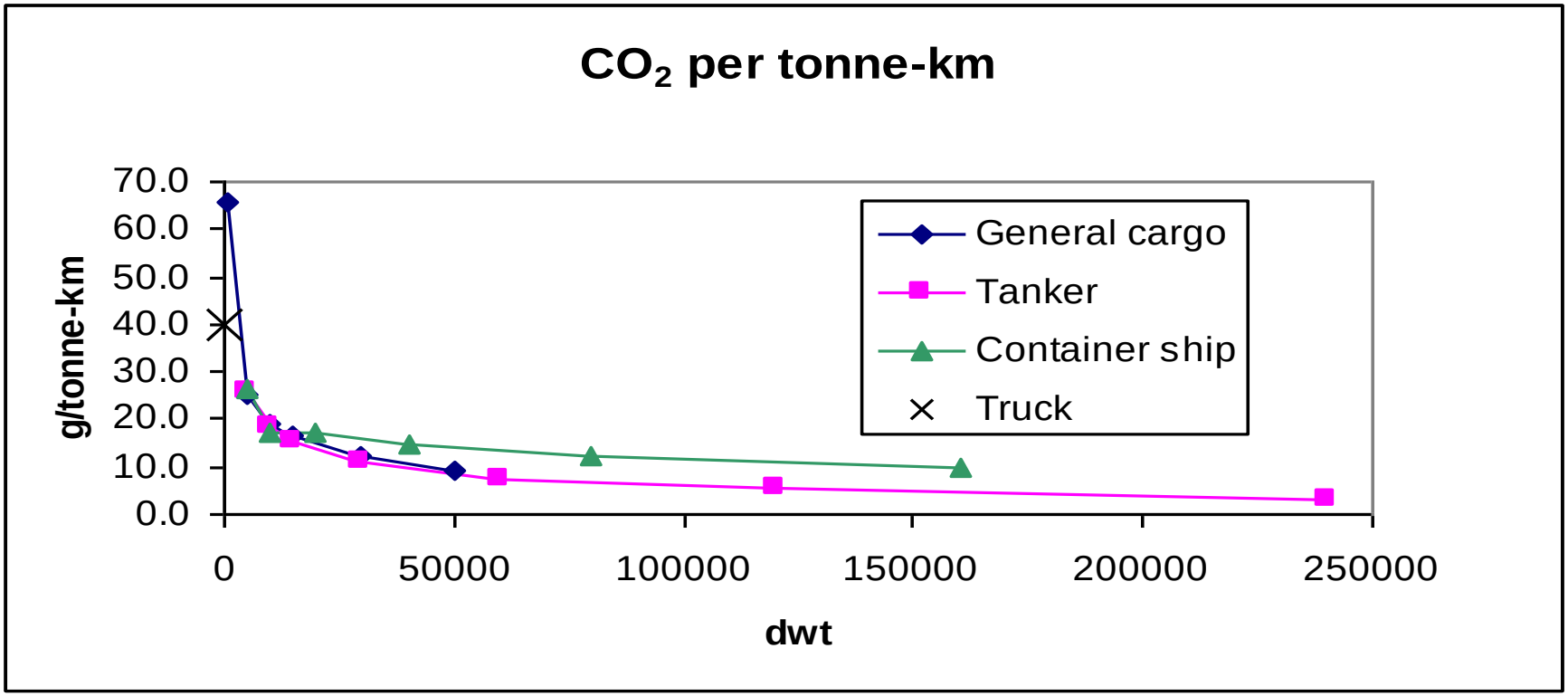
erik.fridell@ivl.se

Air pollution from shipping-overview

- Particles: Incresed mortality and morbidity. PM cause 100 000 deaths annually in Europe. Shipping large source.
- SO_2: Acidification and corrosion. Forms particles. Shipping major source
- NO_X: Eutrophication and acidification, Particle formation. Shipping one of the dominating sources
- CO_2: Climate Change (also particles and other gases)
- Ozone: Formed after NO_X emissions. Damages health and vegetation.

erik.fridell@ivl.se

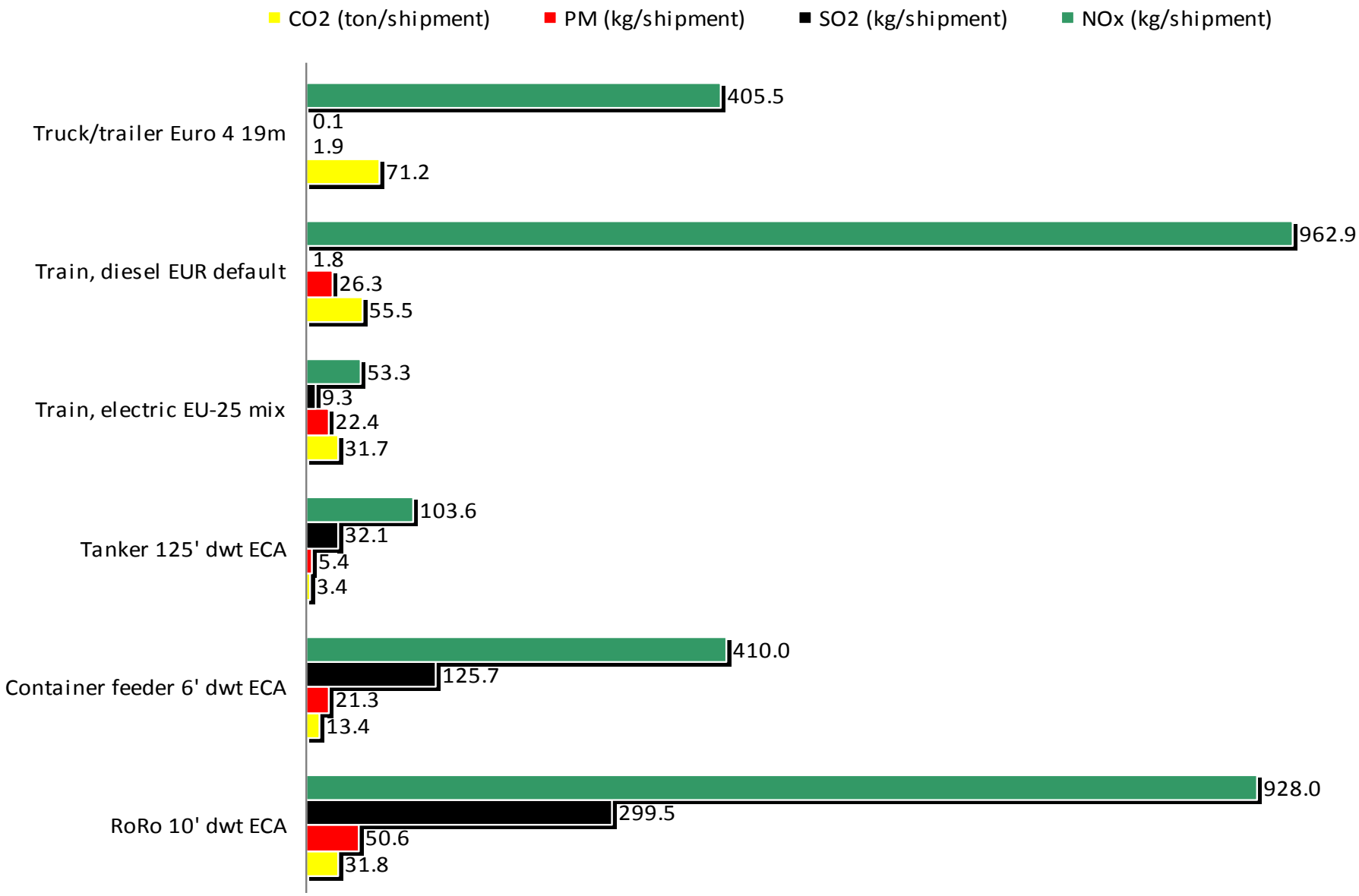
CO_2 emissions depends on size!



Data from IMO documents

erik.fridell@ivl.se

Göteborg-Rotterdam



IVL Swedish Environmental Research Institute

erik.fridell@ivl.se

Air pollution shipping
Drivers

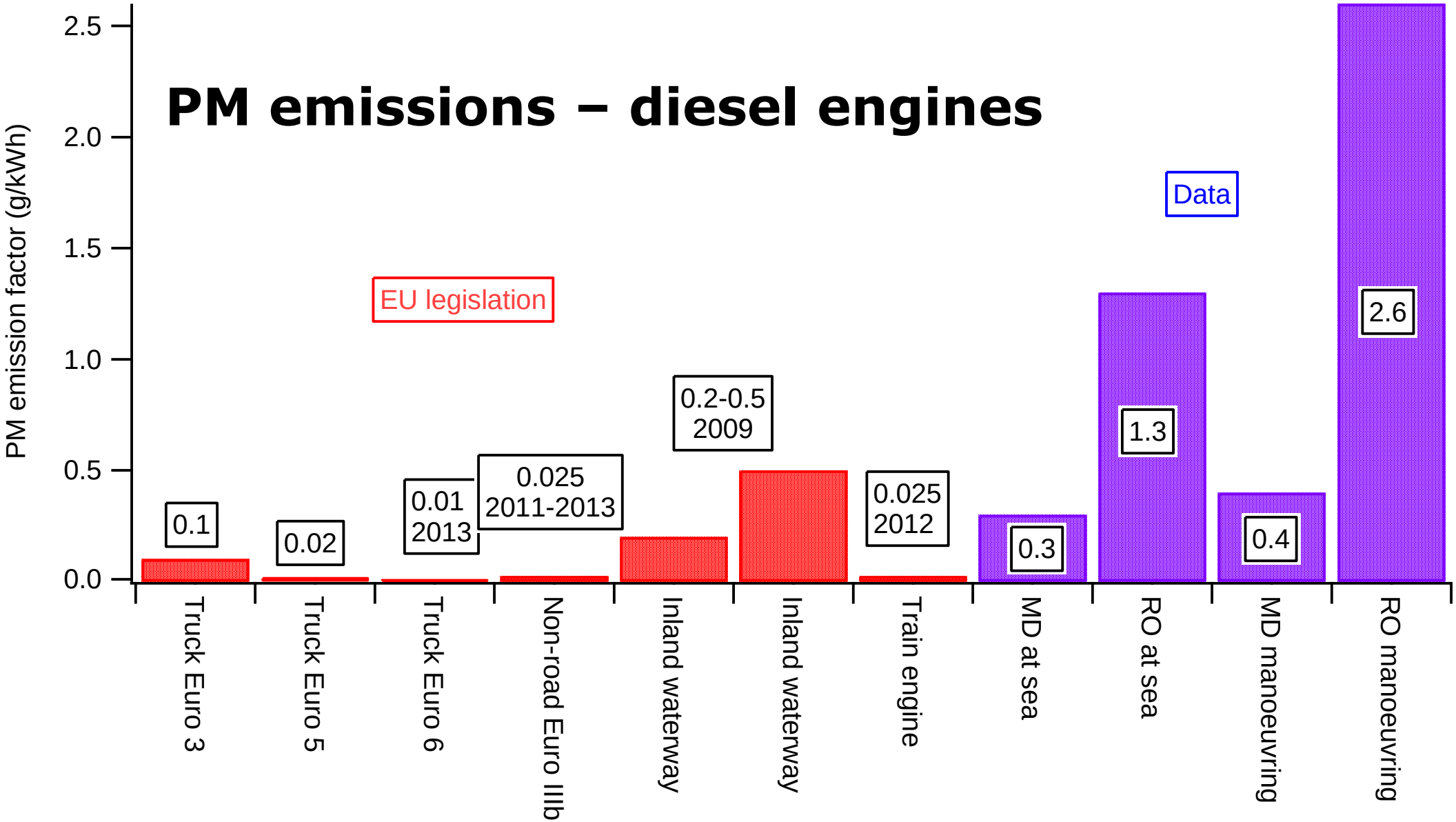
- ”Peak-oil”
- Global warming
- Air pollution

Solutions

- Reduce fuel consumption
- New fuels
- Abatement methods

erik.fridell@ivl.se

PM emissions – diesel engines



erik.nilsen@ivl.se

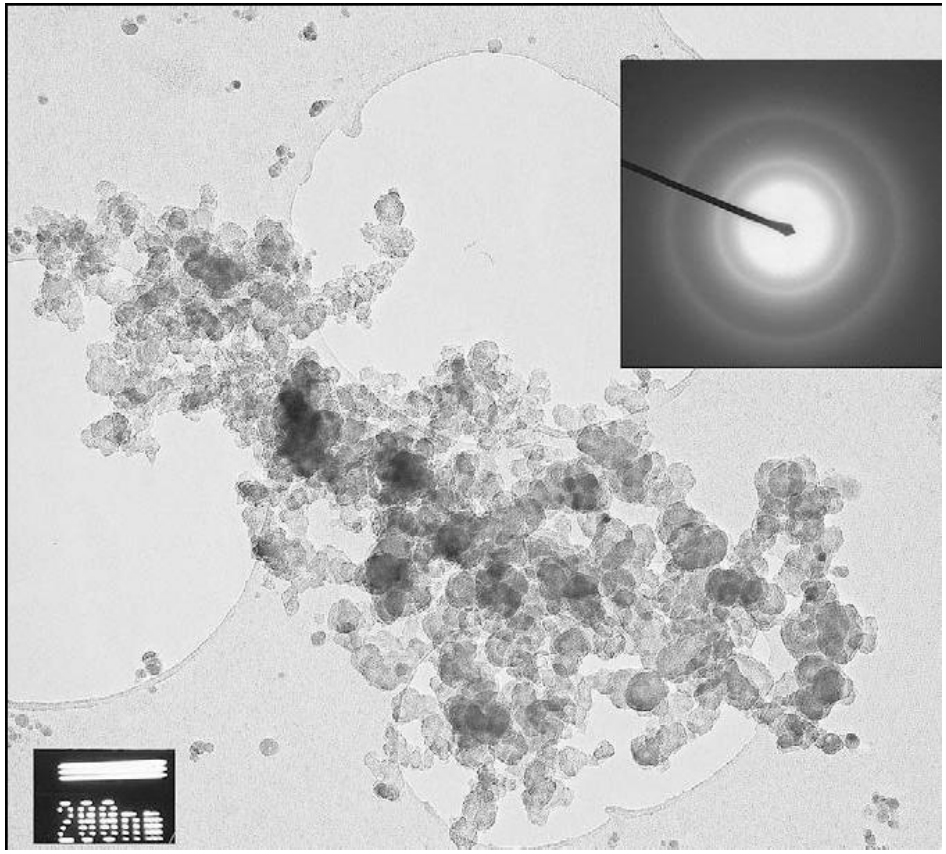
Characterisation of particles

- Sulphate particles. Aerosols formed from SO_3. Around 60 – 100 nm
- Organic matter. Aerosols from unburnt fuel, 60-100 nm
- Nitrate particles. From NO_X. 60-100 nm
- Black carbon. From combustion. 10 nm and large agglomerates
- Char. From unburnt fuel. 10 -15 μm.
- Ash 100 nm and agglomerates

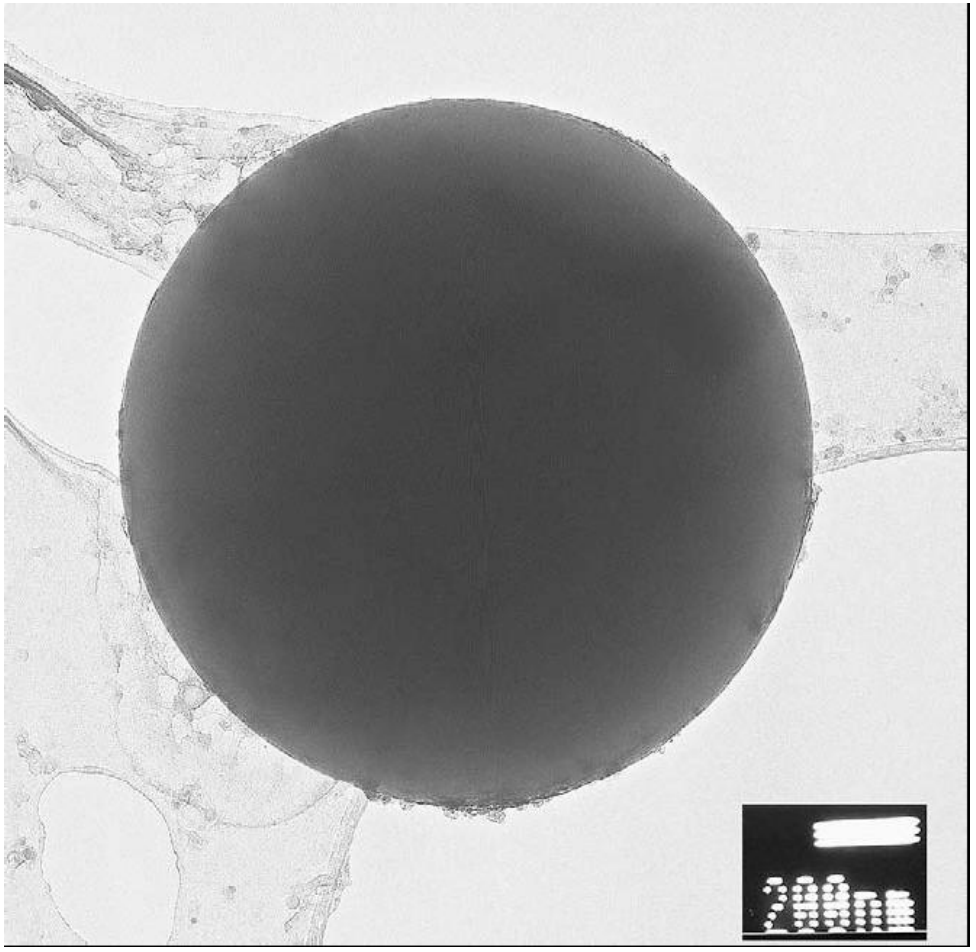
erik.fridell@ivl.se

TEM images

Soot

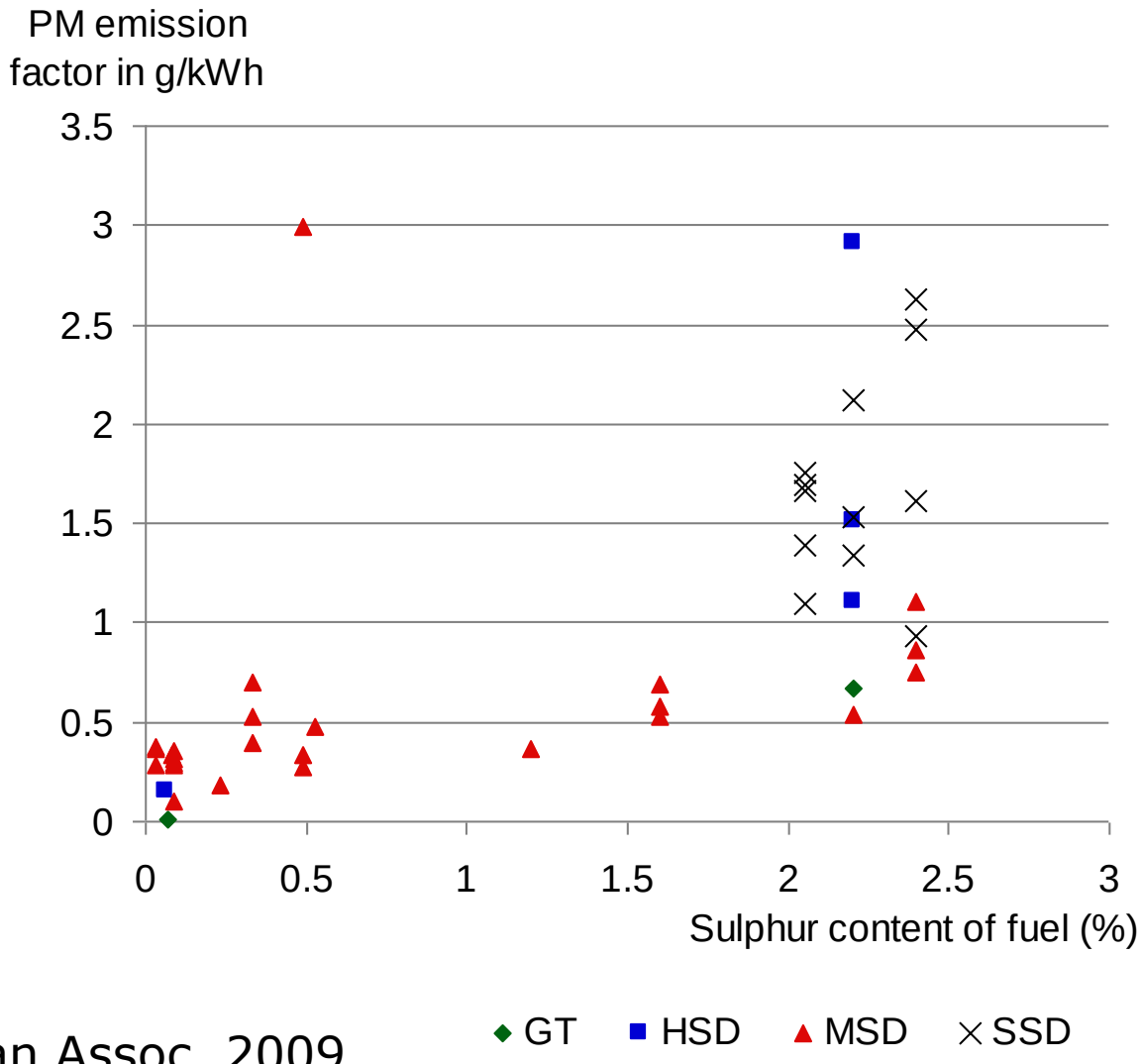


Char



erik.fridell@ivl.se

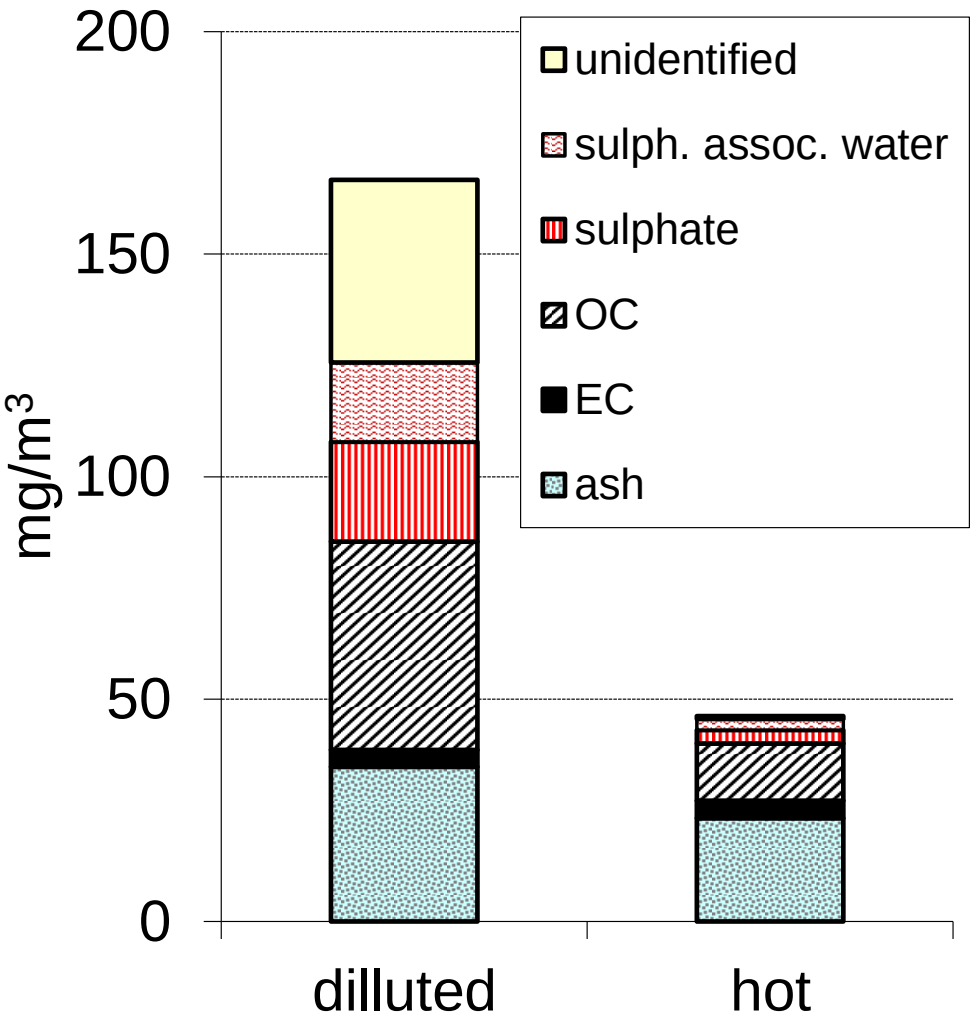
PM formation vs fuel sulphur



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

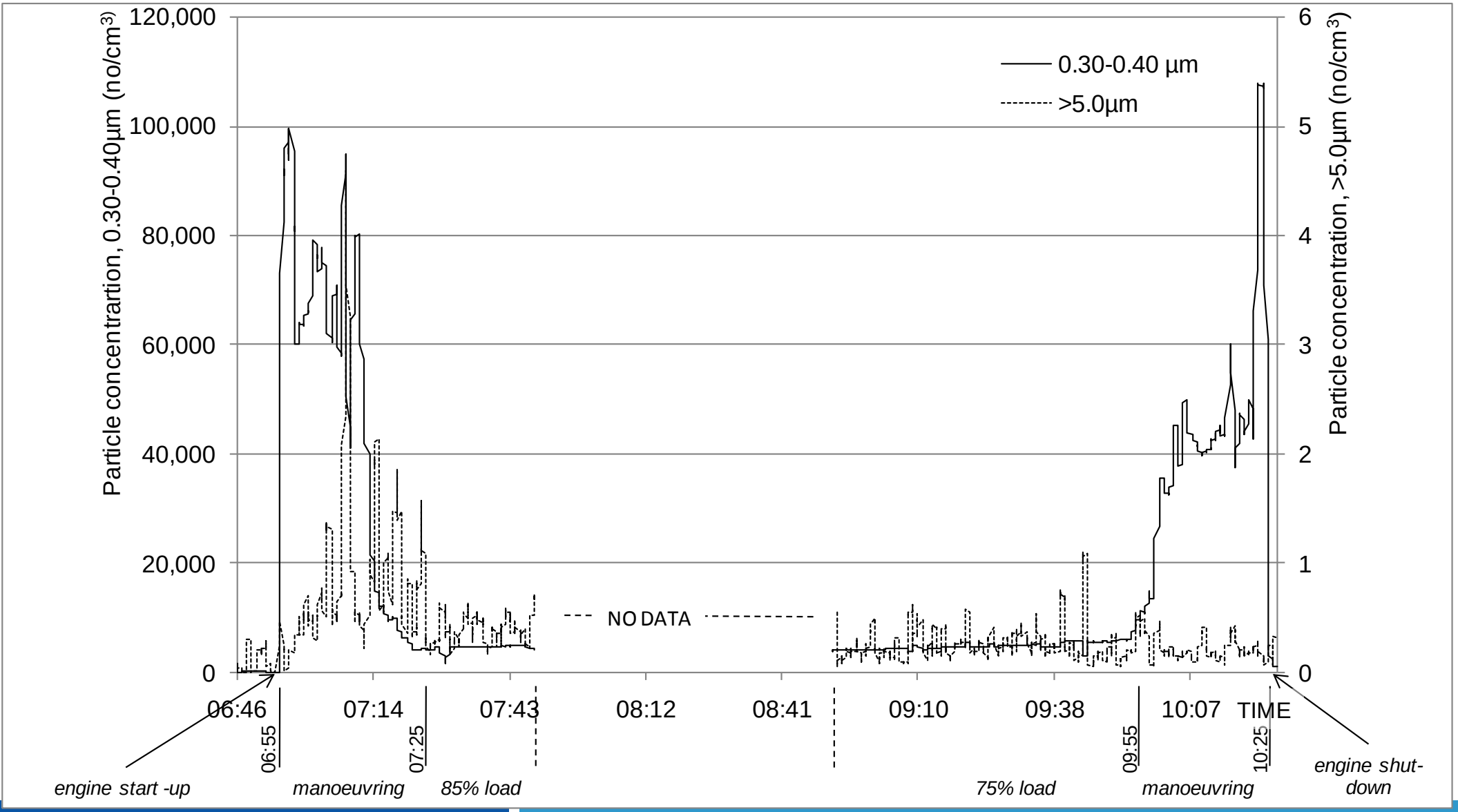
erik.fridell@ivl.se

Composition of PM (as mg/m³ exhaust gas) collected on filters in the diluted and hot exhaust gas (Moldanová et al., 2009).



erik.fridell@ivl.se

Manoeuvring – Particle emissions



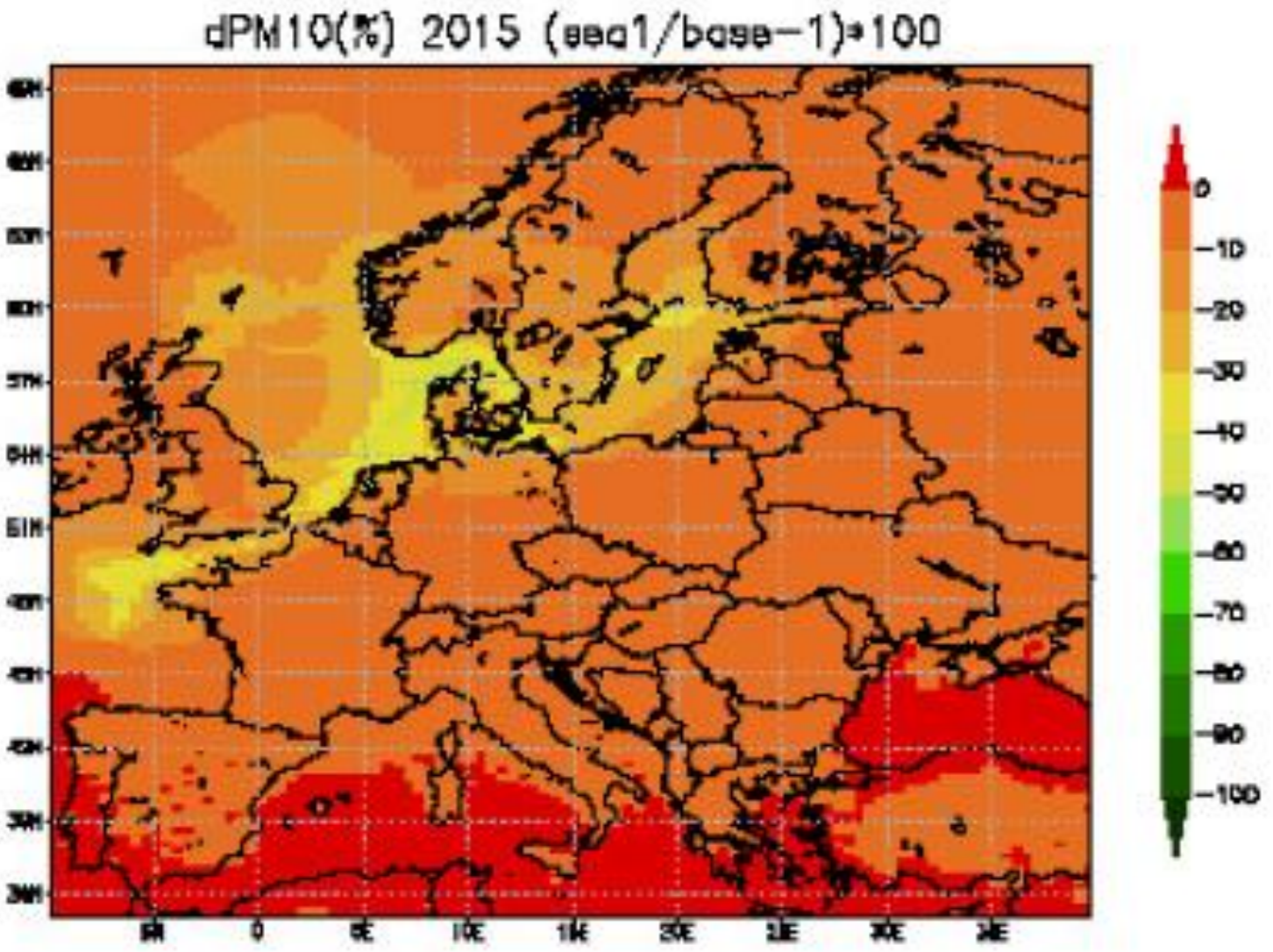
Winnes and Fridell, Transportation research D 2010

IVL Swedish Environmental Research Institute

erik.fridell@ivl.se

Change in PM10 from SECAs in Baltic and North seas, 2015

20-30% reduction in coastal areas



Bosch et al (2010) Cost Benefit Analysis to Support the Impact Assessment accompanying the revision of Directive 1999/32/EC

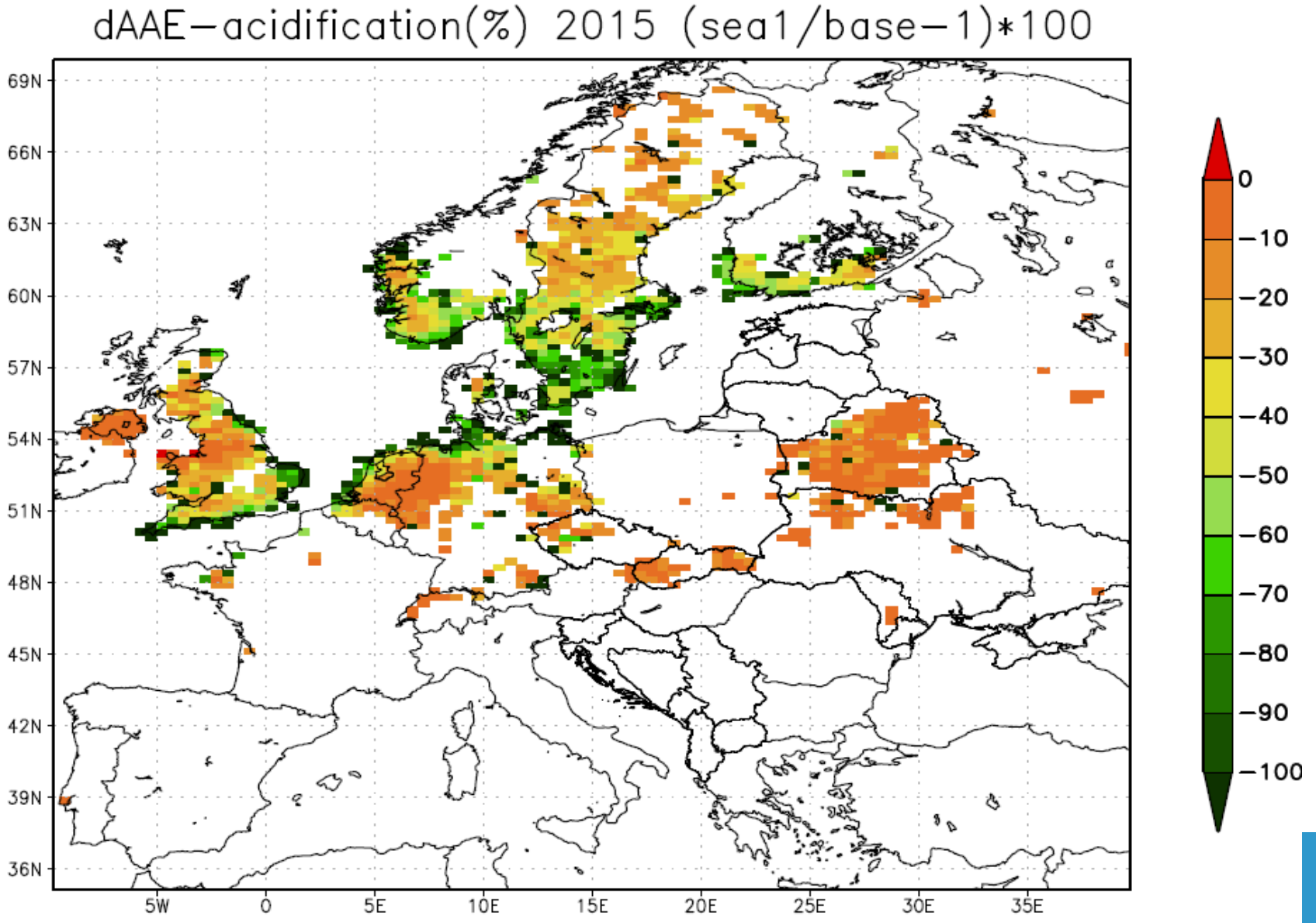
IVL Swedish Environmental Research Institute

erik.fridell@ivl.se

Change in acidification from SECAs in Baltic and North seas, 2015

- Up to 100% reduction in coastal areas
- 35% decrease in S-deposition in Sweden

Bosch et al (2010) Cost Benefit Analysis to Support the Impact Assessment accompanying the revision of Directive 1999/32/EC



Consequences of sulphur regulations on fuel types

- Fuel with 0.1% S is most likely marine gasoil
- Fuel with 0.5% S is marine diesel, i.e. a mixed product

Costs for fuels in 2020. Base cost 420 $/tonne

adapted from
Purvin&Gertz, 2009, Avis M.J., Birch C.H.,
IMPACTS ON THE EU REFINING INDUSTRY & MARKETS OF IMO SPECIFICATION
CHANGES & OTHER MEASURES TO REDUCE THE SULPHUR CONTENT OF CERTAIN
FUELS

abatement cost.

Option (%S in fuel)	Low cost [$ / tonne]	High cost [$ / tonne]
Fuel shift (2.94 → 1.5)	20	20
Fuel shift (2.94 → 1)	30	30
Fuel shift (2.94 → 0.5)	120	170
Fuel shift (2.94 → 0.1)	280	330
Fuel shift (0.5 → 0.1)	160	160

erik.fridell@ivl.se

Other alternatives to comply

- Liquified natural gas (LNG)
- Biofuels
- Synthetic diesel
- Abatement of SO_2 (scrubbers)

erik.fridell@ivl.se

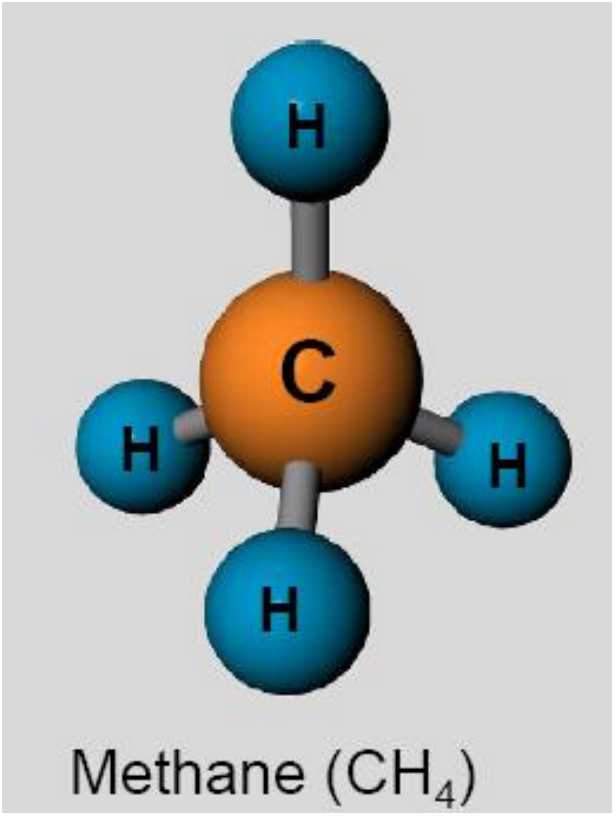
LNG (liquified natural gas)

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



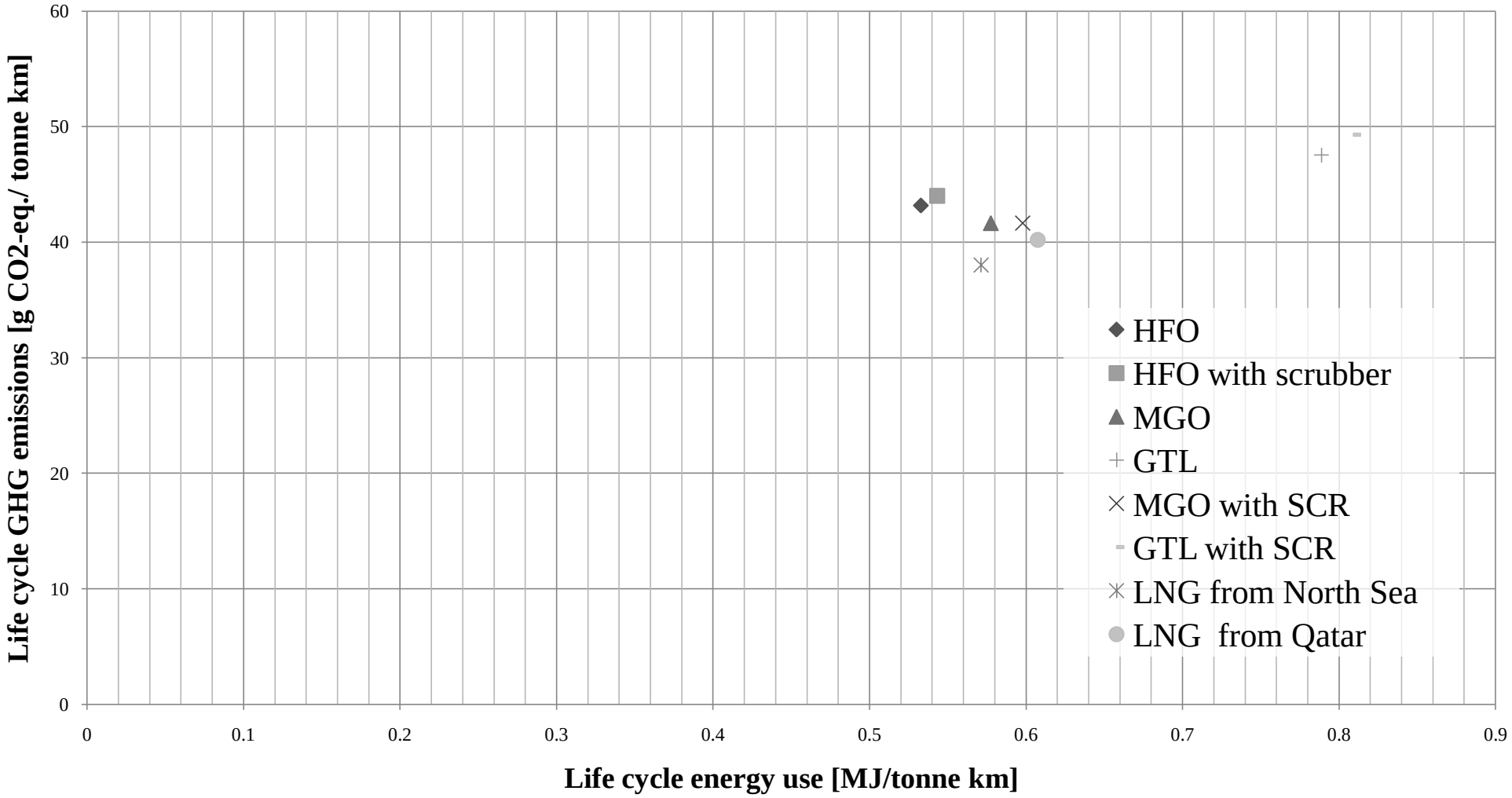
Methane (CH_4)

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

erik.fridell@ivl.se

Marine fossil fuels

HFO – Heavy Fuel Oil
MGO – Marine Gas Oil
GTL – Gas-to-Liquid
LNG – Liquified Natural Gas

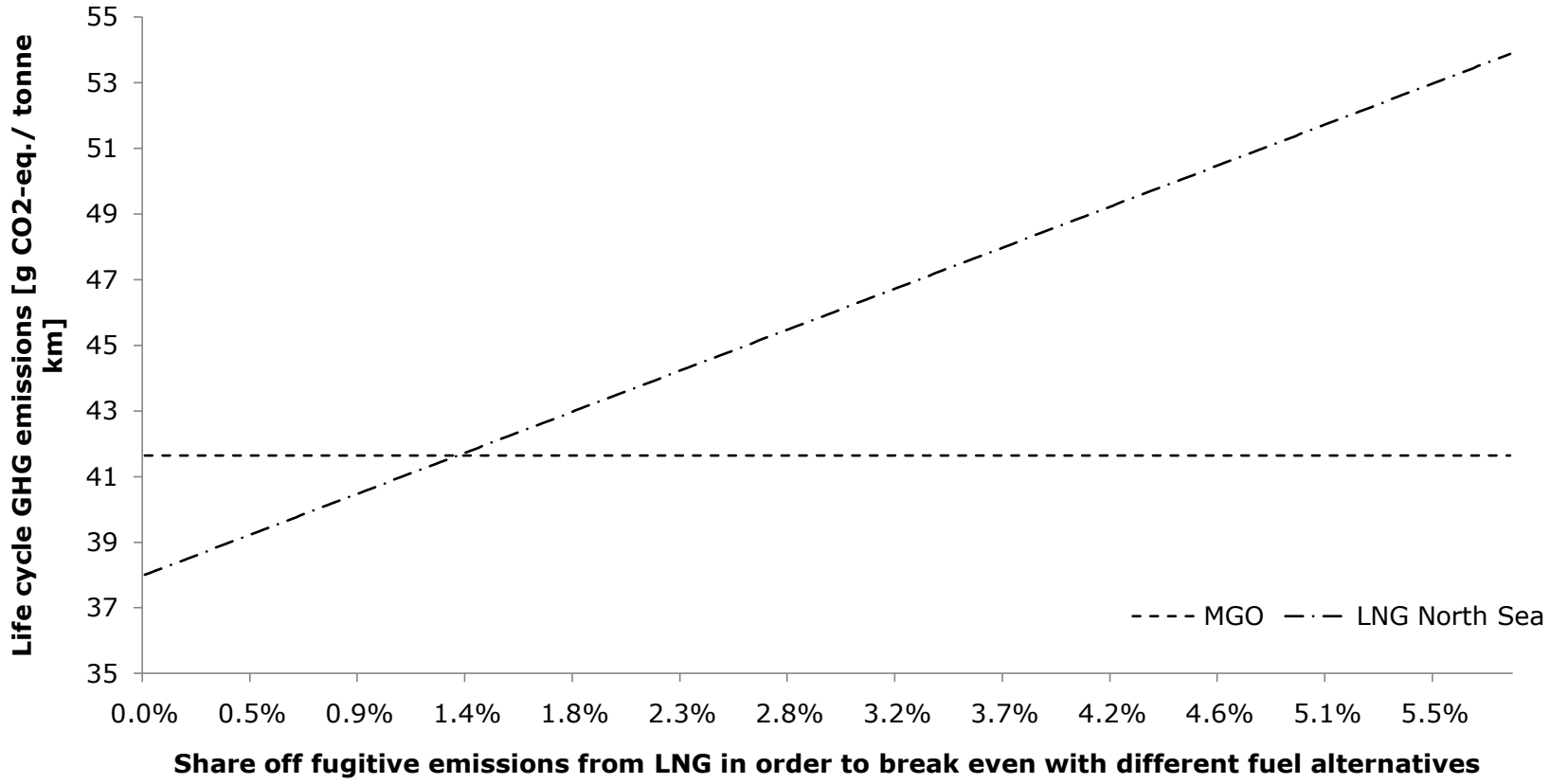


Selma Bengtsson et al., Journal of Engineering for the Maritime Environment, 2011

IVL Swedish Environmental Research Institute

erik.fridell@ivl.se

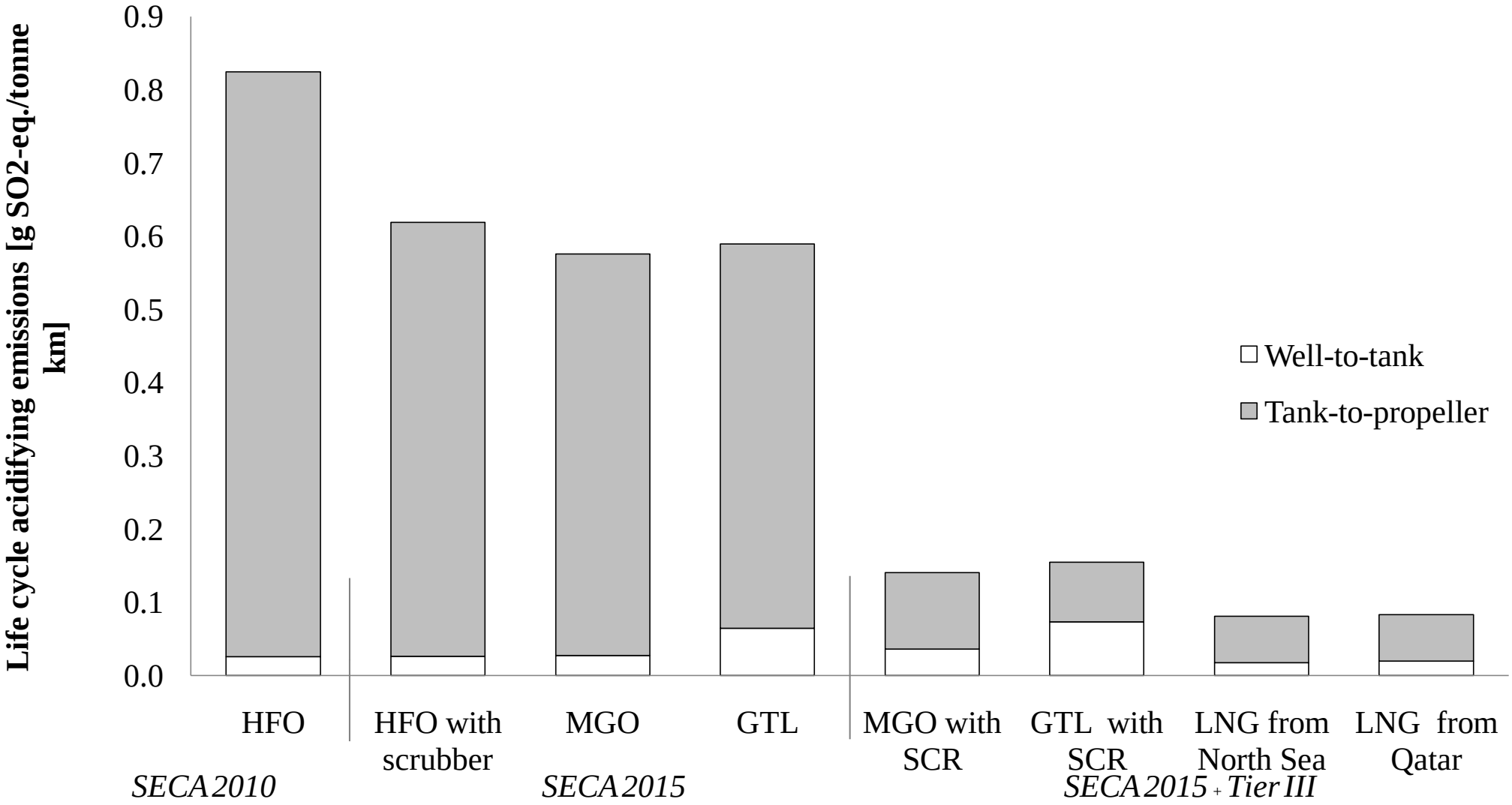
Methane -slip



Selma Bengtsson et al, 2010

erik.fridell@ivl.se

Acidification potential



Selma Bengtsson et al, 2010

erik.fridell@ivl.se

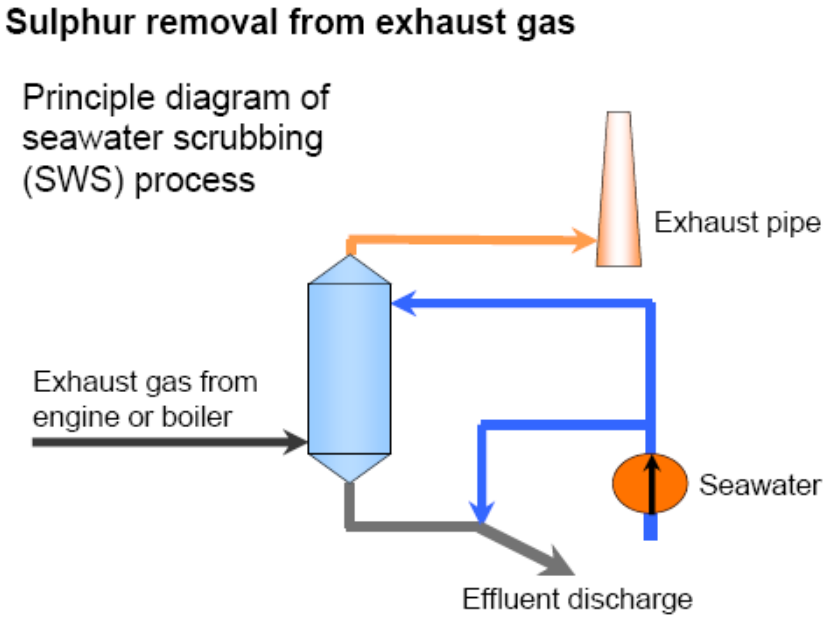
Biofuels

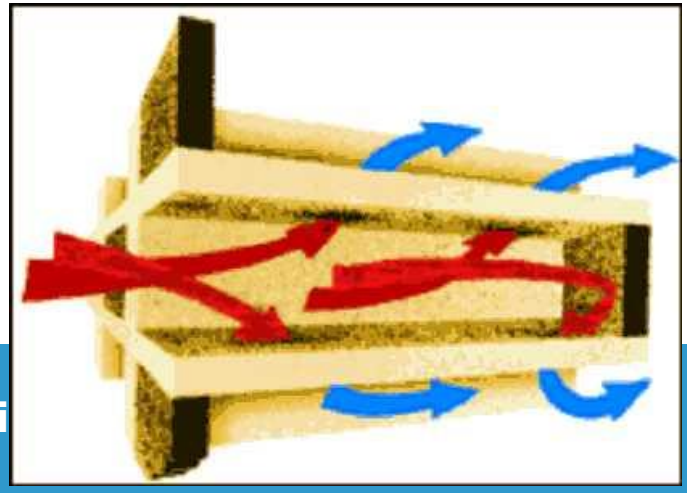
- Engines exist that use biofuels like palmoil, rapeseedoil, RME, ethanol, methanol, DME
- Price, availability, food prices, technical issues
- Low sulphur emission
- NO_X emissions still a problem
- Hydrocarbon emissions (e.g., aldehydes from alcohols)
- Possibility to mix with regular fuels

erik.fridell@ivl.se

Reduce particle emissions

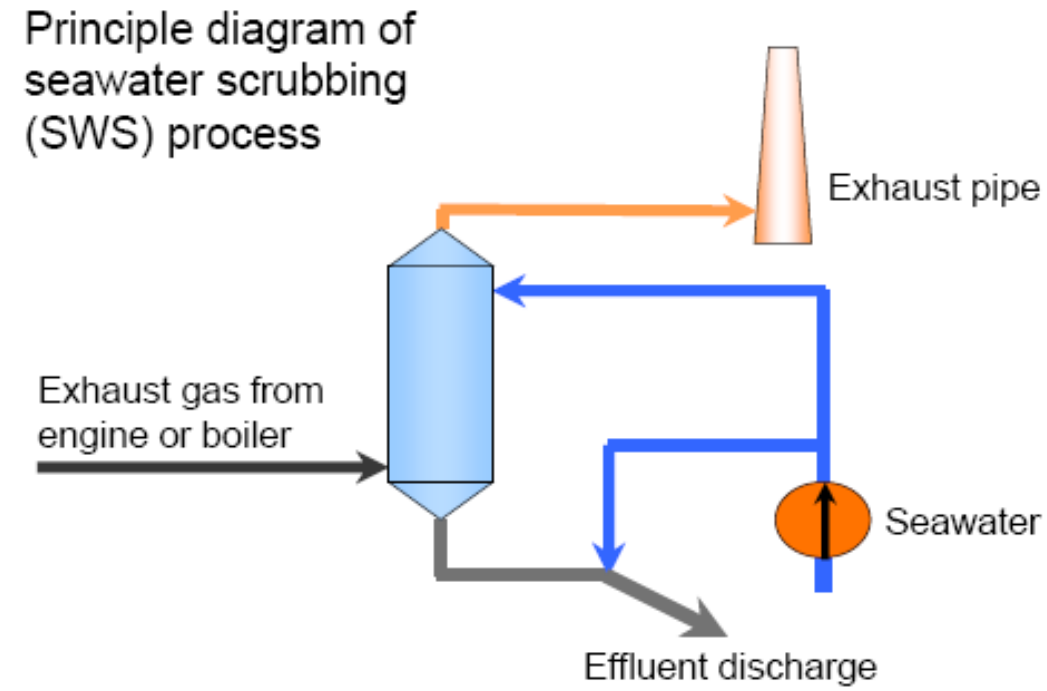
- Shore side electricity
- Low sulphur fuels
- Scrubbers can remove particles
- Particle filters at least for auxillary engines





Scrubbers

Sulphur removal from exhaust gas



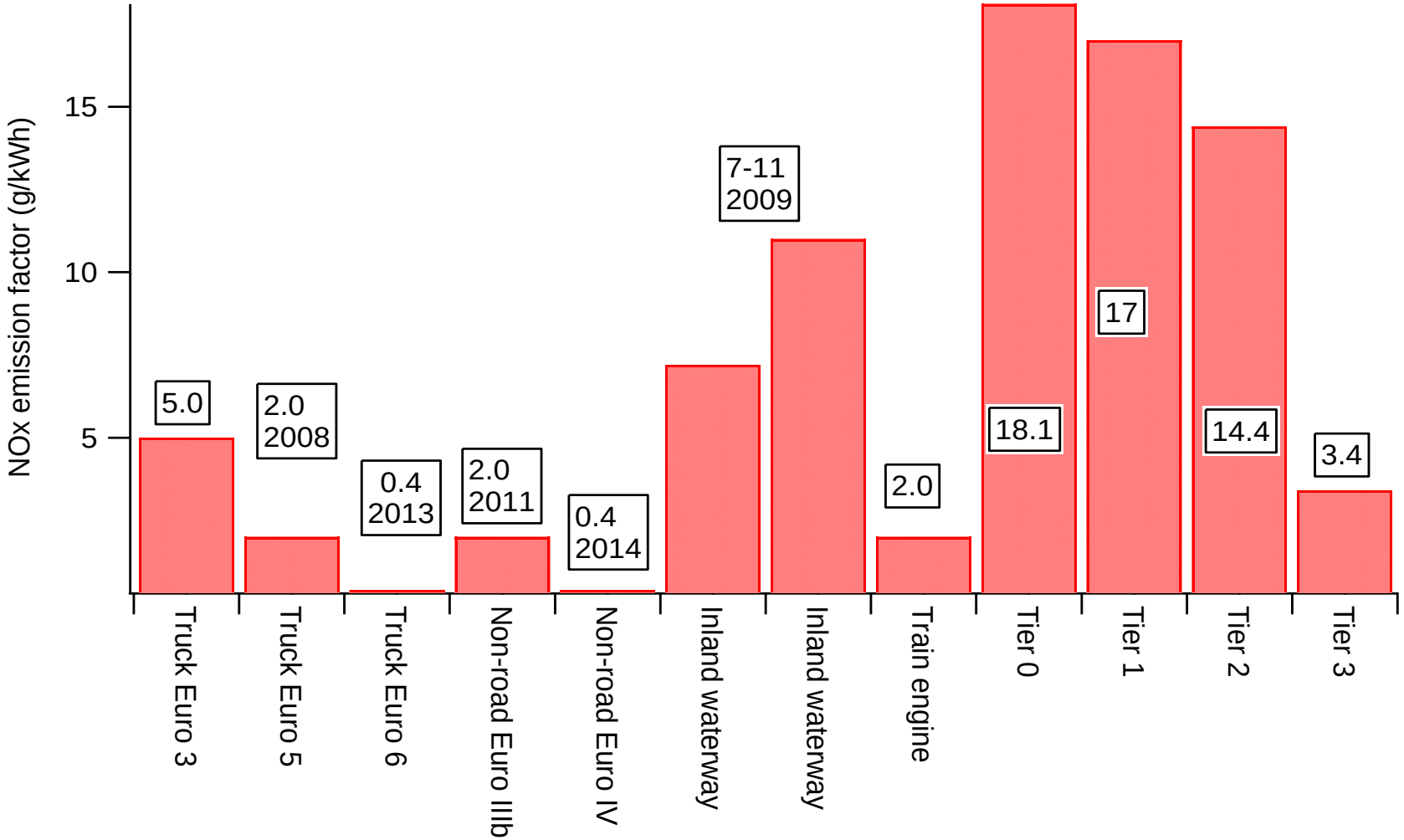
SO_2 (gas) + H_2O + ½O_2 ==> SO_4^{2-} + $2H^+$

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

- 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

erik.fridell@ivl.se

NO_x emissions – diesel engines



erik.fridell@ivl.se

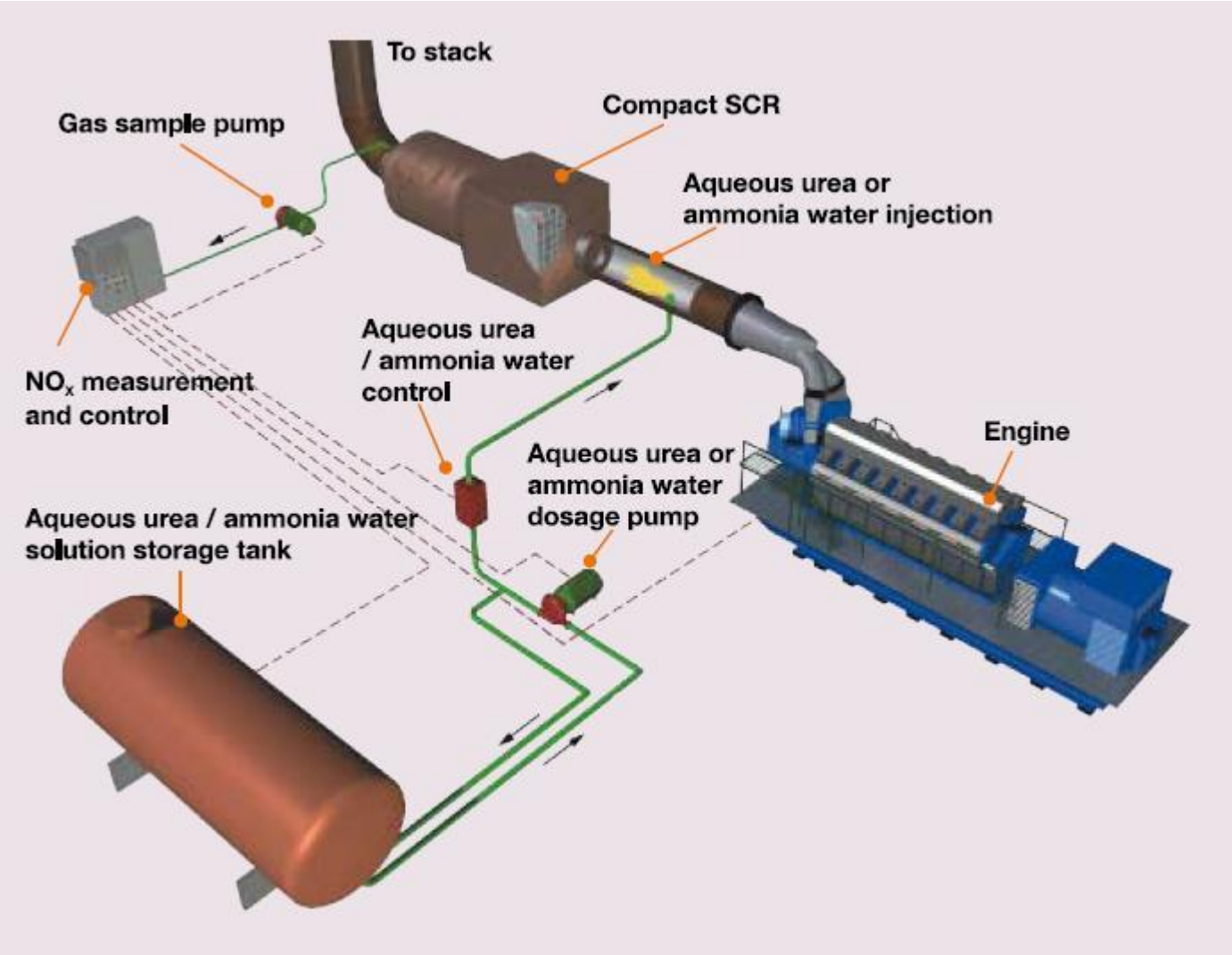
Methods to reduce NO_X emissions

The formation of NO_X via the Zeldovich mechanism during combustion is strongly temperature dependent

- Engine modifications
- EGR, recirculates exhaust
- Cooling of the combustion temperature with water (Direct water injection, Humid air motor, emulsion)
- Selective catalytic reduction

erik.fridell@ivl.se

SCR installation



erik.fridell@ivl.se

Marine SCR

- SCR have been tested in Swedish waters for about 15 years thanks to fairway dues reductions and customer pressure
- Works well in general
- Problems with deactivation (very costly)
- Deactivation probarbly related to urea quality and/or fuel quality
- Low temperature activity is also an issue

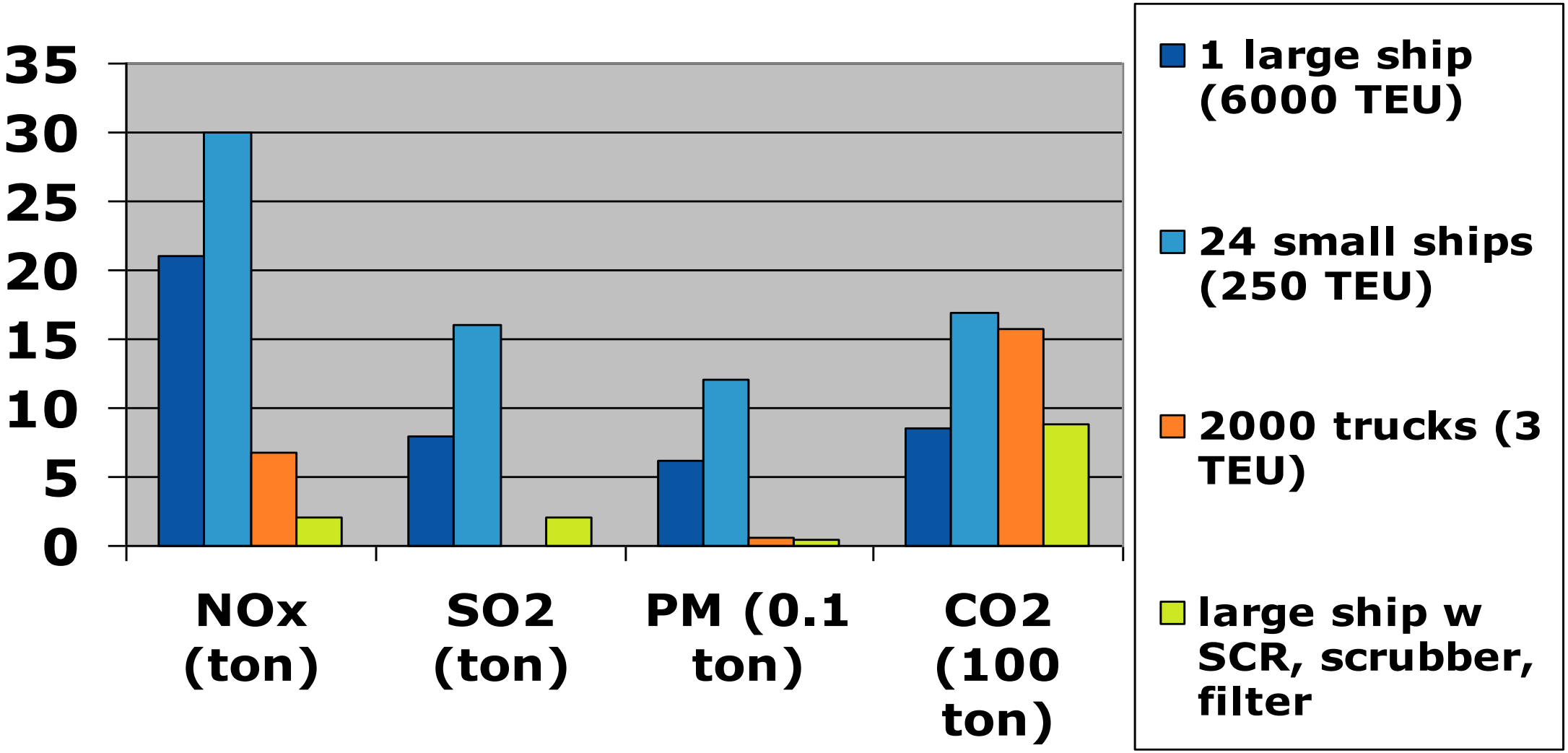
erik.fridell@ivl.se

Shore-side electricity

- To replace the use of AEs while at berth
- About 20 ships in Sweden
- Important solution to local air quality problems
- Effect on CO_2 if ”green” electricity is used

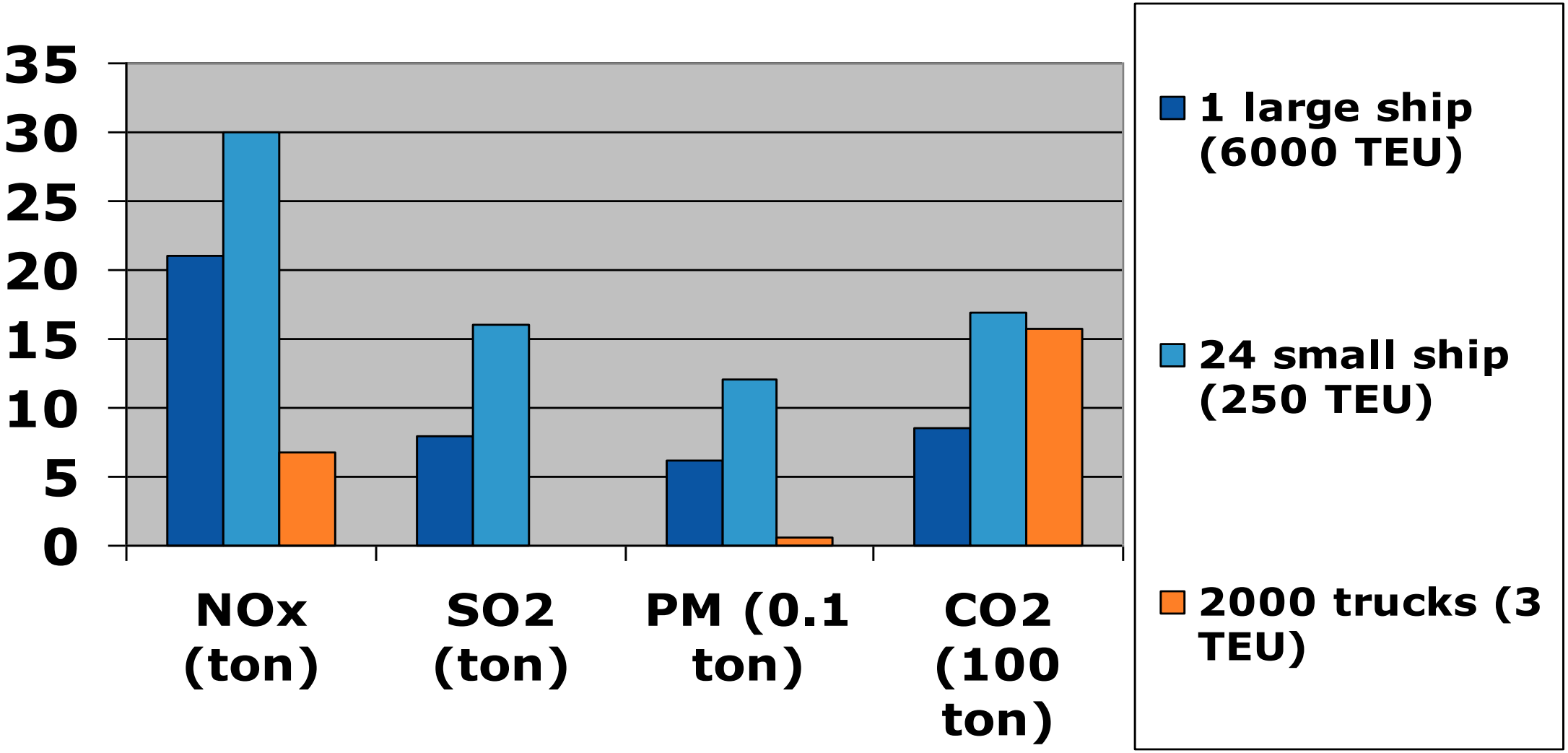
erik.f[illegible]

Example: Emissions Göteborg-



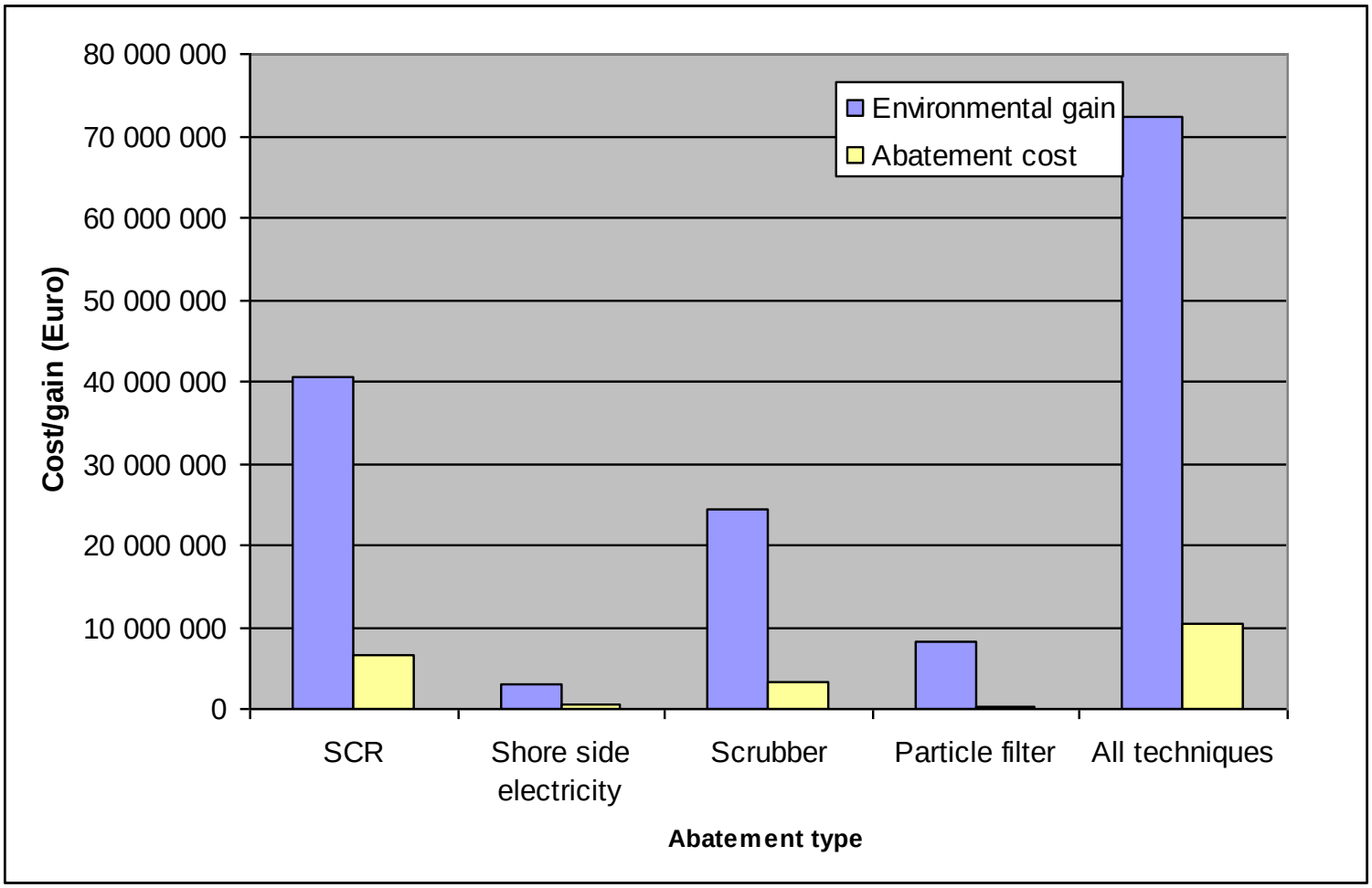
erik.fridell@ivl.se

Example: Emissions Göteborg-Hamburg



erik.fridell@ivl.se

Costs and gains



erik.fridell@ivl.se

Sock on a stack

Los Angeles

erik.fridell@ivl.se

Thank You!

Swedish Environmental Research Institute

erik.fridell@ivl.se