Marine Fuels – Current Issues

P. Kontoulis, M. Mastrokalos, E. Efstathiou & L. Kaiktsis

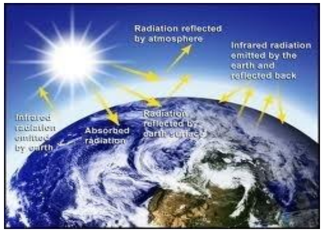
Division of Marine Engineering
School of Naval Architecture & Marine Engineering
National Technical University of Athens

Contact: kaiktsis@naval.ntua.gr

Air Pollutants

Major air pollutants emitted from marine industry:

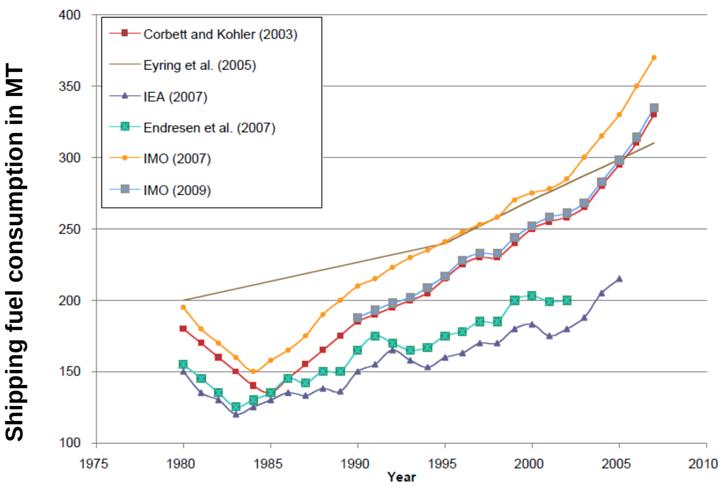
- **Carbon dioxide (CO_2)**
- **Nitrogen oxides (NOx)**
- **Sulphur oxides (SOx)**
- **Volatile organic compounds (VOC)**
- **Particulate Matter (PM) or soot**
- **Black carbon (BC)**



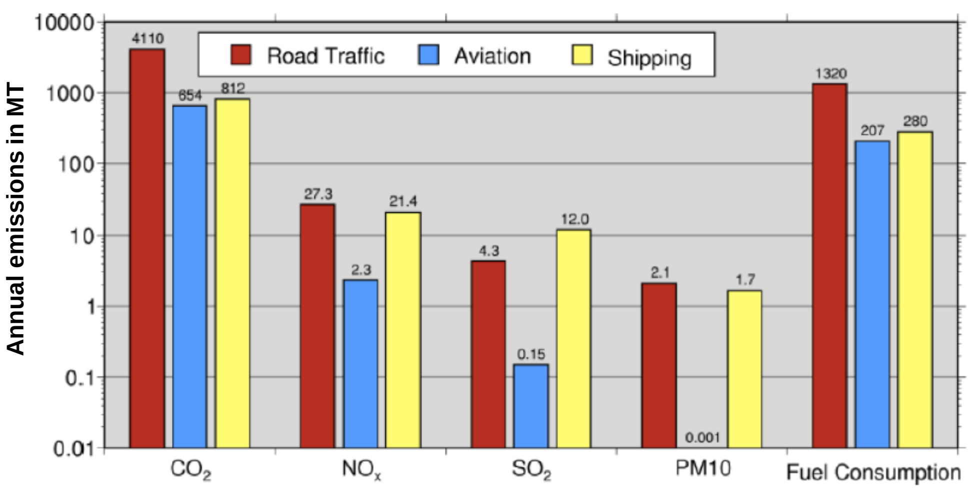
Impact on organisms and environment

- **Respiratory symptoms, cancer**
- **Greenhouse effect**
- **Smog formation**
- **Acid rain**

Air Pollutants

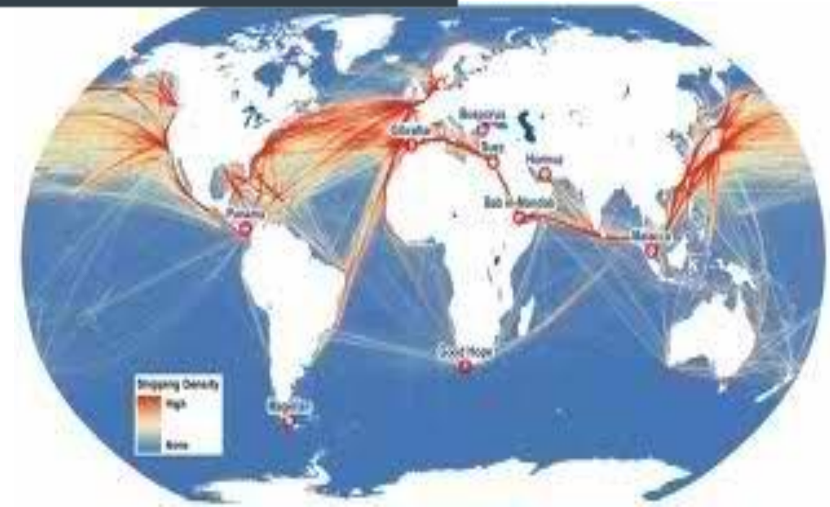


Shipping fuel consumption increases continuously during the last decades



Contribution of shipping regarding NOx and SOx emissions is evident

Emission Control Areas (ECAs)

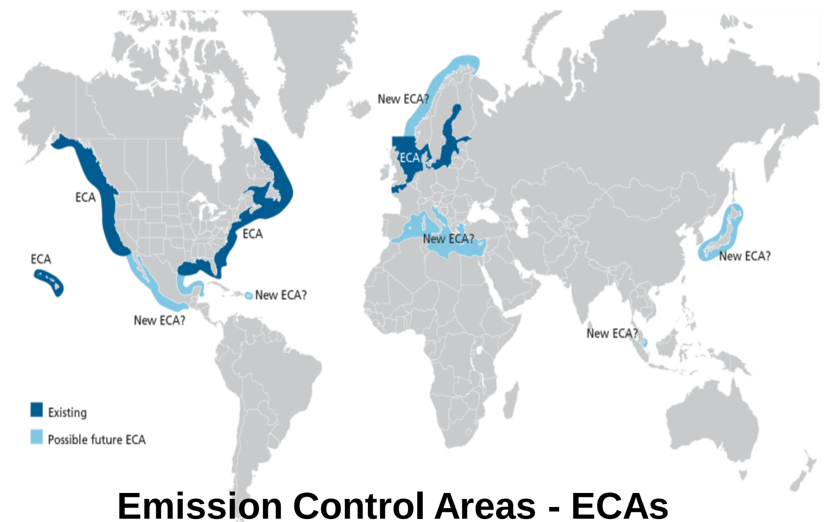


- **High air pollutant concentrations near regions with high density of marine traffic**

- **IMO and local authorities set strict emission control regulations (and areas)**

Expansion of ECAs:

- Zone 1 = Northern Europe
- Zone 2 = Caribbean Sea
- Zone 3 = Northern Mediterranean
- Zone 4 = Singapore, Tokyo bay, Korea, Australia
- Zone 5 = China ports/sea passages

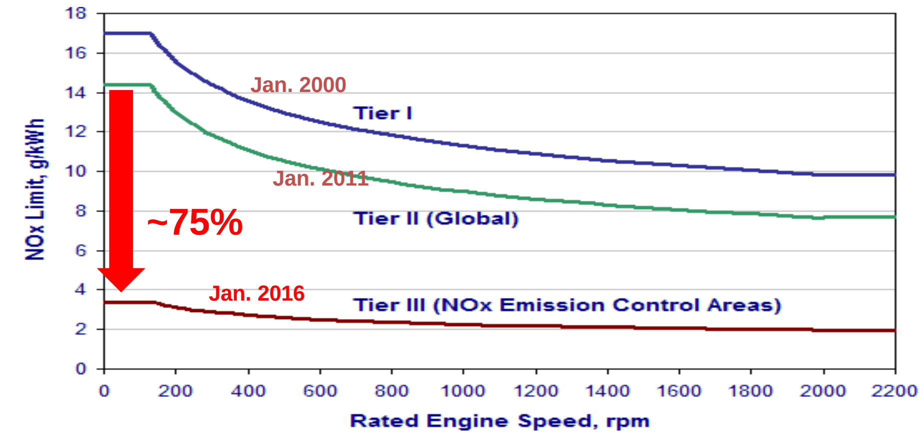


Emission Control Areas - ECAs

Emission Control Regulations

IMO MARPOL ANNEX VI
Regulations for the Prevention of Air Pollution from Ships

- GHG : EEDI & SEEMP (new Chapter 4)
- NOx : Tier I, II, III standards (Reg. 13)
- SOx : Limits on sulphur content (Reg. 14)
- Black carbon: pending

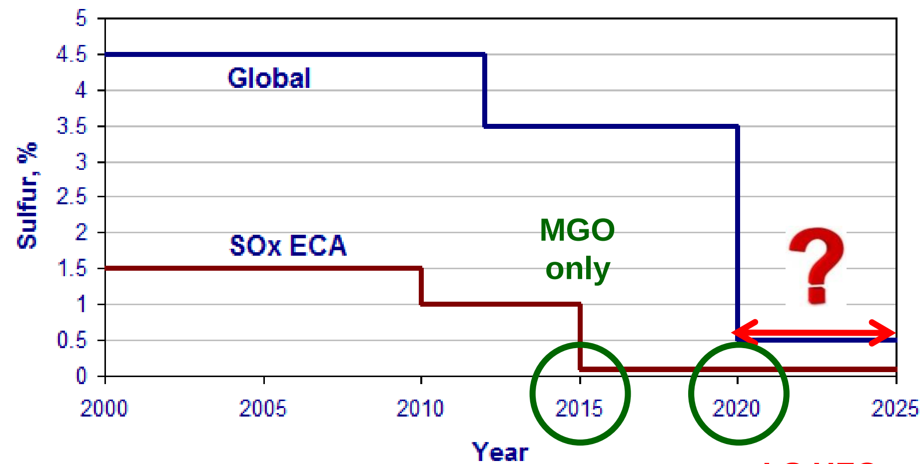


Energy Efficiency Design Index - EEDI:

- New-building vessels from 1 January 2013
- Exceptions:
  - Diesel-Electric propulsion systems
  - Steam-driven vessels
  - Hybrid propulsion installations

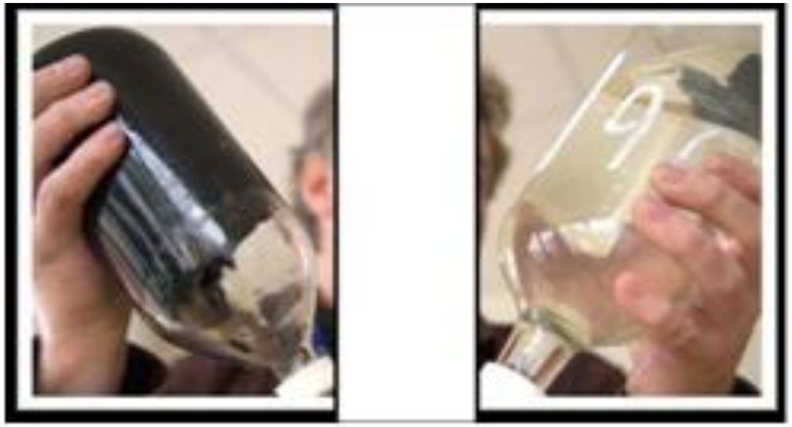
Ship Energy Efficiency Management Plan - SEEMP:

- All vessels from 1 January 2013



extra LS HFO availability ?

Marine Fuel Oils



Residuals

Grades (ISO 8217:2017)

Residual (Non-distillate) fuels are designated by the prefix **RM** and their nominal viscosity

RMA10, RMB30, RMD80,

RME180

RMG180, RMG380, RMG500,

RMG700, RMK380, RMK500, RMK700

Distillates

Grades (ISO 8217:2017)

DMX, DMA, DMB and DMZ

Classification of Marine Fuel Oils

MGO (Marine Gas Oil) – (also called DMA): is a general purpose marine distillate which contains about 60% aromatics; it is free from traces of residual fuel. Due to high aromatic content, the density will be higher than straight run gas oil (860 kg/m^3 at 15 ^{o}C).

MDO (Distillate Marine Diesel Oil) - (also called DMB): is a blend of heavy gas oil that may contain very small amount of black refinery feedstocks (low viscosity up to 12 cSt - no need to be heated). Possible traces of residual fuel (high in sulphur).

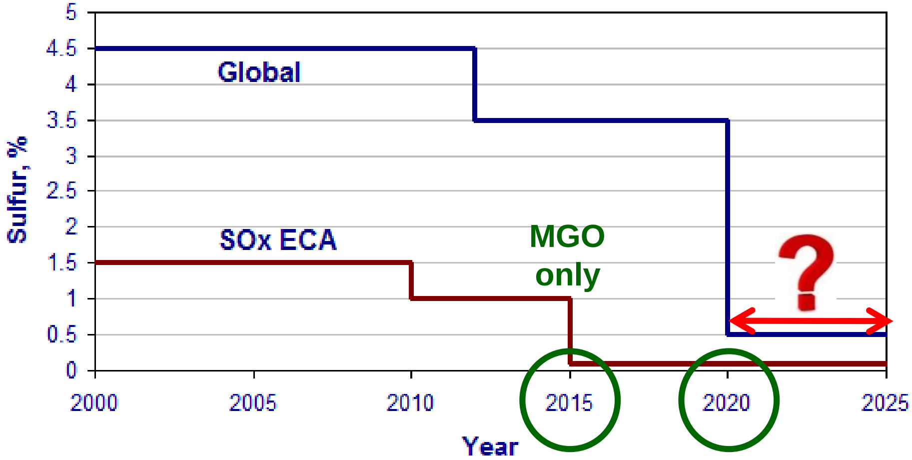
Blended Marine Diesel Oil - (also called DMC): can contain up to 10% IFO with either marine gas oil (MGO/DMA) or distillate marine diesel (MD/DMB).

HFO (Heavy Fuel Oil) - (also called MFO - Marine Fuel Oil): is pure or nearly pure residual fuel oil.

IFO (Intermediate Fuel Oil) - A blend of HFO with less gas oil than MDO
IFO-380 - Intermediate Fuel Oil with max viscosity of 380 cSt at 50^{o}C
IFO-180 - Intermediate Fuel Oil with max viscosity of 180 cSt at 50^{o}C

LS-380 - Low sulphur Intermediate Fuel Oil with max viscosity of 380 cSt at 50^{o}C
LS-180 - Low sulphur Intermediate Fuel Oil with max viscosity of 180 cSt at 50^{o}C

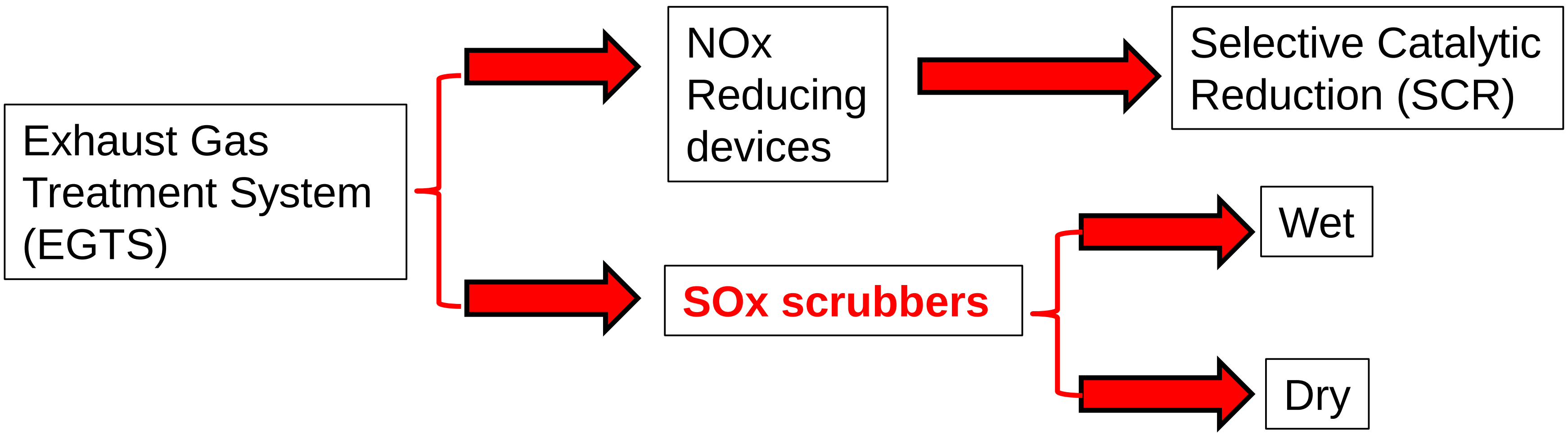
2020 Prospect



POSSIBILITIES:

1) Scrubbers
2) Dual-fuel engines
3) MGO

SOx scrubbers



SOx scrubber:

→ Allows an operator to meet SOx emission limits without using low-sulphur fuels

→ Contributes to 70% up to 90% removal rates of Particulate Matter (PM)

SOx scrubbers

Wet SOx scrubber types

- ‘Open Loop' Systems → Use Seawater
- ‘Closed Loop‘ systems → Use fresh water + Alkaline Chemical
- ‘Hybrid' Systems → Can operate in both 'open loop' and ‘closed loop' modes

SOx scrubbers

Wet '<u>open loop</u>' SOx scrubbers

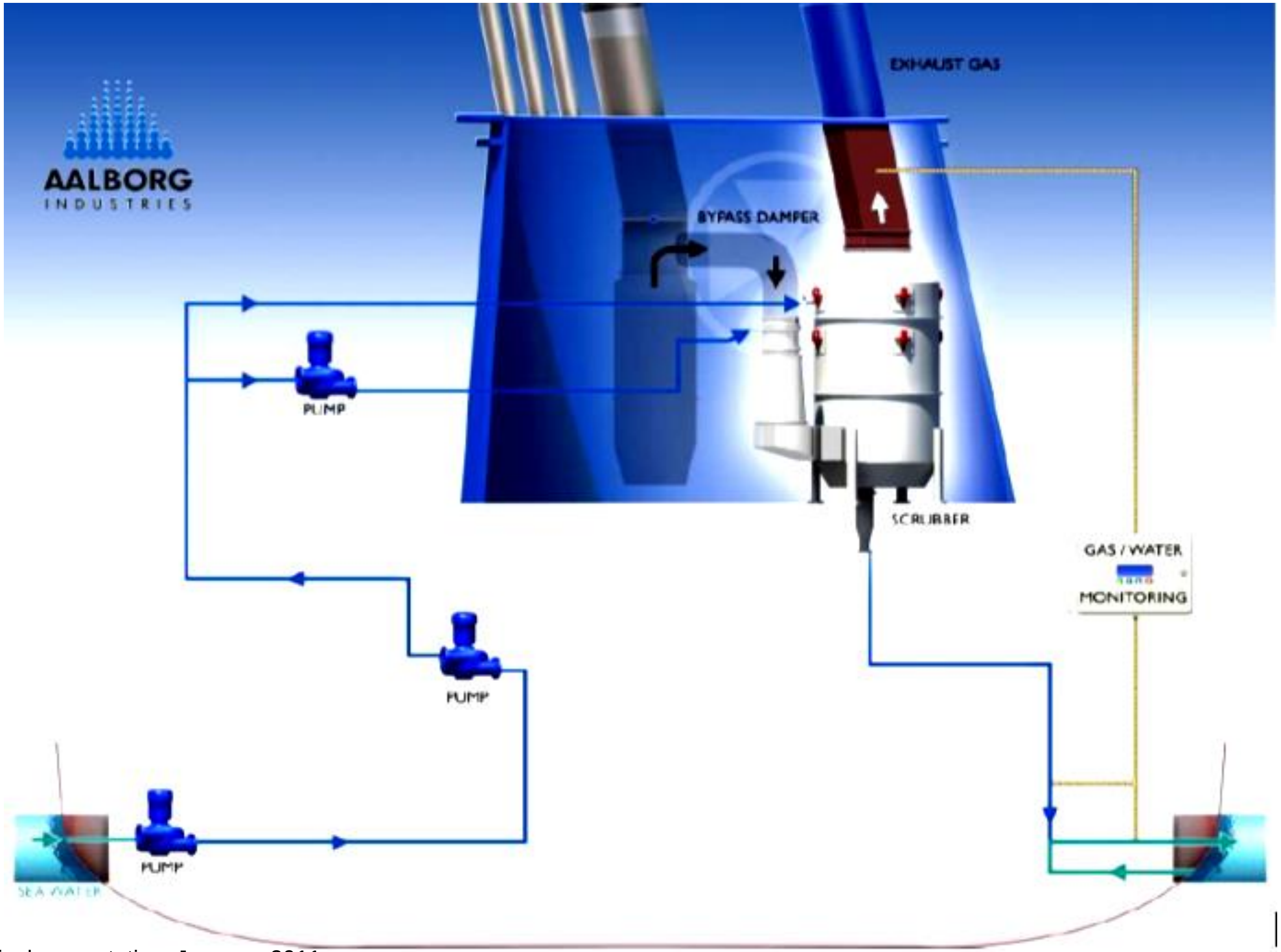
- Seawater is pumped from the sea through the scrubber, cleaned and then discharged back to sea
- Wash-water is not re-circulated
- Wash-water flow rate: ~**45 m^3/MWh**
- SO_x removal rate close to 98% + full alkalinity
- Compatibility with 2020 regulations for sulphur

(*) In the design process seawater temperature also has to be considered (SO_2 solubility reduces at higher seawater temperatures)

SOx scrubbers

Wet SOx Scrubbers

Wet 'open loop' SOx scrubbers



"Exhaust Gas Cleaning", Aalborg Industries technical presentation, January, 2011

SOx scrubbers

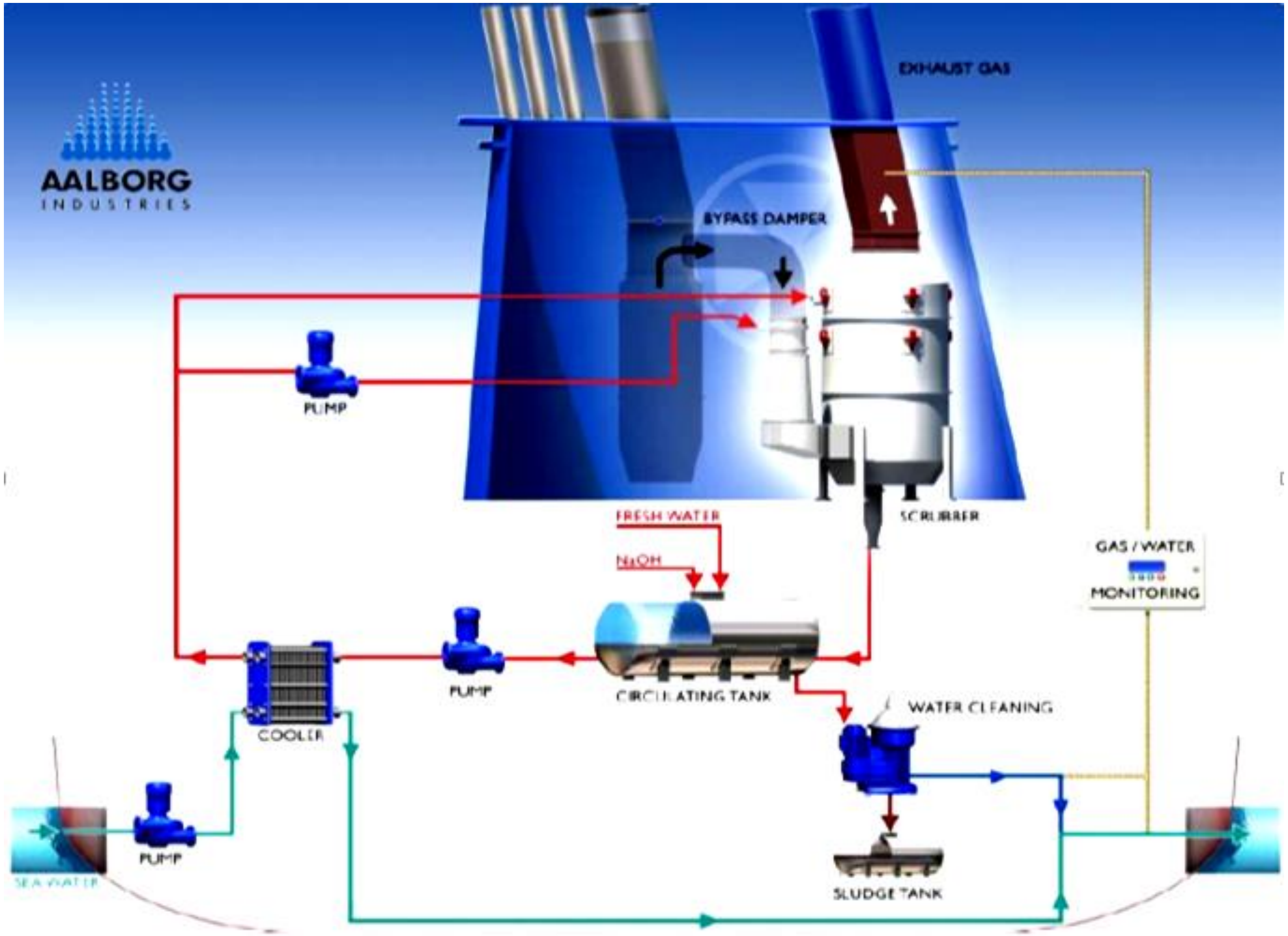
Wet 'closed loop' SOx scrubbers

- Use fresh water treated with sodium hydroxide (NaOH - commonly known as caustic soda) as the scrubbing media
- Removal of SOx from the exhaust gas stream as sodium sulphate
- Wash-water passes into a process tank where it is cleaned before being re-circulated and relevant sludge is stored onboard
- Measurement and control of PH of wash-water by dosing with sodium hydroxide enables re-circulation rate
- Power consumption is estimated to be about half than ‘open loop’ systems and equal to approximately **20 m^3/MWh** and between 0.5 – 1% of the power of the engine being scrubbed
- Can also be operated when the ship is operating in port or estuary waters, where the alkalinity would be too low for ‘open loop’ operation
- By addition of a wash-water holding tank in the system can operate in ‘zero’ discharge mode for a period of time

SOx scrubbers

Wet SOx Scrubbers

Wet '[closed loop]' SOx scrubbers



"Exhaust Gas Cleaning", Aalborg Industries technical presentation, January, 2011

SOx scrubbers

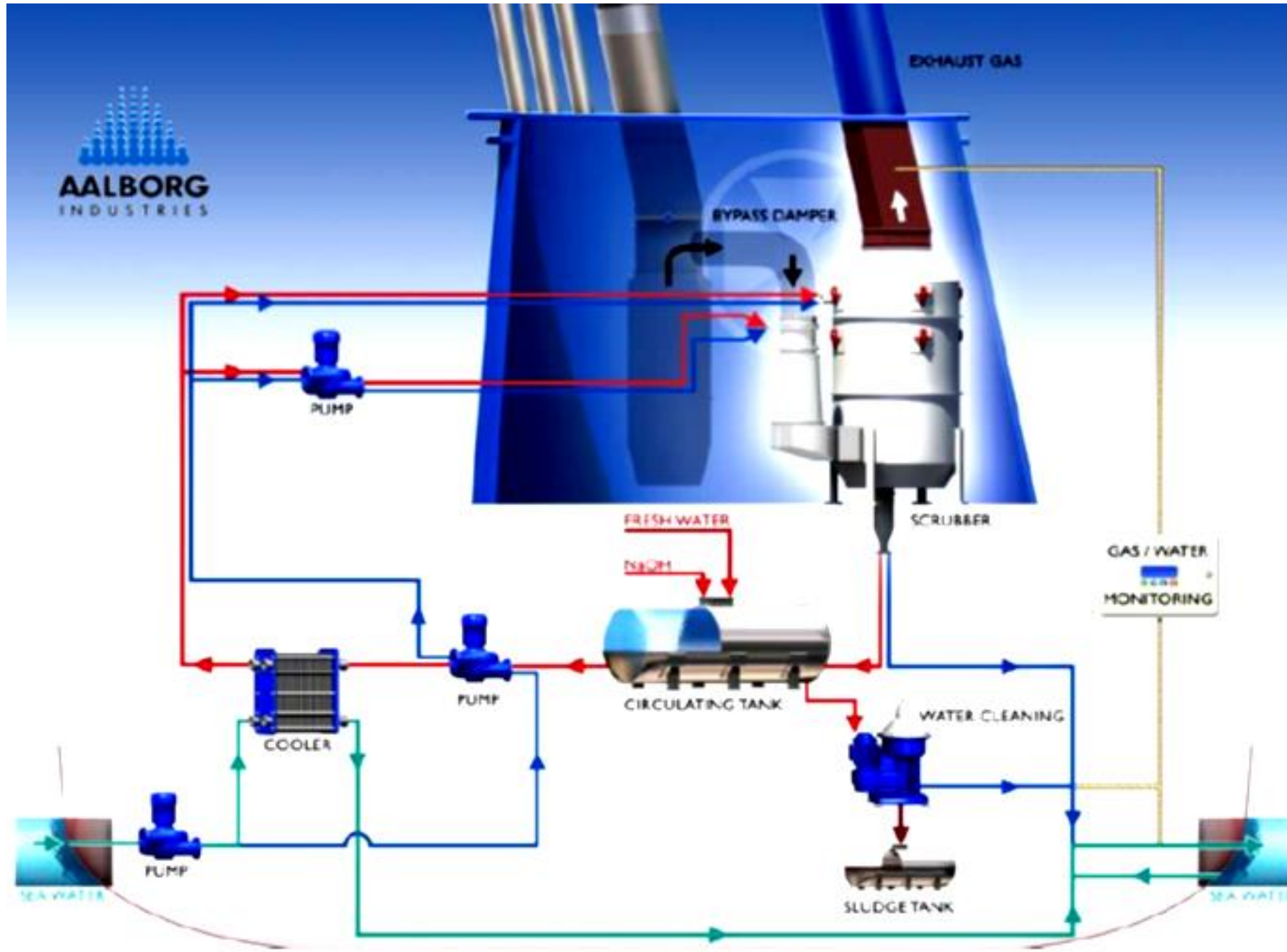
Wet 'hybrid' SOx scrubbers

- Can be operated in either ‘open loop’ mode or ‘closed loop’ mode
- Operate in ‘closed loop’ mode (including ‘zero’ discharge mode) where the water alkalinity is insufficient or wash-water discharge is restricted
- Operate in ‘open loop’ mode without consuming sodium hydroxide.
- Limited use of sodium hydroxide by reducing handling, storage and associated costs.
- Reduction in fresh water consumption.
- More complex than ‘open loop’ or ‘closed loop’ SOx scrubbers.

SOx scrubbers

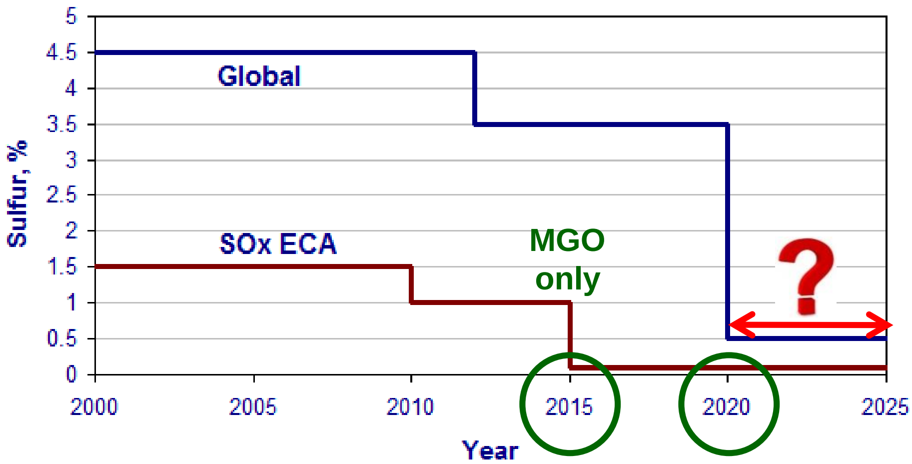
Wet SOx Scrubbers

Wet '[hybrid]()' SOx scrubbers



"Exhaust Gas Cleaning", Aalborg Industries technical presentation, January, 2011

2020 Prospect



POSSIBILITIES:

1) Scrubbers
2) Dual-fuel engines
3) MGO

Dual-fuel marine engines

Operation → **Liquid Fuel Mode** → **Separate backup liquid fuel system**

Operation → **Gas Fuel Mode**

Wärtsilä
4T 50DF engine

Multi fuel flexibility:
- ➢ **Distillate fuels <u>or</u> HFO (Liquid mode)**
- ➢ **Natural Gas <u>or</u> LPG (Gas mode)**

Marine applications:
- ➢ **Redundancy**
- ➢ **Reliability**
- ➢ **Safety**
- ➢ **Emission regulations compliance**

Switch-over procedure:
- ➢ **Instantaneous**
- ➢ **Automatic**
- ➢ **No power and speed oscillations**

MAN Diesel & Turbo
2T ME– (L)GI engine

Gas fuel mode

Gas mode

Low pressure admission
4T & 2T engines

- **Natural gas (gaseous form)**
- **Homogeneous lean-burn air-gas mixture**
- **Independent ignition sources and methods**
  - **pilot injected liquid fuel**
  - **pre-combustion chamber**
- **Premixed air/gas mixture combustion**

High pressure injection
4T & 2T engines

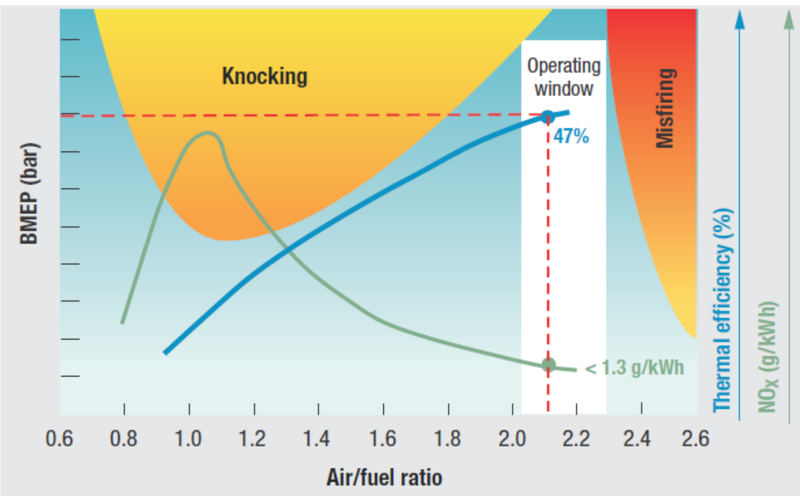
- **Diesel pilot injection**
- **Diesel auto-ignition**
- **Natural Gas (gaseous form) or LPG (liquid form) injection after pilot injection**
- **Gas diffusion combustion**

Gas fuel mode

Low pressure admission

Homogeneous lean-burn principle

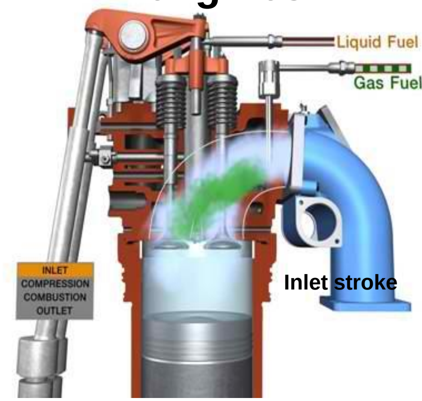
Global air/fuel ratio: 2.2
Homogeneous air/gas mixture
Gas admission during inlet stroke
Low pressure gas delivery system (less than 16 bar)



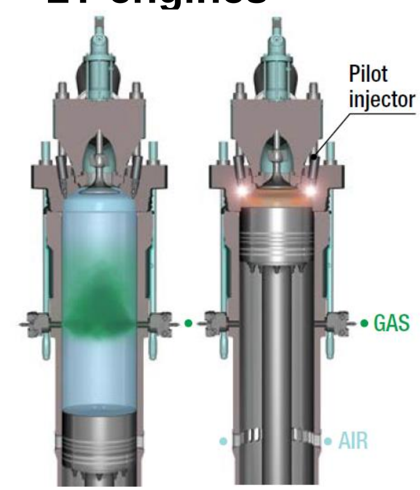
Narrow window for optimal operation:

- **High efficiency**
- **Low NOx emissions**
- **Knock and misfiring prevention**

4T engines



2T engines



Gas admission Ignition

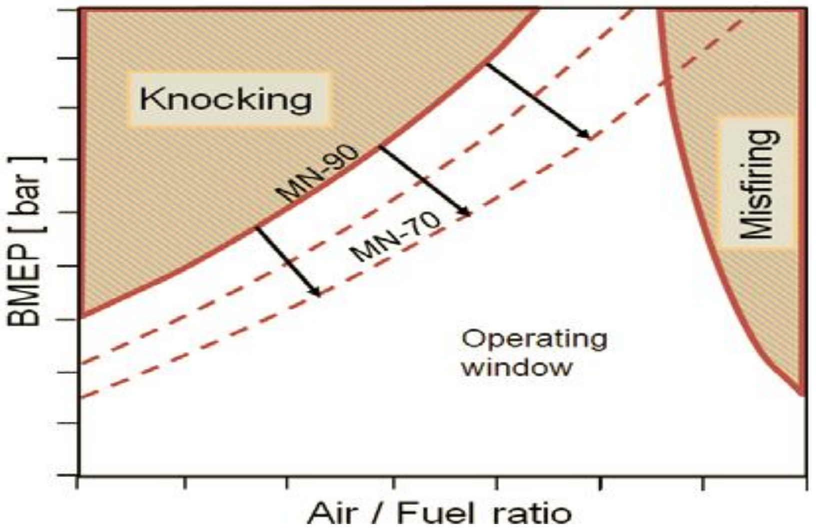
Source: Wärtsilä

Gas fuel mode

Low pressure admission

Operation window depends on site conditions:

- **Ambient temperature**
- **Methane Number (MN)**



Methane Number:

- **Representative of *ignition quality***
- **Defined in terms of *composition* of a prototype mixture:**
  - **Pure methane - MN=100**
  - **Pure hydrogen - MN=0**

Higher alkanes (i.e. LPG) => Low MN values ➡ **Expansion of knocking limit**

Operation outside optimal window

- **Knock**
- **Misfiring**

➡

- **Mechanical stress**
- **Reduction in thermal efficiency and power**
- **Methane slip: High unburned [HC] driven to atmosphere**

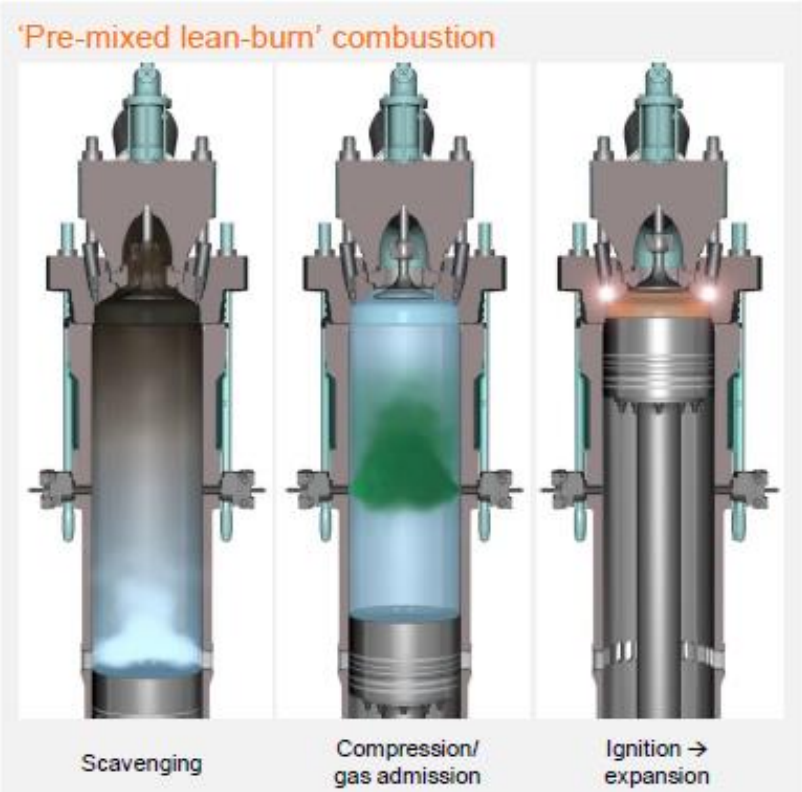
•Safety (fire inside exhaust gas receiver)
•Environment (Greenhouse effect)

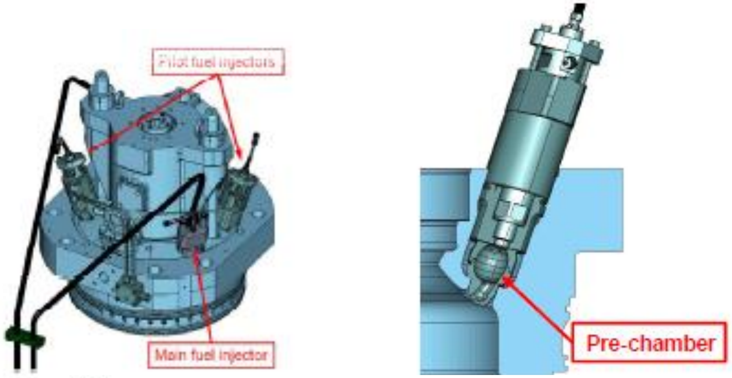
Gas fuel mode

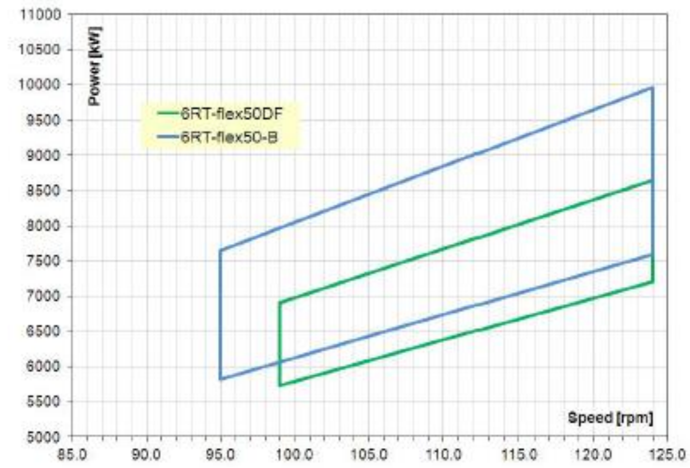
Low pressure admission

First low pressure 2-T large dual fuel marine engine

- Low pressure gas admission
- Ignition by means of pilot injection







Emissions:

CO_2	NOx	SOx	PM
-25%	-85%	-99%	-98%

Source: Winterhur Gas & Diesel

Gas fuel mode

High pressure injection

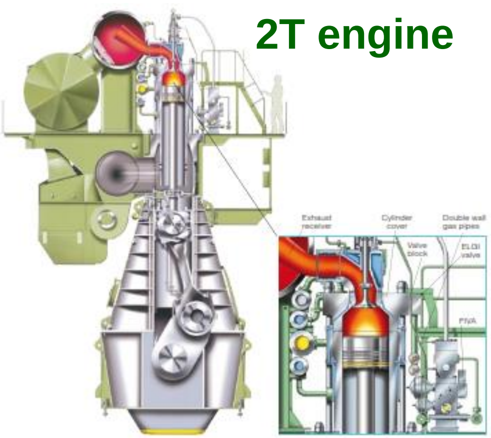
Operation principle

- A minimal metering of distillate fuel (MGO, MDO) or HFO is pilot injected (~5%)
- Auto-ignition
- Premixed combustion of pilot injected fuel
- Natural Gas (gaseous form) injection - 350 bar <u>or</u> LPG (liquid form) injection - 550 bar
- Gas diffusion combustion
  - Short time window for combustion
  - No sufficient time for mixing and chemical reactions
  - Local air-fuel ratio close to stoichiometric at flame front
  - High local temperature levels

No significant reduction of NOx emissions

Combination with advanced technology:
- EGR
- State-of-the-art supercharging
- Exhaust gas after-treatment

2T engine



Source: MAN Diesel & Turbo

4T engine

Source: Wärtsilä

Gas fuel mode

Current portfolio

Marine Engine Builders DF Portfolio

WÄRTSILÄ

WIN GD Winterthur Gas & Diesel

4T GD: Gas Diesel Engines – HP

Output range : 2.5 ~ 19 MW

- Offshore constructions (FSO, FPSO) as prime mover for alternators

4T DF: Dual-Fuel Engines – LP

Output range : 1 ~ 18 MW

- LNG tankers, offshore supply vessels, coastal vessels, tugs and passenger ferries for propulsion
- LNG tankers and offshore constructions (FSO, FPSO) as prime mover for alternators

2T RT-flex & X DF: Dual-Fuel Engines – LP

Output range : 5 ~ 64 MW

- LNG tankers, oil tankers, container vessels, bulk carriers, RoRo ships for propulsion

MAN Diesel & Tubo SE

4T DF: Dual-Fuel Engines – LP

Output range : 6 ~ 18 MW

- Offshore supply vessels, coastal vessels, tugs and passenger ferries for propulsion
- LNG tankers and offshore constructions (FSO, FPSO) as prime mover for alternators

2T ME-GI: Natural Gas Injection – HP

2T ME-LGI: LPG Injection – HP

Output range : 4.5 ~ 87 MW

- LNG tankers, offshore supply vessels, coastal vessels and tugs for propulsion

Source: Winterhur Gas & Diesel

What about 2020?

Approach for a number of owners: *run with MGO*

- **By choice (MGO price?)**
- **Due to not implementing changes**

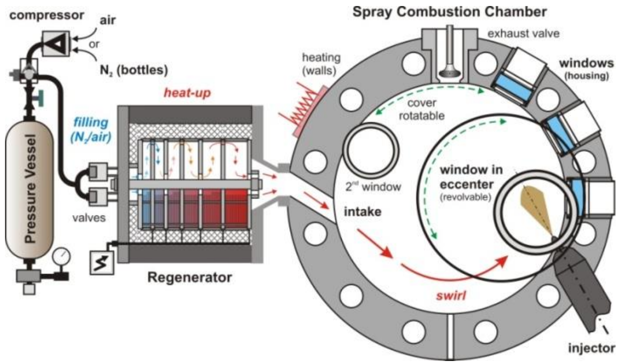
New fuels will be developed (by 2019) – *Previous experience with HDME 50, AFME 200 of ExxonMobil*

Questions:

- **Availability**
- **General uncertainty on landscape !!!**

HFO - LFO Spray Visualization

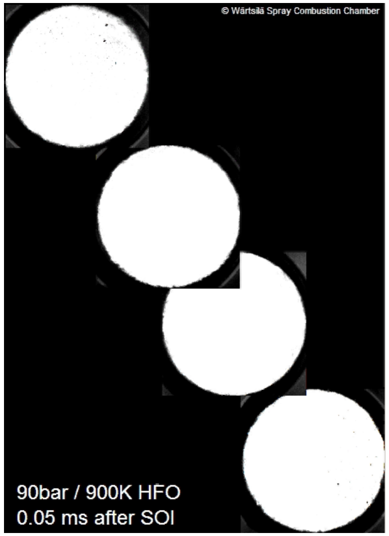
Experimental test configuration

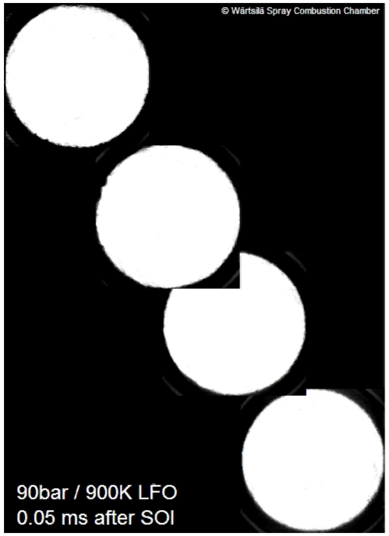


Non-reactive (N_2) spray evolution: 900 K / 90 bar (33.7 kg/m^3)

HFO

fuel preheating





LFO

no preheating

Source: WinGD

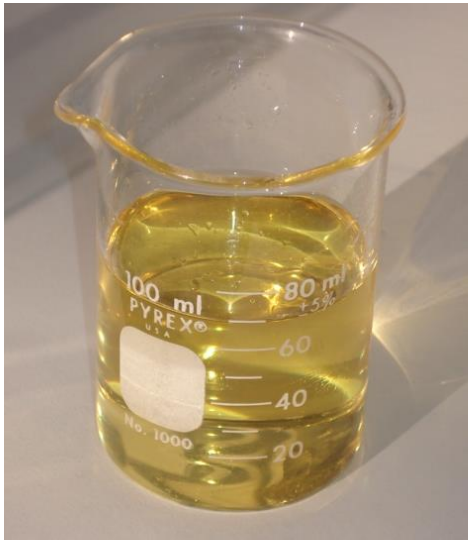
Biodiesel (FAME)

❑ FAME (Fatty Acid Methyl Esters) is the chemical name of Biodiesel.

❑ It is a product manufactured through the trans-esterification of vegetable oils and animal fats with methanol which is blended with diesel.

❑ FAME can be manufactured from waste cooking oils, animal fats, and vegetable oils. Oils such as rapeseed, palm, and sunflower are among the most common.

Biodiesel from soybean oil



❑ When FAME is added to conventional diesel to make 'B**X**' blends, the '**X**' stands for the percentage of biodiesel added. For example; a B5 blend contains 5% biodiesel and 95% regular refinery diesel.

Biodiesel (FAME) Advantages

Advantages:

❑ <u>Fuel system and engine combatibility</u>

Many marine engine manufacturers have certified their engines for operation on biodiesel or a blend of biodiesel and diesel fuel.

B20 represents a fuel of 80% diesel fuel and 20% biodiesel.

❑ <u>Lower SOx emissions</u>

Neat biodiesel contains almost no sulfur, so SOx exhaust emissions are practically zero. Blending with regular diesel lowers the sulfur content proportionally.

❑ <u>Safety</u>

It has a <u>higher flash point</u> than diesel, is biodegradable, and degrades quickly in water. The flash point of B100 is approximately 300°F (149°C), compared to 120–170°F (49–77°C) for petroleum diesel.

❑ <u>Availability</u>

Biodiesel is commercially available at prices comparable to those of marine diesel fuel. For quality control, it is produced to specifications set by the American Society for Testing and Materials (ASTM) and the European Union (EU).

Biodiesel (FAME) Drawbacks

Drawbacks:

❑ Low temperature operation

Biodiesel has a high cloud point compared with petroleum diesel that can result in filter clogging and poor fuel flow at low temperatures (i.e., 32°F (0°C) and lower).

❑ Fuel system and engine compatibility

In higher concentrations, can dissolve certain non-metallic materials, such as seals, rubber hoses, and gaskets and metallic materials, such as copper and brass.
For an existing ship, the fuel system and engines may have to be modified.

❑ Cleaning effect

In higher concentrations, has a solvent/scrubbing action that cleans/removes deposits from the fuel system, resulting in clogged fuel filters. The fuel system should be thoroughly cleaned, removing all deposits and residual moisture before using biodiesel or there will be inordinate high use of fuel filters.

❑ Long term storage stability

Biodiesel can degrade over time, forming contaminants of peroxides, acids, and other insolubles.

Questions?