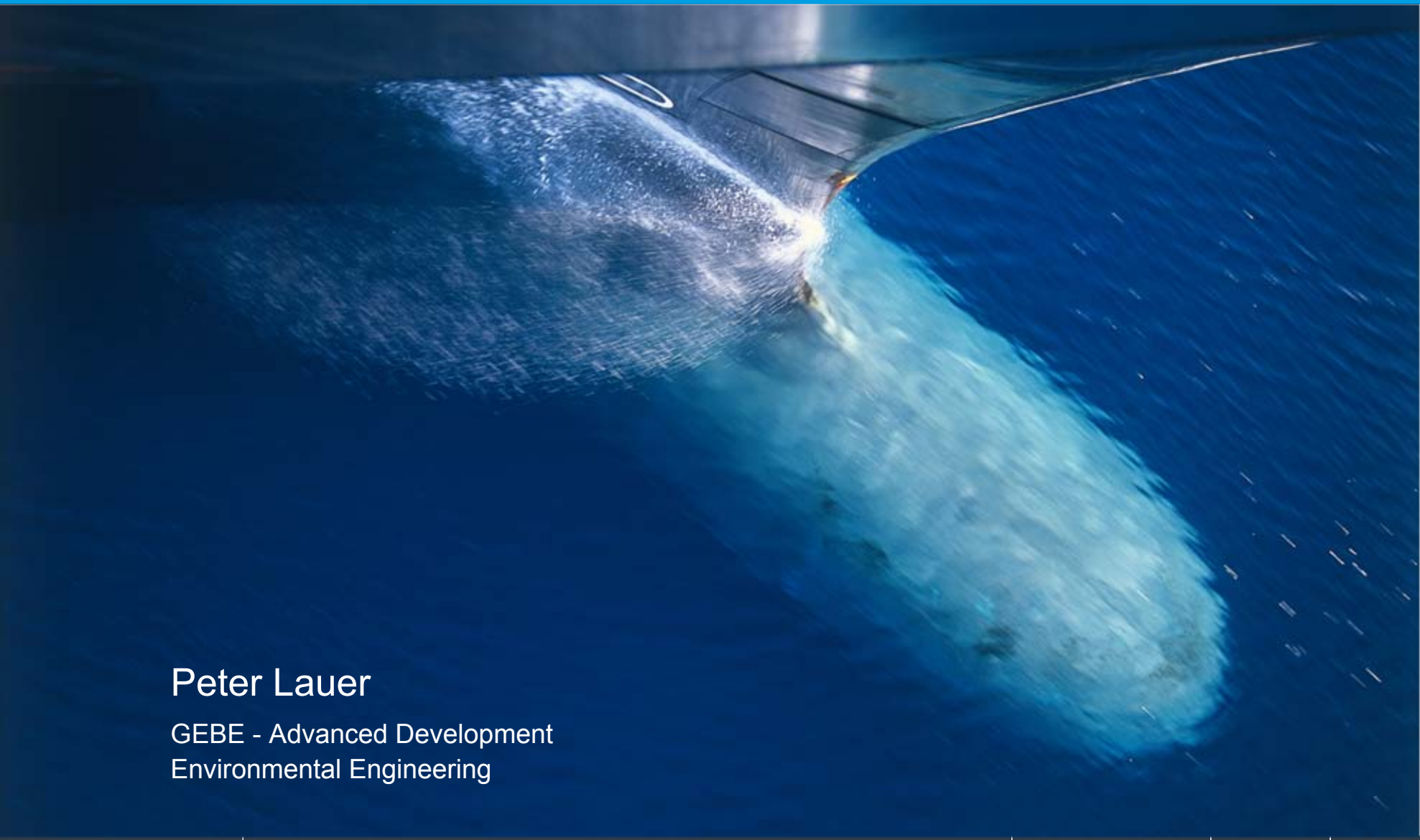
Actual changes in emission limits for ships



Peter Lauer

GEBE - Advanced Development
Environmental Engineering

Outline

- **Marine** emission standards are either regional (e.g. US-EPA, CARB, EU, Rhine river, Norway, Sweden) or **international** (IMO)

- **This presentation** will focus on:
  - **Contribution** of shipping, and **background** information for policy making
  - **IMO** general information, present international standards, and future limits

Emissions and ships contribution

- **Shipping in numbers** globally (2007):
  100,000 ships >100 gt
  total of 369 million tons fuel per year
  whereof 286 million tons of HFO
  (~50 % of worldwide HFO production)
  and 83 million tons of marine distillates

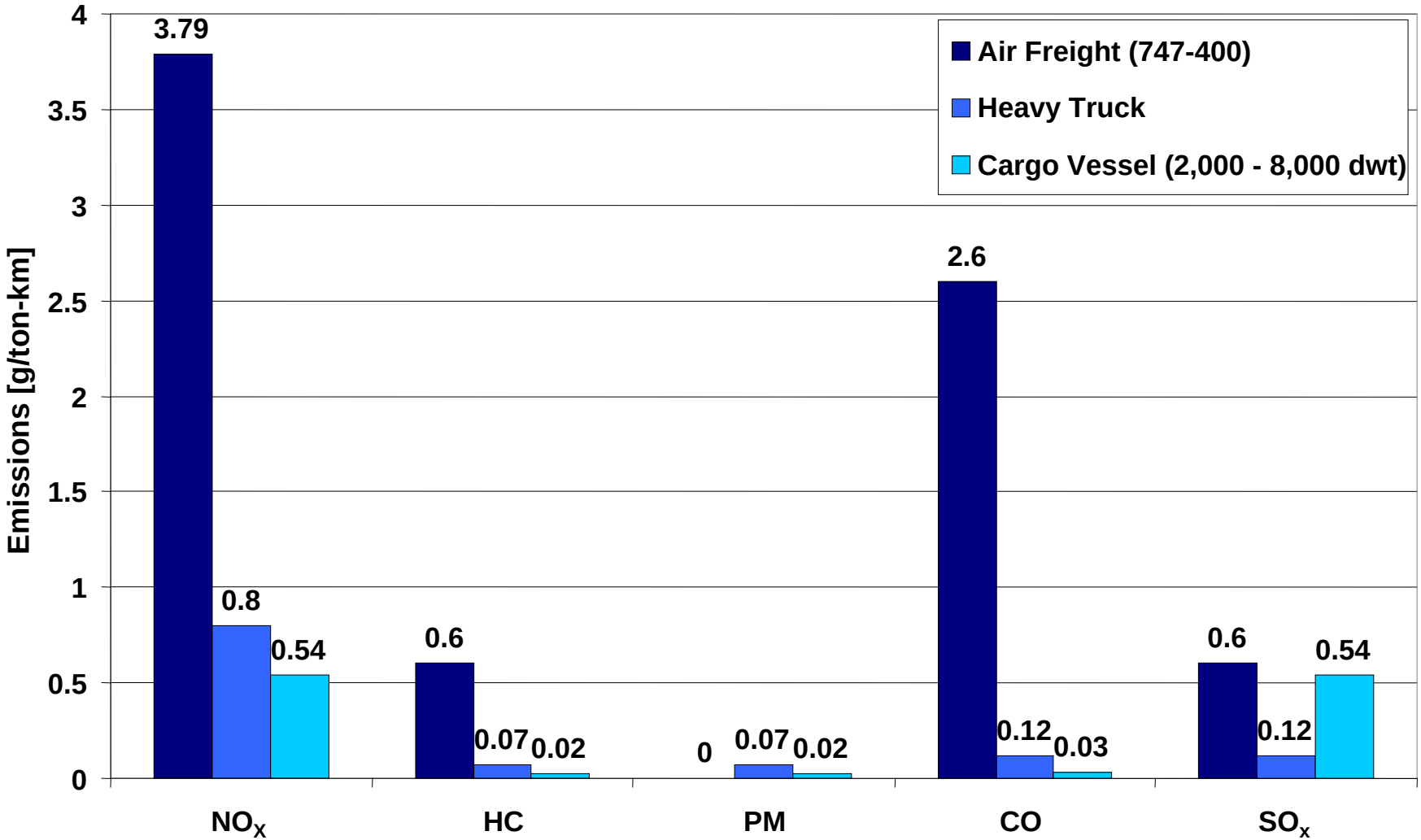
- Shipping is the **most efficient** method for transportation of any cargo and demand is **driven by the world economy**

- **95 %** of trans-continental transport and 70 % of total global trade

- **Responsible** for 14% of anthropogenic NO_x 7% of SO_2 and **only** 3.3% of CO_2 (total transport sector is responsible for 42% NO_x, 10% SO_2 and 27% CO_2)

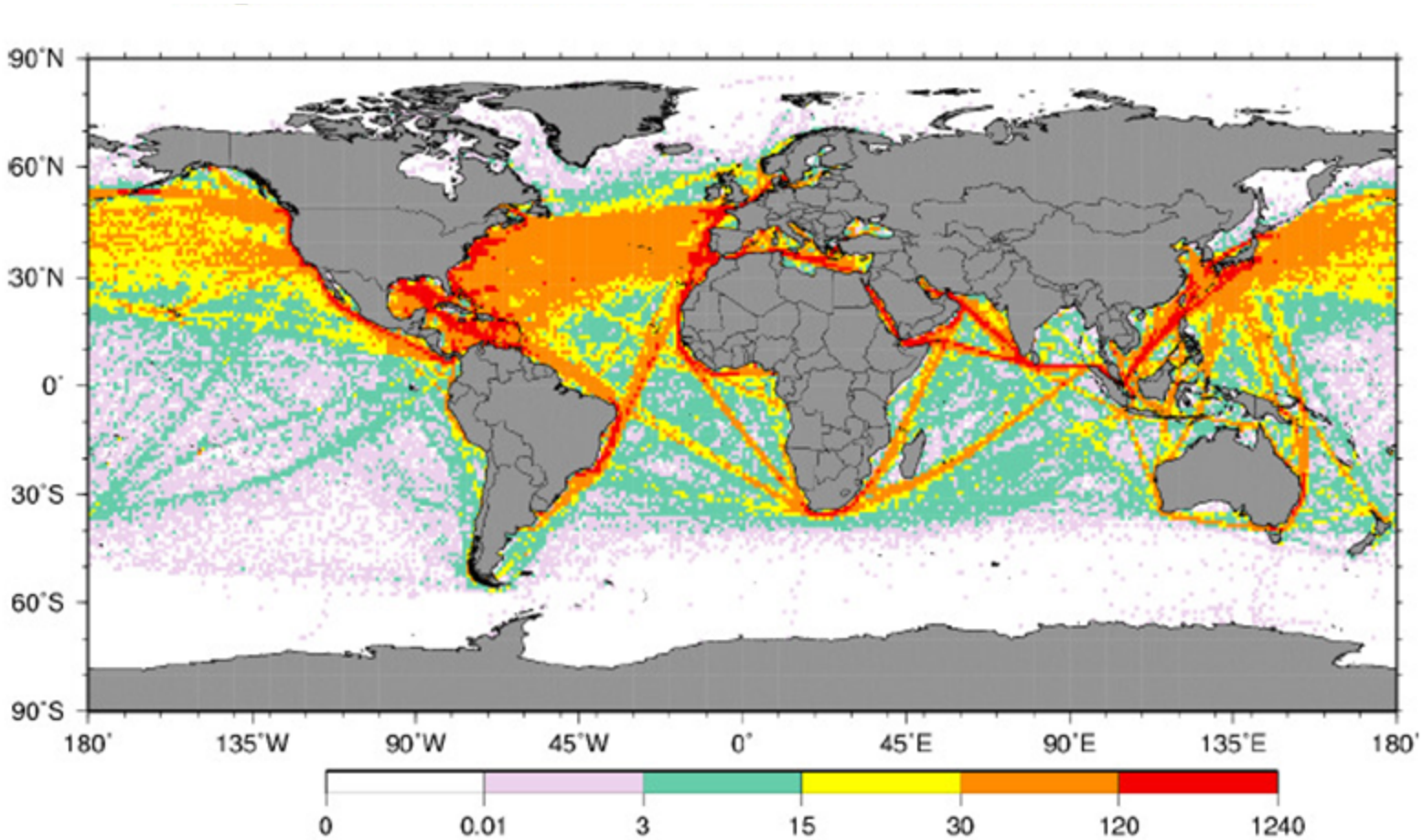
- Nevertheless **improvements** are possible

Specific emissions by transport modes (distillate vs. HFO)



Source: Swedish Network of Transport and the Environment

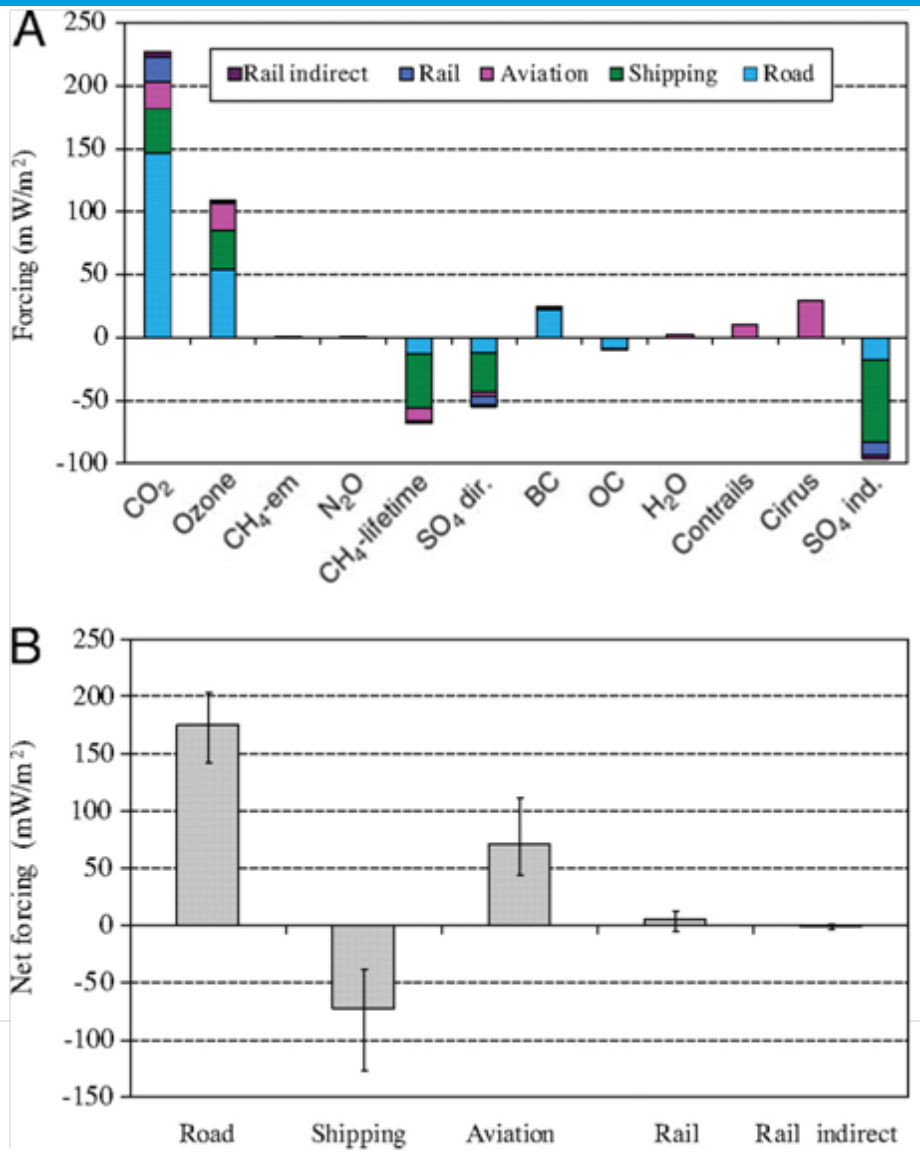
NO_X emissions from shipping worldwide distribution



NO_X Emissions from Shipping in g(NO_2)/box

Source: Ministry of Ecology, Corbett 2007, Ship Emissions: A Global Assessment

Radiative forcing since preindustrial times by substance & transport sector



(A) Global mean RF (mW/m^2) for 2000 due to transport, relative to pre-industrial times.

(B) Global mean net RF (including all components in A) for 2000 due to transport, relative to pre-industrial times, per sector. Uncertainty ranges are given for 1 SD.

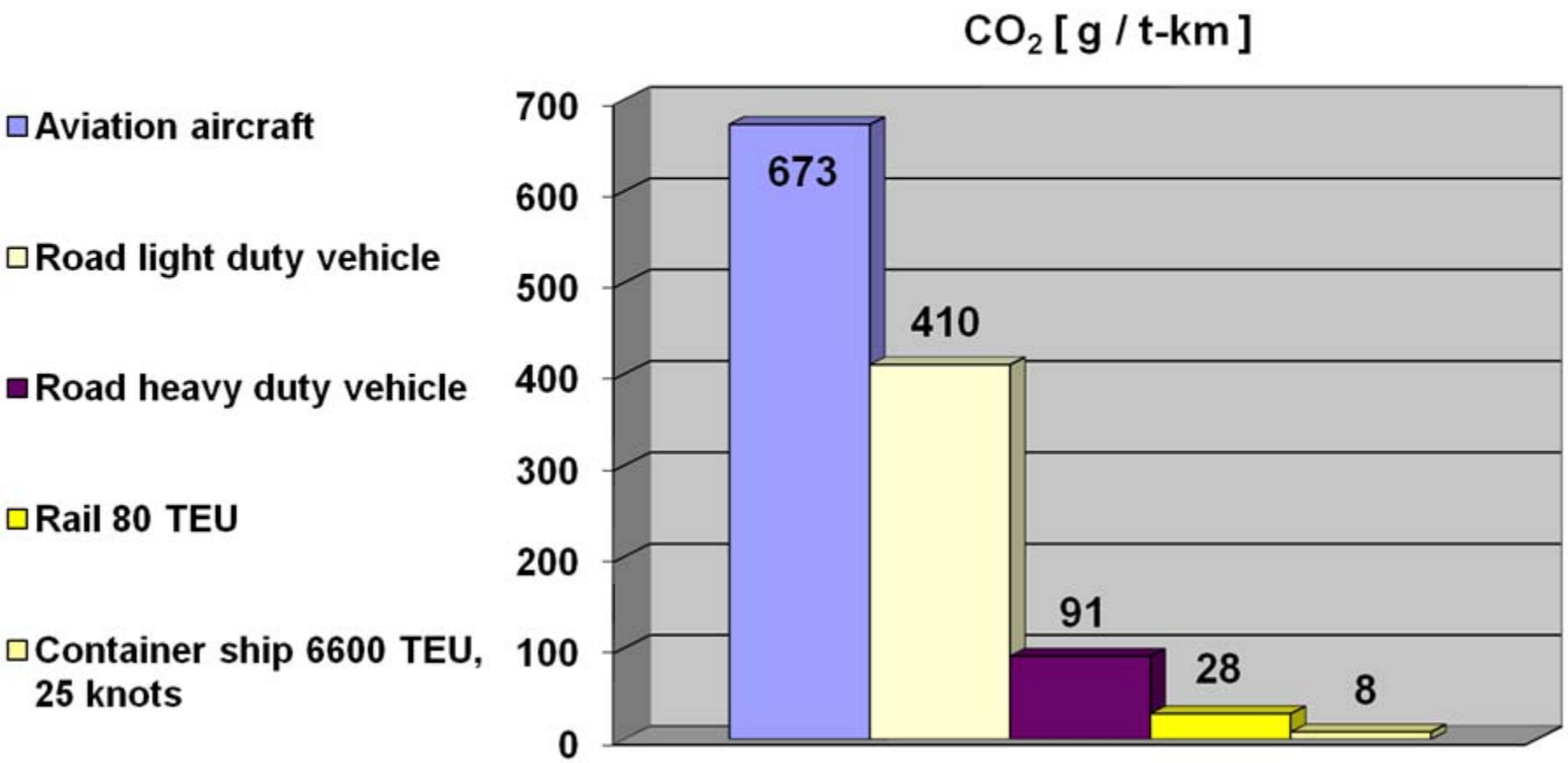
! But:

CH_4,$SO_{4\ dir/ind.}$ are short-lived substances compared to CO_2

 Fuglestvedt J. et.al. PNAS 2008;105:454-458

PNAS

CO_2 emissions by different transport modes



Source: ICS Climate change and shipping ECSA position paper, Jan 2008

CO_2 emissions

- **Today** no mandatory regulations for ships about CO_2 emissions exist
- **Future** restrictions under the Green House Gas (GHG) discussions are likely but not decided yet
- **Efficient** CO_2-reduction requires a holistic approach of the **whole** ship
  - Energy efficiency **design** index:
    Assesses the overall efficiency of the vessel design
  - Energy efficiency **operational** index:
    Assesses the overall efficiency of the ship operation
  - **Market** based instruments:
    Under controversial discussion (UNFCCC annex I vs. annex II states)

Outline

- **Marine** emission standards are either regional (e.g. US-EPA, CARB, EU, Rhine river, Norway, Sweden) or **international** (IMO)

- **This presentation** will focus on:
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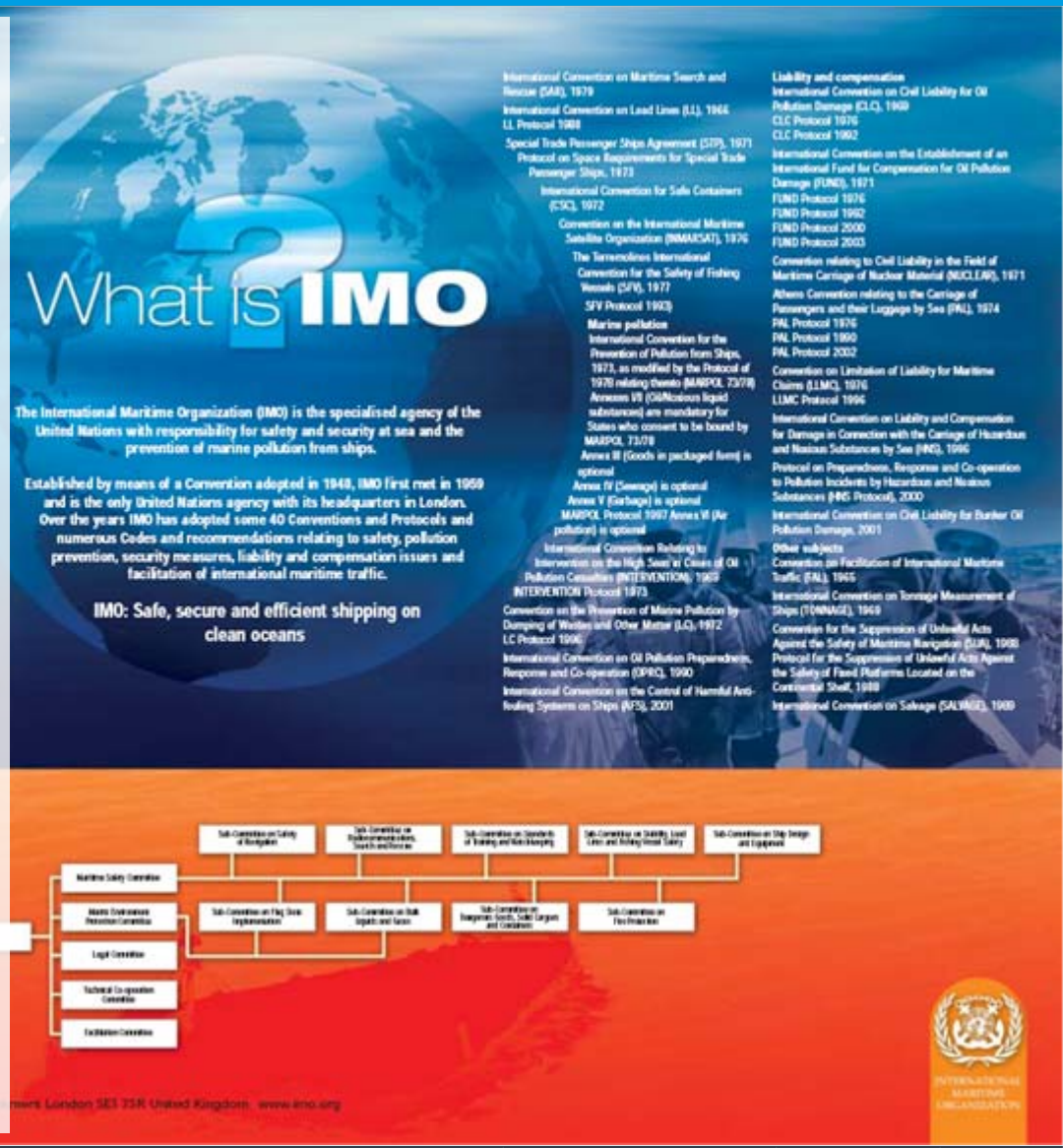
  - **IMO** general information, present international standards, and future limits

International Maritime Organization

- **Specialized** agency of the United Nations with responsibility for safety and security at sea and the prevention of maritime pollution from ships
  (**worldwide harmonized** regulations)
- IMO Convention 168 **member states**
  (ship safety regulations e.g. SOLAS)
- **MARPOL73/78** 148 member states (99% world merchant fleet)
  (ship pollution e.g. sewage, garbage, oil spill)
- MARPOL73/78 **Annex VI** actually **ratified** by 54 states covering about 83% of the world merchant fleet
  (ship air pollution e.g. NO_x SO_x)
- Organizational **structure**:
  Assembly, Council, Committee, Sub-Committee, Working-/Drafting- /Correspondence-Groups
- Working **principle**: one state = one **vote**



IMO present standards

- **NO_x– limit, Regulation 13(3) (Tier I):**
  17.0 g/kWh n < 130 rpm
  45 * n $^{-0.2}$ (130 rpm < n < 2000 rpm)
  9.8 g/kWh n >= 2000 rpm
  (01 Jan 2000, **30% reduction** compared to mid 1990ies)

- **SO_x – limit, Regulation 14:**
  worldwide fuel sulfur cap @ 4.5 wt.% S (19 May 2006) and
  SO_x-emission controlled area (SECA) @ 1.5 wt.% S or scrubber
  (e.g. Baltic Sea 19 May 2006 & North Sea + Channel 21 Nov 2007)

- **Adopted** in September 1997,
  in force since 19 May 2005
  with effective date 01 January 2000 (for NO_x)

- **Actually** 54 states covering about **83% of the world merchant** fleet have ratified the MARPOL Convention Annex VI

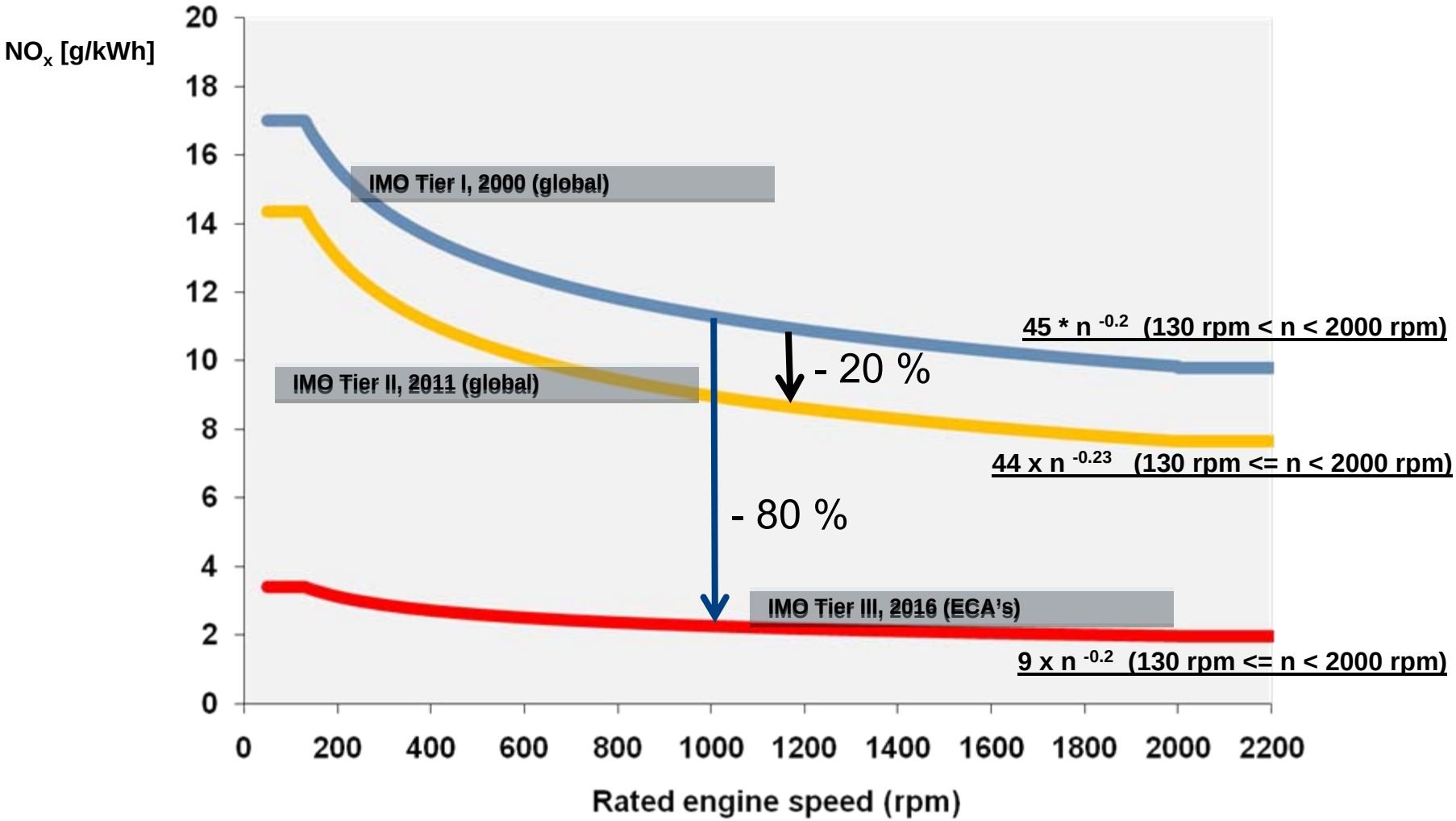
IMO future NO_x limits Tier II & III
Revised MARPOL Annex VI

- **Tier II: NO_x– limit, Regulation 13(4)**
  14.4 g/kWh n < 130 rpm
  44 x $n^{-0.23}$ (130 rpm <= n < 2000 rpm)
  7.7 g/kWh n >= 2000 rpm
  about **20% reduction** vs. Tier I

- **Tier III: NO_x– limit, Regulation 13(5):**
  3.4 g/kWh n < 130 rpm
  9 x $n^{-0.2}$ (130 rpm <= n < 2000 rpm)
  2.0 g/kWh n >= 2000 rpm
  80% reduction vs. Tier I
  only in **Emission Control Areas** (ECA), for other areas Tier II

- MEPC adoption: 09 October 2008
- Effective date IMO Tier II: **01 Jan 2011**
- Effective date IMO Tier III: **01 Jan 2016**

IMO NO_x Regulation 13



IMO SO_x Regulation 14
Revised MARPOL Annex VI

- **Global** IMO Regulations, mandatory:
  - **4.50 wt.%** S prior to 01 Jan 2012
  - **3.50 wt.%** S on and after 01 Jan **2012** and
  - **0.50 wt.%** S on and after 01 Jan **2020** (or 2025, subject to availability review)

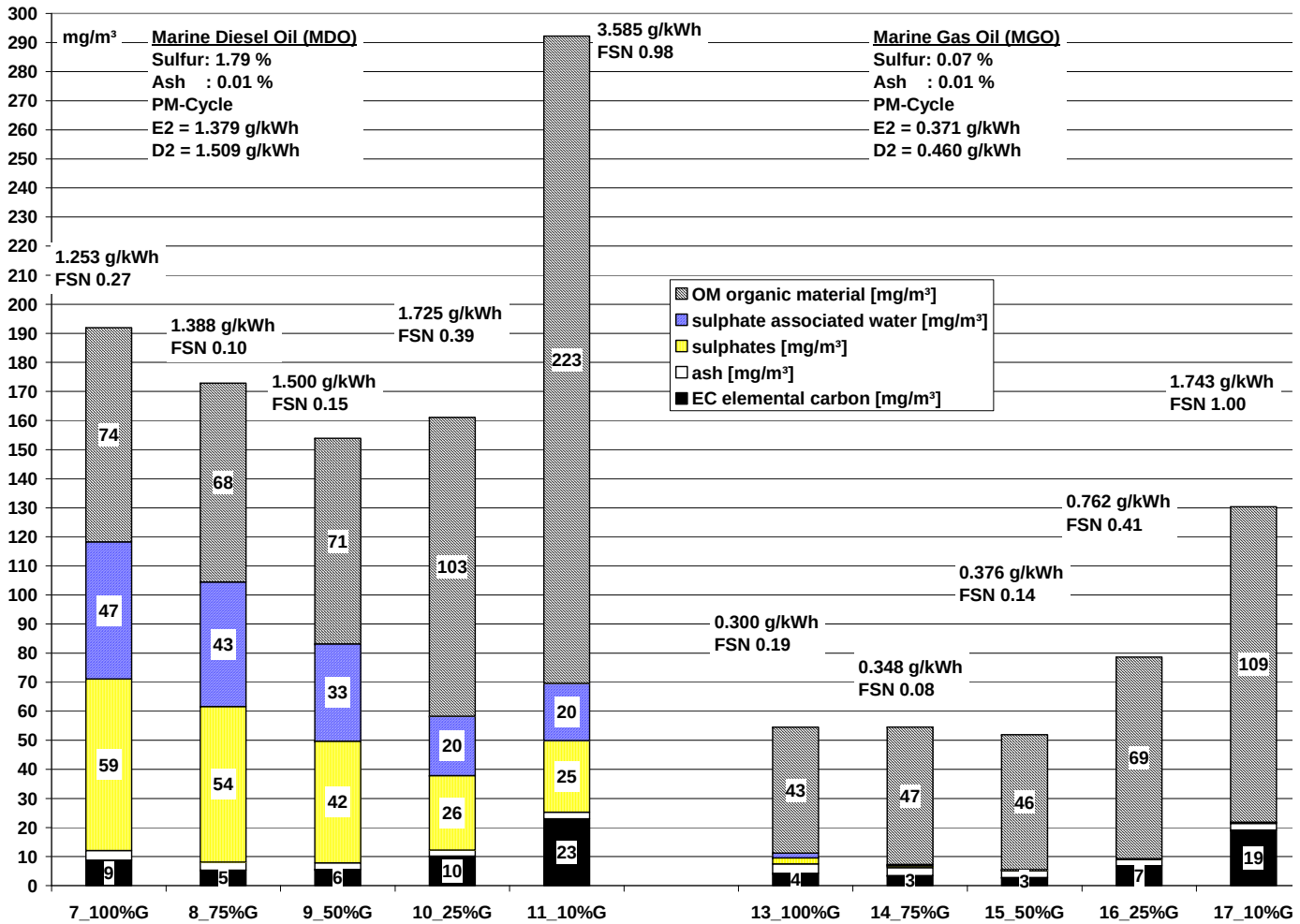
- **Emission Controlled Areas** (ECA), mandatory:
  - **1.50 wt.%** S prior to 01 July 2010
  - **1.00 wt.%** S on and after 01 July **2010** and
  - **0.10 wt.%** S on and after 01 Jan **2015**
  - Existing: Baltic Sea, North Sea & Channel
  - Expected: Black Sea, Mediterranean Sea, US Coast + Canada, Caribbean

- **Distillate** not mandatory, **alternatively** Exhaust Gas Cleaning (EGCS) allowed

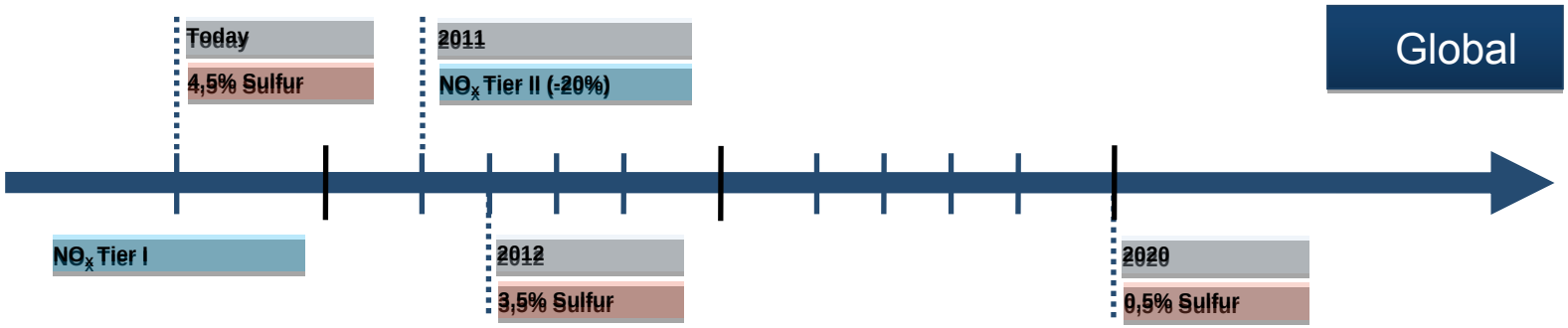
- **PM reduction** by fuel sulphur reduction, no explicit PM limits

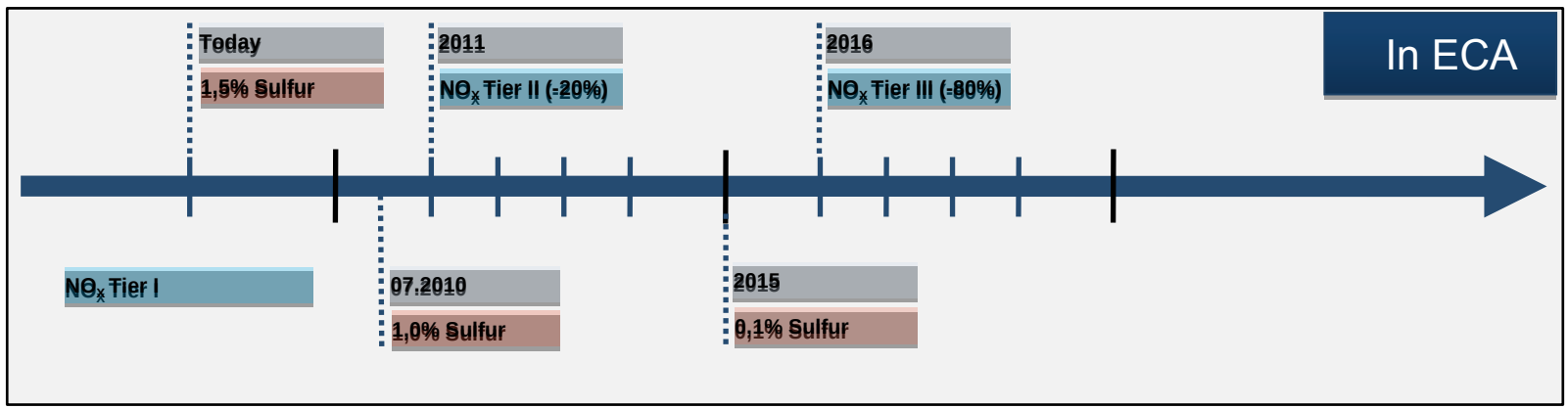
PM reduction by fuel S limitation

- **No** explicit PM limitation mandatory
- **PM reduction** by fuel sulphur reduction
- **Reduction** from e.g. 1.8% down to 0.07% sulphur results in PM reduction of about **70%**

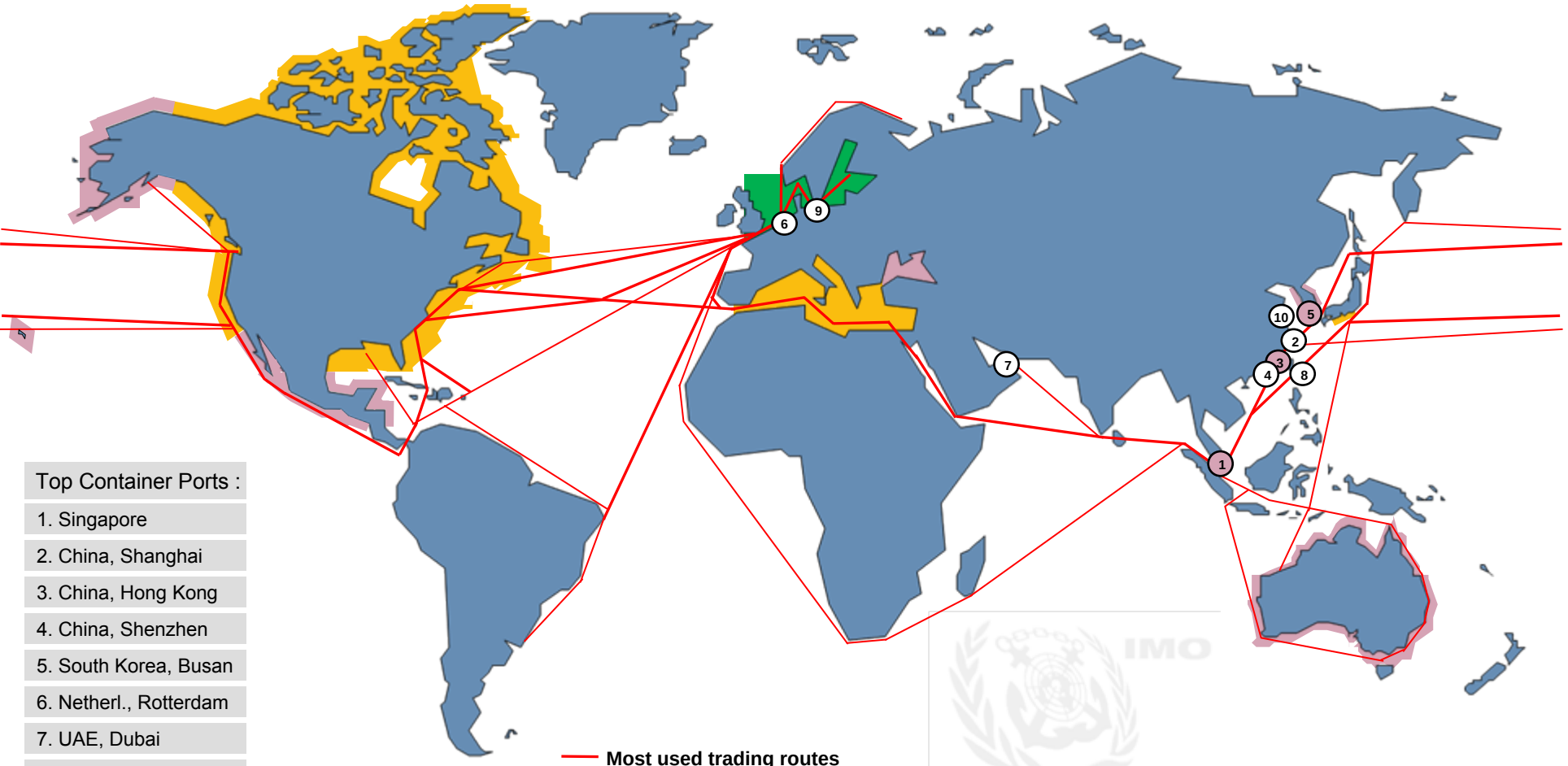


IMO Implementation Schedule
Revised MARPOL Annex VI





Emission Controlled Areas



Top Container Ports :

1. Singapore
2. China, Shanghai
3. China, Hong Kong
4. China, Shenzhen
5. South Korea, Busan
6. Netherl., Rotterdam
7. UAE, Dubai
8. Taiwan, Kaohsiung
9. Germany, Hamburg
10. China, Qingdao

IMO Consequences

Expected long term ship emission reductions due to Revised MARPOL Annex VI

	Global	ECA
NO_x	15 – 20 %	80 %
SO_x	80 %	96 %
PM	73 %	83 %

Source: Second IMO GHG Study 2009, International Maritime Organization London UK, April 2009, Buhaug et al.

Abbreviations

- **IMO:** International Maritime Organization (United Nations Agency) http://www.imo.org
- **MEPC:** Marine Environmental Protection Committee
- **MARPOL:** International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978
- **Annex VI:** Regulations for the Prevention of Air Pollution from Ships
- **EIAPP** Engine International Air Pollution Prevention Certificate
- **ECA:** Emission Control Area
- **HFO:** Heavy Fuel Oil
- **GHG:** Green House Gases
- **EGCS:** Exhaust Gas Cleaning System
- **UNFCCC:** United Nations Framework Convention on Climate Change
- **US-EPA:** United States Environmental Protection Agency
- **NGO:** Non Governmental Organization

References

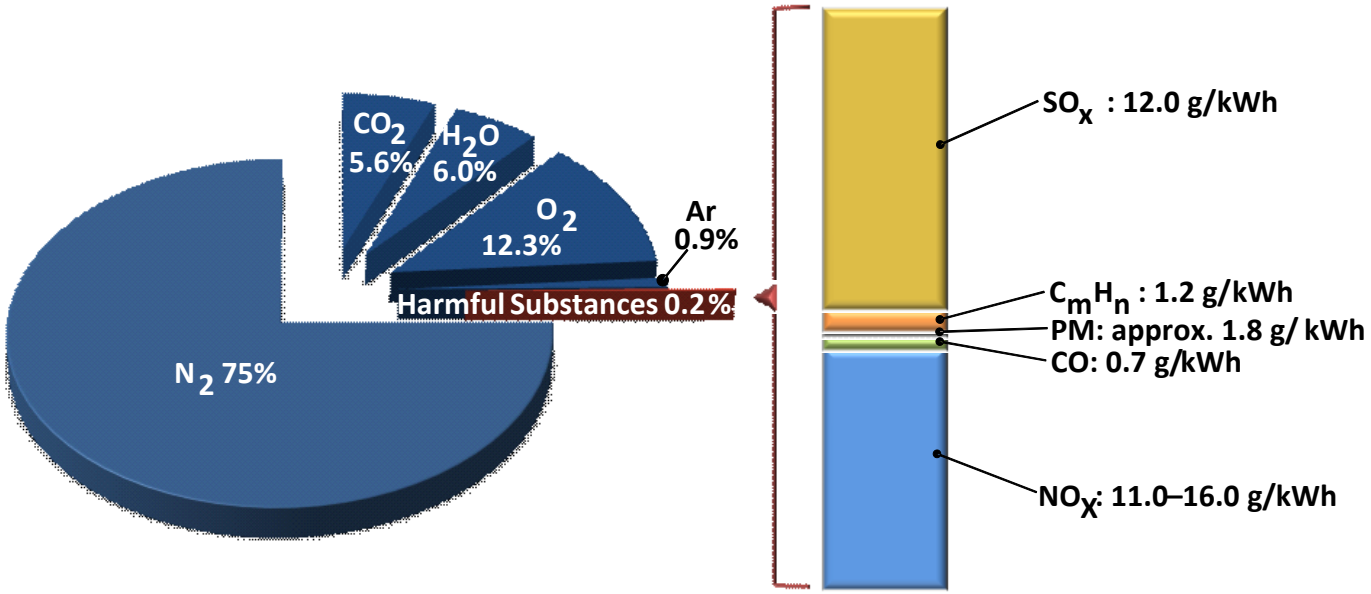
- PNAS The National Academy of Sciences of the USA, Fuglestvedt J. et al. , 2008; 105: 454-458
- Lloyd's Register Fairplay database, 2007
- Second IMO GHG Study 2009, International Maritime Organization London UK, 9th April 2009, Buhaug et al.
- BP oil products
- Swedish Network of Transport and the Environment
- Ministry of Ecology, Corbett 2007, Ship Emissions: A Global Assessment
- ICS Climate change and shipping ECSA position paper, Jan 2008

Thank you for your attention!

Backup

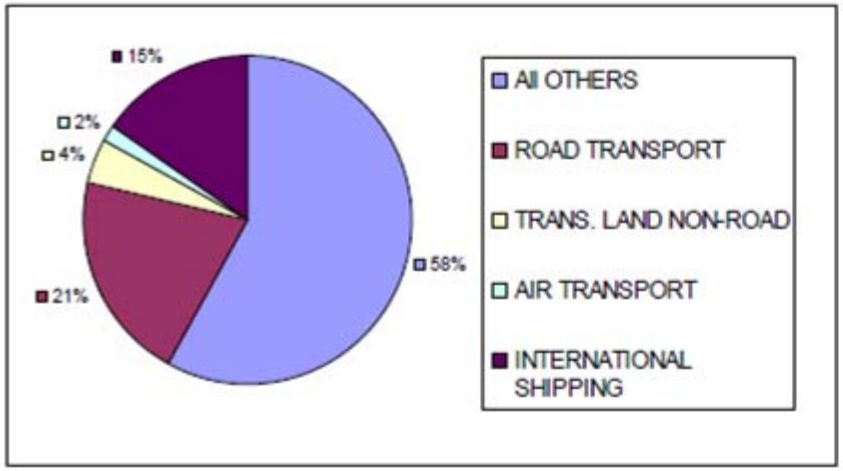
Emissions and ships contribution

- **Exhaust** gas composition of HFO operated 4-stroke Diesel engines
- **Fuel** sulphur content 3 % m/m



NO_x & SO_2 emissions

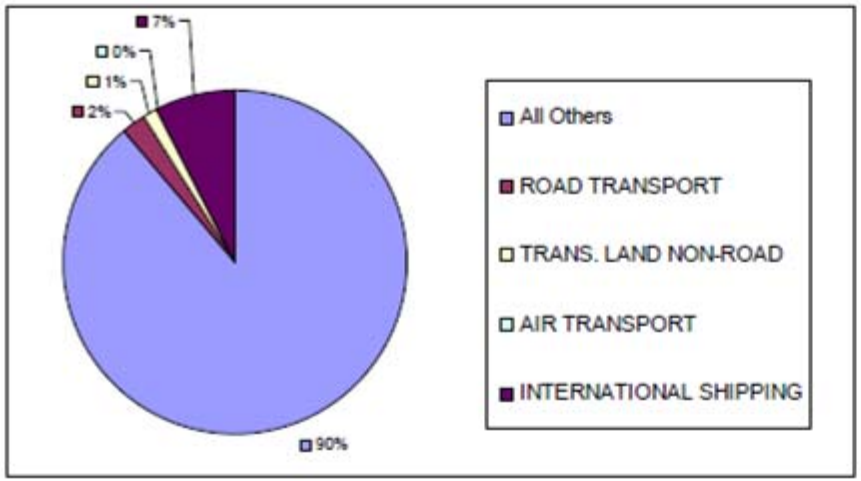
Anthropogenic NO_x and SO_2 emissions in 2000



Anthropogenic NO_x Emissions 2000

from EDGAR 32FT2000

Total 138.336 Gg(NO_2)



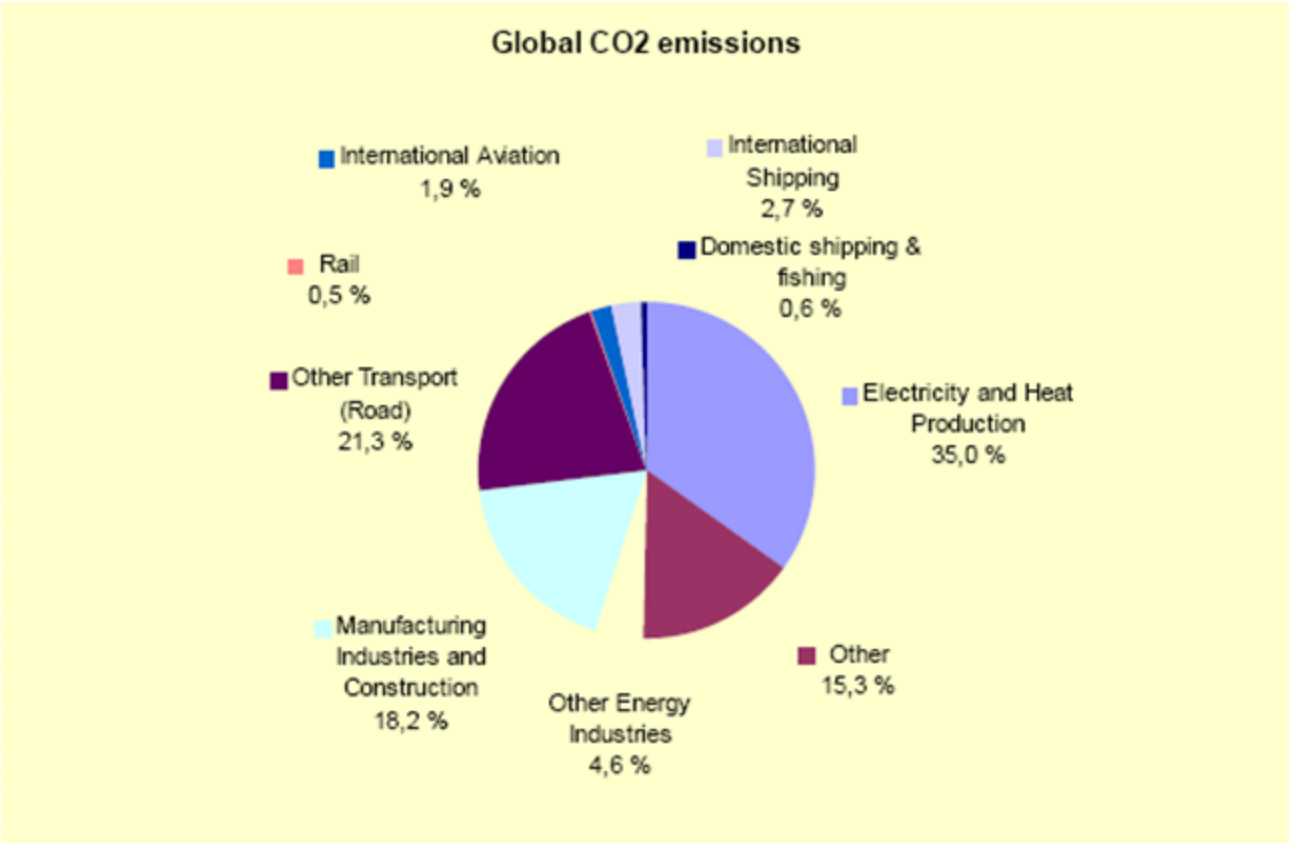
Anthropogenic SO_2 Emissions 2000

from EDGAR 32FT2000

Total 154.526 Gg(SO_2)

http://edgar.jrc.it

CO_2 emissions



Source: Second IMO GHG Study 2009, International Maritime Organization London UK, April 2009, Buhaug et al.

Ship efficiency

- **Expected GHG emission reduction 25 - 75% by ship efficiency increase through technical and operational measures**

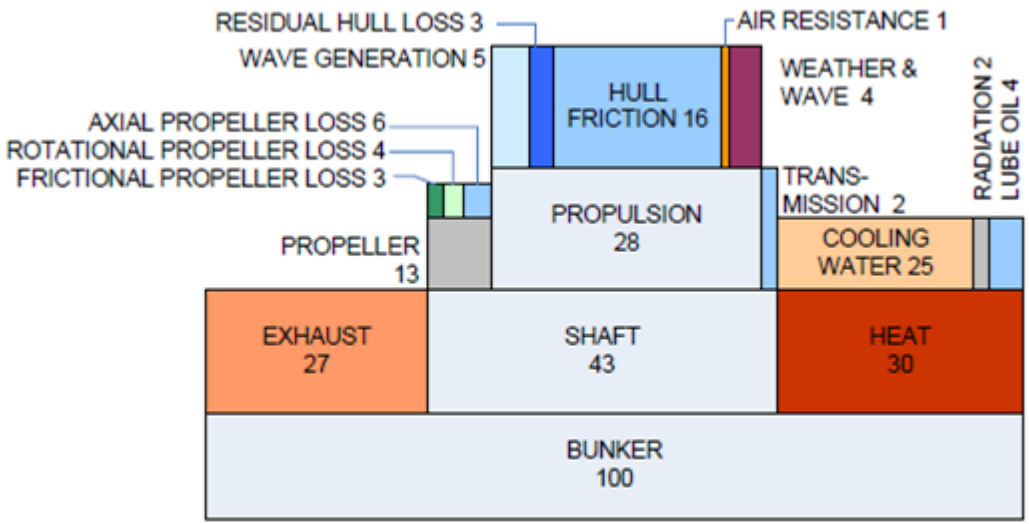
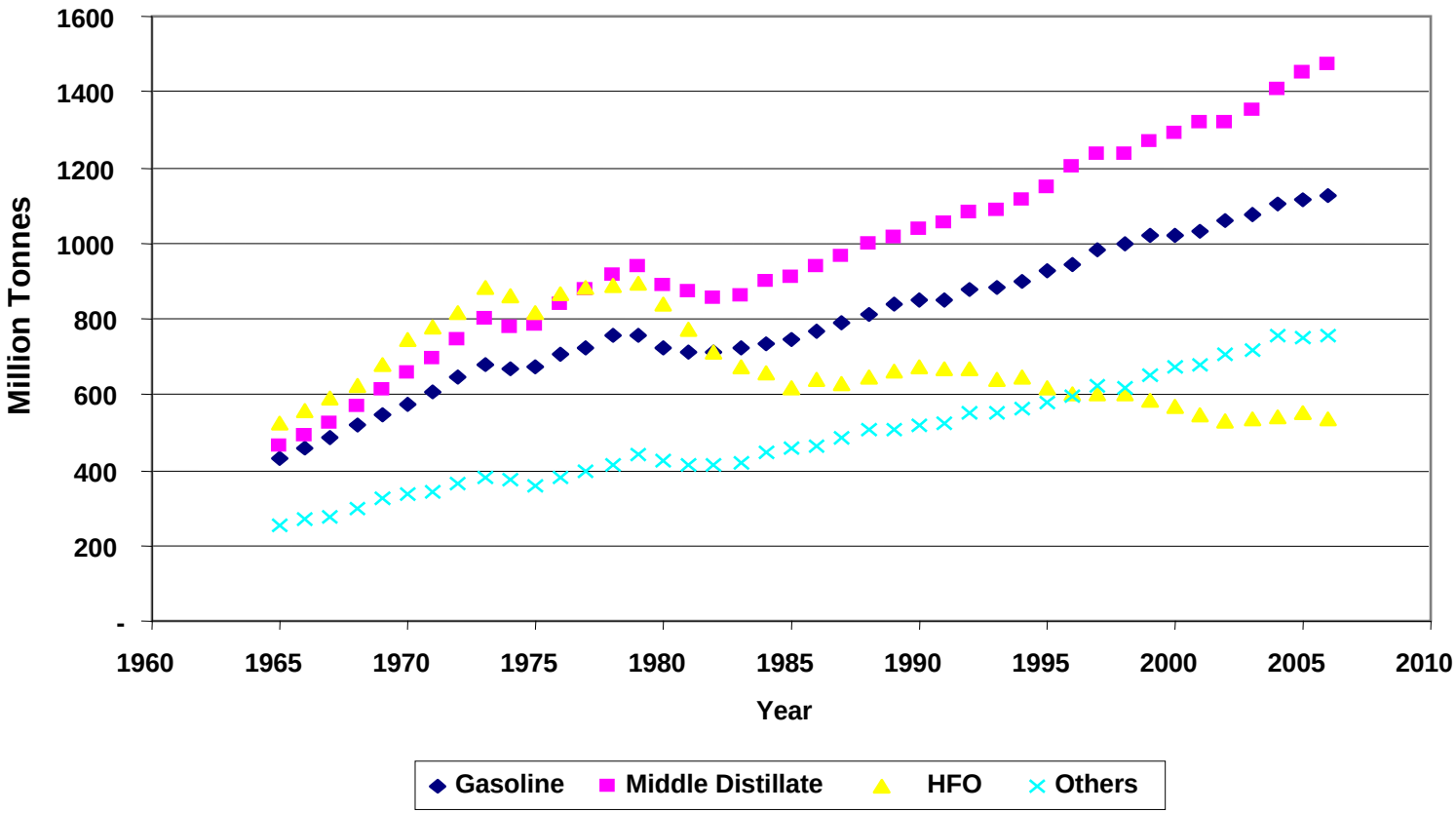


Figure A2-1 – Use of propulsion energy on board a small cargo ship, head sea, Beaufort 6

Source: Second IMO GHG Study 2009, International Maritime Organization London UK, April 2009, Buhaug et al.

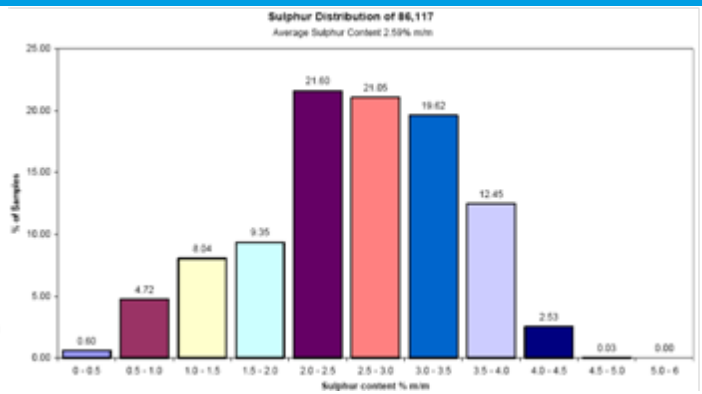
Oil products - worldwide



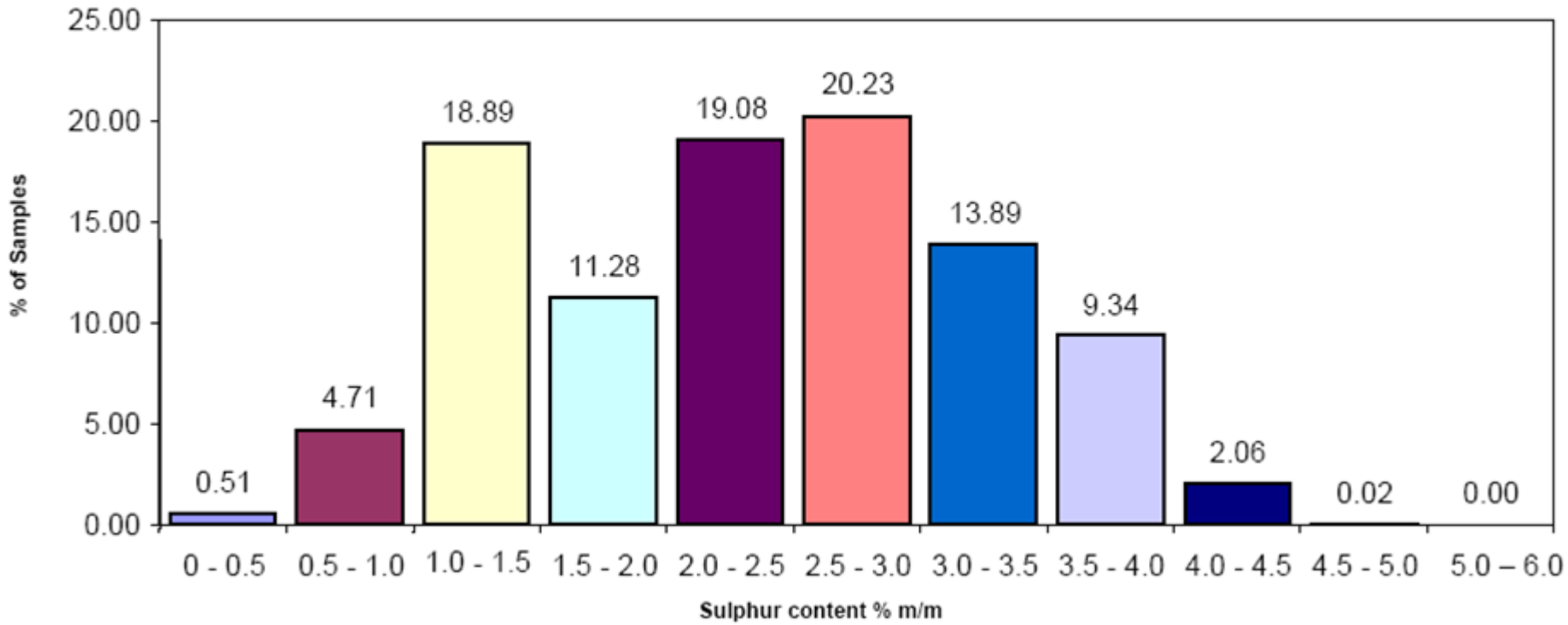
Source: BP

Quality of fuel oil for ships
MEPC 59/4/1 as of 3 Feb. 2009

Sulphur **monitoring** 2008 vs. 2006



Sulphur **distribution** of 106,925 samples
representing 97,600,555 tonnes of fuel oil

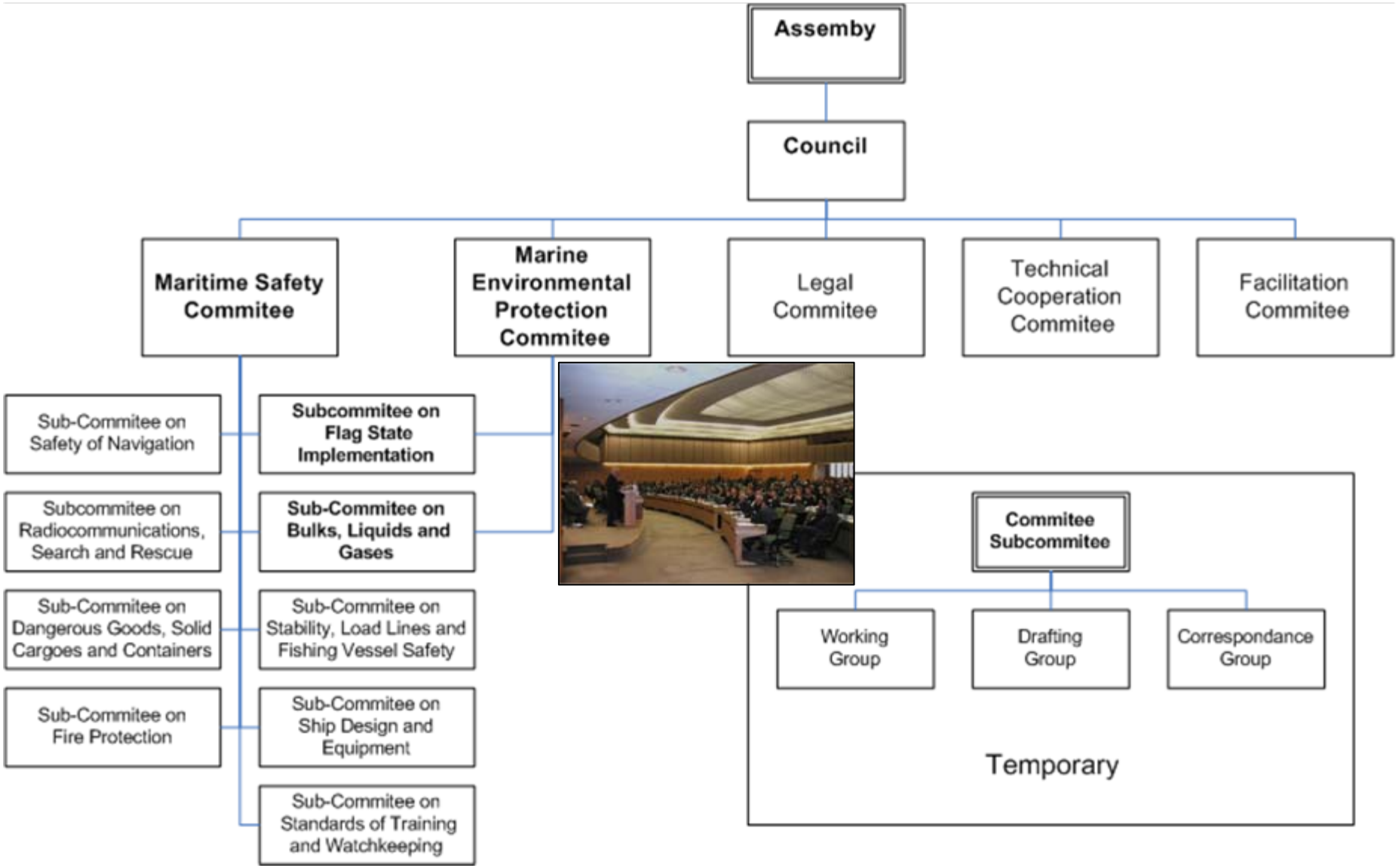


Quality of fuel oil for ships
MEPC 59/4/1 as of 3 Feb. 2009

Sulphur monitoring programme 1999-2008

Year	Document reference	Corresponding quantity of residual fuel oil (tonnes)	Number of samples tested	Tonnes per bunkering	Average sulphur content
1999	MEPC 45/INF.12	47,000,000 tonnes	53,000	886	2.7%
2000	MEPC 47/INF.2	49,000,000 tonnes	54,000	907	2.7%
2001	MEPC 48/INF.4	56,000,000 tonnes	62,000	903	2.7%
2002	MEPC 49/4/1	59,000,000 tonnes	63,000	936	2.6%
2003	MEPC 52/4/8	67,395,141 tonnes	66,958	1006	2.7%
2004	MEPC 53/4	74,408,066 tonnes	66,312	1122	2.7%
2005	MEPC 55/4/1	82,436,438 tonnes	79,592	1035	2.7%
2006	MEPC 56/4	86,857,565 tonnes	86,117	1008	2.59%
2007	MEPC 57/4/24	92,757,373 tonnes	97,172	954	2.42%
2008	**MEPC 59/4**	**97,600,555 tonnes**	**106,925**	**913**	**2.37%**

Structure of the IMO



Working principle

States (1 vote) & **non governmental organizations** (NGO) (consultative, nonvoting)

Assembly:

- **Adopts** new conventions (**75%** consensus) → national ratification

Committee:

- **Adopts** annexes & amendments (**>50%** consensus) → national ratification

Sub-committee:

- **Develops** draft for annexes & amendments, works in close collaboration between states and NGO's

Working- / Drafting- / Correspondence-Groups:

- Installed by (sub-) committee according to **defined terms of references** to **elaborate** matters of technology / limits / competence / applicability / details / draft text / delivers background information / collects sentiments, works in close collaboration between states and NGO's

States & NGO's

168 states ministerial delegations, supported by consultants, e.g. Germany:

- Ministry of Transport (BMVBS)
- Consultants: GL, SeeBG, UBA, VdR, VSM
- Delegation (**1 vote**) approx. 2 - 20 persons, but European Commission may dictate how to vote

approx. 65 NGO's, e.g.:

- Friends Of The Earth International (FOEI), Greenpeace International
- International Organization for Standardization (ISO)
- International Association of Classification Societies (IACS)
- Oil Companies International Marine Forum (OCIMF)
- Association of European Manufacturers of Internal Combustion Engines (EUROMOT)
- Delegation (**nonvoting**) approx. 1-3 persons

US-EPA

- **United States Environmental Protection Agency emission limits: US-EPA 40 CFR Parts 94 and others, Control of emissions of air pollution from locomotive engines and marine compression-ignition engines less than 30 liters per cylinder; Final Rule, Federal Register Vol. 73 No 88, May 06 2008**

- **Applicable for all US flagged vessels**

US EPA Tier 2 present standard

Category	Swept volume / cyl.	NO_x + HC	CO	PM	Year
1	<0.9 and >=37kW	7.5	5.0	0.4	2005
1	0.9 - <1.2	7.2	5.0	0.3	2004
1	1.2 - <2.5	7.2	5.0	0.2	2004
1	2. 5 - <5	7.2	5.0	0.2	2007
2	5 - <15	7.8	5.0	0.27	2007
2	15 - <20 and <3300kW	8.7	5.0	0.5	2007
2	15 - <20 and >=3300kW	9.8	5.0	0.5	2007
2	20 - <25	9.8	5.0	0.5	2007
2	25 - <30	11.0	5.0	0.5	2007
3	>=30	NO_x = IMO	-	-	2007

US EPA Tier 3

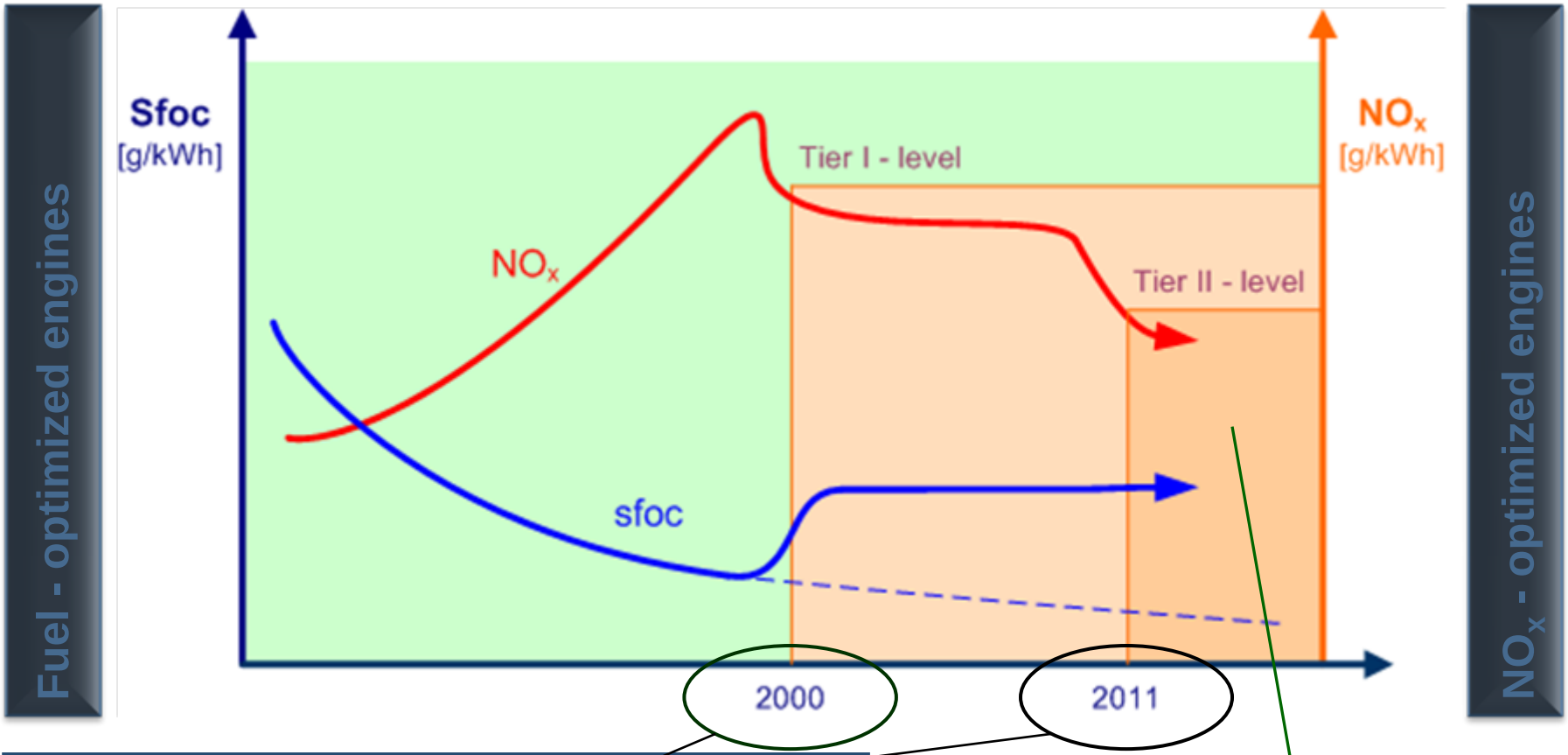
Category	Swept volume / cyl.	NO_x + HC	CO	PM	Year
1	<0.9 and >=75kW	5.4	5.0	0.14	2012
1	0.9 - <1.2	5.4	5.0	0.12	2013
1	1.2 - <2.5	5.6	5.0	0.11	2014
1	2. 5 - <3.5	5.6	5.0	0.11	2013
1	3. 5 - <7.0	5.8	5.0	0.11	2012
2	7.0 - <15	6.2	5.0	0.14	2013
2	15 - <20 and <3300kW	7.0	5.0	0.34	2014
2	15 - <20 and >=3300kW and <3700kW	7.0	5.0	0.27	2014
2	20 - <25 and <3700kW	9.8	5.0	0.27	2014
2	25 - <30 and <3700kW	11.0	5.0	0.27	2014

US EPA Tier 4

- **Applicable for all (Category 1 and 2 engines) <30 liters/cyl.**

Category	Swept volume / cyl.	NO_x	HC	CO	PM	Year
600<1400kW	All	1.8	0.19	5.0	0.04	2017
1400<2000kW	All	1.8	0.19	5.0	0.04	2016
2000<3700kW	All	1.8	0.19	5.0	0.04	2014
>=3700kW	<15	1.8	0.19	5.0	0.12	2014
>=3700kW	15 - <30	1.8	0.19	5.0	0.25	2014
>=3700kW	All	1.8	0.19	5.0	0.06	2016

The Diesel Dilemma



Achieved through changes in:

Injection	Combustion	Supercharging
- Timing + VIT	- Charge air pressure	Valve timing -
- Spray pattern	- Compression Ratio	
-	Turbo charging eff.	
-	Inter cooling	

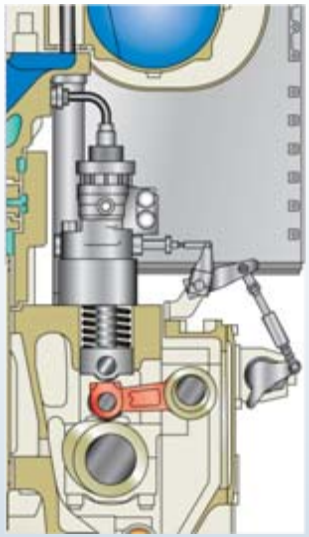
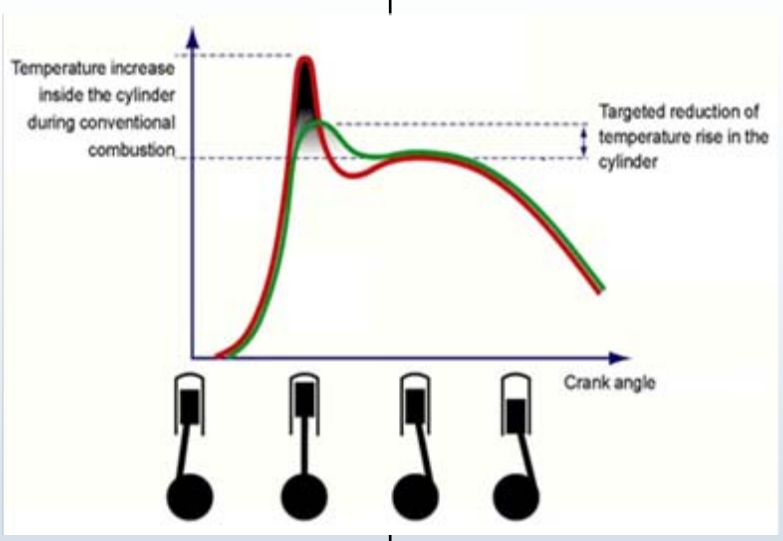
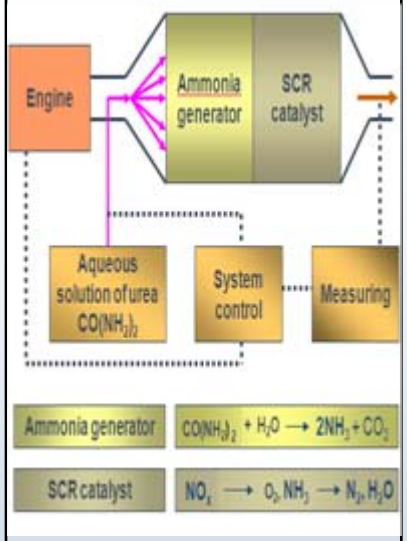
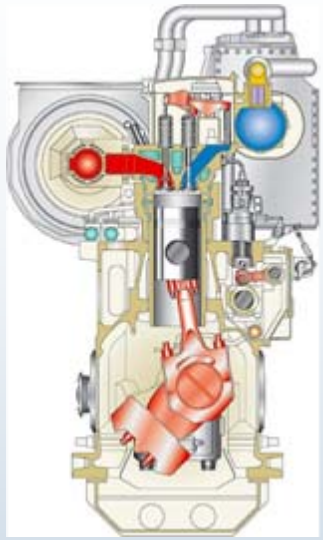
Future measures:

- Miller Process
- Variable Valve Timing + Variable Turbine Area
- Injection Rate Shaping
- 2-stage- and Sequential Turbo charging

IMO Tier II & III Consequences

- **Consequences Tier II**
  - **Required NO_x-reduction achievable with internal measures**
- **Consequences Tier III**
  - **At present knowledge only with SCR achievable**
  - **Switch to low sulphur fuel required**
  - **Certain exhaust gas temperatures required for SCR operation**
  - **Alternatively Dual Fuel engine in gas mode**

Reduction technologies 4-stroke

Internal measures	FWE (Fuel-Water-Emulsification)	HAM (Humid-Air-Motor)	SCR (Selective Catalytic Reduction)	Conversion into Dual fueled engine
				
Working principle				
Variation of changes in: • **Combustion Process** • **Fuel Injection** • **Turbo charging** **-> NO_x-optimized engine configuration**	**Water from injected emulsion evaporates during combustion:** **-> Reduced combustion temp.** **-> Improved fuel spraying**	**Humidification of the scavenge air increases inert gas fraction/heat capacity and lowers oxygen content:** **-> Slower combustion** **-> Reduced combustion temp.**	**Chemical reactor in exhaust line:** **-> Treatment of exhaust gas after engine**	**Implementation of fuel flexibility to burn either natural gas or HFO:** **->Clean combustion of natural gas**

Potential of NO_x Reduction Technologies