

The green marine engine – A dream or reality?

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FM16



FM24

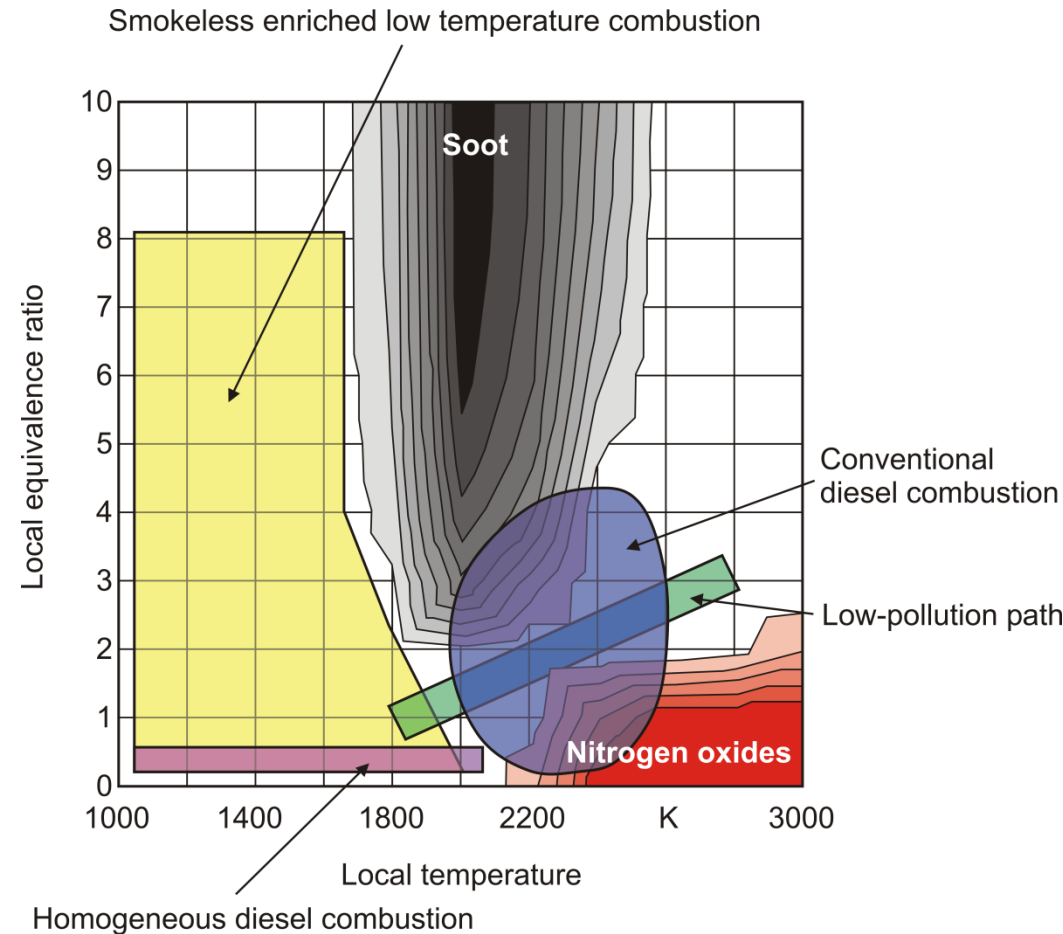


FM35

- Introduction
 - Diesel combustion
 - International shipping
 - Emission limits
- Measures to meet IMO Tier III emission limits
- Results
 - Charge air inerting
 - Exhaust gas recirculation
 - Air separation membranes
 - Dual fuel operation
- Summary

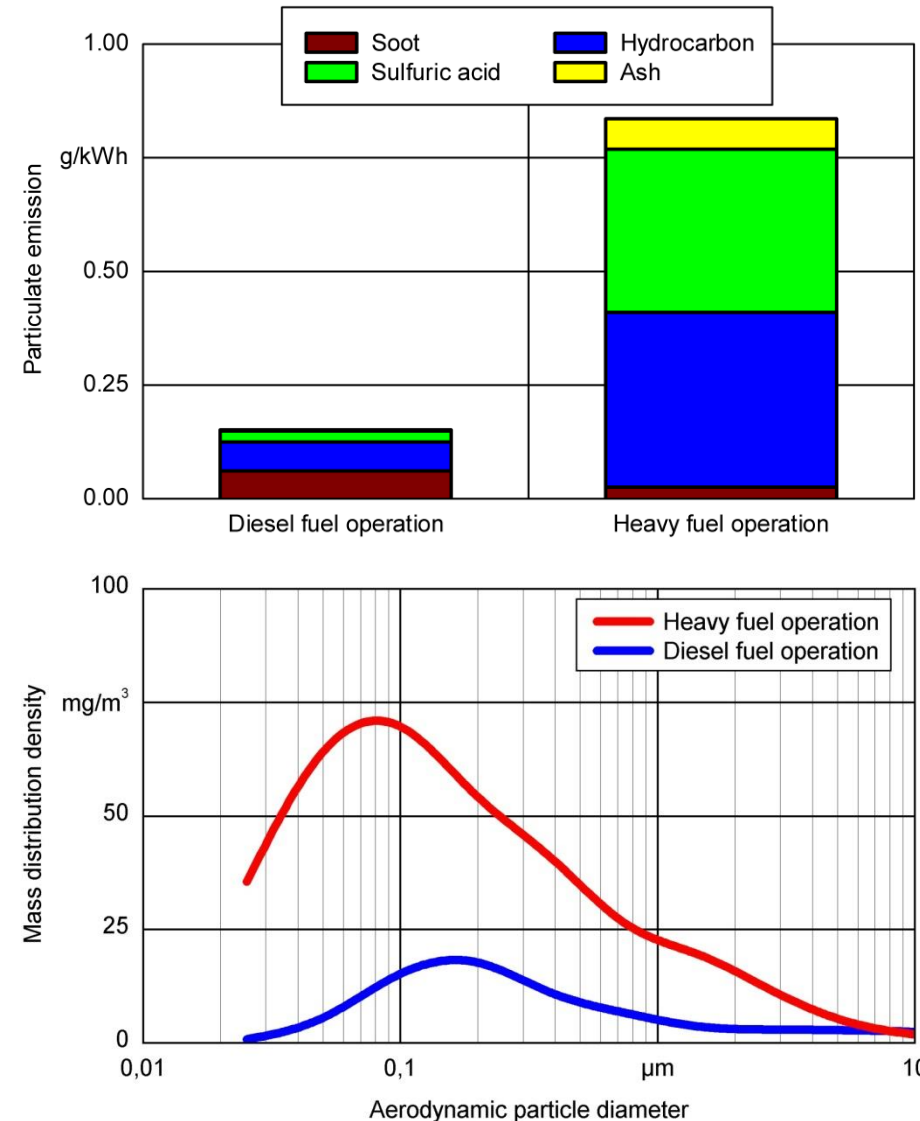
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- NO_x -emissions are caused by high combustion temperatures
 - Early start of injection
 - High charge air temperatures
 - Stoichiometric mixture
- Soot emission is the difference of soot production and soot oxidation → at rich mixture conditions there is no oxygen left for the oxidation process

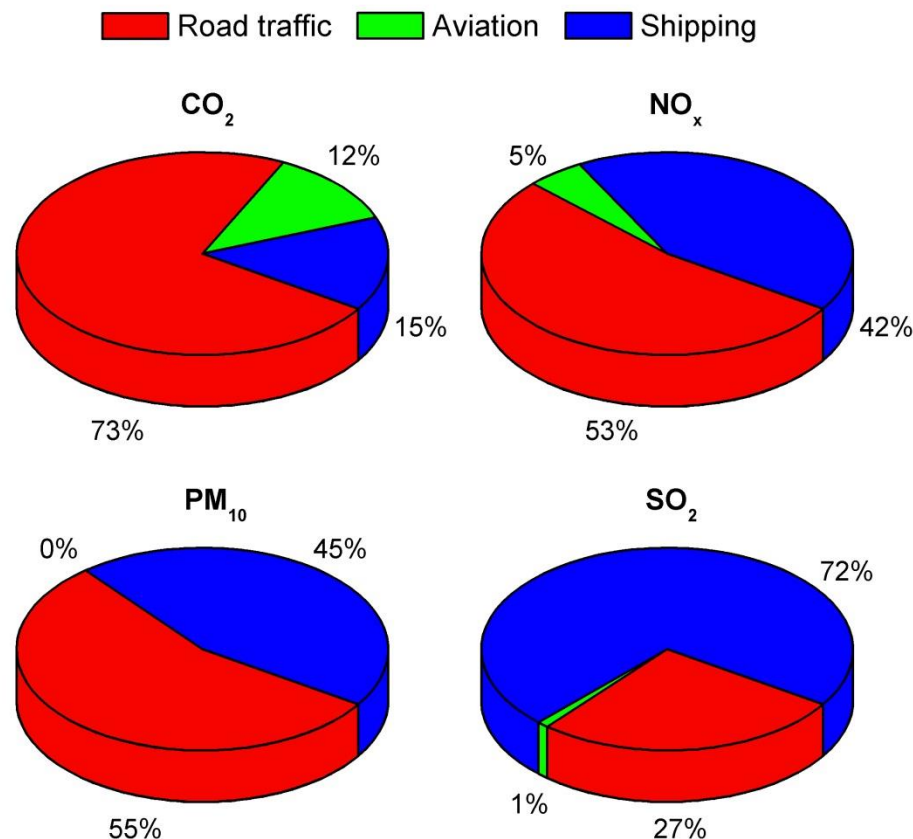


Source: Author's illustration based on Neely, G. D. et al.: New Diesel Emission Control Strategy to Meet US Tier 2 Emission Regulations, 2005

- In diesel fuel operation most of the particulate emissions consists of soot and unburnt hydrocarbons
- In heavy fuel operation a lot of sulfuric acid, ash and unburnt hydrocarbons are emitted
- The particle diameters in heavy fuel operation are smaller compared to diesel fuel operation



- International shipping contributes 42 to 72 % to the emission of NO_x , PM_{10} and SO_2
- CO_2 -Emission is with 15 % on the same level as aviation but shipping accounts for more than 90 % of global trade in transported tons per mile
- Further growth of international shipping expected for the coming years

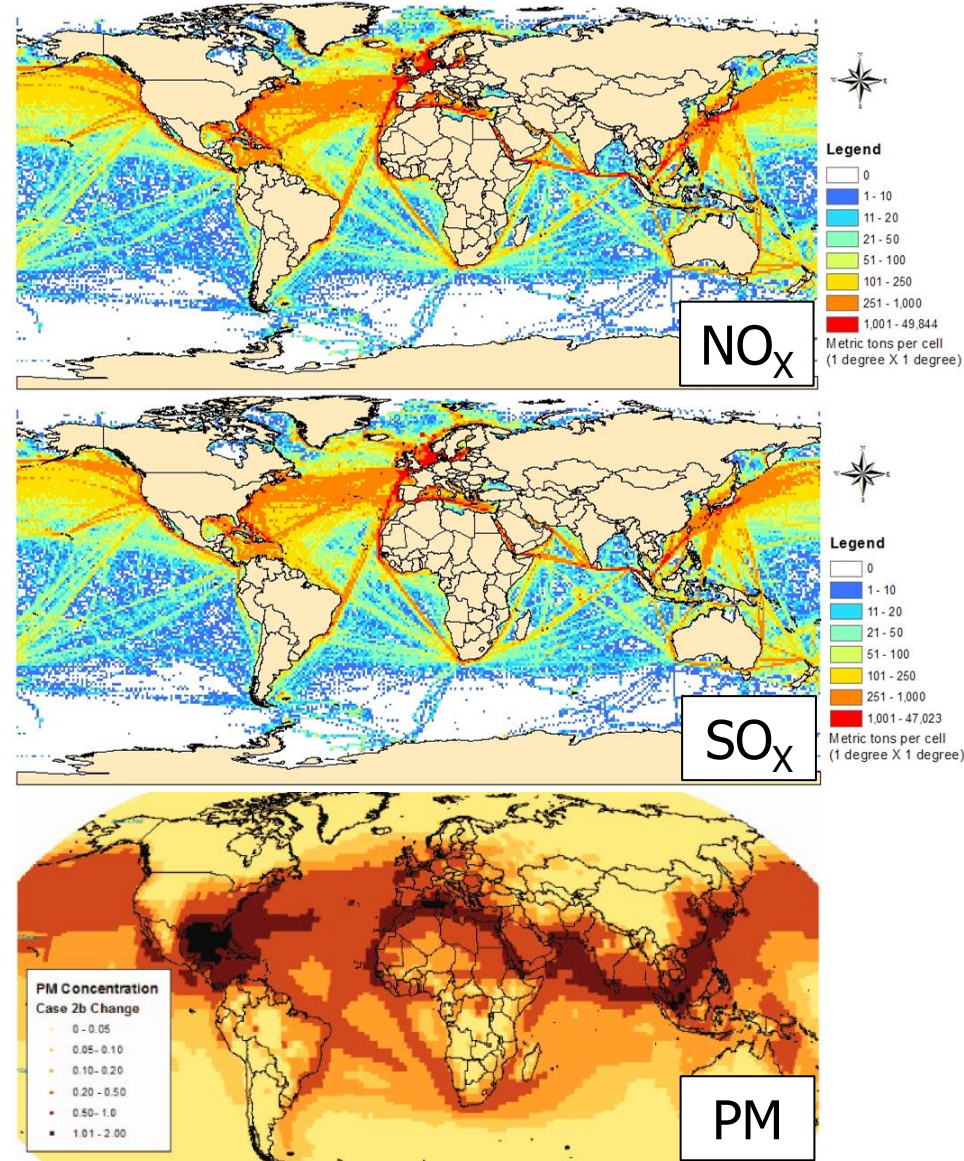


Source: Author's illustration based on SeaKLIM Final Report, 2011

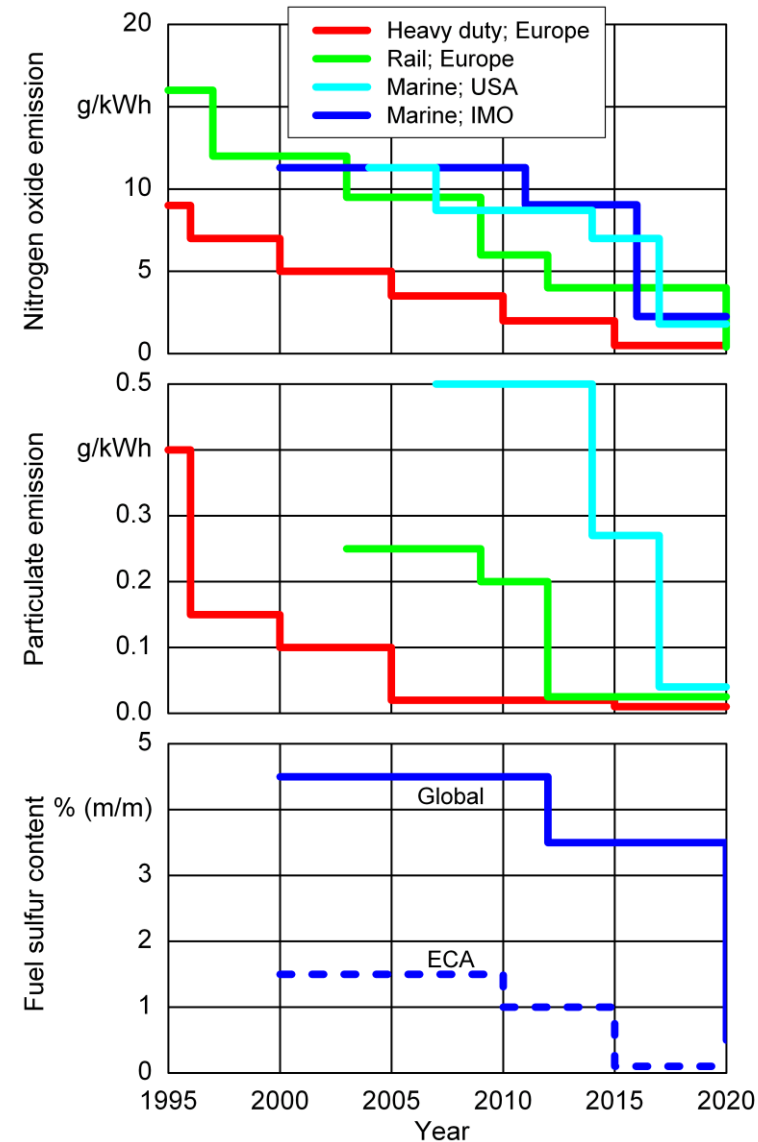
Introduction – International shipping

- Increased NO_x , SO_x and PM concentration along the major shipping routes
- PM emissions from international shipping contributes approx. 60.000 deaths annually according to Corbett
- → Acute need for legal requirements to improve the pollutant emission of marine diesel engines

Source: Marine Policy Program, University of Delaware, 2004
and Corbett, J. et al.: Mortality from Ship Emissions, 2007

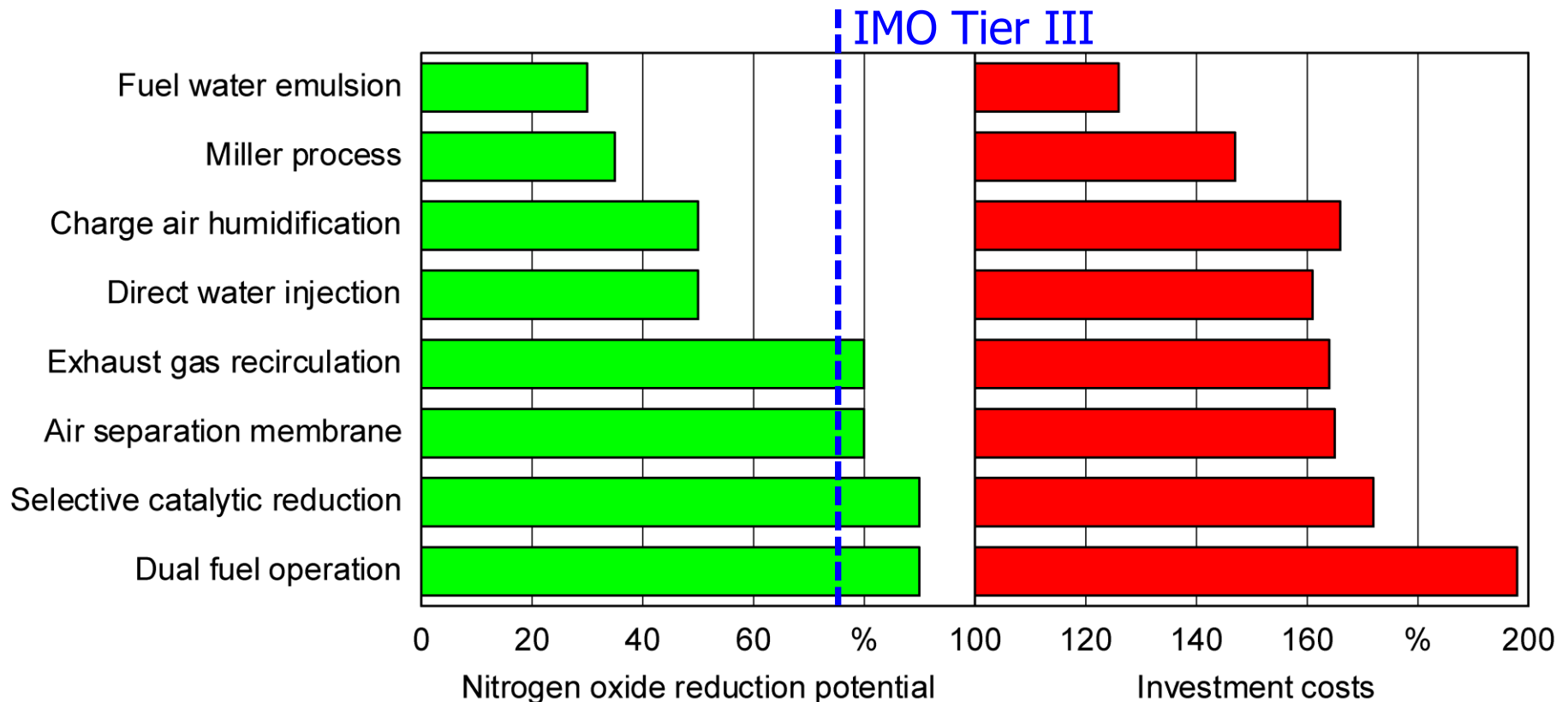


- Gradual reduction of the NO_x - and PM-emission for heavy duty engines in Europe
- With some delay also tightening of emission limits for railway and marine diesel engines
- At the moment **no** limit for particulate emissions of international shipping according to IMO
- **But** HFO ban in arctic region to limit emission of black carbon in discussion



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- Four practical measures to meet the IMO Tier III legal requirements
- Exhaust gas recirculation, air separation membranes and dual fuel operation are investigated at WTZ



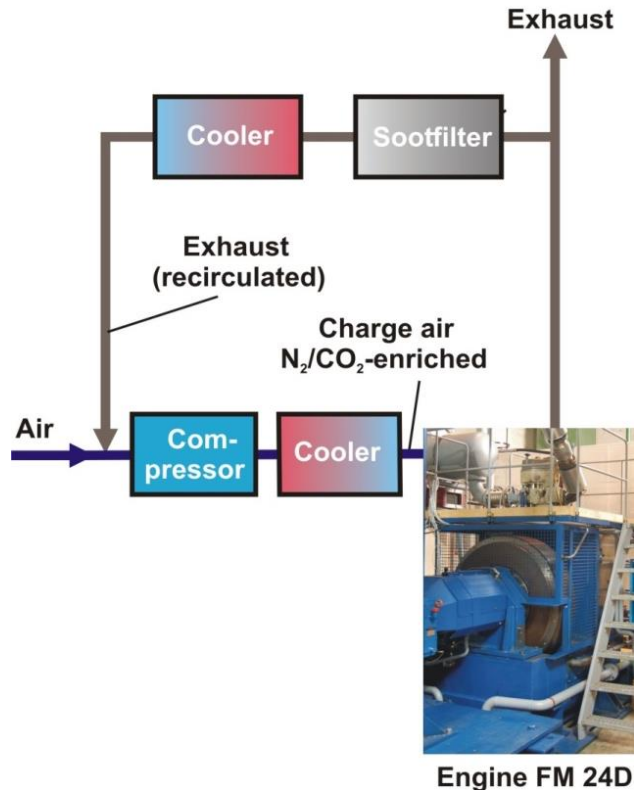
Source: Author's illustration based on Schlemmer-Kelling, U.: Einfluss der Abgasgesetzgebung auf die Motorenentwicklung von Großgasmotoren, Sept. 2010 and Thielen, C. and Rulfs, H.: Minderung der Stickoxid-Emissionen auf Schiffen, 2008

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Exhaust gas recirculation:

Pros: - No reducing agent needed,
low space consumption

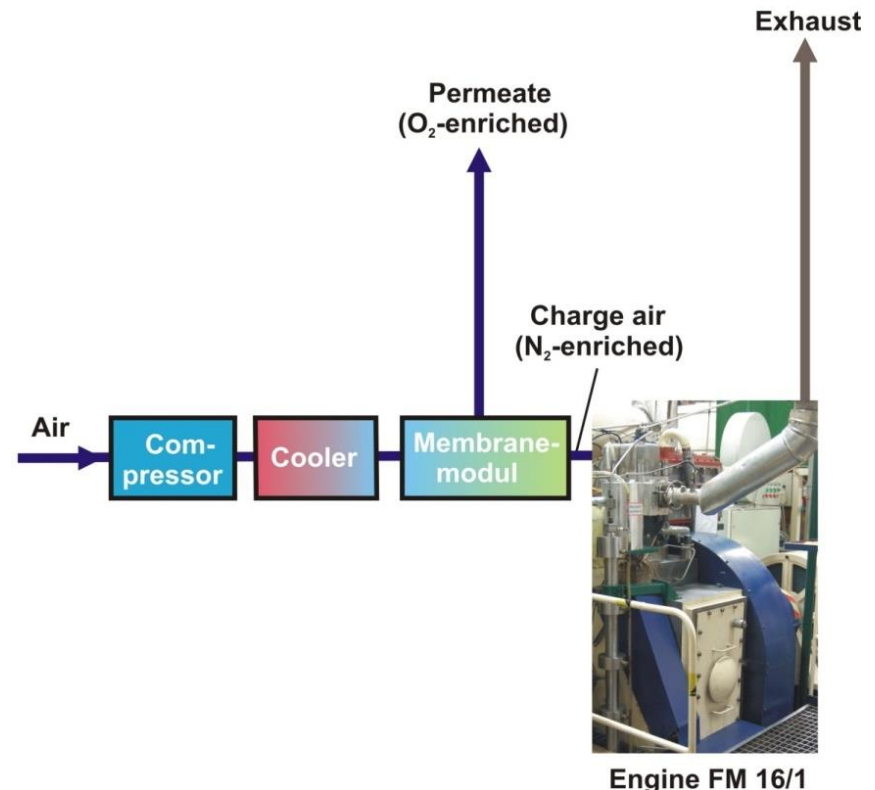
Cons: - Sooting and corrosion of
charge air components



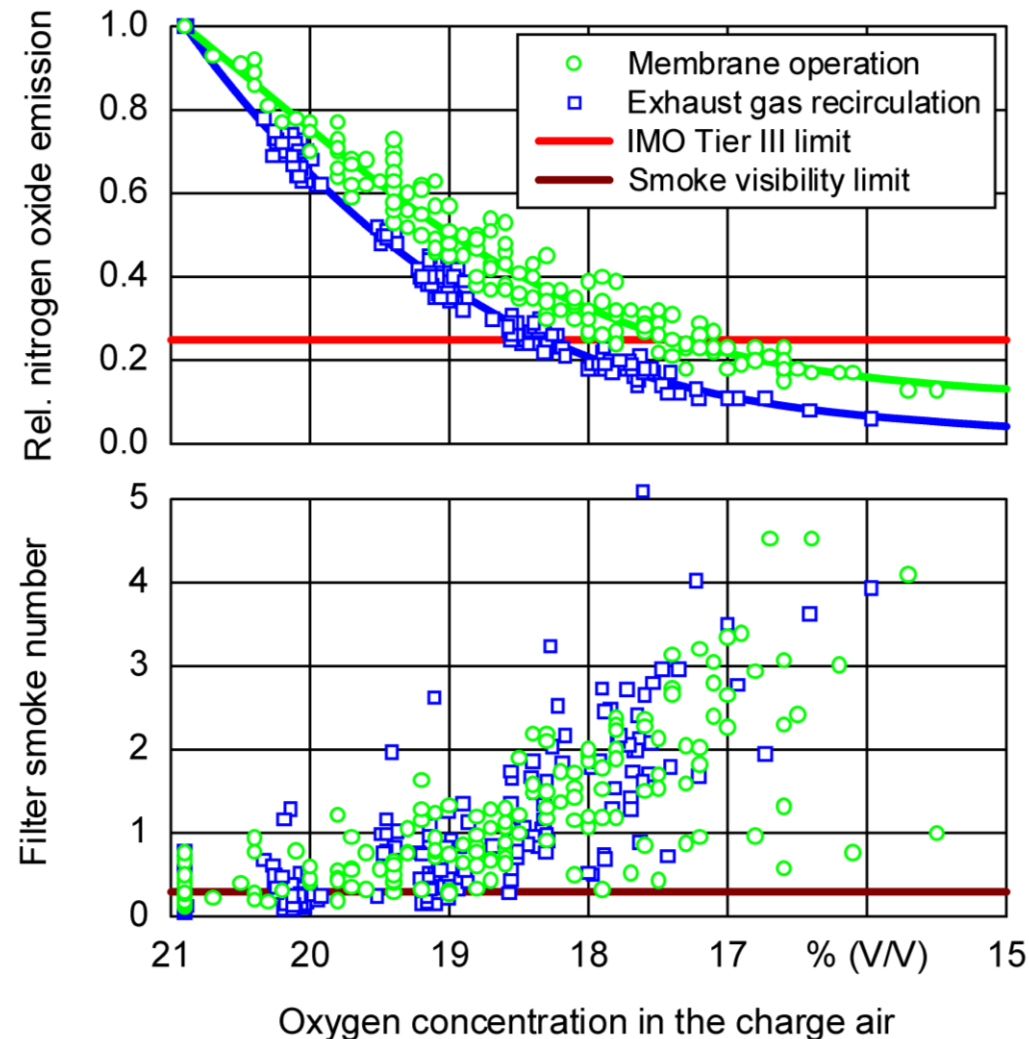
Air separation membrane:

Pros: - Clean charge air system
without sooting

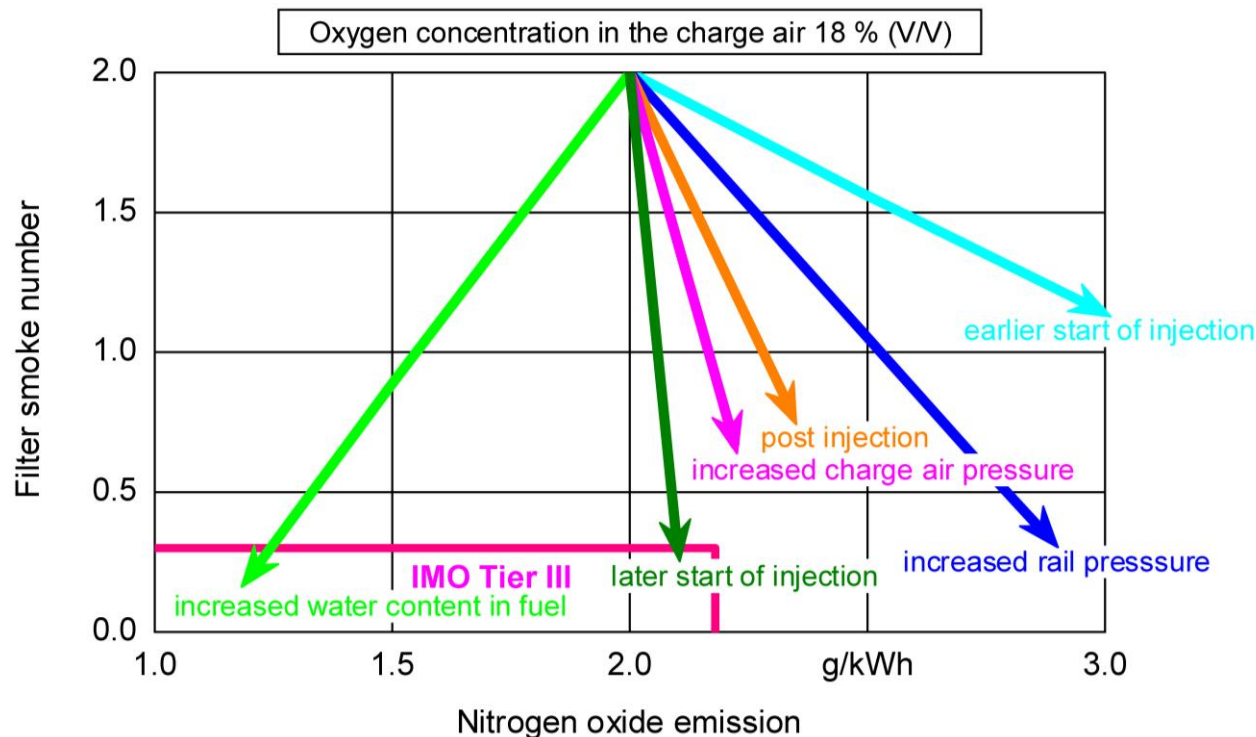
Cons: - Increased charge air
pressure necessary



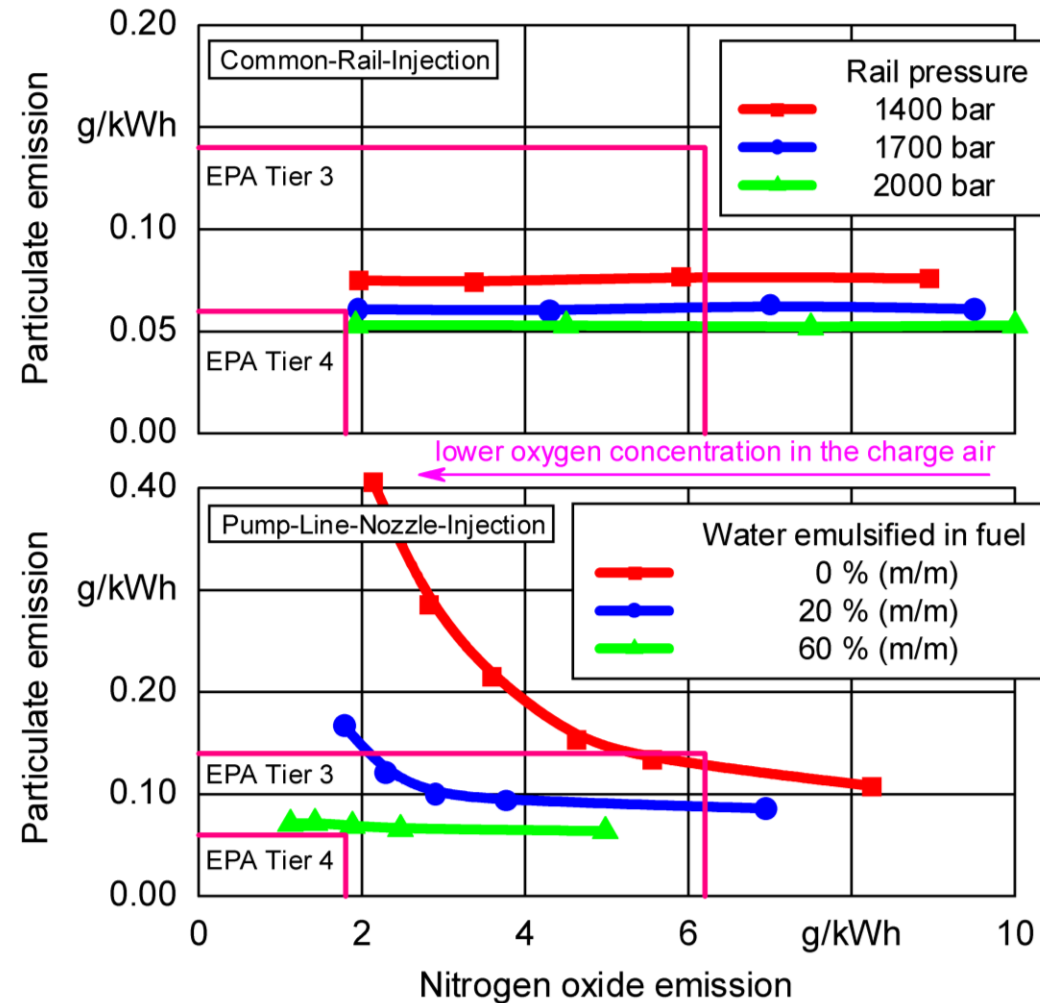
- Significant reduction of NO_x -Emission of 80 – 90 % due to charge air inerting
 - IMO Tier III NO_x limit can be reached with membrane operation and exhaust gas recirculation
- Smoke behavior is not acceptable
 - Additional measures necessary to come below the visibility limit



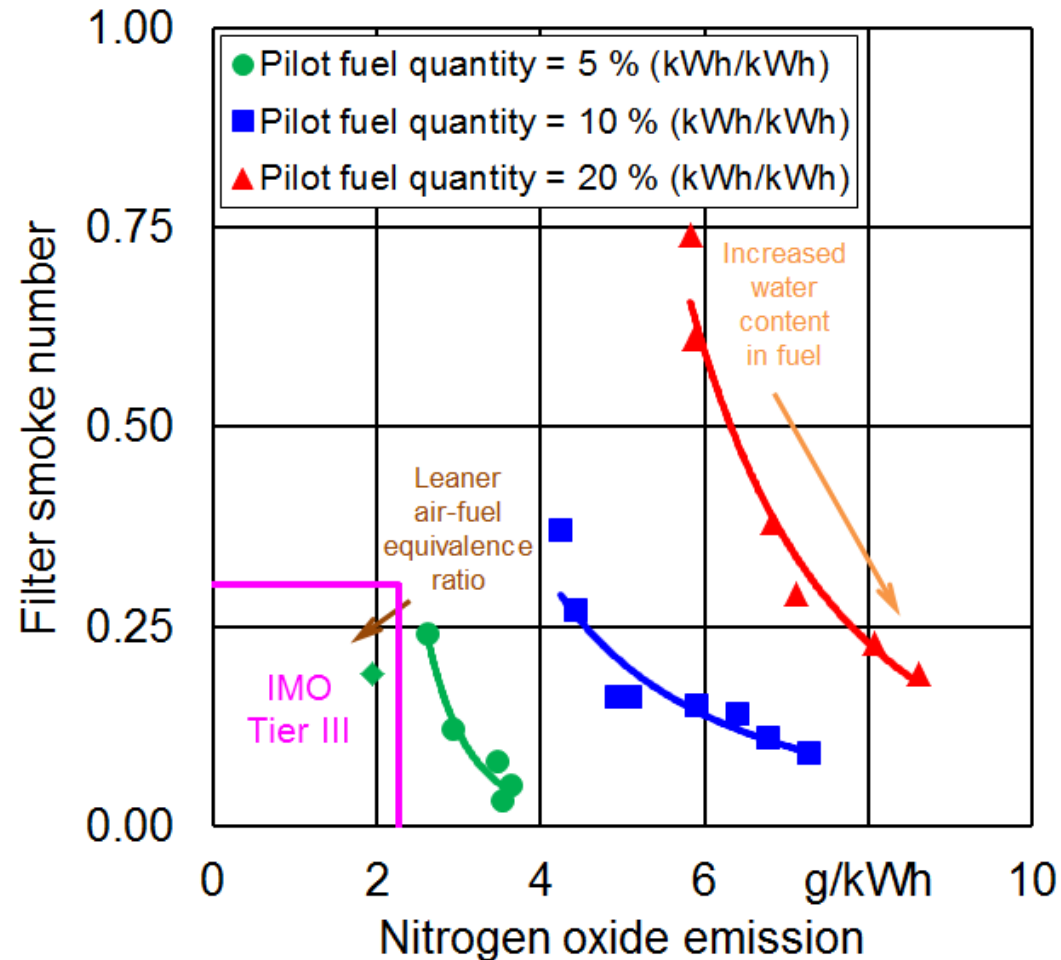
- Improving the smoke behavior by:
 - Usage of fuel water emulsion
 - Delaying the start of injection
 - Increasing the rail pressure
 - Combination of different measures



- Particulate emission can be lowered with a common-rail-injection system by increasing the rail pressure
- With a conventional pump-line-nozzle-injection system the particulate emission is lowered by increasing the water content emulsified in the fuel

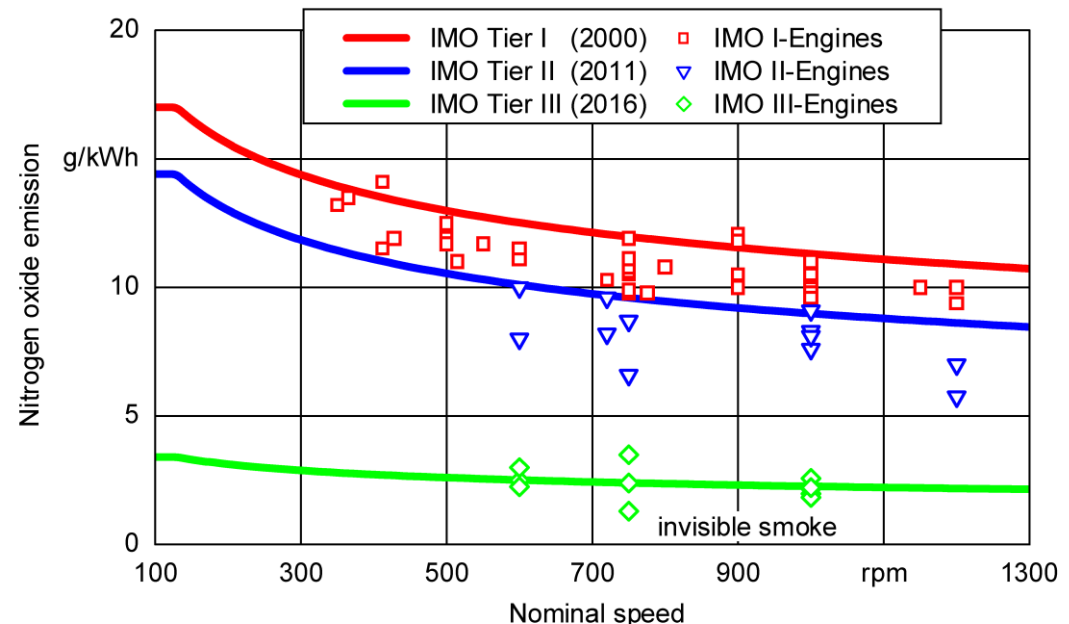


- Investigation of dual fuel operation in combination with fuel water emulsion
- FSN- NO_x -trade-off is improved for lowered pilot fuel quantities
- Increased water content in emulsion leads to improved FSN and worsens the NO_x emission
- IMO Tier III target can be reached with adjustment of air-fuel equivalence ratio and for low pilot fuel quantities



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- Gradual tightening of the emission limits for marine diesel engines
- Engine-internal measures were investigated at WTZ Roßlau to undercut the IMO Tier III NO_x limit at invisible smoke
 - Exhaust gas recirculation, air separation membranes and dual fuel operation are measures to meet the legal requirements
- A limit for particulate emission might follow within the next years
- The dream of a green marine diesel engine is becoming reality!



From the drawing board...



...to practical solutions

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