Emissions

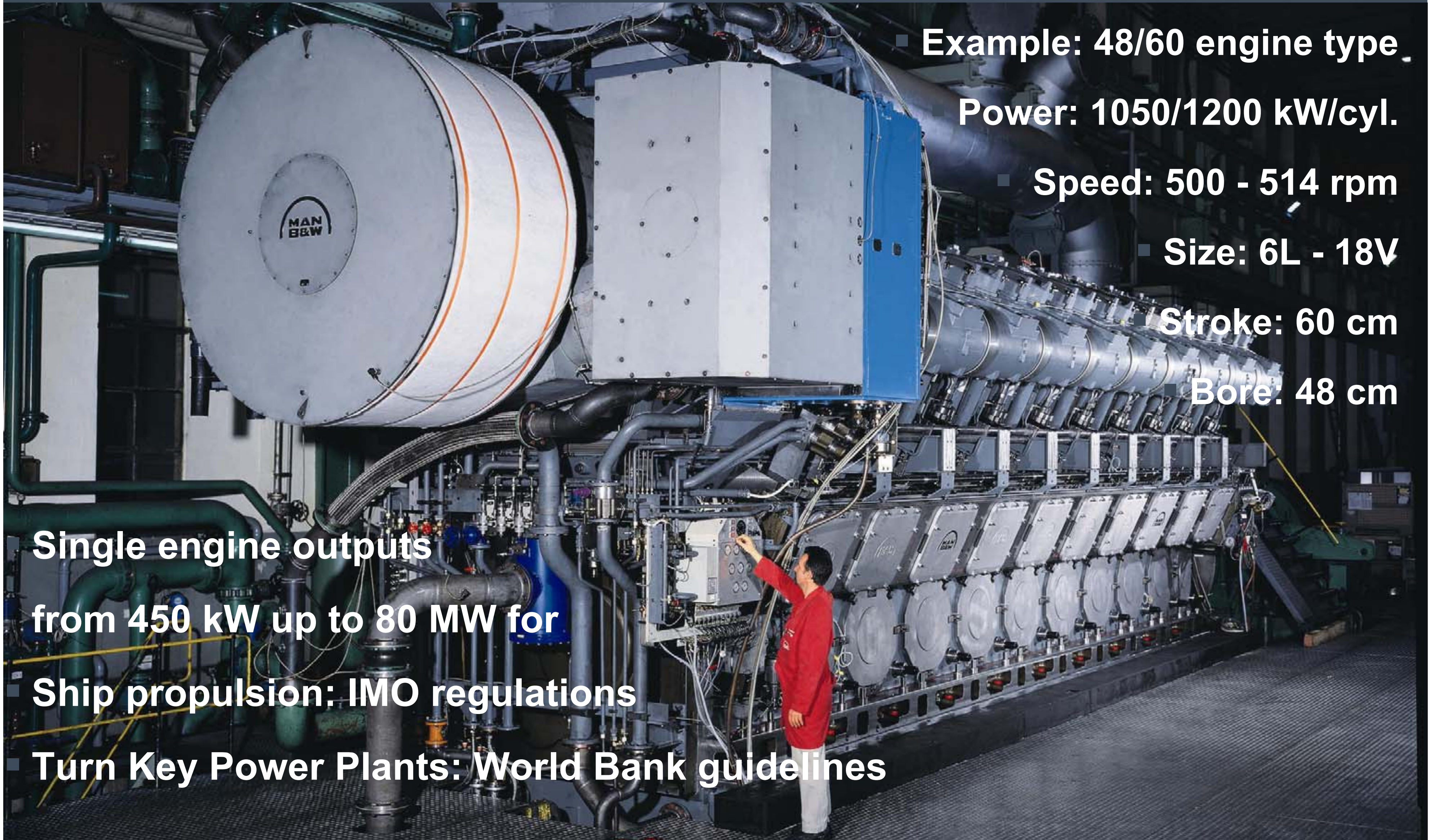
World-Bank and IMO

for large 4-stroke Diesel engines

Outline

- **Engine specifications and applications**
- Current applicable standards IMO & World Bank
- NO_x Emission reduction potential
- Future IMO and World Bank standards
- Fuel oil quality

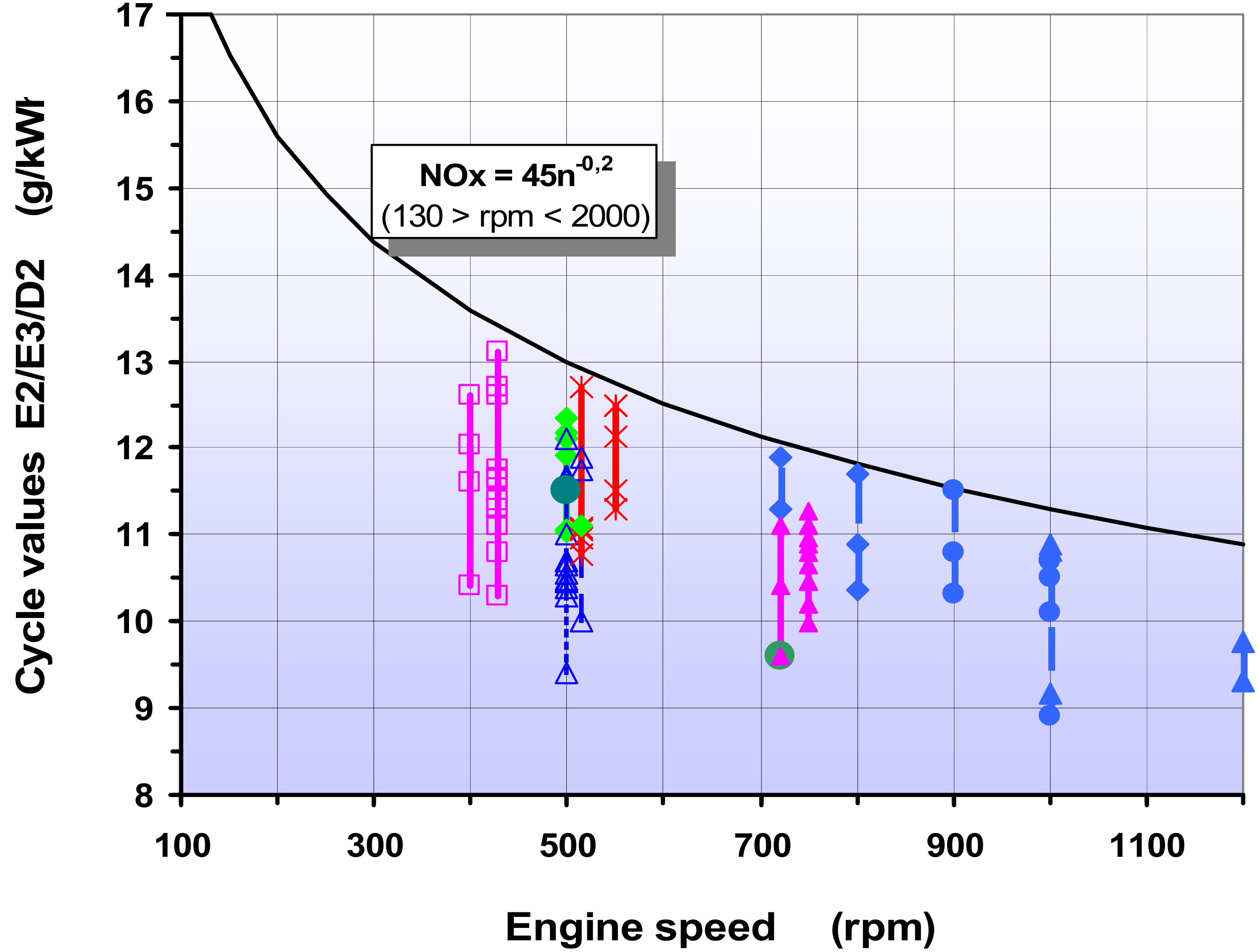
Engine specification & application



- Example: 48/60 engine type
- Power: 1050/1200 kW/cyl.
- Speed: 500 - 514 rpm
- Size: 6L - 18V
- Stroke: 60 cm
- Bore: 48 cm

- Single engine outputs from 450 kW up to 80 MW for
- Ship propulsion: IMO regulations
- Turn Key Power Plants: World Bank guidelines

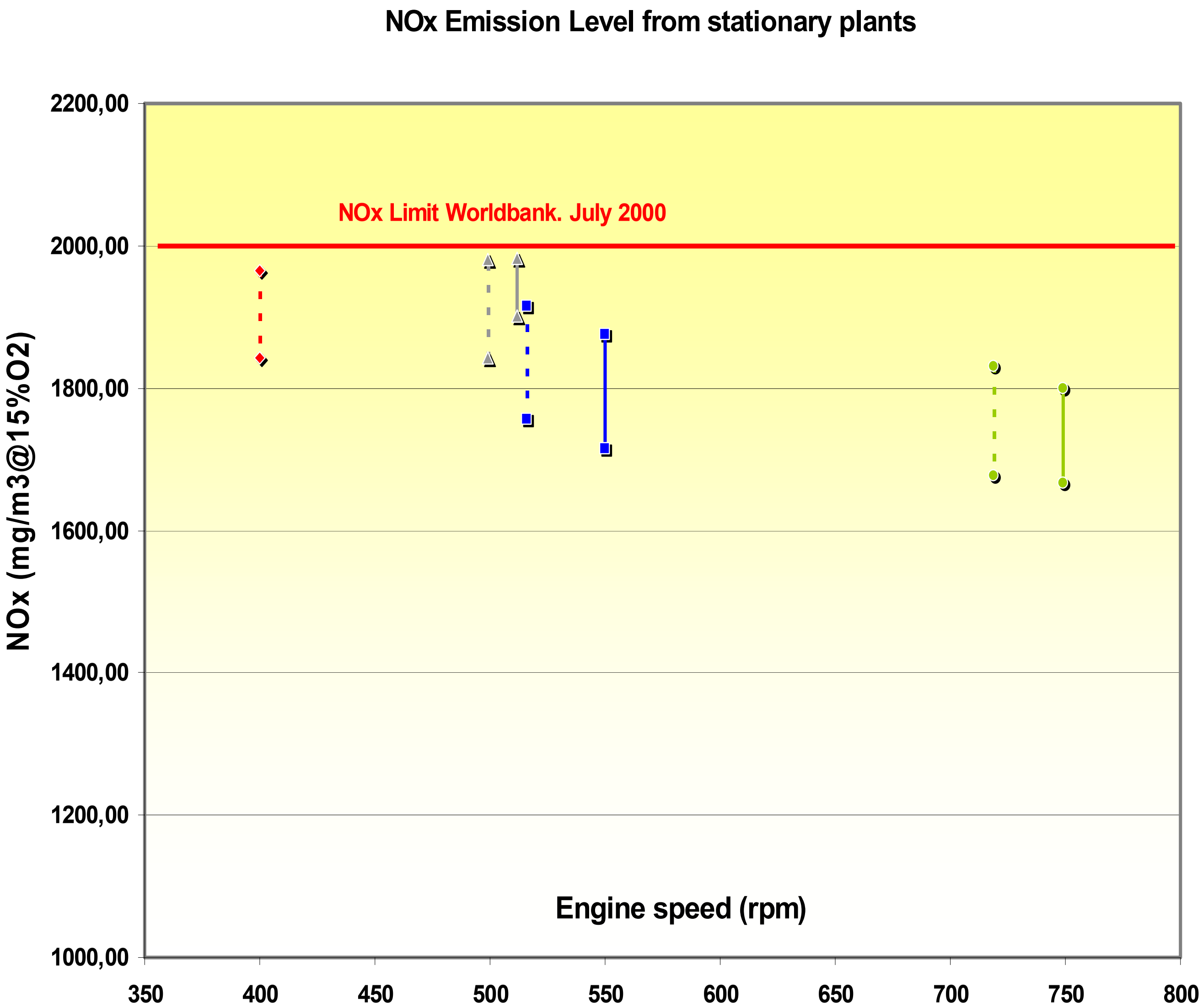
Marine engines: NO_x vs. IMO Tier1



Boundary conditions

- Distillate Test Fuel
- Correction for ambient conditions
- Cycle values
- Units: g/kWh
- 13 g/kWh equiv. to 1800 mg/Nm³@15%O_2

Stationary engines: NO_x vs. World Bank



Boundary conditions

- Actual Fuel
- At site conditions
- High load operation
- Units:

  mg/Nm³@15%O_2

Considerations for NO_x Reduction

For current IMO and WB limits: fuel system modification and increase in specific fuel oil consumption (SFOC)

Potential of NO_x reducing measures for future limits:

- Internally:

  Miller cycle, high compression ratio, high charge air and firing pressures, variable valve timing, common rail injection
  Depending on NO_x-reduction level: increase in SFOC + reduction of output
  With today‘s SFOC, T/C performance, and output of stationary engines from 2011 a NO_x-reduction is possible by:

2-stroke	10 – 15 %
4-stroke HFO design	up to 20 %
4-stroke distillate design	20 – 25 %

- Additional measures possible if site conditions allow and at increased invest and operating cost:

Fuel water emulsion (FWE)	15 – 25 %
Air Humidification (limited to available heat and water)	40 – 60 %
SCR (limited to low-sulfur fuel use)	80 – 85 %

NO_x emission limits current and future

- With <u>residual</u> fuel:

World Bank (July 2000):		2000 mg/Nm³@15%O_2
IFC/WB new EHSG:		1850 mg/Nm³@15%O_2

- With <u>distillate</u> fuel and <u>reference conditions</u>:

IMO Tier1 (2000) 48/60	12.91 g/kWh ~	1790 mg/Nm³@15%O_2
IMO Tier2 (2011) 48/60	10.47 g/kWh ~	1450 mg/Nm³@15%O_2

- For IMO Tier3 (2016) 48/60 2.58 g/kWh ~ 360 mg/Nm³@15%O_2 an environmental quality need driven approach which requires a low sulfur fuel and SCR is foreseen for sensitive coastal areas and harbors only.

<u>Note</u>

IMO: reference fuel / reference condition

World Bank: site conditions

15 – 25 % NO_x difference between DM-grade (distillate) and RM-grade (residual) fuel.

Quality of fuel oil for power plants I

Country	Average sulfur content
	[%]
India	3.01
Cuba	3.00
Dominican Republic	2.20
Egypt	2.57
Guatemala	2.06
Pakistan	2.59
Sudan	2.26
El Salvador	2.00
China	2.96
Vietnam	2.80

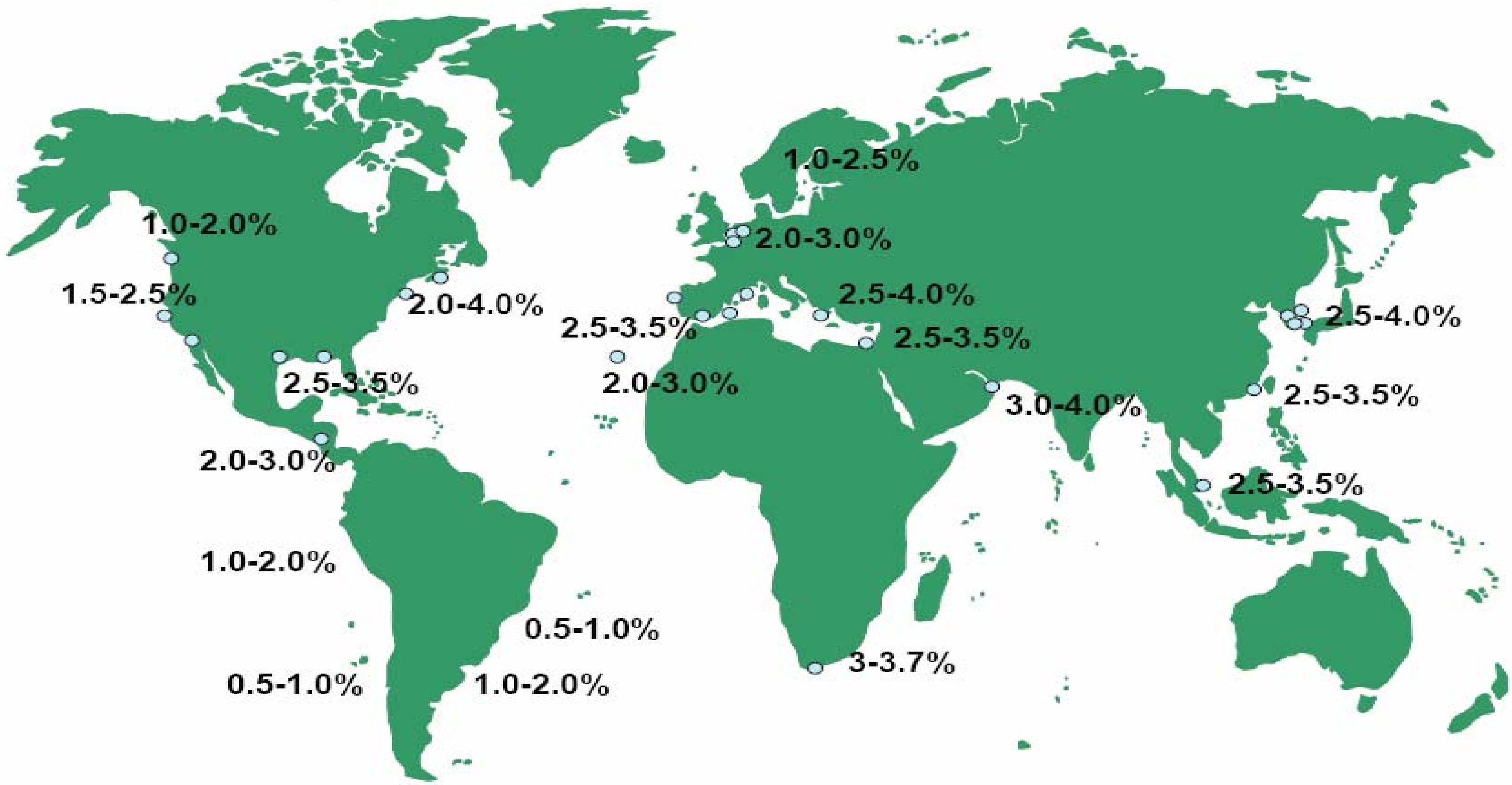
Quality of fuel oil for power plants II

Country	Average sulfur content
USA, Canada, Iceland (Diesel)	<0.1
Spain	1.0 (prior 2.0 – 3.0)
Portugal	1.0 (prior 3.0)
Turkey	3.0 – 5.0
Israel	1.0
Lebanon	0.5 – 1.5
Belarus, Kazakhstan, Moldavia, Ukraine, Serbia and south of Russia	up to 3.5
Mauritania	2.0
Kuwait (Diesel)	0.1 – 0.5
Romania (Diesel)	0.03

Note: **Diesel (distillate fuel) may contain up to 2 % S according to ISO-8217**

Quality of fuel oil for stationary power plants

Worldwide HFO sulphur levels (all suppliers)



Chevron 2005 DOC ID 11

"Low sulphur fuel oil, Product availability, supply and concerns"; Monique Vermeire Bergen, Norway 10 October 2005, Chevron seminar

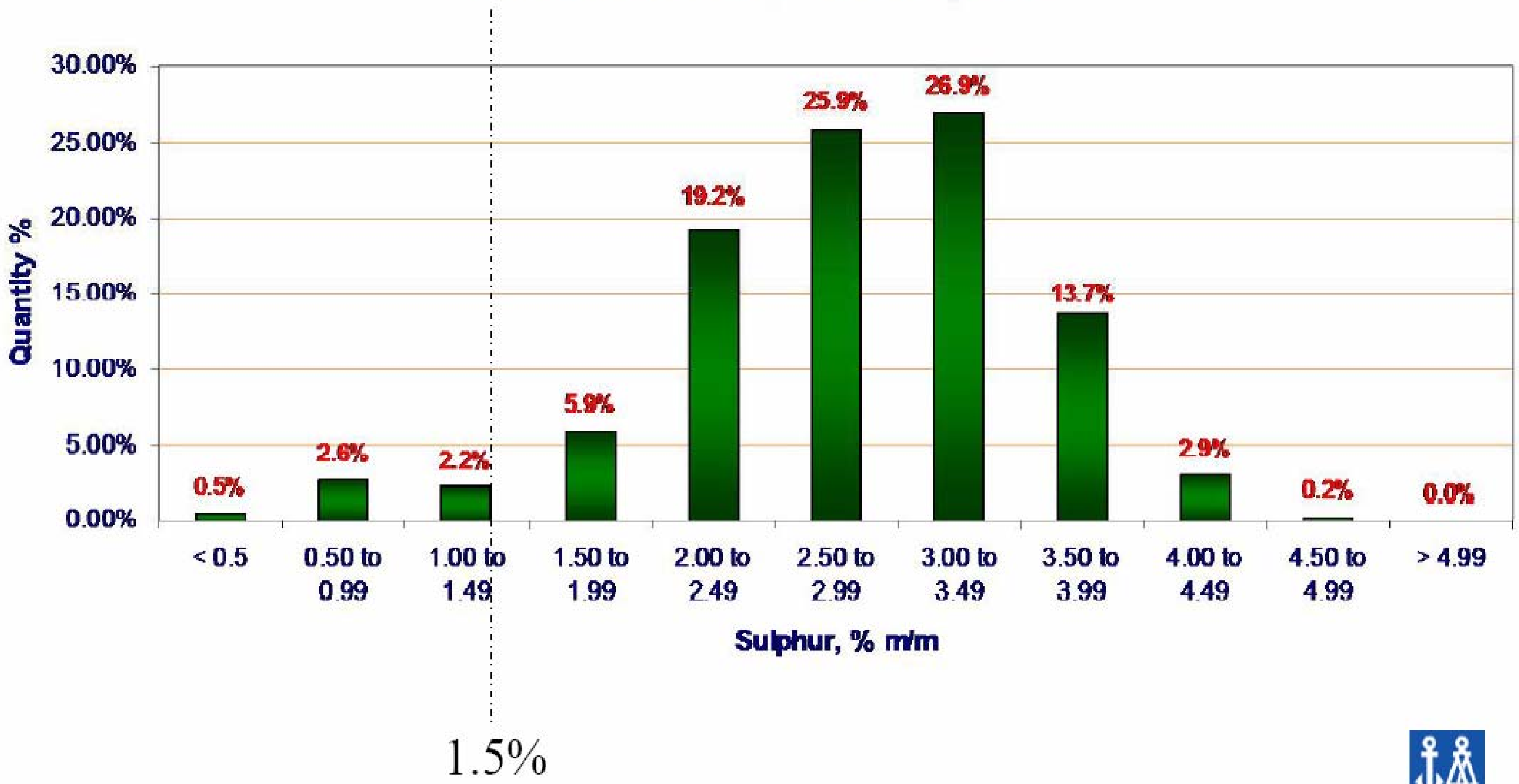
Thank you for your attention !

Back-up

- Fuel quality for ships
- Additional NO_x reduction measures
  - FWE for minor NO_x reduction requirements
  - HAM for medium NO_x reduction requirements
  - SCR for strong NO_x reduction requirements
- Gas engines

Quality of fuel oil for ships

2004 Worldwide fuel sulphur distribution



MANAGING RISK DNV

Fuel Water Emulsification

- FWE is an add on method which is able to reduce NO_x by about 20 %, provided the design of the injection system offers sufficient reserves. Also fresh water (drinking water quality) is needed: About 20 % of the consumed fuel amount.
- Fuel consumption at higher water contents increased.
- Smoke emission not adversely affected.
- It requires the adaptation of the low pressure fuel system (engine and plant) to handle the higher pressures needed to avoid evaporation of the water.
- Further some additional safety measures and maintenance are needed.
- The system has been running for some years on several vessels and has proven not to affect the reliability of the engine.
- Invest cost increase about 1.5 – 2.5 %.
- Running cost increase (fresh water).

Humid Air Motor

- HAM is an add on method which allows for a NO_x reduction of 40 – 60 %. For this, a huge amount of water is needed: About twice of the consumed fuel quantity.
- There are less possibilities for waste heat recovery which may result in additional fuel consumption.
- The space requirements and investment costs are large.
- On modern engines output reduction may be necessary.
- The HAM technique is not widely used yet: The system has been running with low-sulfur fuel on one ship and on one stationary plant.
- Very high invest cost increase about 33 %.
- Low running cost (sea water).

Selective Catalytic Reduction

- SCR is the most effective technology for the reduction of NO_x. An efficiency of up to 85 % in dynamic operation is achievable.
- The space requirements, investment and operating costs are considerable.
- Operation on standard HFO with a sulfur content higher than 1 % may lead to clogging of the catalyst because the exhaust gas temperatures of today‘s four-stroke engines are too low, at least under usual operating conditions.
- High invest cost increase about 15 %.
- Very high additional running cost (ammonia or urea, maintenance).

Achievable NO_x values for dual fuel engines

- Large 4-stroke Dual Fuel (DF) engines with natural gas and liquid pilot fuel injection:

  in Gas mode: 400 mg/Nm^3 @ 15% O_2

  at increased SFOC also possible: 200 mg/Nm^3 @ 15% O_2

  in Diesel mode: World Bank- / IMO-limits (see above)

- Strong efficiency decrease (SFOC increase) towards lower NO_x in gas mode.
- Secure ignition (energy input) of lean cylinder charging no longer assured towards lower NO_x in gas mode with a liquid pilot fuel.
- No experience for other gases besides natural gas.