Dynamic Positioning Committee

Marine Technology Society

ENVIRONMENT

The Diesel Engine and the Environment

David Steffens
Wartsila North America, Inc.

Session Chair – Wayne Cole, Cole Engineering

September 16-17, 2003
Houston, Texas

The diesel engine and the environment

- rules and regulations

- emission reduction technologies

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Typical composition of diesel engine exhaust gas

Together > 99.5%	Nitrogen	N_2:	76%	
	Oxygen	O_2:	13%	
	Carbon dioxide	CO_2:	5%	Low due to high efficiency
	Water	H_2O:	5%	
	Sulphur oxides	SO_X		Fuel choice related
	Carbon monoxide	CO		Low due to good combustion
	Hydrocarbons	C_XH_y		Low due to good combustion
	Particles			Low at steady state operation Influenced by fuel ash and sulphur content
	Visible smoke	FSN		Low load related (<25% load)
	Nitrogen oxides	NO_X		To be controlled

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Exhaust compounds and their environmental impact

NO_x:

– acid rain, acidification

– ozone/smog formation in the lower atmosphere (potential damage on vegetation and human health)

Particulates:

– some considered carcinogenic

– blackening with soot

SO_x:

– acid rain, acidification

– potential detrimental effect on human health

CO:

– ozone/smog formation in the lower atmosphere

Hydrocarbons:

– ozone/smog formation in the lower atmosphere

– some considered carcinogenic

– contribute to the greenhouse effect

CO_2:

– the major greenhouse gas

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Annex VI to MARPOL 73/78

- Applies to: Ships of 400 GRT or above,Platforms and Drilling Rigs

- Enters into force: 12 month after the date on which not less than 15 states, constituting not less than 50% of the gross tonnage of the world's merchant fleet, have signed the protocol

- It is important to note that the NOx emission regulation is linked to the date, 1st of January 2000. Ships constructed after this date will be required retroactively to comply with these requirements when Annex VI enters into force.

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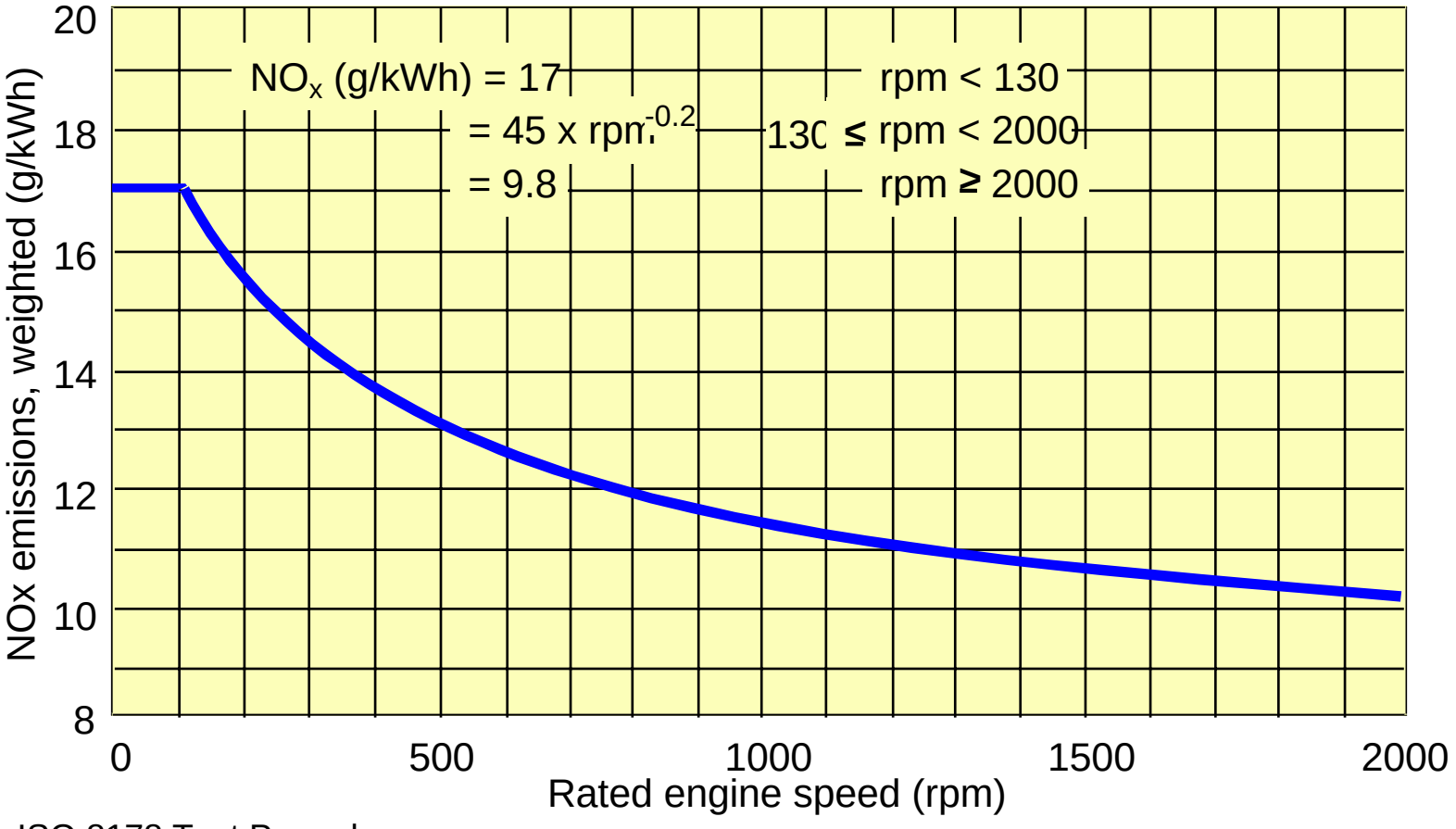
IMO MEPC Proposal for Global Marine NO_x Legislation



ISO 8178 Test Procedure
Reference Fuel: Marine Diesel Oil

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Diesel NO_X Formation

- Thermal NO_X formation (65-75%)
- Nitrogen source: combustion air
- Formation process: extremely complex including hundreds of different reactions
- Strong temperature influence (exponential)

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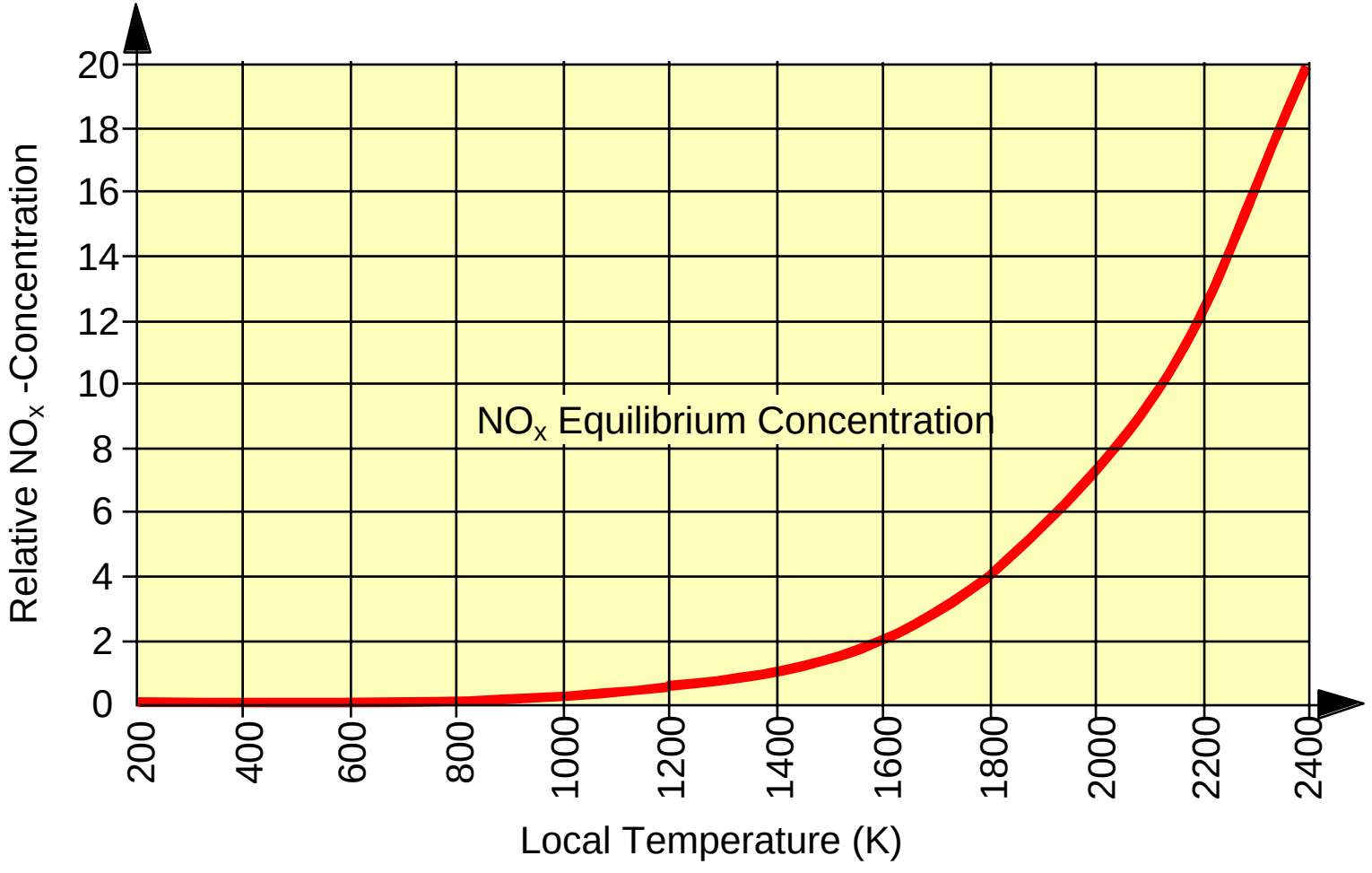
Thermal NO_x Formation



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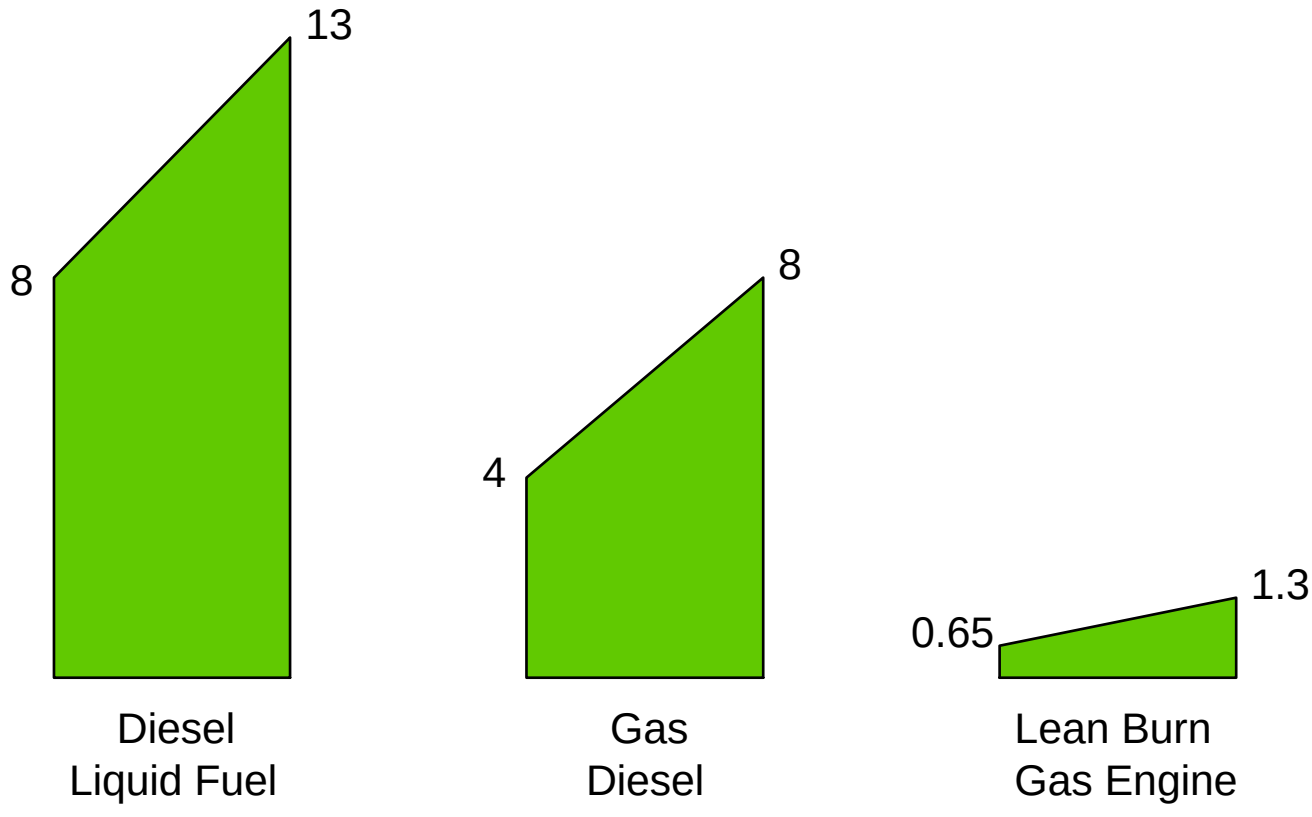
Typical NO_x-Emissions for Different Types of Engines

Typical NO_x Emissions in g/kWh:



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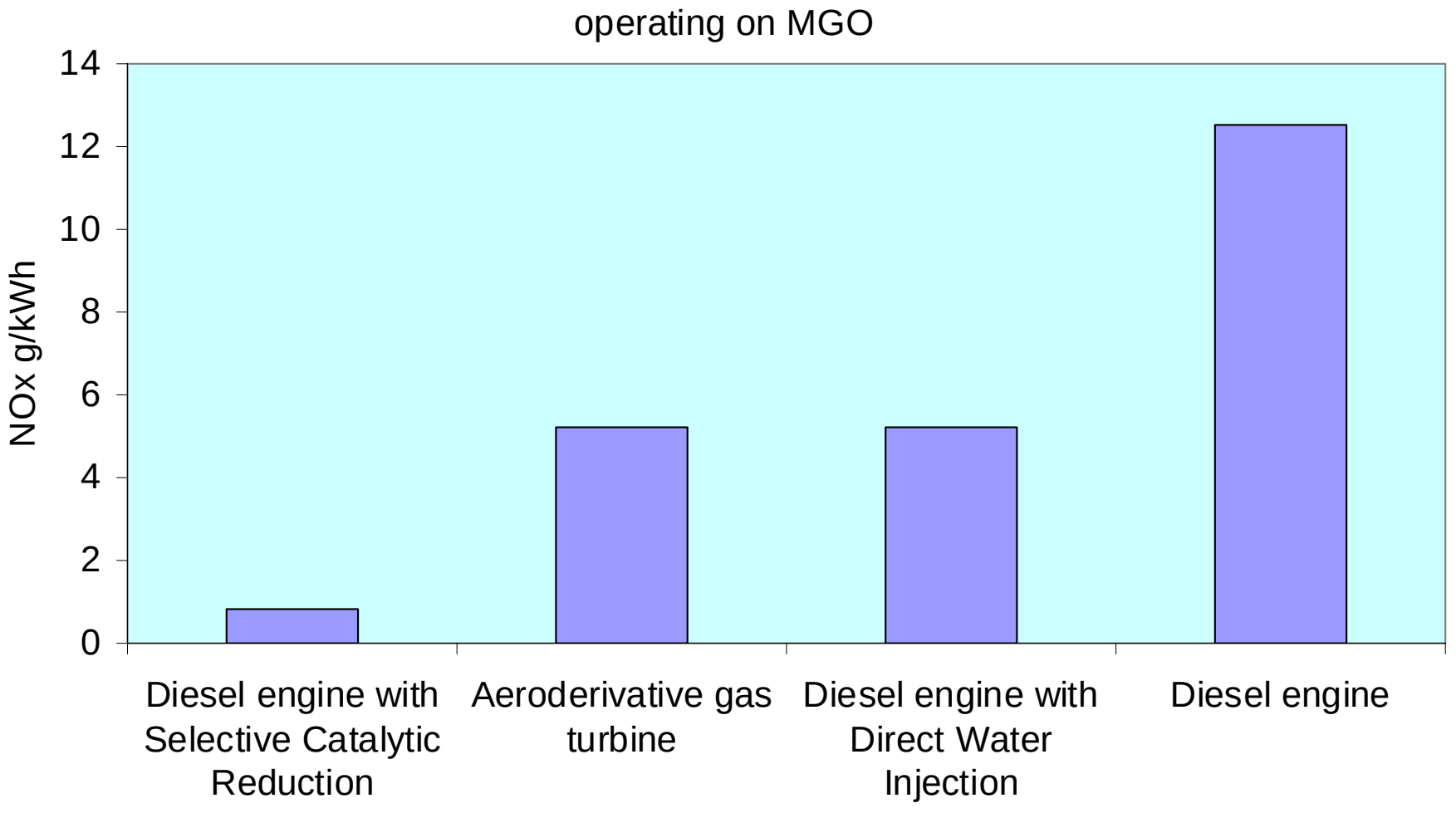
NOx emissions of different prime movers



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Technologies to reduce emissions:

- Primary Methods - During Combustion
- Secondary Methods - After Combustion

Primary NO_x control - diesel engines

Available today - Combustion Modification

- Emission rating
  - Adjustment of fuel injection timing/TC specification
  - NO_x reduction potential: 10 - 20 %
  - Simple and cheap
  - Increased fuel consumption and thermal load
- Low NO_x combustion
  - Rearranged diesel cycle
  - NO_x reduction typically: 25 - 35 %
  - NO_x well below the IMO limit
  - Unchanged or improved fuel consumption

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Primary NO_x control - diesel engines

Available today - Water Injection

- Water-in-fuel emulsions
  - Humidification of the combustion process
  - NO_x reduction potential typically: 20 %
  - Limitations
    - emulsion stability
    - fuel injection system capacity
    - poor engine performance in “non-water” operational mode
    - cavitation risk in injection system

- Direct water injection
  - Humidification of the combustion process
  - NO_x reduction typically: 50 - 60 %
  - Improved thermal load and engine cleanliness

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Low NO_X Combustion Engine Design

- Rearranged diesel cycle
  - Very late fuel injection start
  - Higher compression ratio
  - Early inlet valve closing (4-stroke)
  - Late exhaust closing (2-stroke)
  - Optimized combustion chamber
  - Optimized fuel injection pressure
- Results
  - Lower combustion temperatures
  - Shorter duration at high temperatures
- Conclusions
  - NO_X reduction typically 25-35%
  - Unaffected fuel consumption

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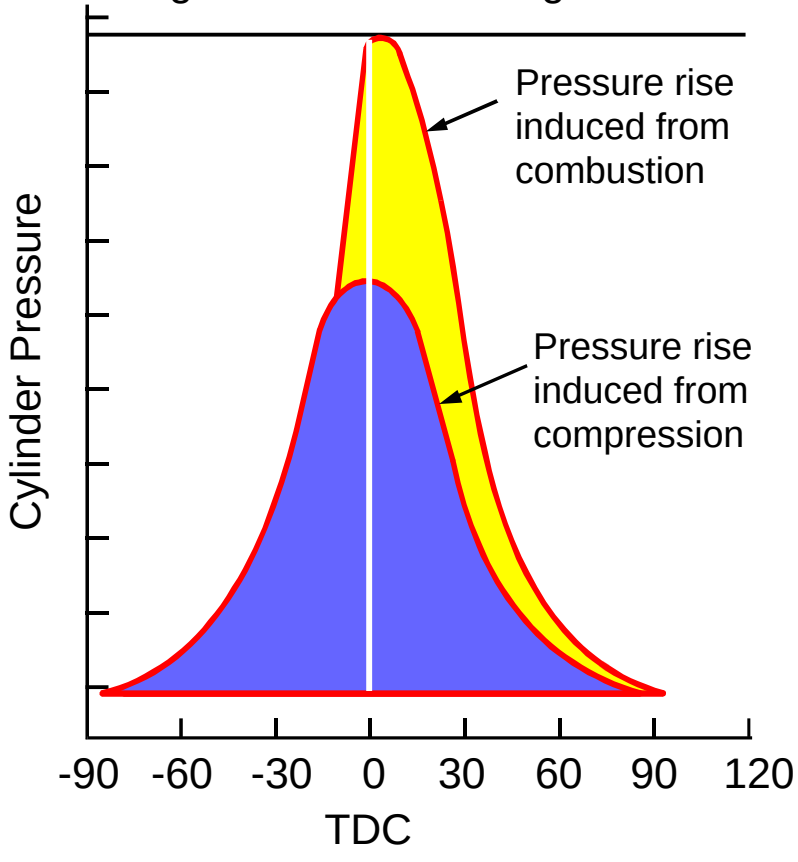
Low NO_x Combustion

Application: All Fuel Types

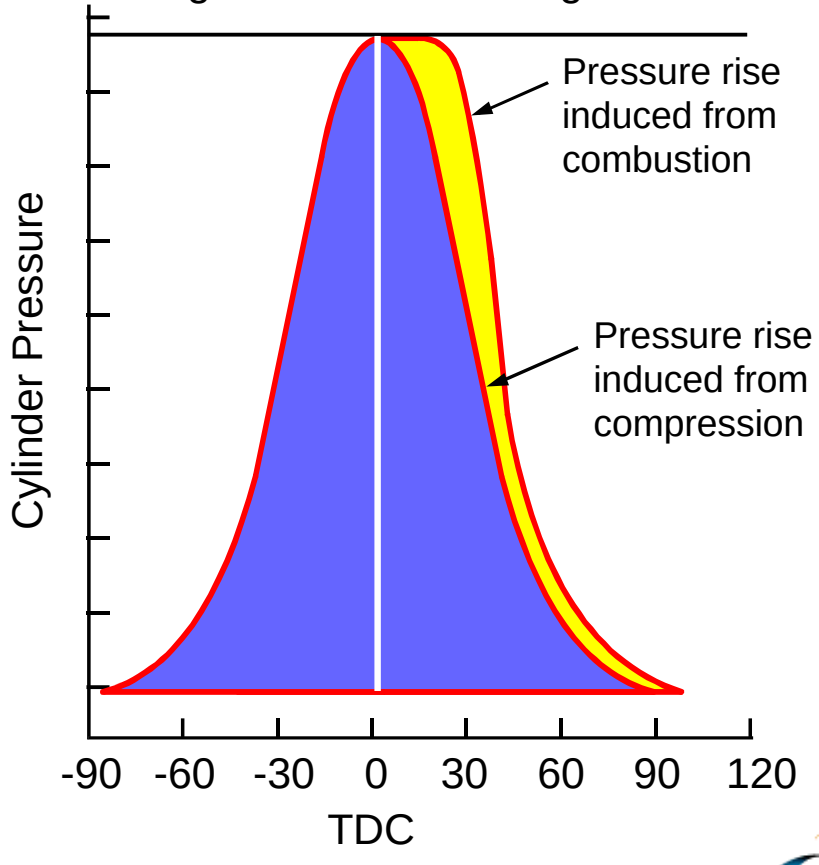
Conventional Design

Engine Maximum Firing Pressure



Low NO_x Design

Engine Maximum Firing Pressure



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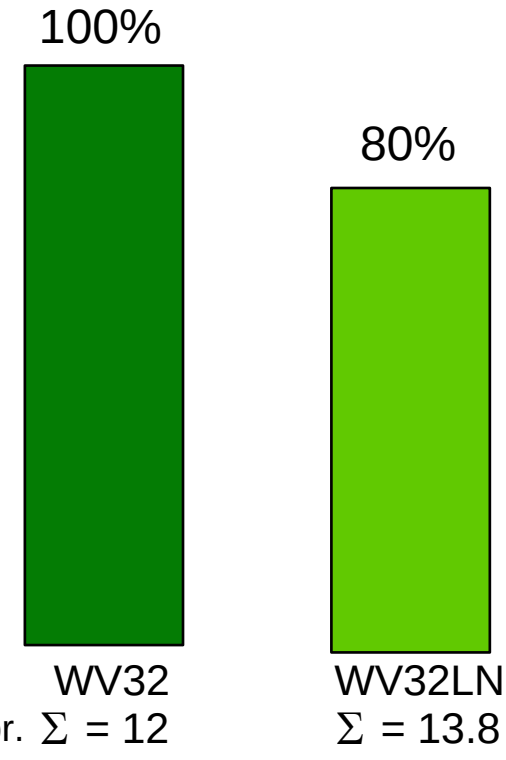
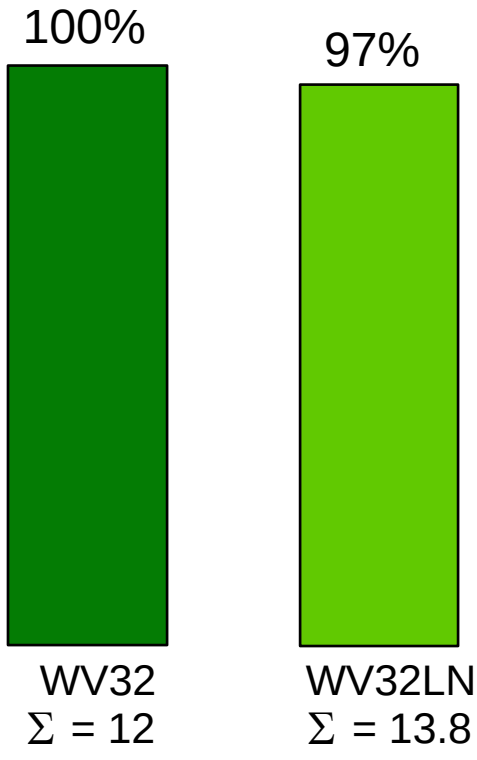
Implementation of Low NO_x Combustion on Wärtsilä Vasa 32b

Relative NO_x Emissions



Relative Spec. Fuel Cons.



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Features of fuel-water emulsions

Disadvantages

- **Increased camshaft torque and cam load.**
- **Full load of engine not possible at high water ratios due to limitations in the fuel injection equipment.**
- **Same nozzles not optimal for operation with and without emulsion.**
- **Negative impact on injection equipment reliability and lifetime.**
- **Increased fuel viscosity, higher preheating temperatures needed.**

Advantages

- **Improved low load smoke.**
- **Lower NOx. The NOx limitation is limited to about 20%, because unlimited water amounts cannot be kept in a stable emulsion.**

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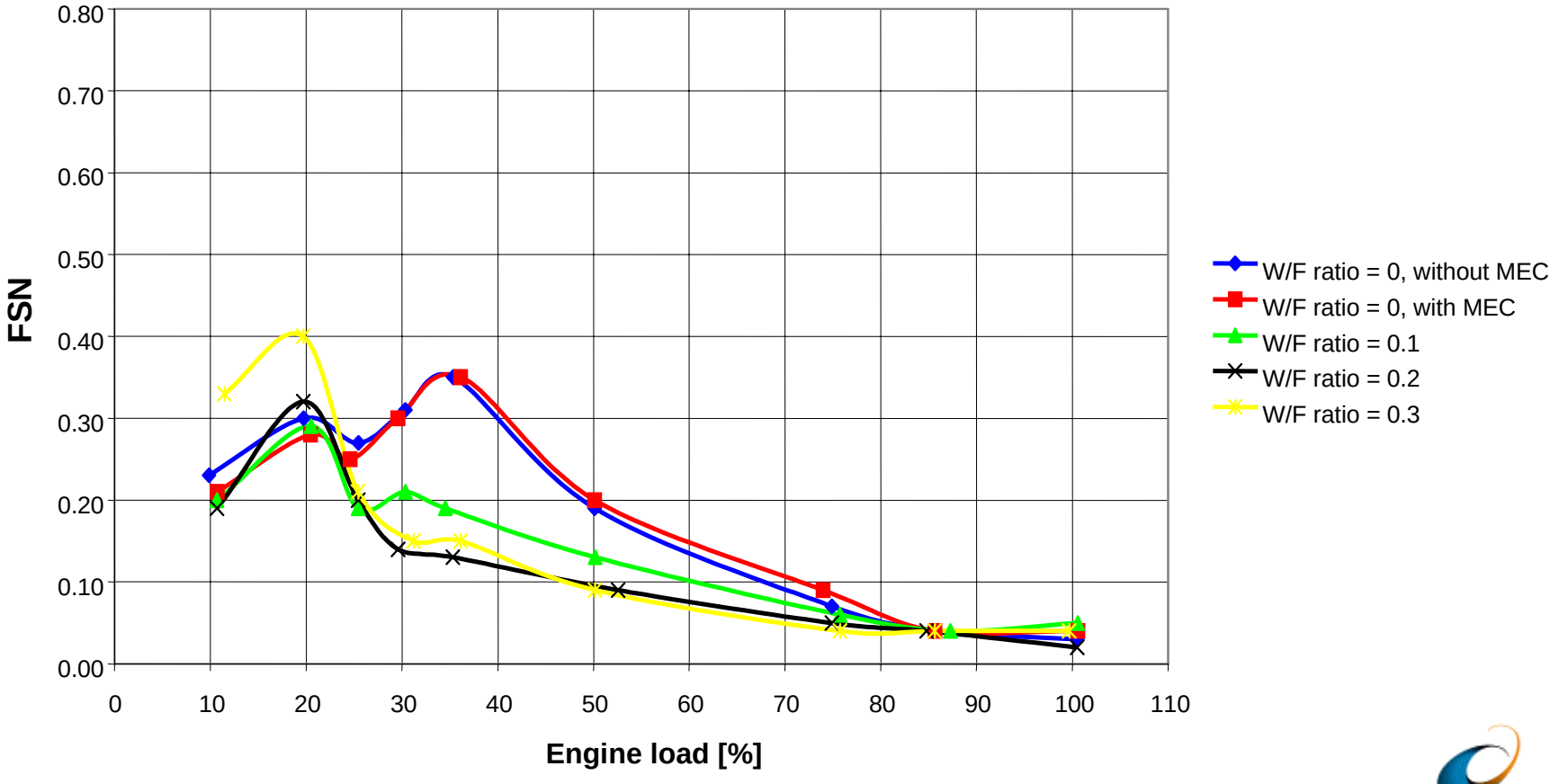
MEC Test on W6L46CR, Vaasa
2-19 December 2002
INFLUENCE OF WATER EMULSION ON FSN
Standard Nozzle: 12x0.64x160°, Fuel: HFO



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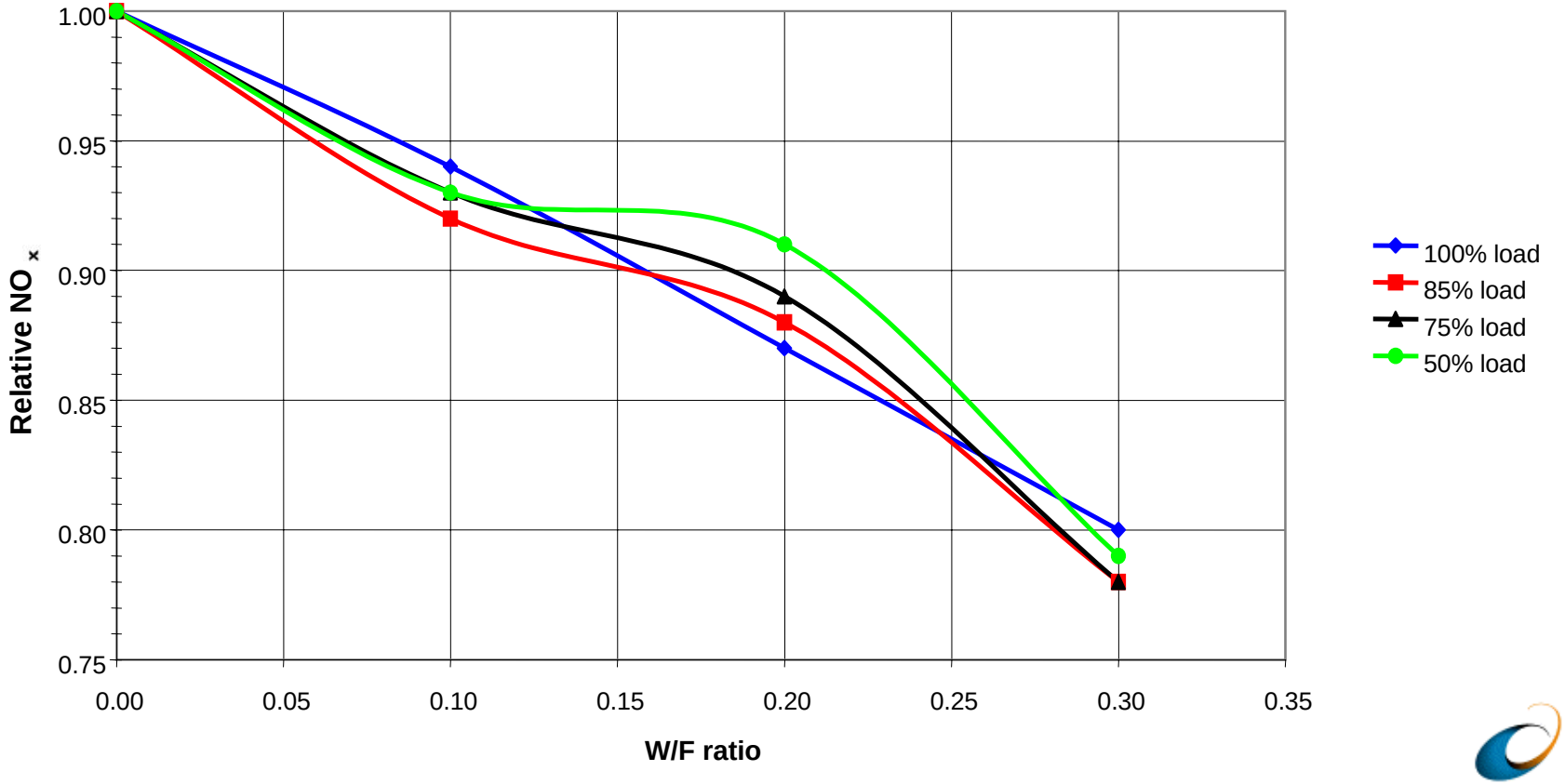
NO_x emissions

MEC Test on W6L46CR, Vaasa
2-19 December 2002
INFLUENCE OF WATER EMULSION ON NO_x EMISSIONS
Standard Nozzle: 12x0.64x160°, Fuel: HFO
Reference NO_x Without MEC



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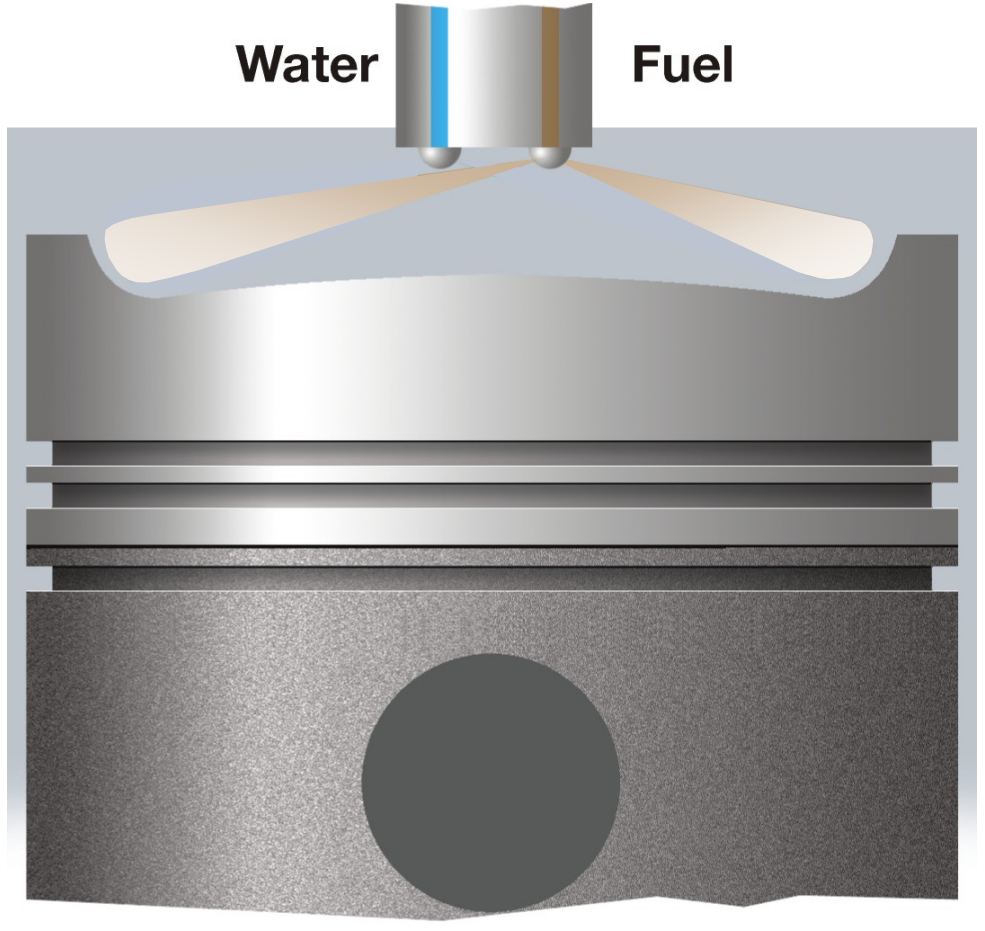
The principle of Direct Water Injection



- Water needle and fuel needle in the same injector

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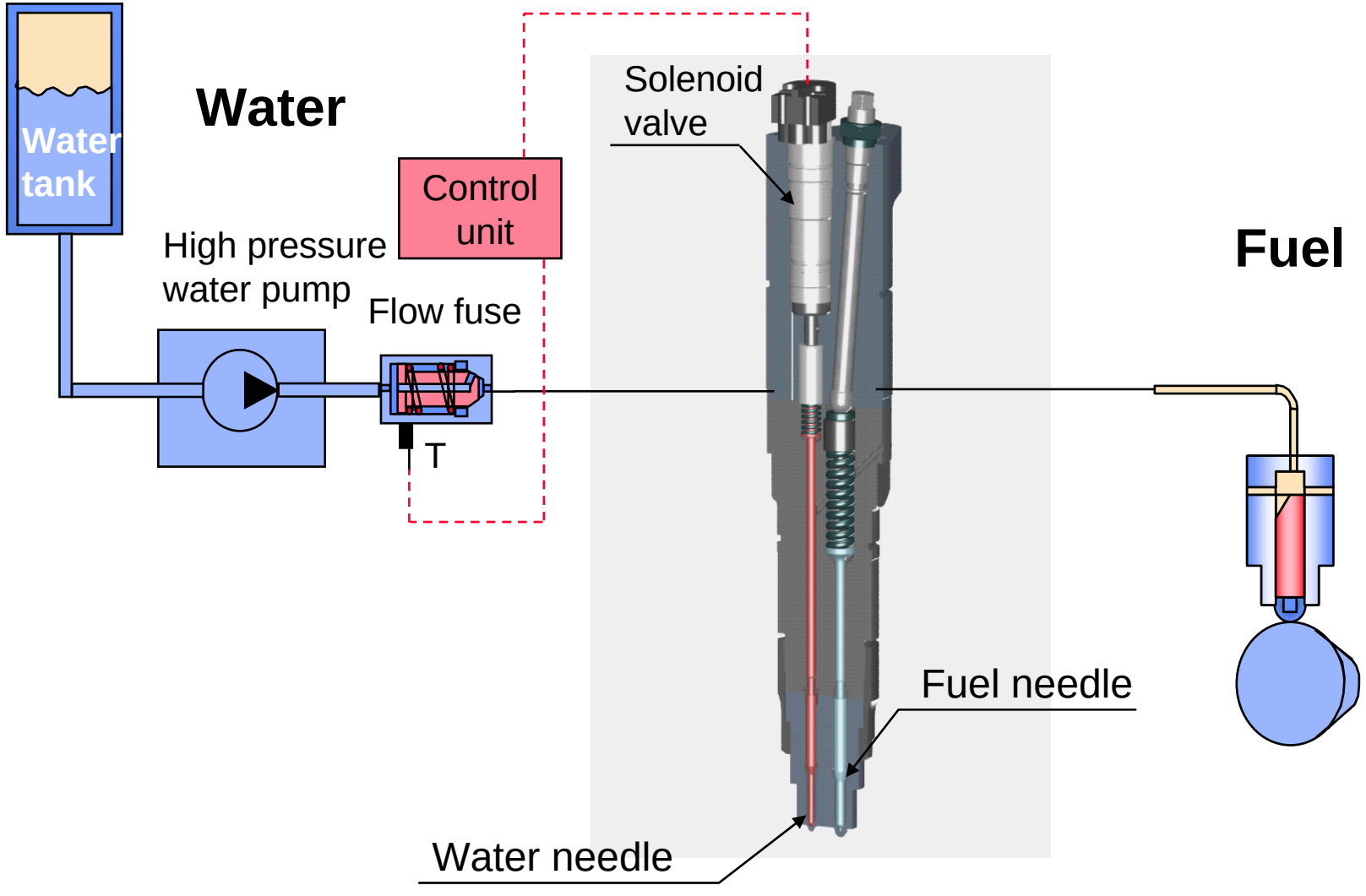
Direct Water Injection



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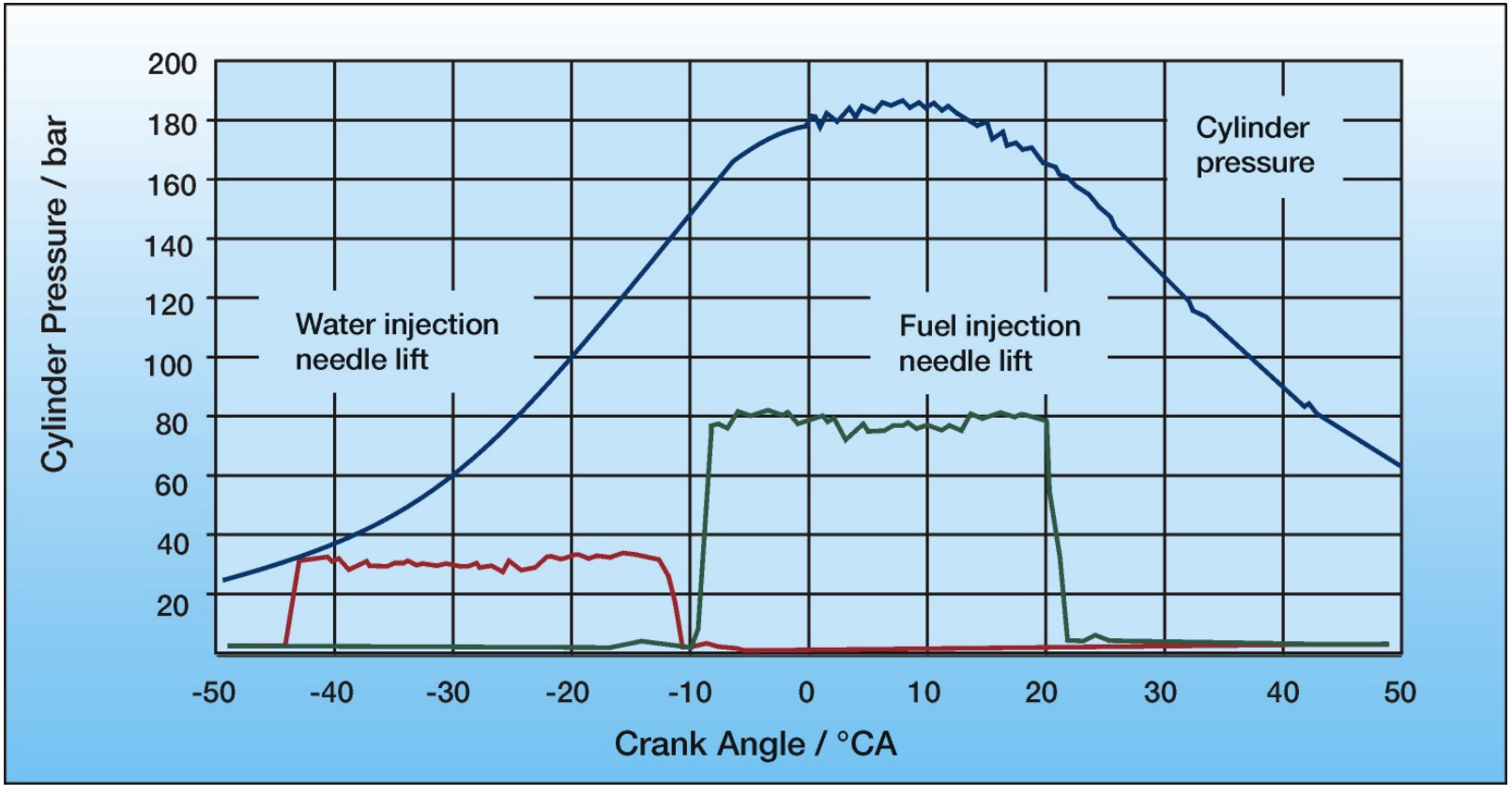
Direct Water Injection
typical water/fuel timing and duration



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Emission Control Technologies - Tomorrow's solutions

Future Technologies:

- CASS (Combustion Air Saturation System)

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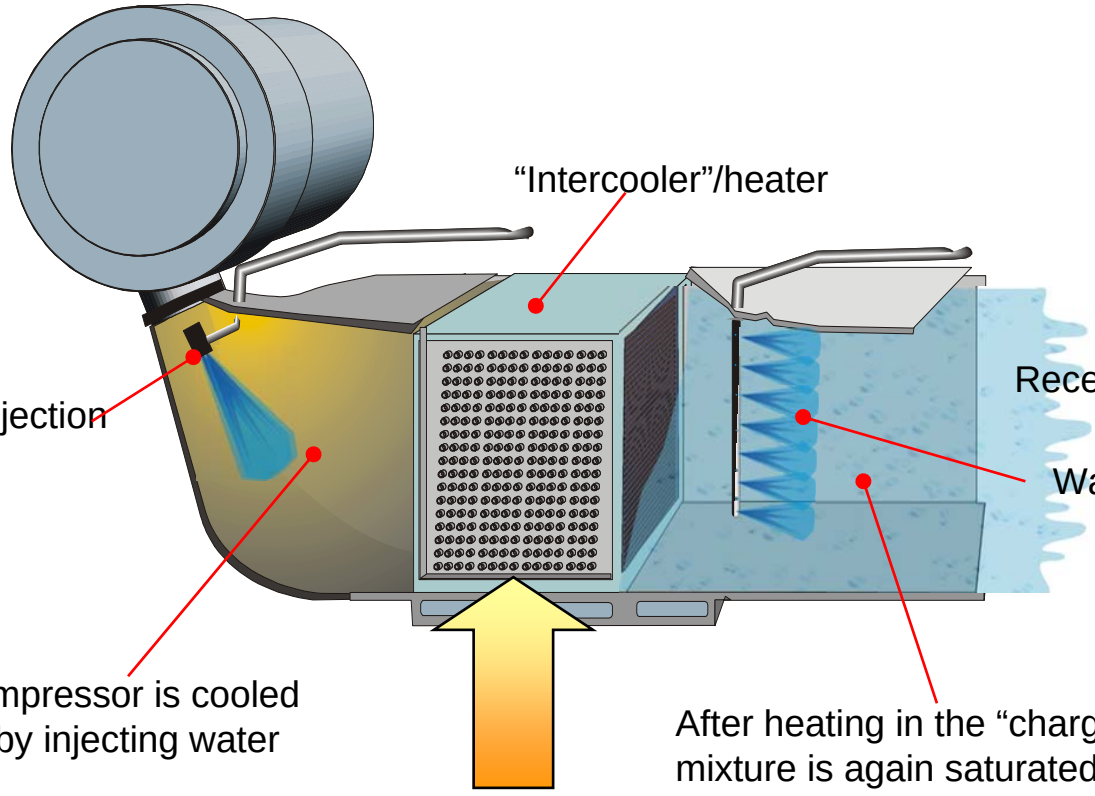
CASS



Heating of the air by HT-water

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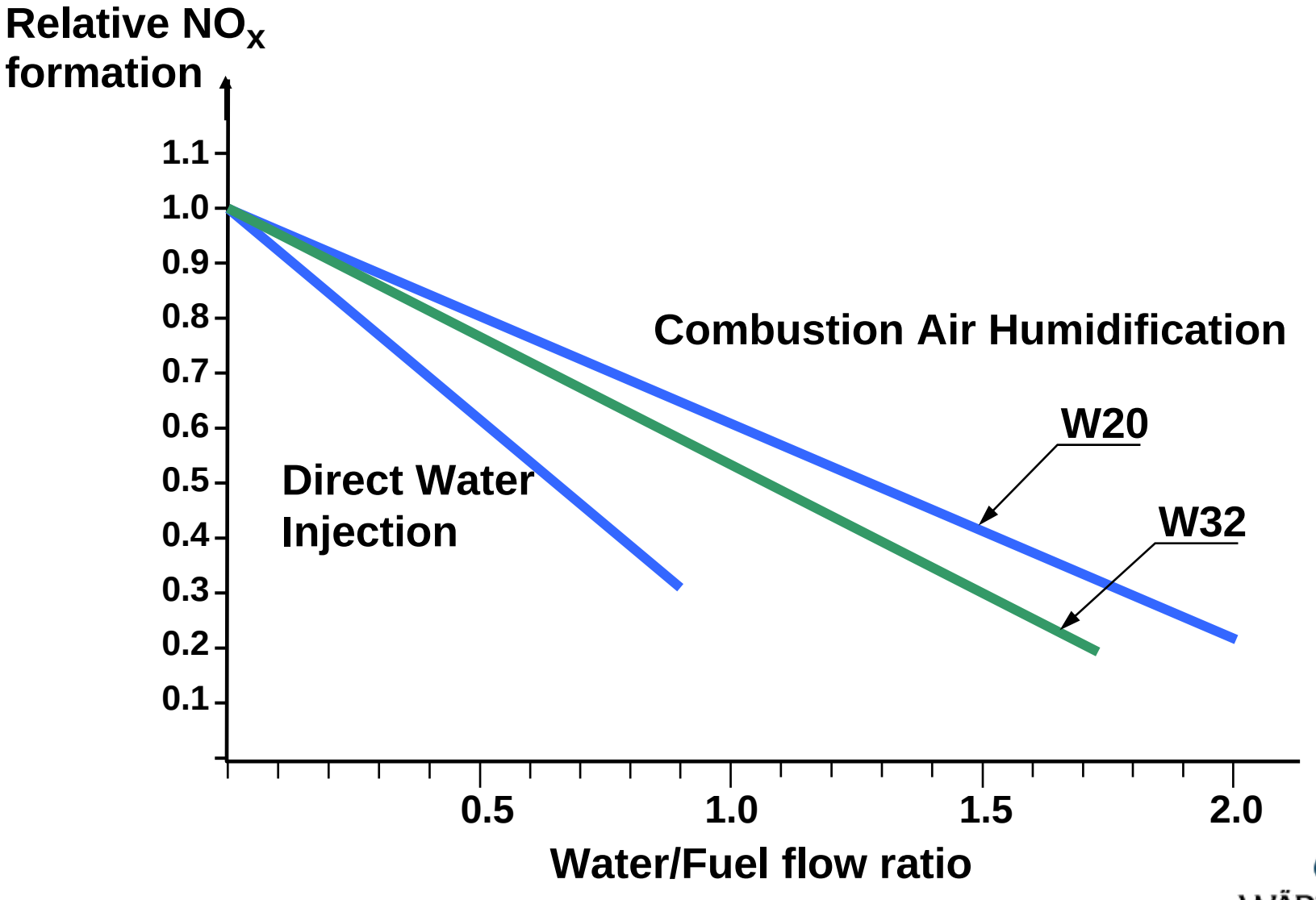
Efficiency of humidification methods



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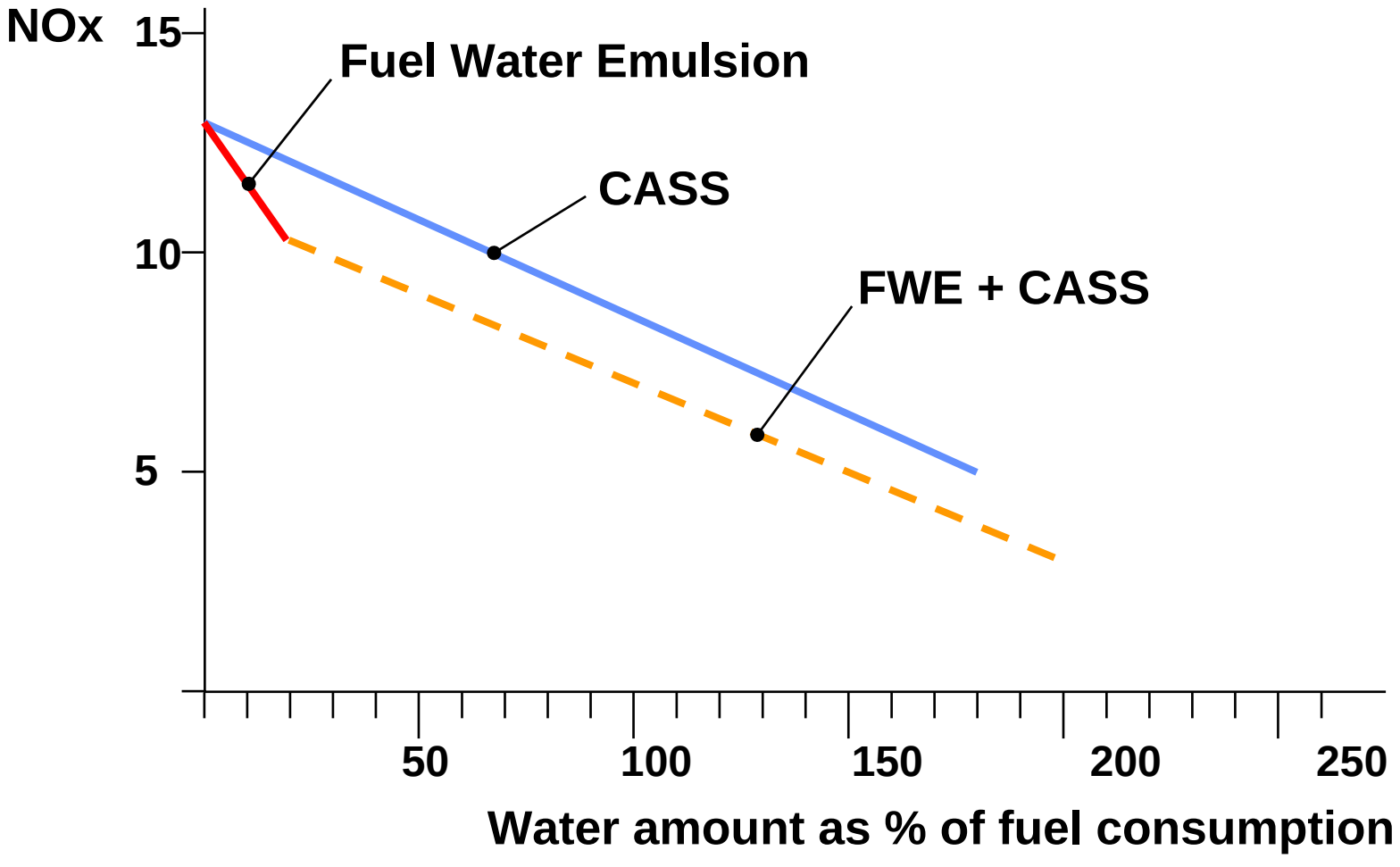
Predicted NOx behavior with different control methods on Wärtsilä 46



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Secondary NO_x control - diesel engines

Available today

- Selective catalytic reduction (SCR)
  - NO_x reduction typically: 85 - 95 %
  - Urea/water solution injected
  - Integrated part of the engine package
  - Exhaust temperature window 330 - 450 °C at HFO operation
  - Investment and operating costs relatively high

- Compact SCR
  - Combined silencer and SCR unit
  - Minimized size

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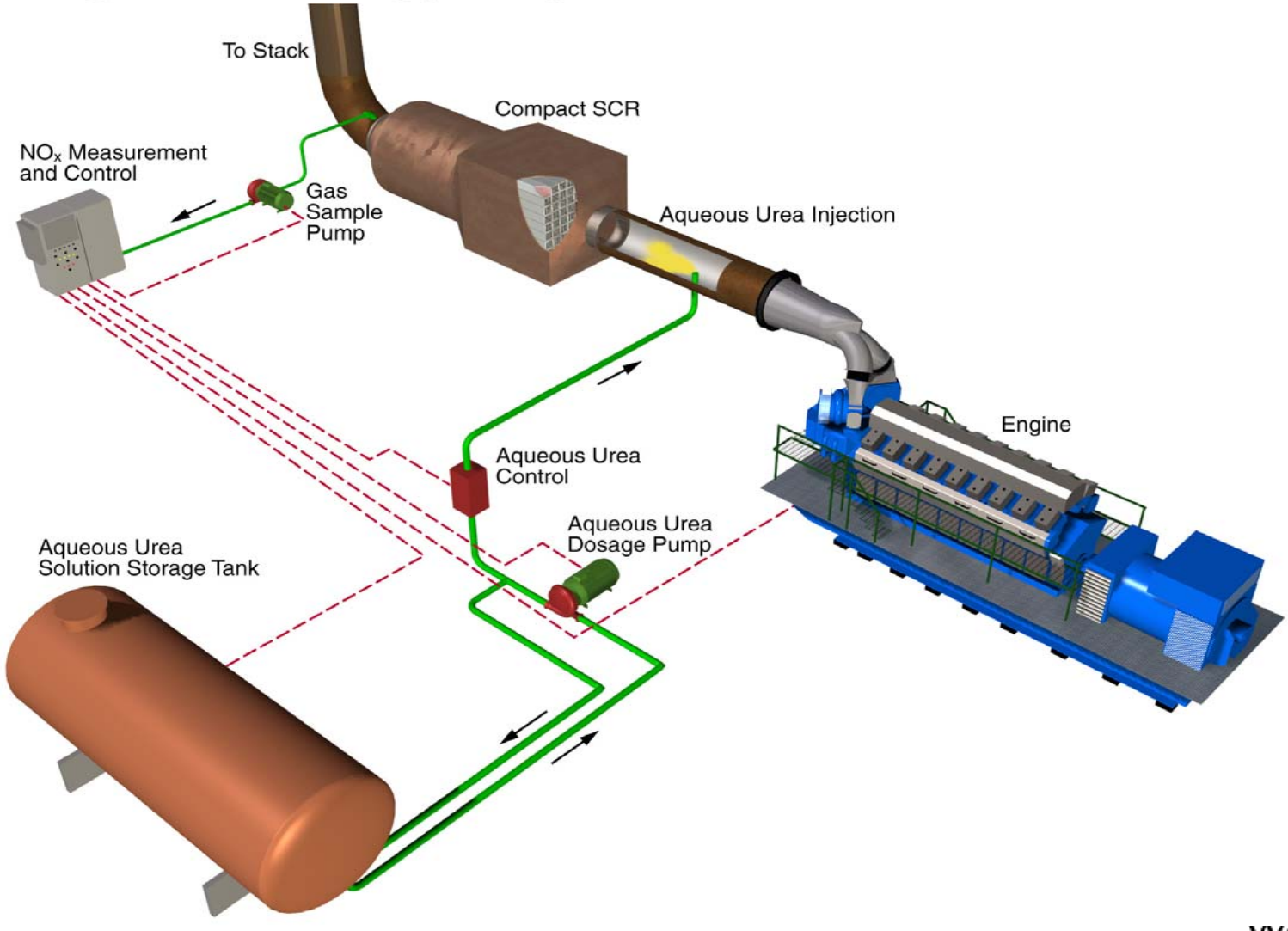
Principle of Selective Catalytic Reduction

NO_x Reduction Typically: 85 - 95%



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SCR Reactions With Urea

- Before Entering the Reactor:

$$(NH_2)_2\,CO + H_2O \longrightarrow 2\,NH_3 + CO_2$$

- In the Reactor:

$$4\,NO + 4\,NH_3 + O_2 \longrightarrow 4\,N_2 + 6\,H_2O$$

$$6\,NO_2 + 8\,NH_3 \longrightarrow 7\,N_2 + 12\,H_2O$$

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Retrofit of Compact SCR

Birka Princess at Lloyd Werft

SCR plants have been retrofitted in several passenger ships in existing engine casing = no lost space!

A Compact SCR occupies a little more space than a normal silencer which it replaces.

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Smokeless Diesel Engine

Particle Emissions

- Particle emissions are seen as smoke
- More prevalent at low loads and start-up

Smoke Reduction Methods

- Common rail fuel injection

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Targets for the <u>Smokeless Engine</u>

- No visible smoke at start-up
- No visible smoke at any load
- NO_x emissions to be reduced
- CO_2 emissions to be reduced even lower by further improvements in efficiency

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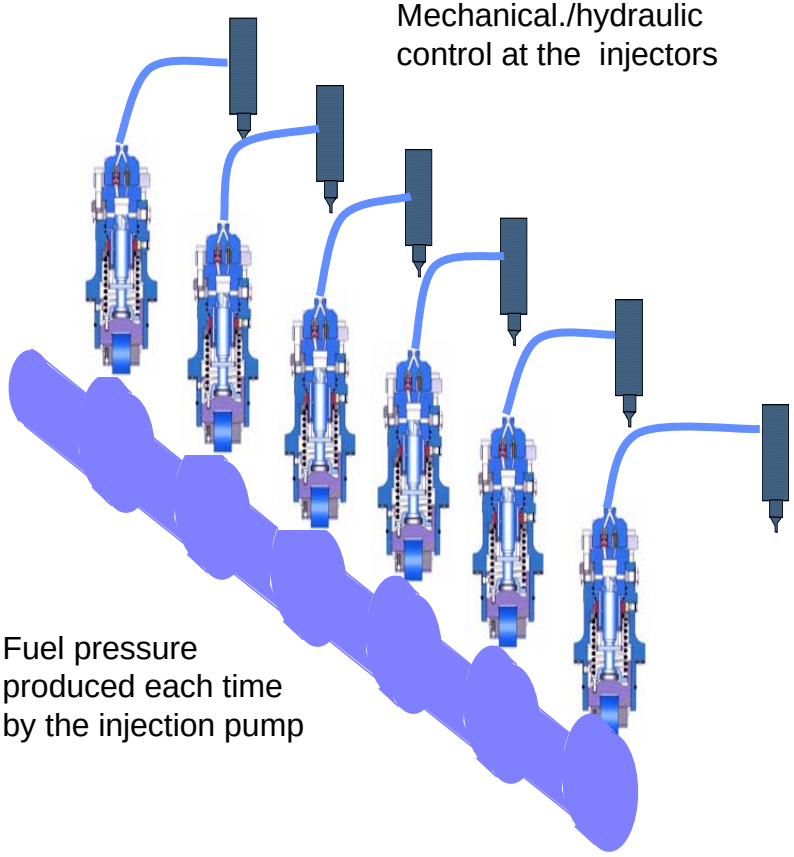
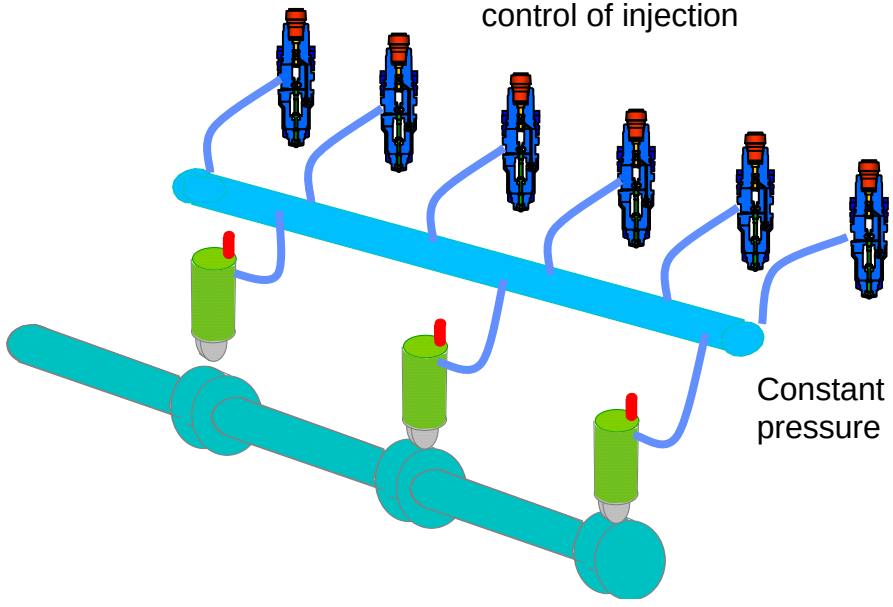
Conventional vs common rail fuel injection

Conventional injection system



Common Rail Injection



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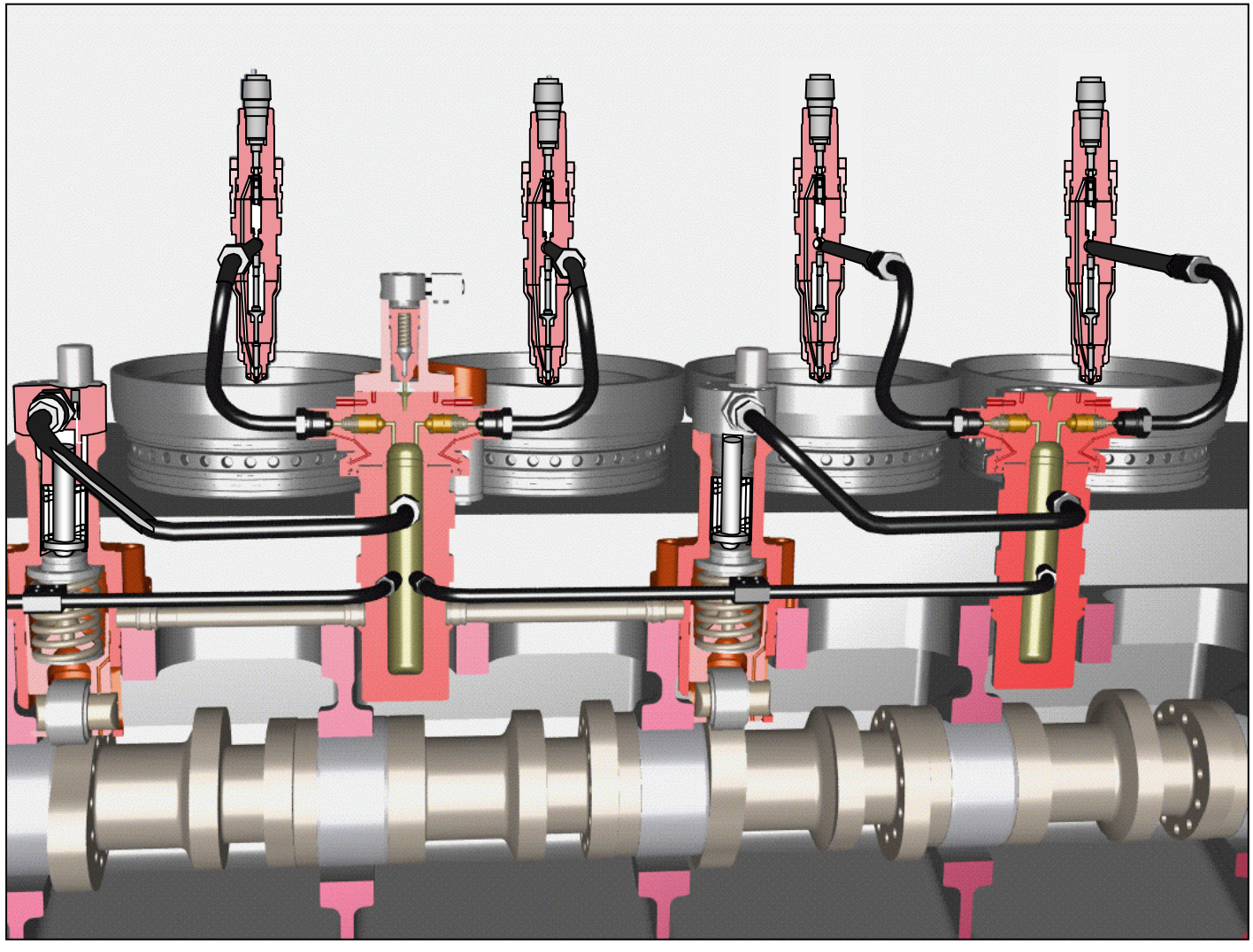

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Common Rail advantages

- Smokeless operation at all loads and speeds.
- Smokeless start of the engine.
- Smokeless load pick-up ramps.
- NOx reduction down to 3…4 g/kWh with humidification possible without visible smoke.
- Improved total fuel economy.
- Flexibility for different fuels without hardware modifications (heavy fuel, diesel oil, gas turbine fuel, water-fuel emulsion).
- Improved safety and comfort because more engines can be kept running with still good fuel economy and no smoke.

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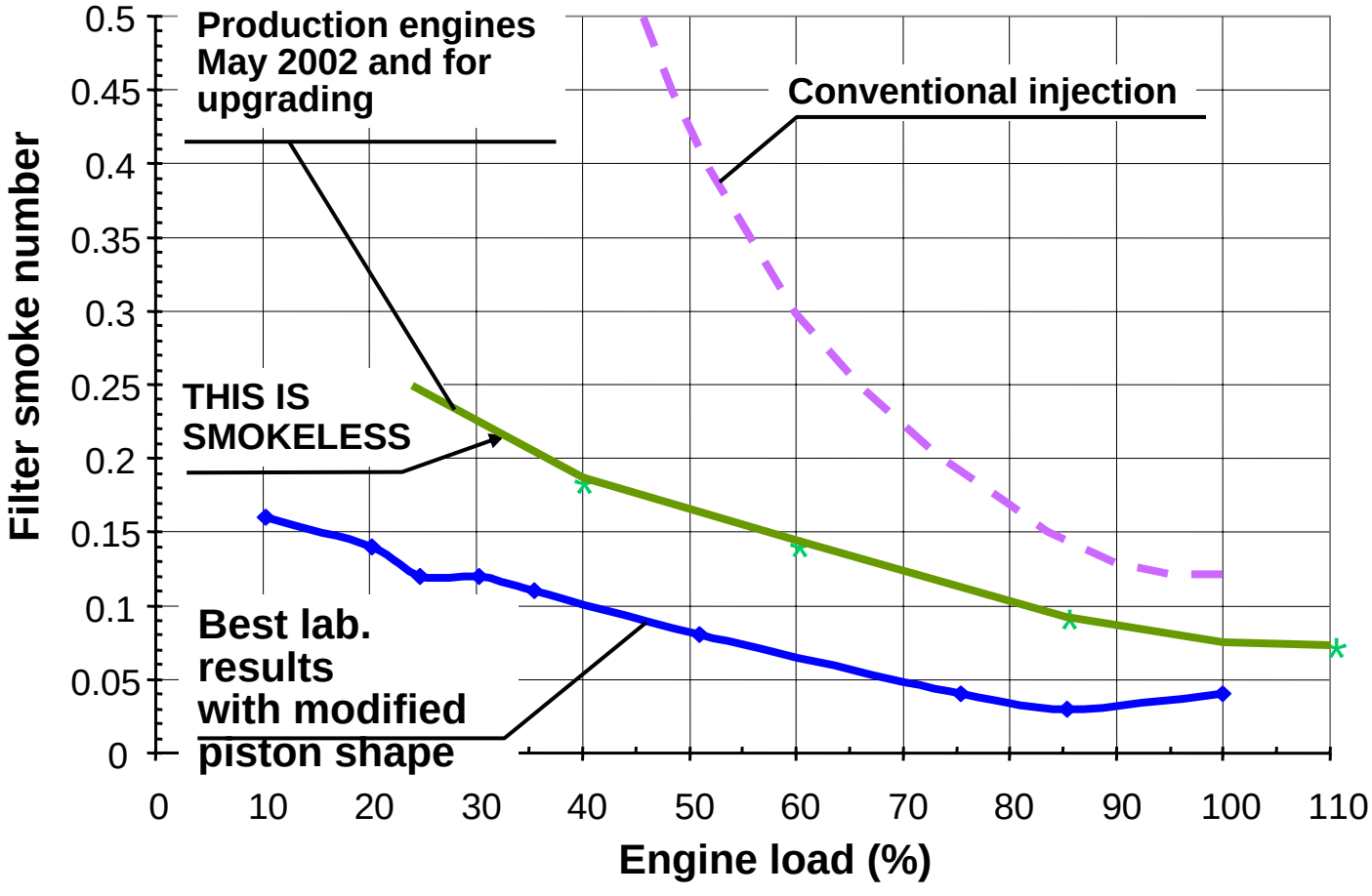
FSN status at engine laboratory and delivery test run



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