



## Emission and fuels - 2014



- 1 Introduction
- 2 Tier III Strategy
- 3 SCR - Selective Catalytic Reduction
- 4 EGR – Exhaust Gas Recirculation
- 5 Fuels
- 6 SO<sub>x</sub> Scrubbing
- 7 Visit to the Test Center

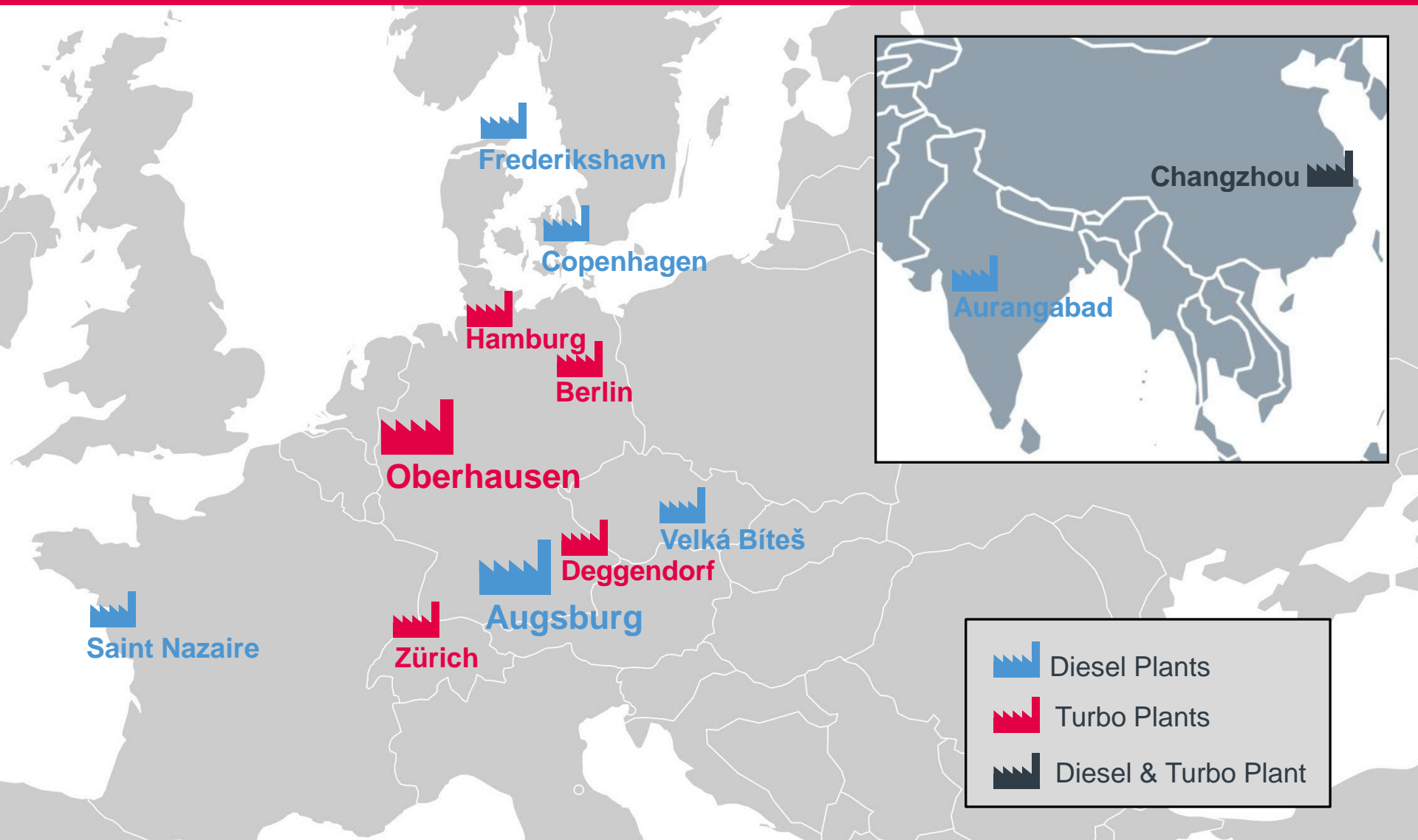
# Company Presentation



- Copenhagen May 22 2014
- Mr. Leif Hauerslev  
Senior Manager, Promotion and Component Sales
- Mrs. Dorthe Jacobsen  
Senior Research Engineer, Process development – fuel and lube
- Mr. Flemming Bak  
Research Engineer, Process development – aftertreatment systems

# Sites

Production network



# Production Sites

Copenhagen, Denmark



**Employees (31.12.2013) : 1,255**

## Products

Engine components  
spare parts



Design of two-stroke engines



2-Stroke engine components



Spare parts





PrimeServ After Sales Service


# Licenseses Overview


## Licensee network





	<b>China P.R.</b>							
	CSIC, Shanghai Qiyao Engine (SQE)					■	■	1980
	CSIC, Shaanxi Diesel Engine Heavy Ind. (SXD)					■		2004
	CSIC, Henan Diesel Engine Heavy Industry (HND)					■		2007
	CSIC, Wuhan Marine Machinery Plant (WMMP)						■	2006
	CSIC, Dalian Marine Diesel (DMD)					■		1980
	CSIC, Yichang Marine Diesel (YMD)					■		1989
	CSSC, Zhenjiang CME (ZJCME)					■	■	1980
	CSSC, Hudong Heavy Machinery (HHM)					■	■	1980
	CSSC - MES Diesel (CMD)					■		2007
	CSSC - Guangzhou Marine Diesel (GMD)					■		2011
	Dalian Locomotive & Rolling Stock Company (DLRC)						□	2004
	Hangzhou Zhonggao Engine (ZGPT)						■	2006
	STX Dalian (STXD), STX Fushun (STXF)					■	■	2007
	Jiangsu Antai Power Machinery (JAD)					■		2007
	Weichai Heavy Machinery (WHM)						■	2008
	CSR Ziyang Locomotive (CSR)						■	2008
	Zhongji Hitachi Zosen Diesel Engine (ZHD)					■		2008
	Hefei Rong An Power Machinery (RPM)					■	■	2008
	Zhenjiang Yungpu Heavy Machinery (YungPu)					■		2009
	Jinan Diesel Engine Works (JDEW)						■	2009


	<b>Croatia</b>							
	Brodosplit					■	■	1967
	Ujanik					■	■	1984
	Adriadiesel						■	1998


	<b>India</b>							
	Kirloskar						■	1977


	<b>Japan</b>							
	Kawasaki					■	■	1911
	Mitsui					■	■	1926
	Mitsubishi						■	1929
	Hitachi					■		1951
	J.F.E. Engineering						■	1964
	Diesel United						■	1963
	Niigata						■	1973


	<b>Korea</b>							
	Hyundai Heavy Industries					■		1976
	STX Heavy Industry, STX Engine					■	■	1977
	Doosan Engine					■	■	1983
	STX Enpaco						■	1995

	<b>Poland</b>							
	H. Cegielski Poznan					■	■	1959

	<b>Russia</b>							
	Bryansk					■	■	1959

	<b>Spain</b>							
	Navantia						■	1965

	<b>U.S.A.</b>							
	Fairbanks Morse Engine						■	1995

	<b>Vietnam</b>							
	Vinashin					■		2004

■ Low-Speed

■ Medium-Speed

□ High-Speed

■ Turbocharger

■ CP-Propeller

# Total Reference List ME / MC

MAN B&W two-stroke engines



ME-GI

ME-B

ME-C

ME

MC-GI

MC

Type	On order/ Delivered
K98	734
K90	586
K80	230
L90	25
L80	143
L70	316
L60	569
L50	304
L42	205
L35	1,185

Type	On order/ Delivered
S90	412
S80	606
S70	2,194
S65	74
S60	4,187
S50	5,669
S46	849
S42	881
S40	49
S35	1,128
S30	3
S26	258

Type	On order/ delivered
G95	5
G80	71
G70	143
G60	150
G50	169
G45	6

Dual fuel eng. type	On order
S90 ME-C-GI	5
G70 ME-C-GI	28
L70 ME-C-GI	5
S70 ME-C-GI	4
S50 ME-C-GI	10
G50 ME-B-LGI	6
S50 ME-B-LGI	3

As of 2014.03.25

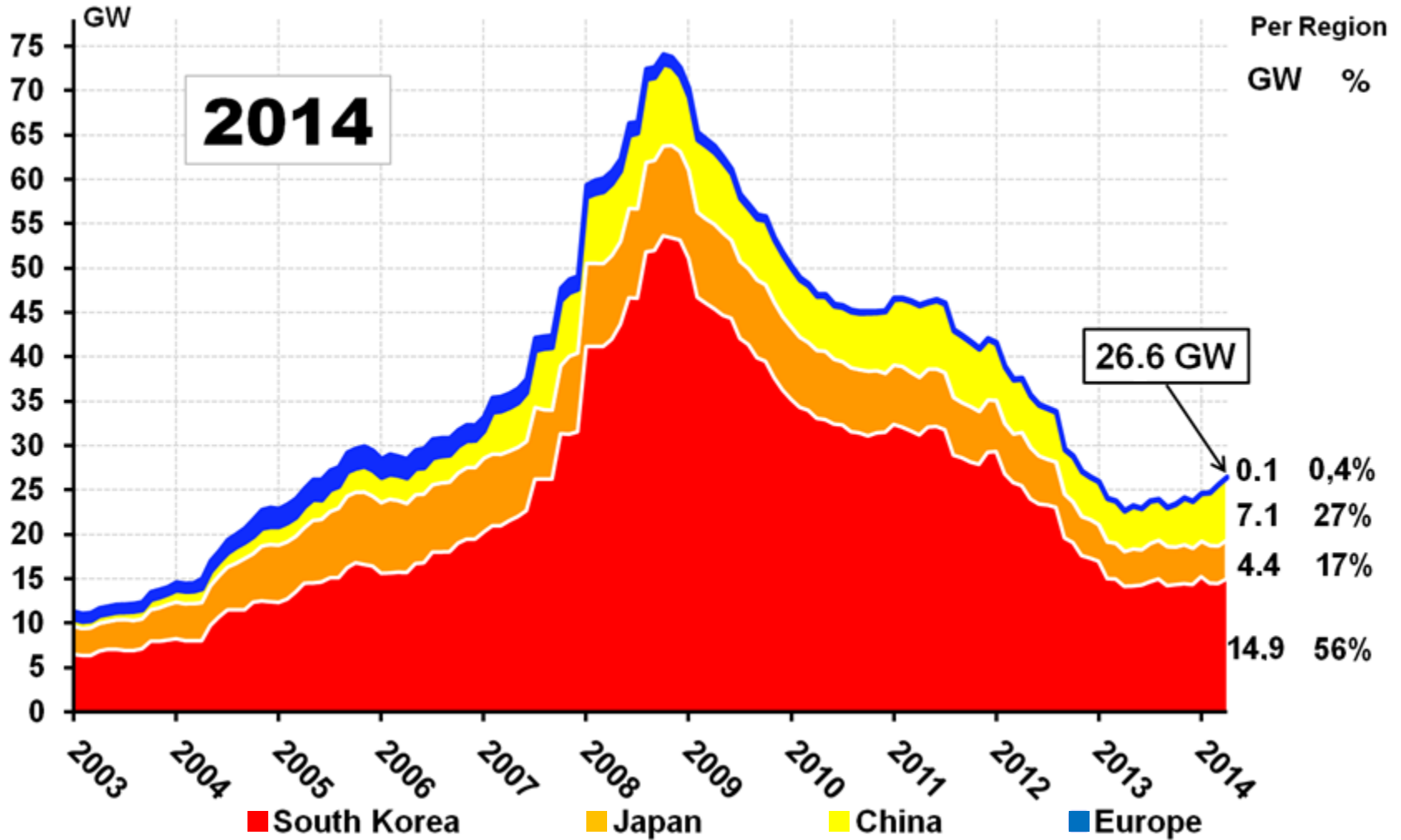
Totals:

314 GW

21, 212 Engines

# Licensees Reported Order Book

Optimism is back, Asia dominates



# Emission Regulation is the Main Development Driver

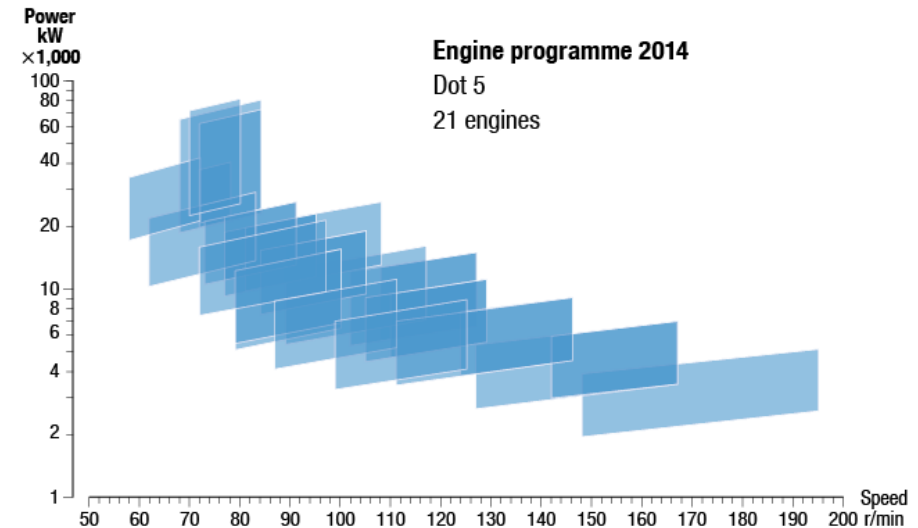
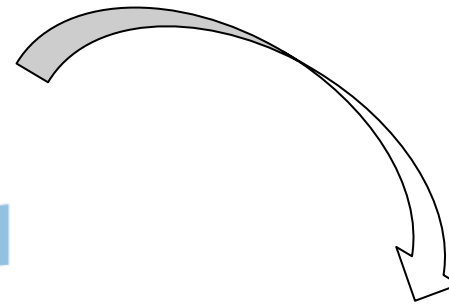
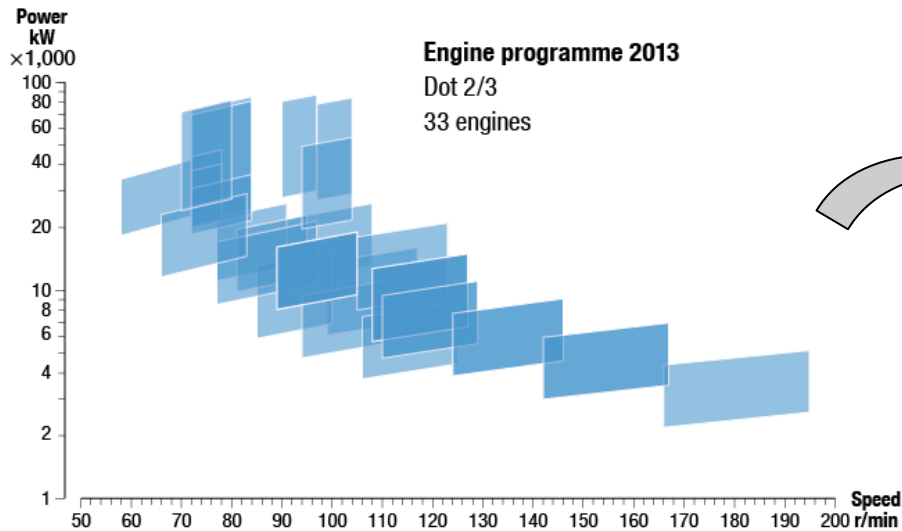


EEDI in force to regulate CO<sub>2</sub> from 2013

Strict Local SO<sub>x</sub> limits in force already  
stricter general SO<sub>x</sub> limits from  
2015 and 2020

NO<sub>x</sub> Tier II in force already  
Stricter NO<sub>x</sub> Tier III from 2016

# Engine Programme 2013 vs. Engine Programme 2014



- Reduced number of engines
- Layout area extended



1 Introduction

**2 Tier III Strategy**

3 SCR - Selective Catalytic Reduction

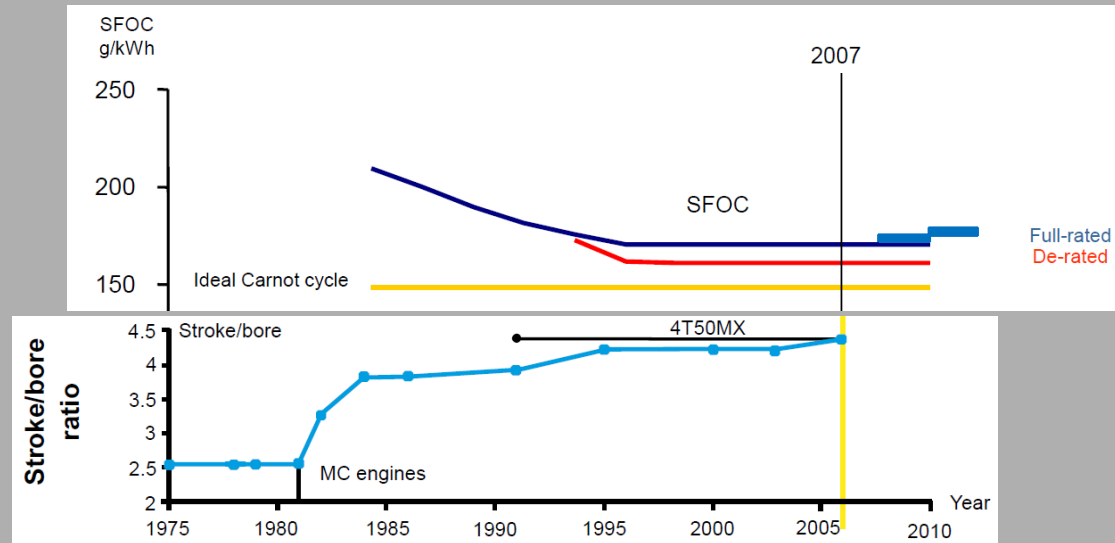
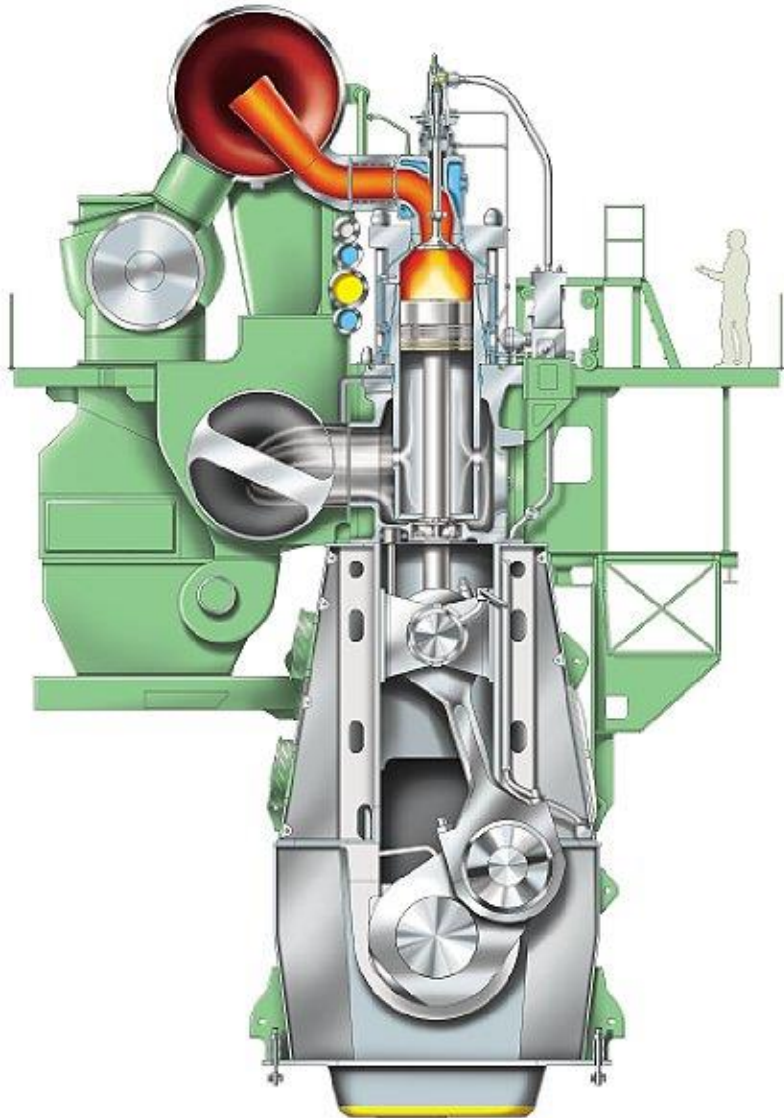
4 EGR – Exhaust Gas Recirculation

5 Fuels

6 SO<sub>x</sub> Scrubbing

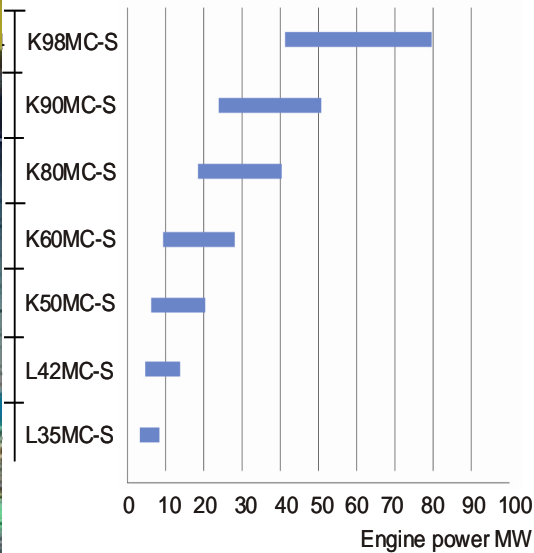
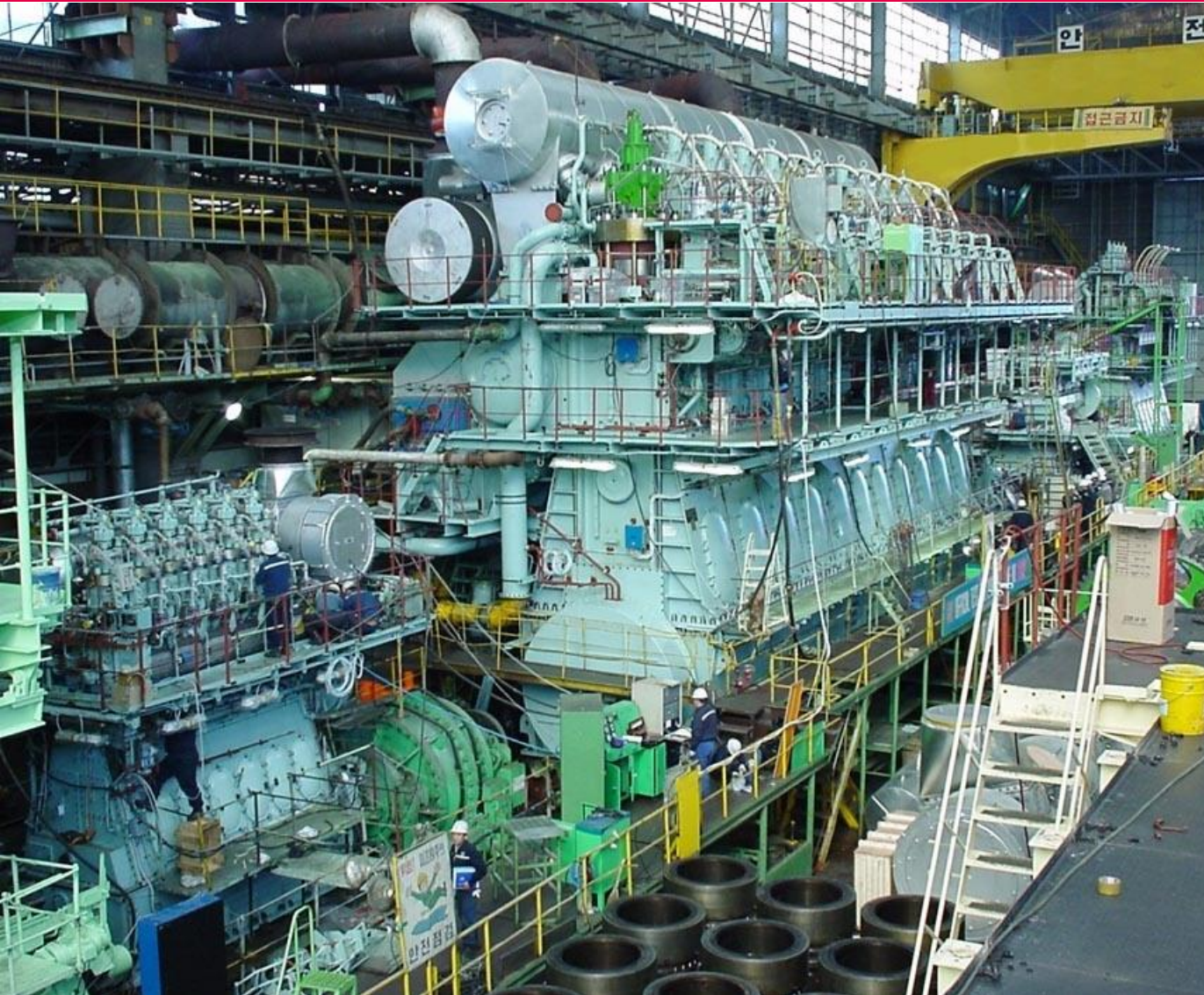
7 Visit to the Test Center

# Diesel Two-Stroke



[Start video](#)

# MAN B&W 6S35MC and MAN B&W 10K98MC-C on Testbed



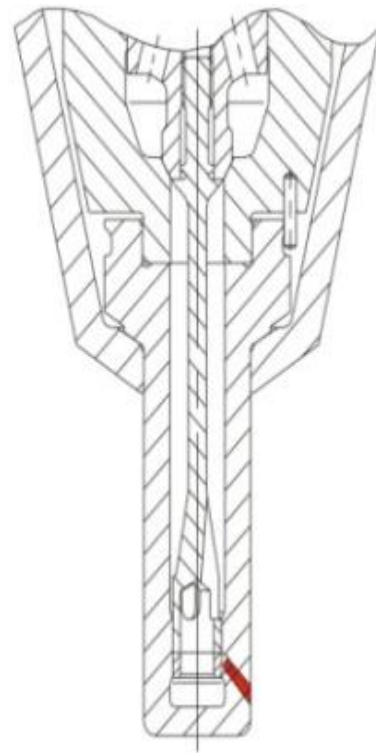
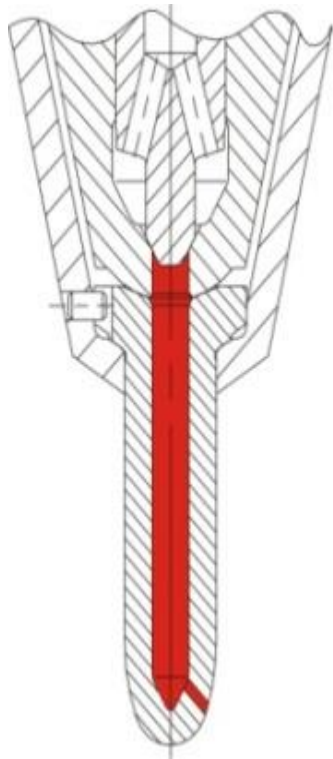
## 14K98MC7:

- 87,220 kW
- 26m x 15m x 4.6m
- 2,400 tons
- Fuel: 370 tons/day
- Lube: 1.3 tons/day

# Slide Fuel Valve



System	NOx	SOx	PM	Other
Slide valve	Red.	-	5-30% red.	CO & HC red.



This is an IMO Approved Methode. 800 engines have to change within the next 5 years, it will reduce the NO<sub>x</sub> emissions in order of 60,000 tonnes per year.

Conventional fuel valve

Slide fuel valve

# Contribution from Shipping



**NOx 68% of total landbased in 2010**

**SOx 78% of total landbased in 2010**

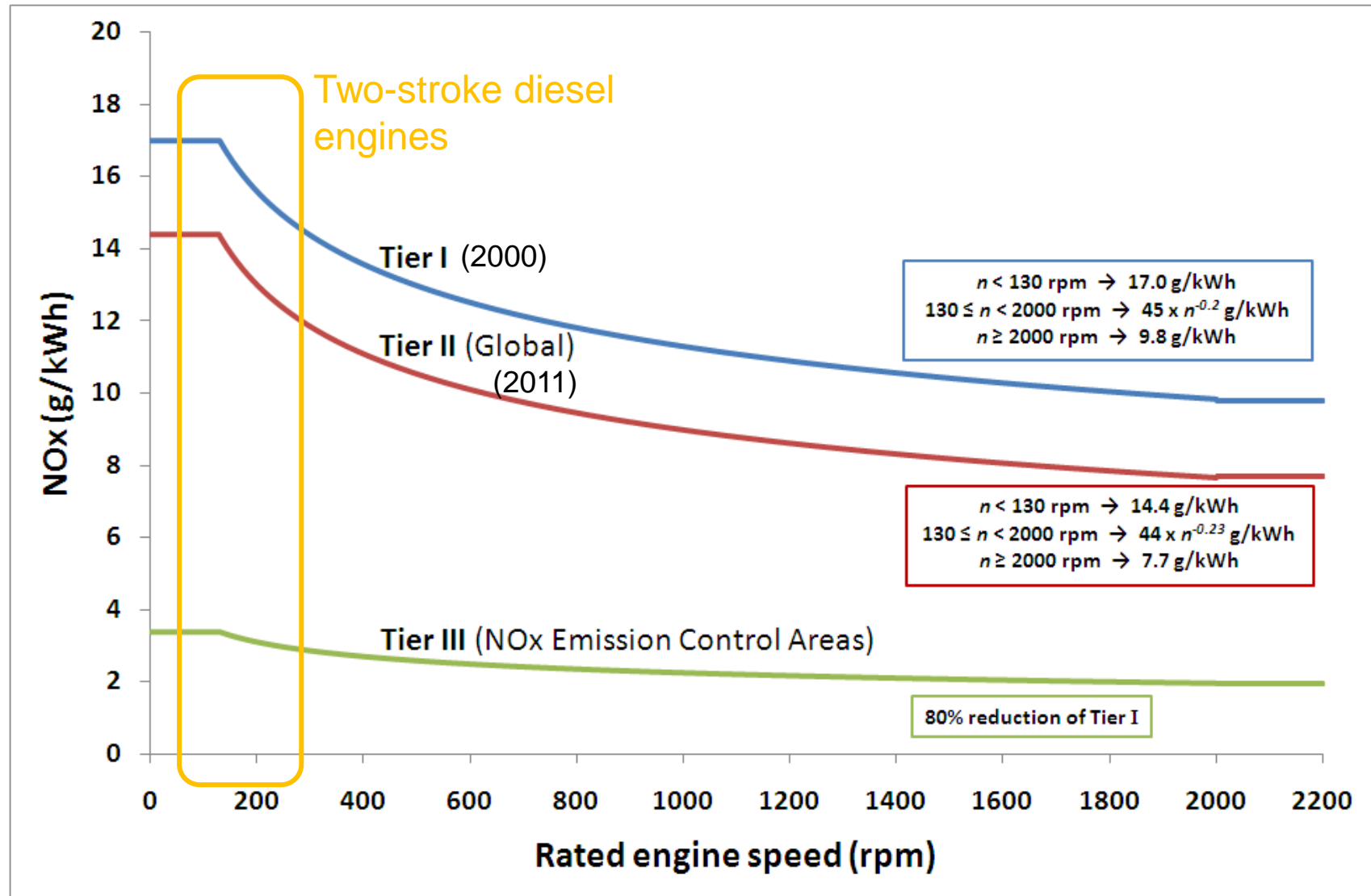
(Source: Jost Bergmann, DNV, IMO study)

**PM 30% of CA's PM emission in 2005**

(Source: Paul Milkey, CARB emission inventory)

# The Challenge

IMO Tier III regulation from 2016 in ECA areas



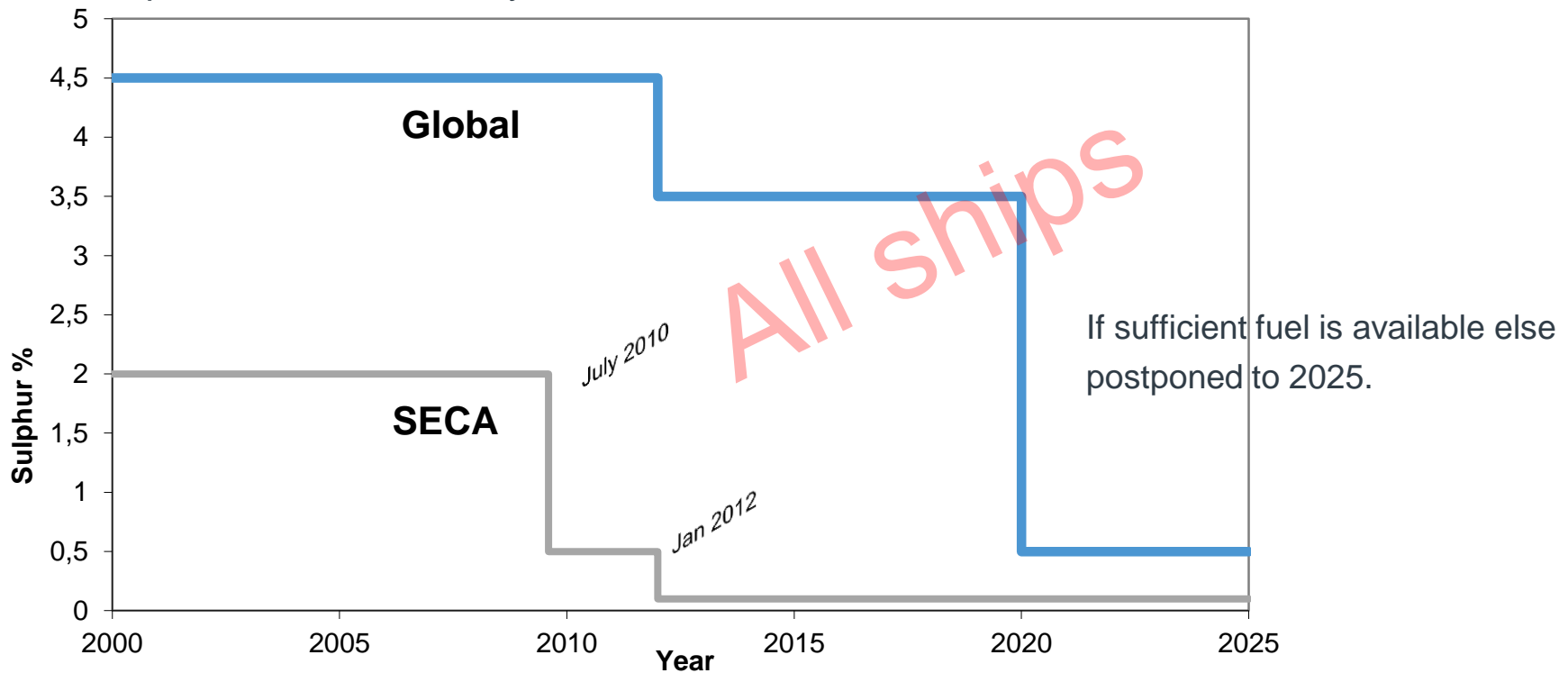
# IMO Fuel-Sulphur Content Limits



MARPOL Annex VI - Decisions of MEPC 58

## Limits of sulphur content in fuel oil

Equivalent methods may be used as an alternative

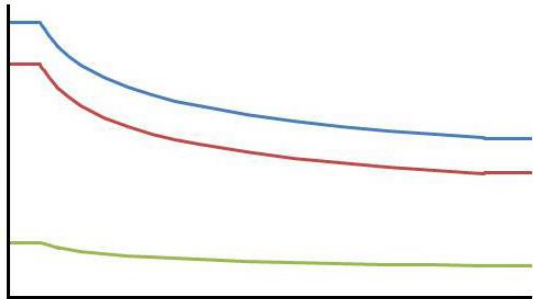


Particulate matter regulated by the sulphur content of the fuel or abatement technology.

# Existing and Future S-ECA Areas (DNV)



# Flexible Two-Way Approach for Fulfilling IMO Demands

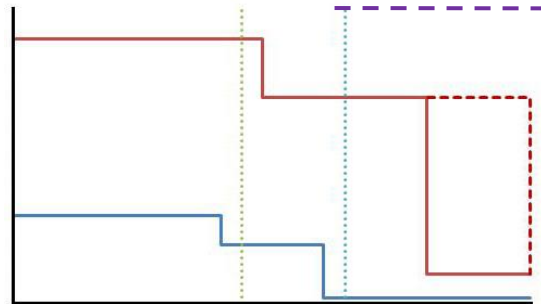


Tier III NO<sub>x</sub>



NO<sub>x</sub> reduction with EGR (Exhaust Gas Recirculation)

NO<sub>x</sub> reduction with SCR (Selective Catalytic Reduction)



SO<sub>x</sub>



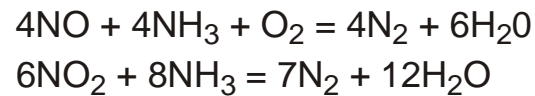
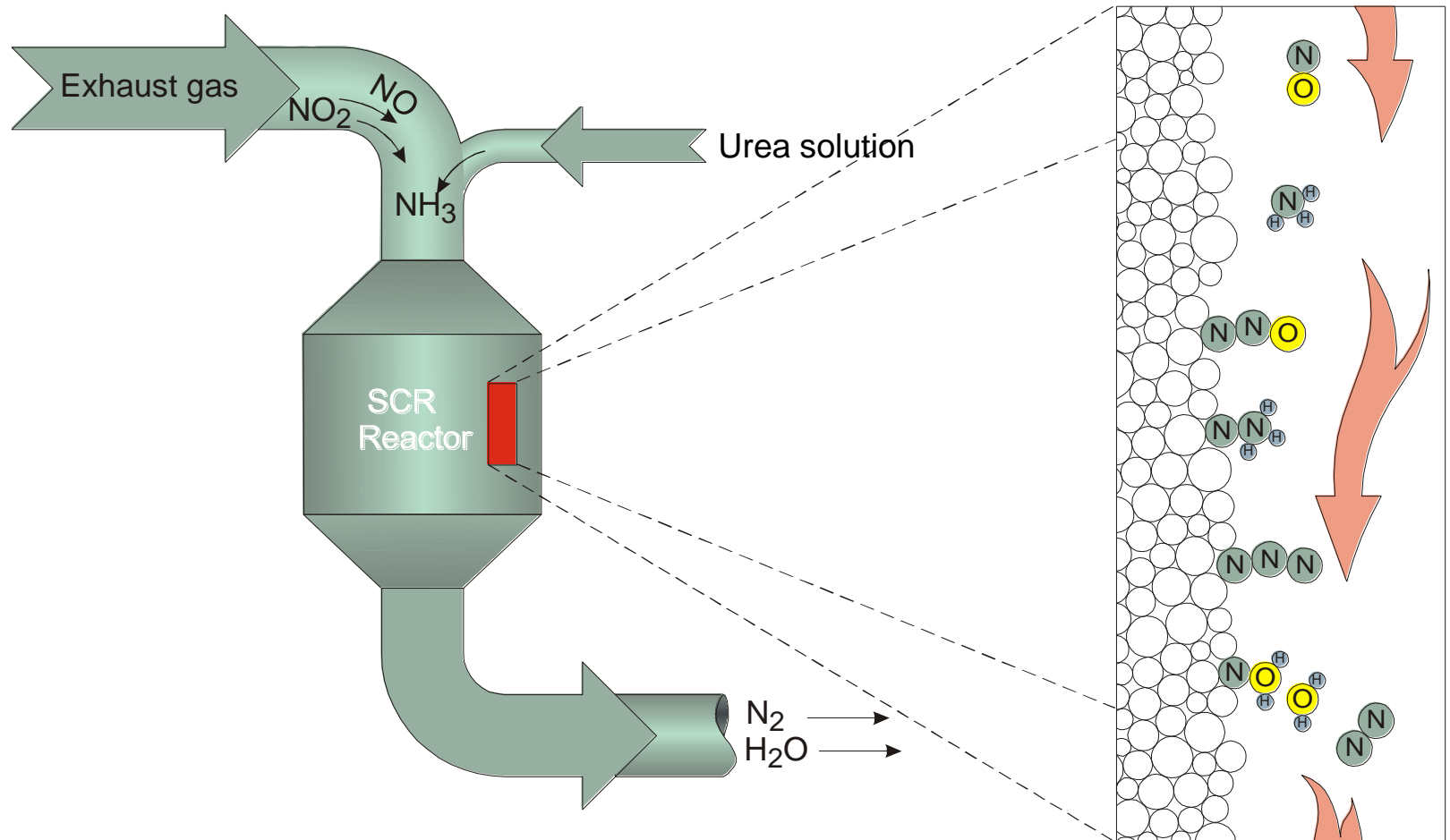
SO<sub>x</sub> reduction with Exhaust Gas Scrubbers

Engine operation on low sulphur fuels: Distillates, LNG



- 1 Introduction
- 2 Tier III Strategy
- 3 SCR - Selective Catalytic Reduction**
- 4 EGR – Exhaust Gas Recirculation
- 5 Fuels
- 6 SO<sub>x</sub> Scrubbing
- 7 Visit to the Test Center

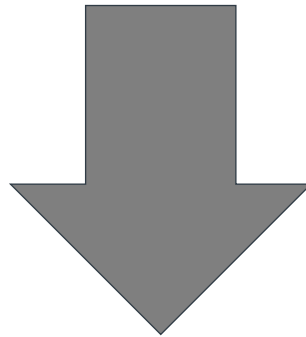
# Selective Catalytic Reduction (SCR)



# Operational Challenges (HFO)

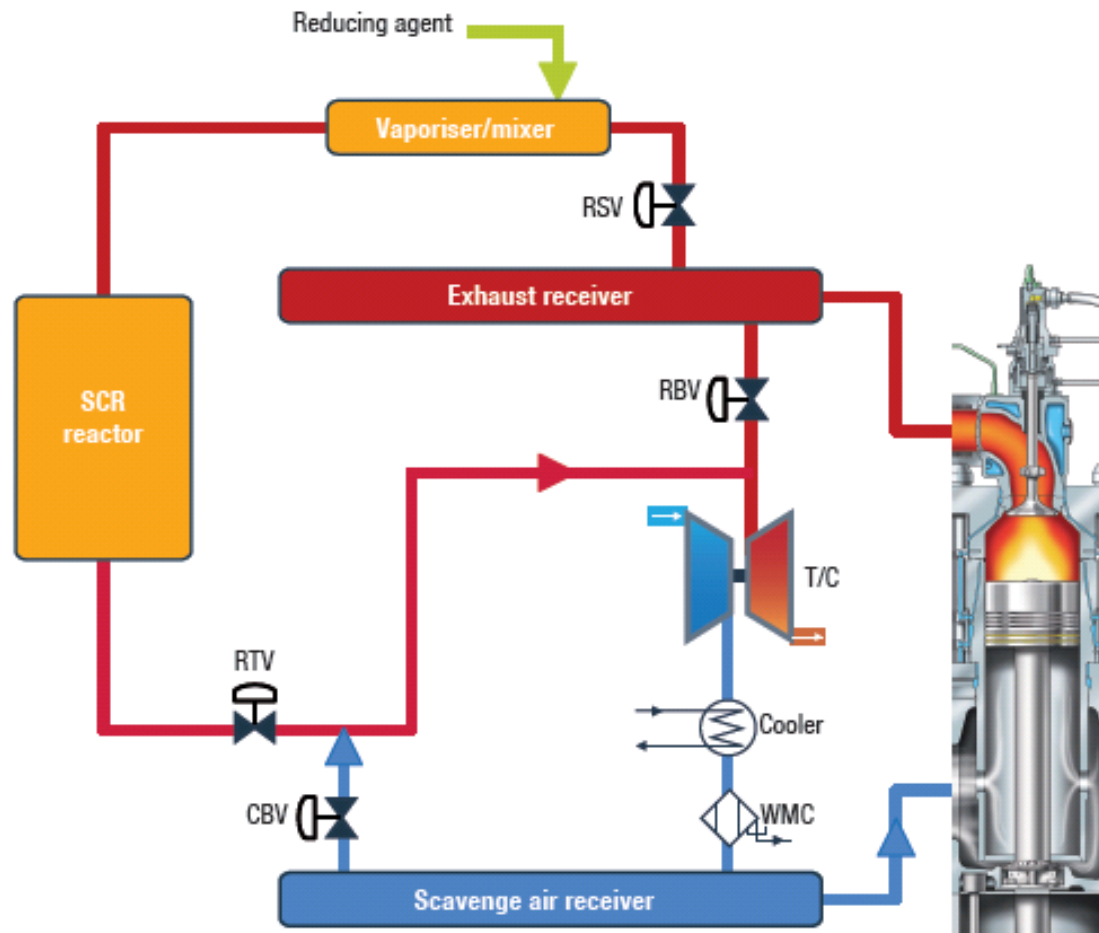


- Inlet gas temperature minimum: 330-350° C
- Max. gas temperature: 500° C
- Exhaust gas after TC: 230-260° C

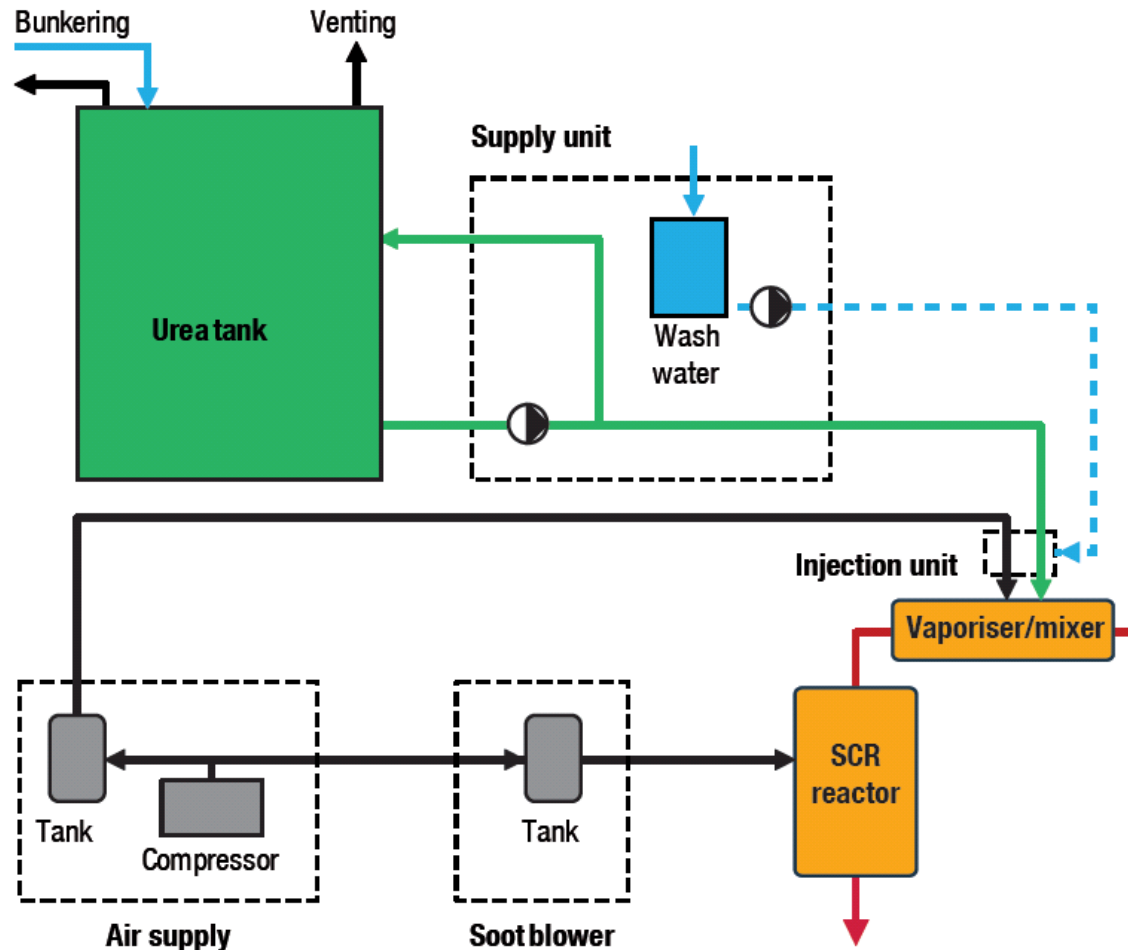


High pressure SCR (before TC)

# High Pressure SCR Principal Layout



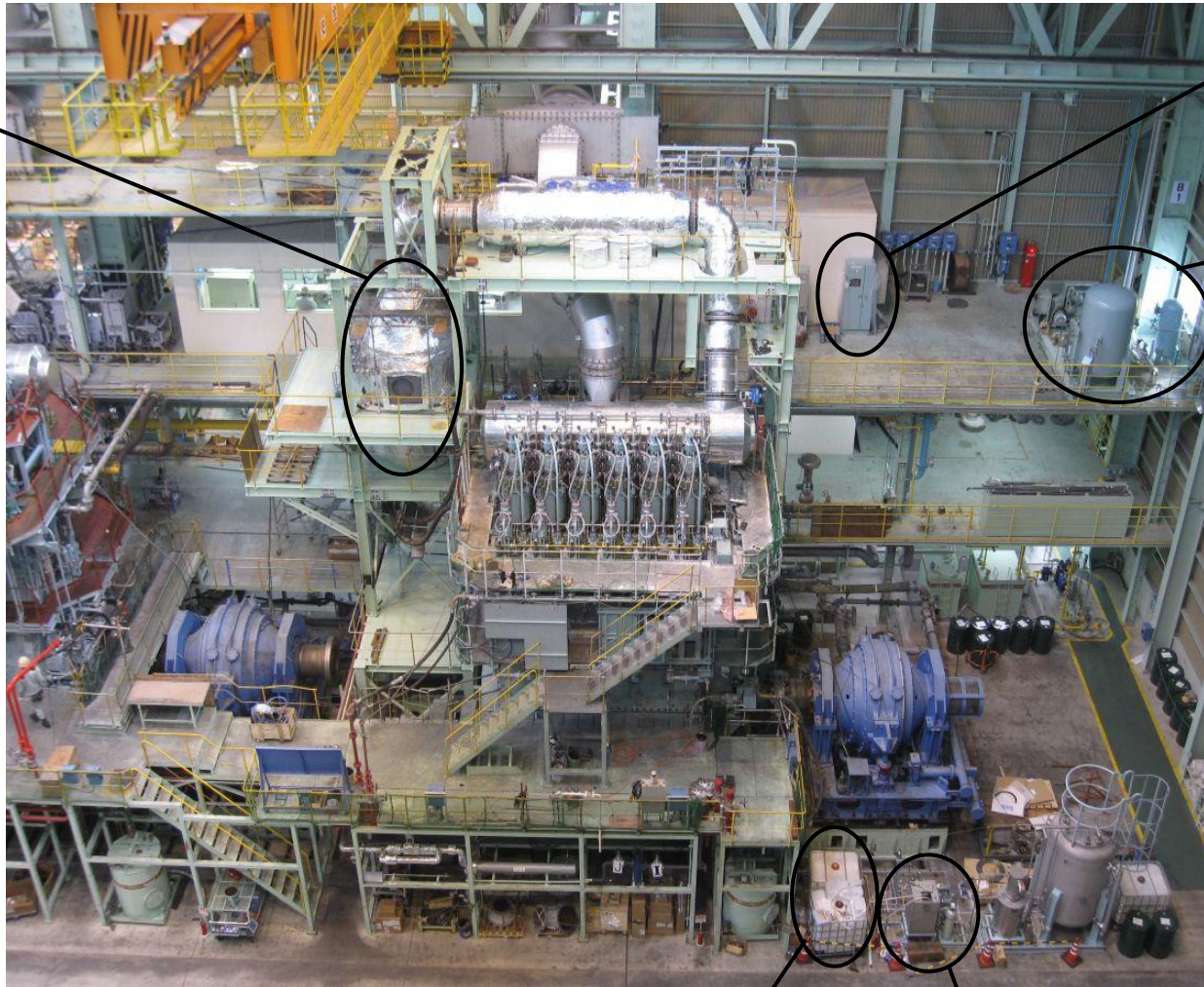
# High Pressure SCR Auxiliary System Layout



# Shop Test of 6S46MC-C with SCR



SCR reactor



Control panel for reductant injection and soot-blow

Air compressor & air tanks

Urea solution tanks

Urea supply unit

Tests were carried out from January to April 2011

# Emission Technology – Tier III

SCR references (in service)



---

<b>Operator / Vessel</b>	<b>Hyundai Heavy Industry</b>
<b>Engine</b>	1 x 6S50MC
<b>MCR kW</b>	7860
<b>Ship type &amp; capacity</b>	37,000 DWT
<b>Builder</b>	HHI
<b>Technology</b>	Stand alone High pressure, Upstream TC SCR

---



---

<b>Operator / Vessel</b>	<b>Nissho Shipping Co., Ltd / M/V Santa Vista</b>
<b>Engine</b>	1 x 6S46MC-C
<b>MCR kW</b>	8280
<b>Ship type &amp; capacity</b>	38,000 DWT, general cargo carrier
<b>Builder</b>	Hitachi
<b>Technology</b>	Stand alone High pressure upstream TC SCR <b>First commercial TIER III compliant SCR engine.</b>

---



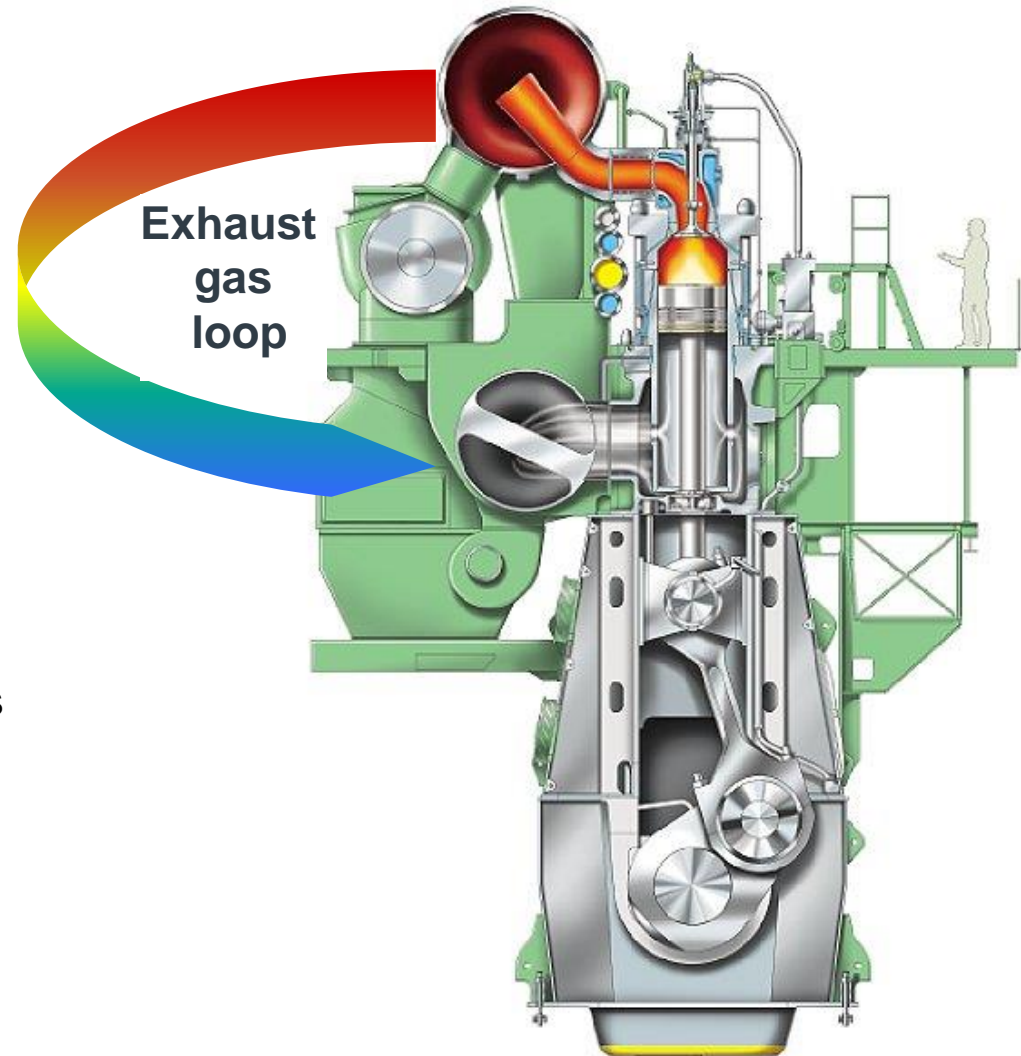


- 1 Introduction
- 2 Tier III Strategy
- 3 SCR - Selective Catalytic Reduction
- 4 EGR – Exhaust Gas Recirculation**
- 5 Fuels
- 6 SO<sub>x</sub> Scrubbing
- 7 Visit to the Test Center

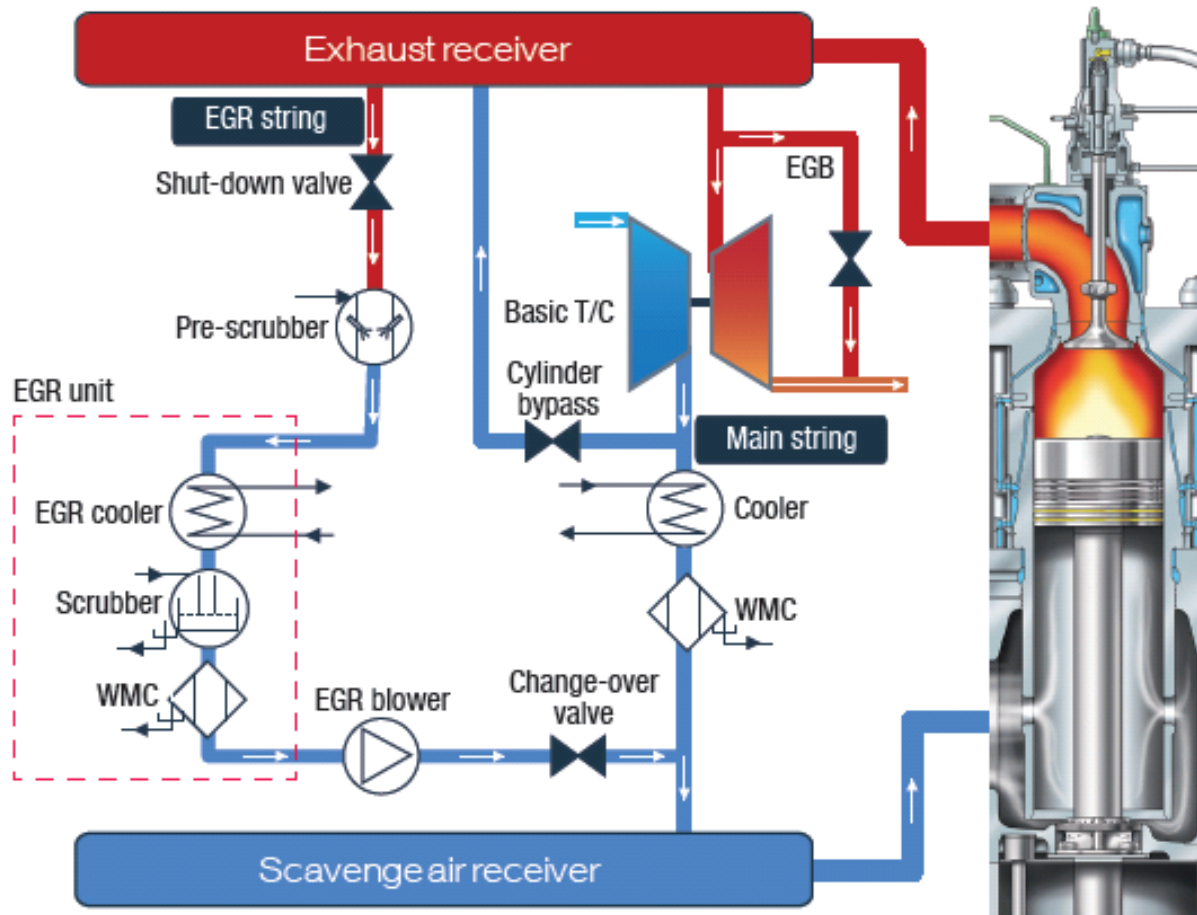
# Basic EGR Principle



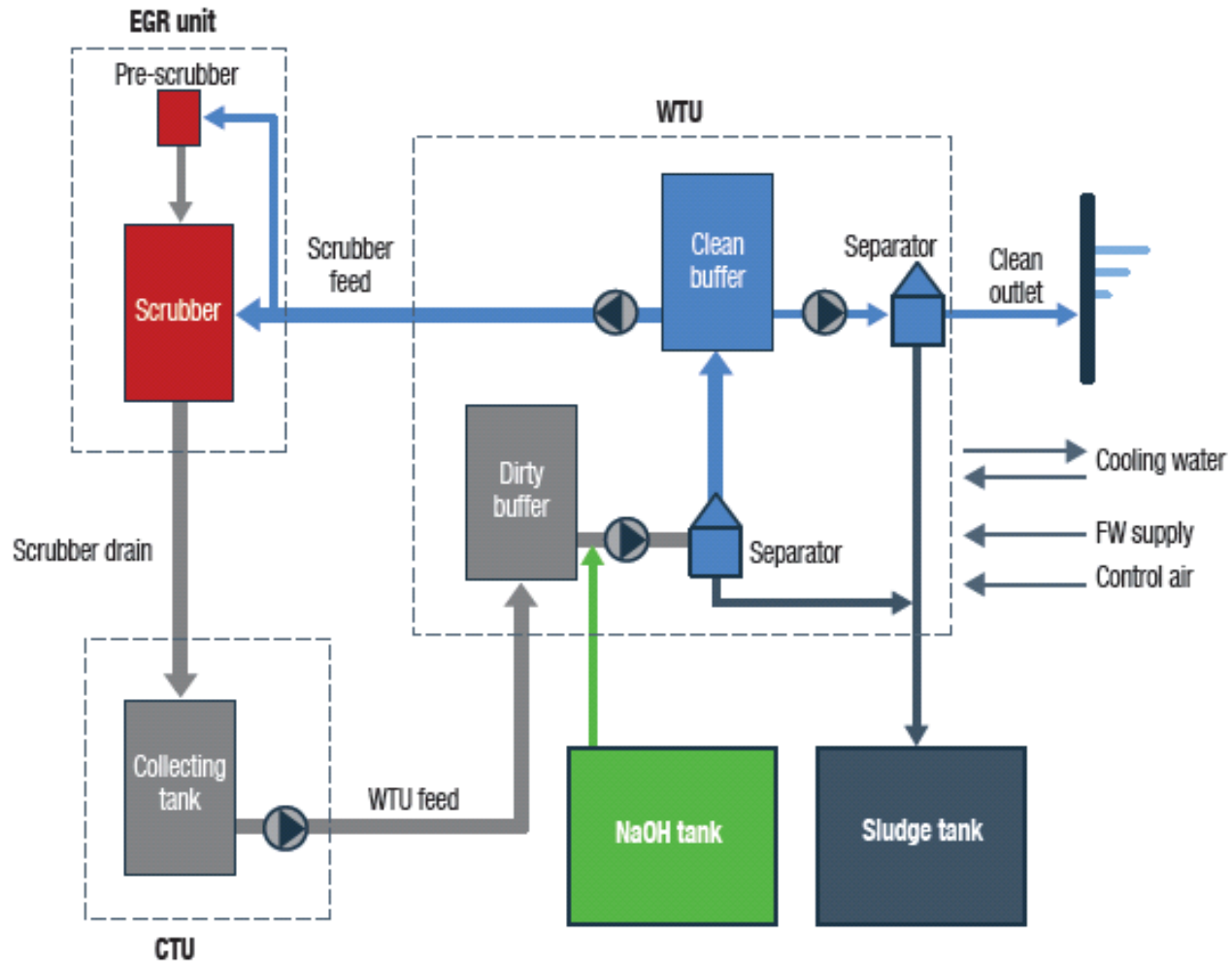
- Part of the exhaust gas is recircled and mixed with the fresh scavenging air
- $O_2$  in the scavenge air is replaced with  $CO_2$ .
- $CO_2$  has a higher heat capacity thus reducing the peak temperatures.
- Reduced  $O_2$  content in the scavenge air reduce the combustion speed thus reducing the peak temperatures.
- Decreased peak temperatures reduces the formation of  $NO_x$



# EGR – Principal System Layout



# EGR – Auxiliary System Layout



# 2'nd EGR Service Test Project



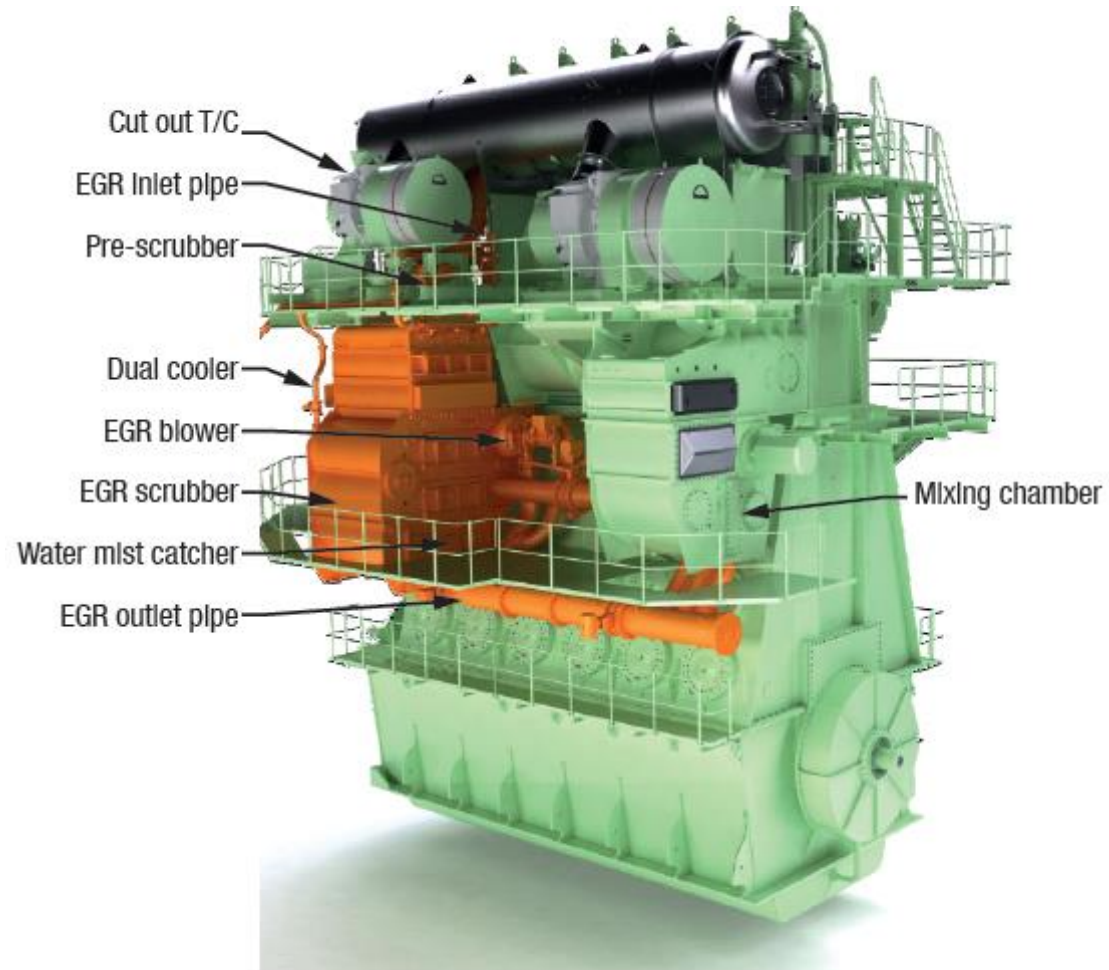
6S80ME-C9.1

27060 kW

@78 rpm

Shop trial at HHI-EMD

APMM derated to  
23MW @ 73.9rpm





- 1 Introduction
- 2 Tier III Strategy
- 3 SCR - Selective Catalytic Reduction
- 4 EGR – Exhaust Gas Recirculation
- 5 Fuels**
- 6 SO<sub>x</sub> Scrubbing
- 7 Visit to the Test Center

# Fuel for Marine: Two Stroke Engines



1 Fuel – Now and in the future

2 Fuel challenges:  
- HFO: Catalytic fines → Wear  
- DO: Viscosity: Start?  
- Switch-over: HFO-DO-HFO

3 **New Fuels:**  
- LNG/Ethan: ME-GI  
- Methanol: ME-LGI  
- More?

# Seaborne Transport Outlook



## Economical prediction:

- Seaborne transport will continue to grow
- Fuel cost will increase
- ECA's will be expanded

## Technical prediction:

Ship will be more technically advanced for:

- Higher fuel efficiency and fuel flexibility
- Increased reliability
- Lower emissions
- Crew skill matching

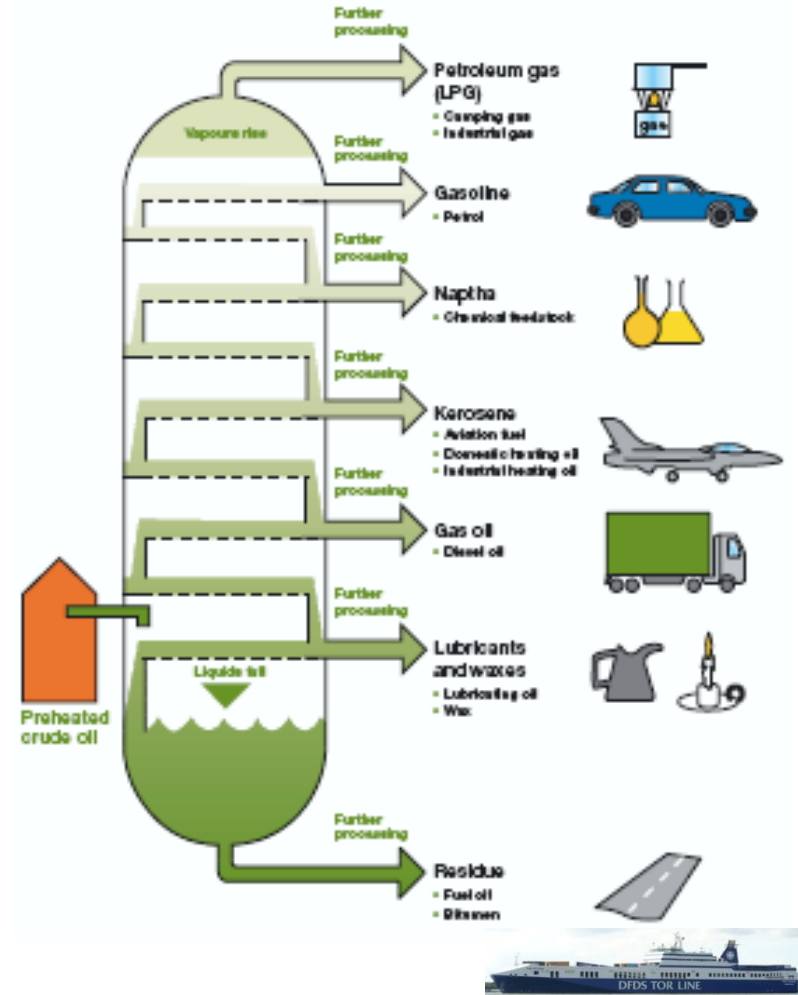


MAN B&W two-stroke engines can operate on:

- Marine Gas Oil - MGO
- Marine Diesel Oil - MDO
- Heavy Fuel Oil - HFO (low and high sulphur)
- Biofuel
- LNG, Ethan, Methanol
- Future: More...

The fuel should be in accordance with:

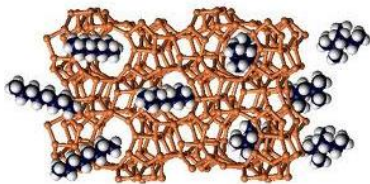
- ISO 8217



# Future Marine Fuels



In the future, marine fuels will not just be distillates & heavy fuel

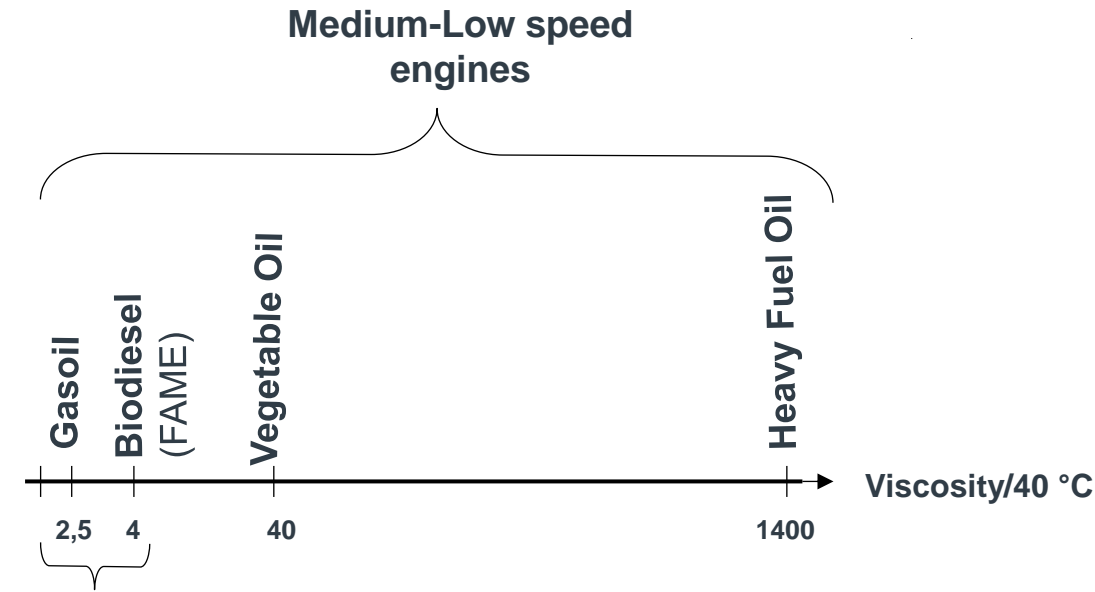


Residue size  
= 5 microns



We will be challenged on our technologies and our knowledge!

# Fuel Viscosity



HFO

high-speed engines

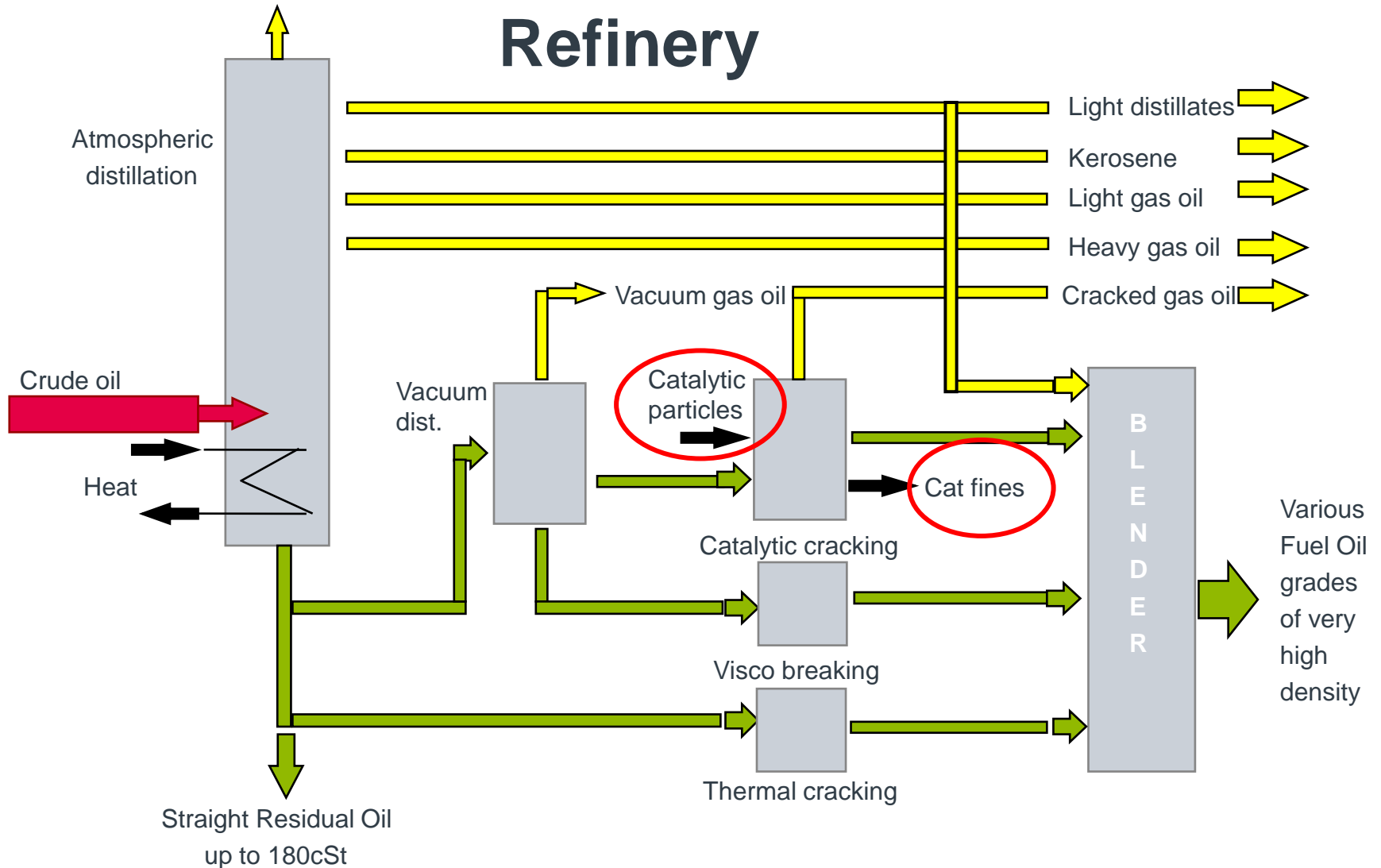


# DRAFT: MAN B&W Fuel Specification at Engine Inlet



	HFO	Distillate
Viscosity	<b>10-15-20 cSt</b> → < 850cSt @ 50C	> 2 cSt
HFRR	-	< 520 μm
Cat fines: Al+Si	< 15 ppm Normal level: 5-10 ppm	-
Contaminants	?	?

# Cat Fines Added in the Production Process



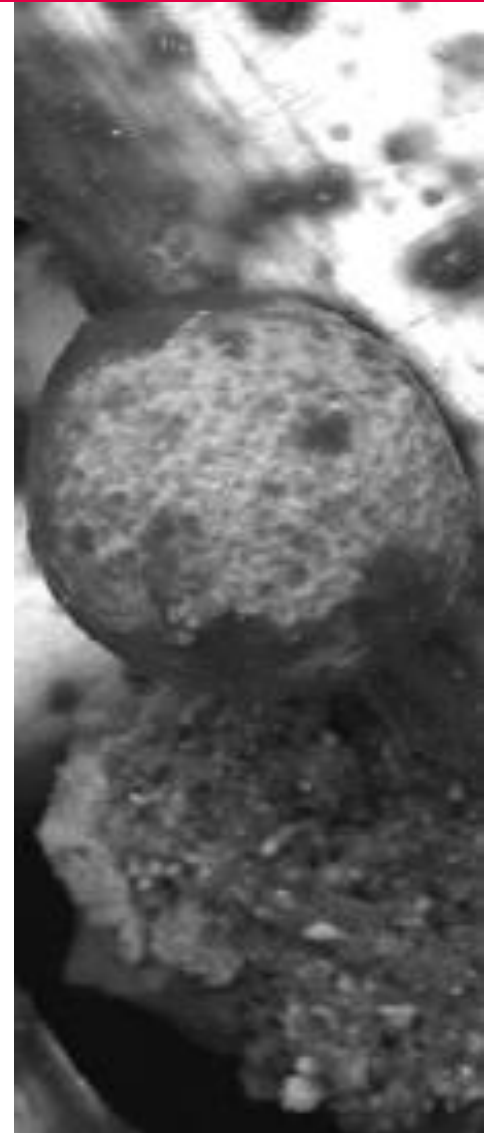
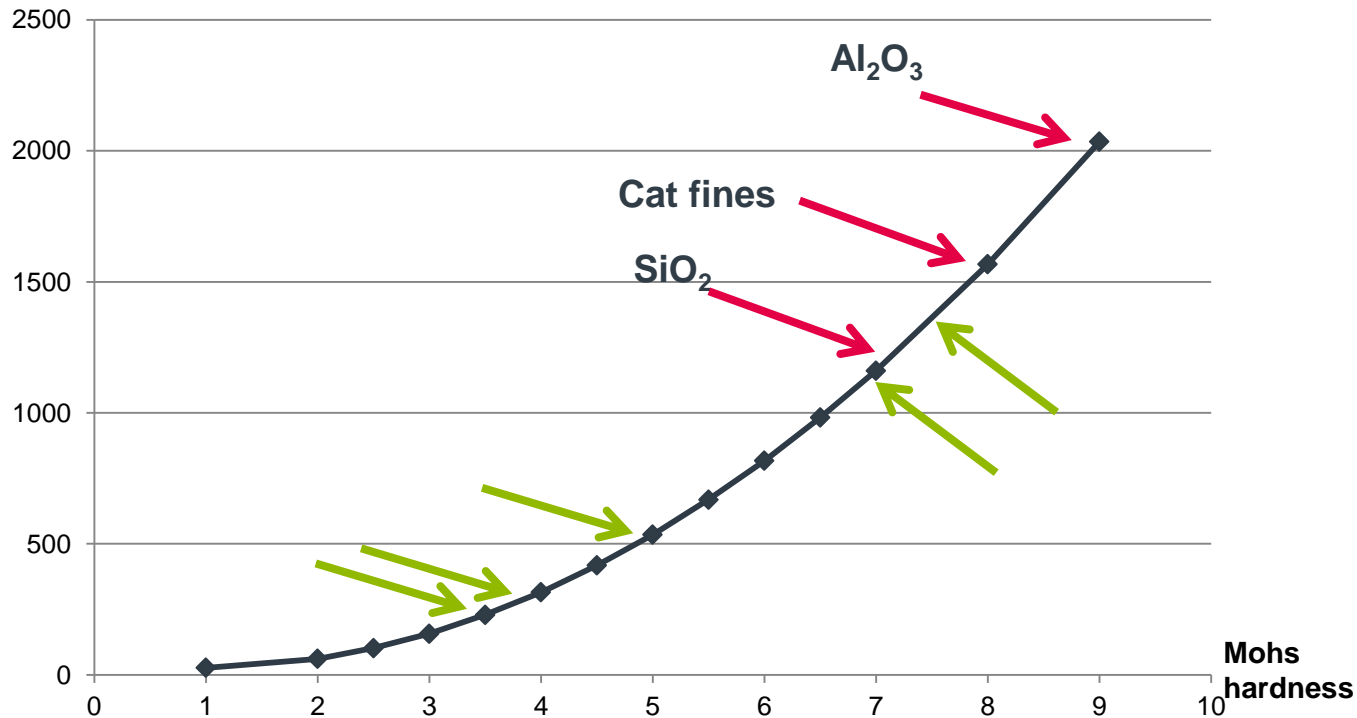
# Hardness Comparison

Engine equipment & wearing particles



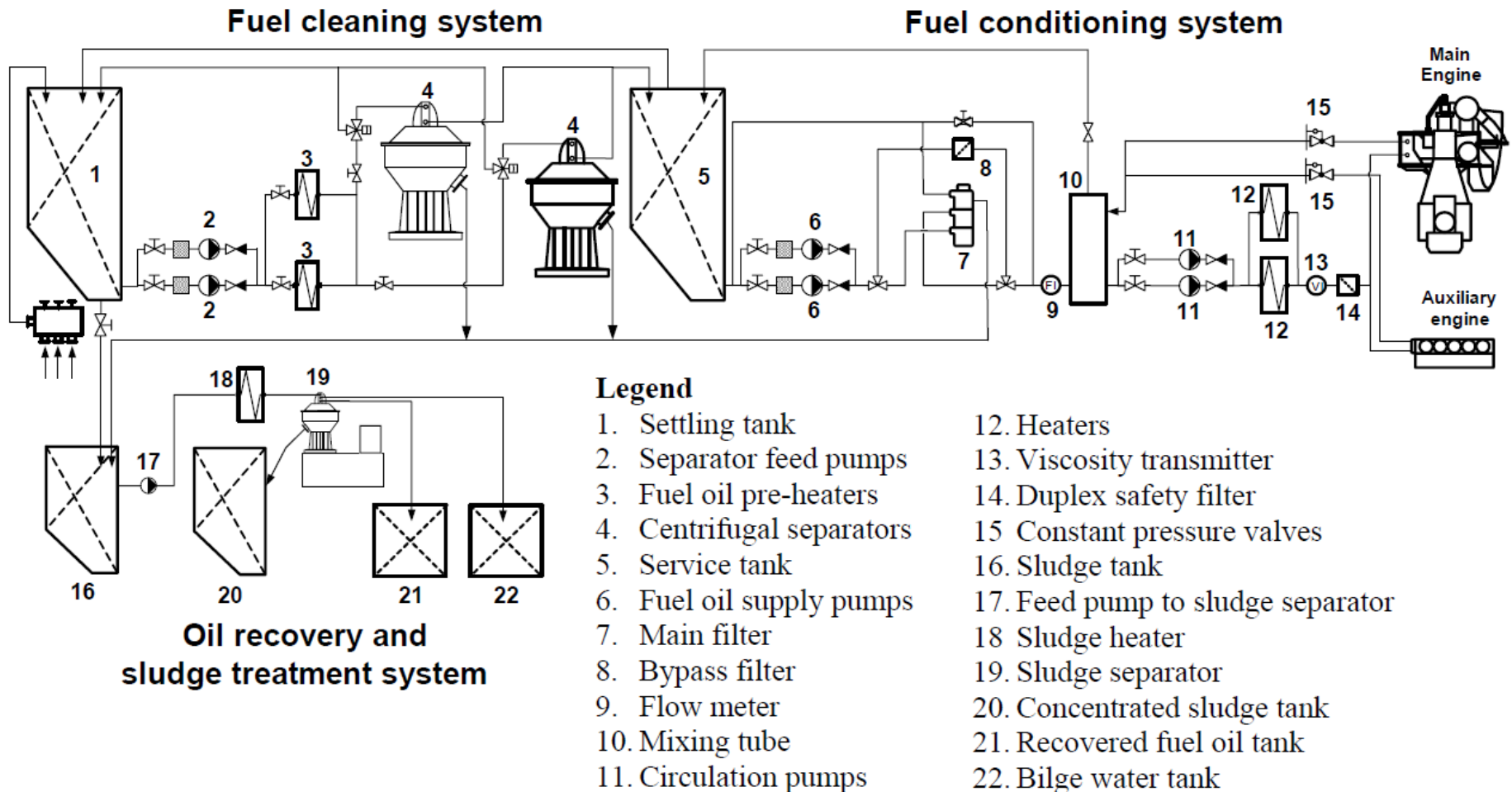
## Correlation between Mohs hardness and Vickers hardness

Vickers hardness



# Fuel System

CIMAC no. 25





## Cat fines in fuel:

- Severe wear of liners
- Severe wear of rings
- Wear out of CL-grooves
- Scuffing



# Operation on Distillate Fuel

## Challenges

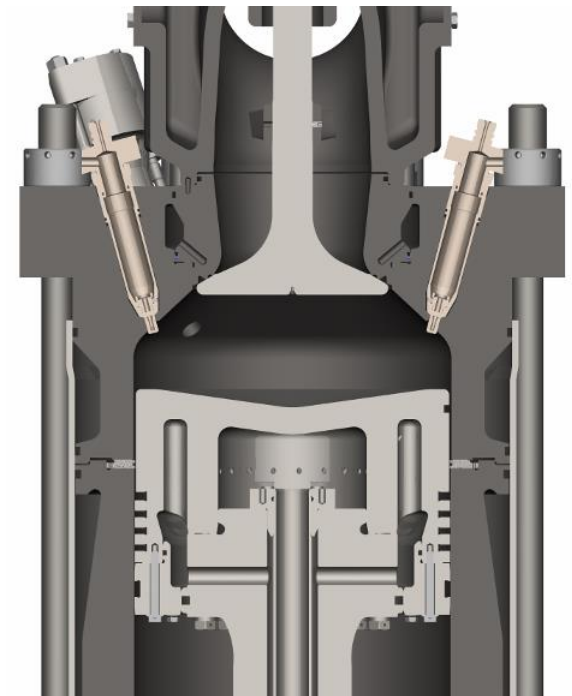
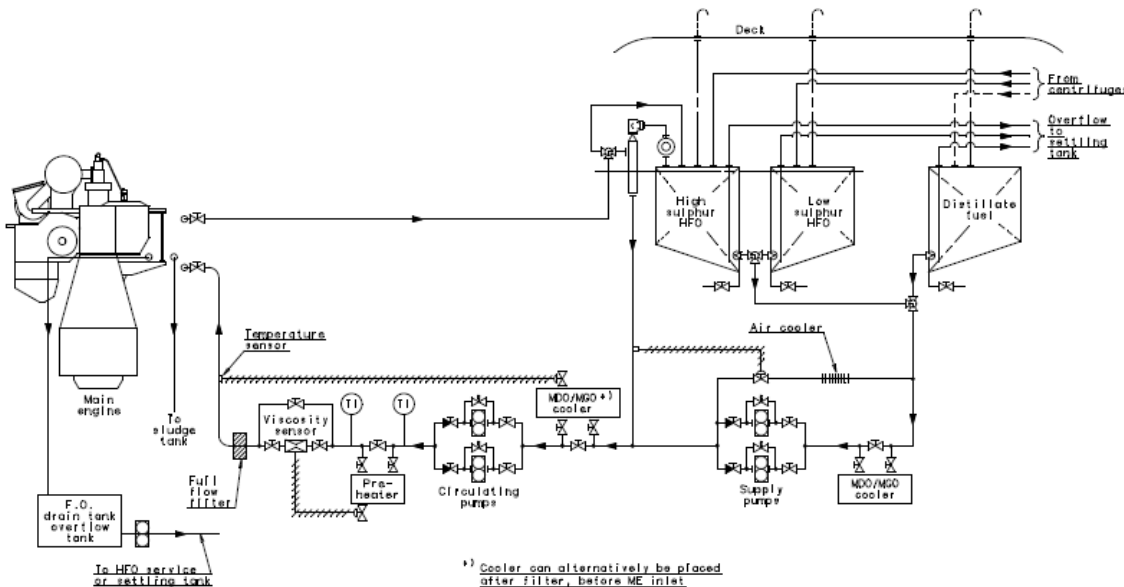


### Fuel system:

- Viscosity and lubricity of the fuel.
- Keeping a sufficiently high fuel pump pressure.
- Change-over between HFO and MDO / MGO

### Combustion Chamber:

- Cylinder liner bore polish
- Deposits



# Operation on Distillate Fuel

## Fuel system



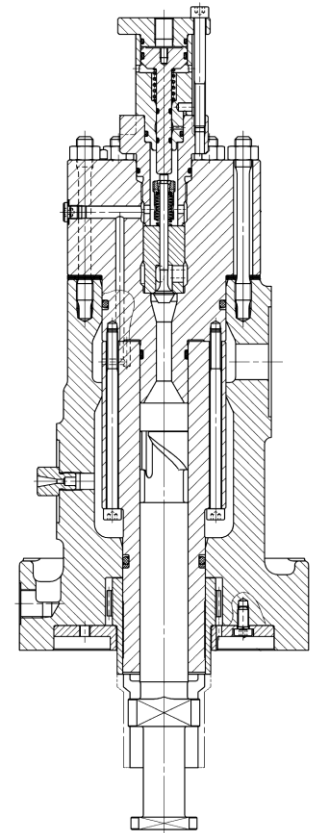
### Challenges:

- Viscosity and lubricity of the fuel.
- Keeping a sufficient high fuel pump pressure.
- Change-over between HFO and MDO / MGO

### Solutions:

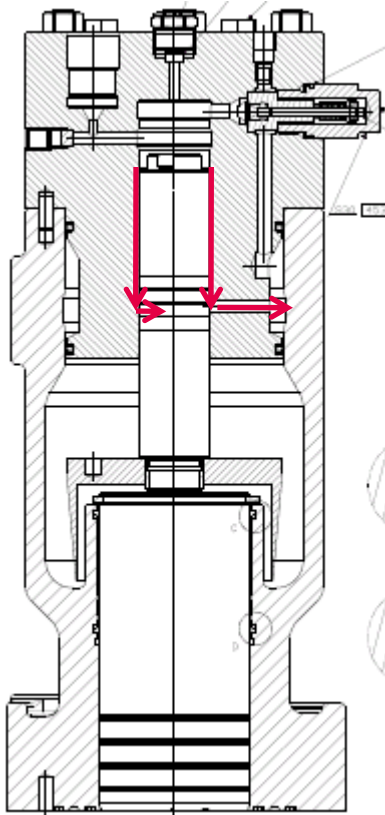
- Keep the viscosity  $> 2$  cSt before engine inlet.
- Test lubricity using fuels  $< 0.05\%$  Sulphur.
  - HFRR wear scar  $< 520 \mu\text{m}$ .
- Max.  $2 \text{ C/min}$ . during change over.
- Test sufficient high fuel pump pressure in open sea:
  - ME-engine: No problem
  - MC-engine:
    - Fuel pump leakage might be too high.
    - Test engine start, stop and reverse.

See Service Letter: SL09-515:  
Guidelines for Operating on  
Distillate Fuel



# Operation on Distillate Fuel

## Fuel system



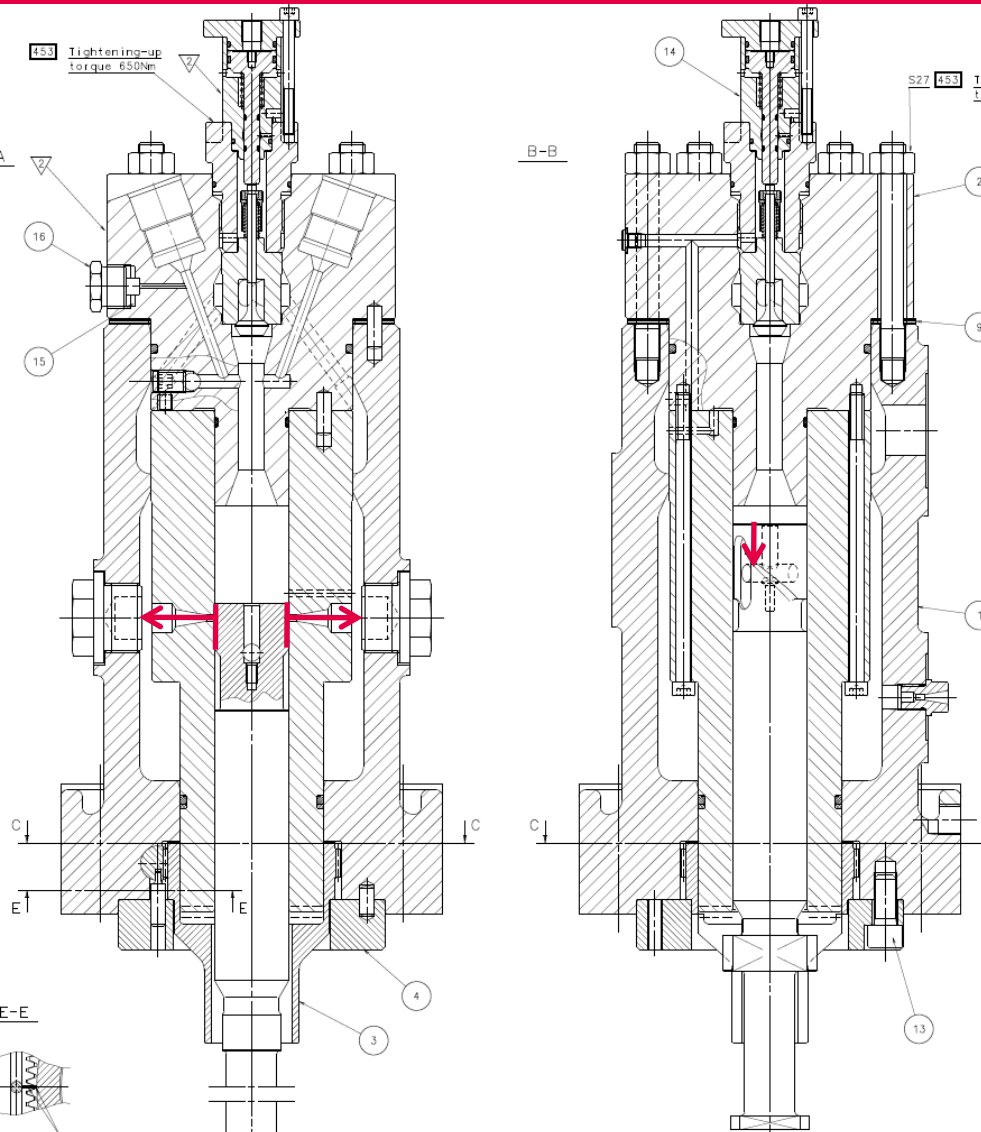
### ME engine Fuel Oil Pressure Booster:

- Plunger velocity governed by supply pressure
- At start conditions 75-78% of full load pressure
- Long leakage path

→ No problem

# Operation on Distillate Fuel

## Fuel system



MC engine:  
Cam driven Fuel Oil  
Injection Pump:

- Plunger velocity governed by engine RPM
- At start conditions 15% of full load engine RPM
- Short leakage path

→ Test for succes?

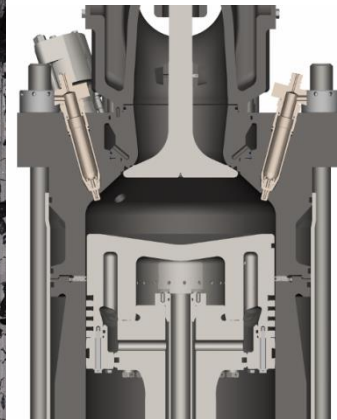
# Continuous Operation on Distillate Fuel

## Combustion chamber



### Challenges:

- Lack of controlled corrosion on liner surface  
→ smearing (bore polish).
- Deposit build up in the combustion chamber from additives in the cylinder lube oil.



### Solutions:

- Reduce the scuffing risk by introducing the hard cermet coating on all 4 piston rings.
- Reduce the deposit build up by:
  - Reducing the amount of additives in the cylinder lube oil.
  - Reducing the cylinder lube oil feed rate.
  - Introducing the PC-ring which scrapes the deposits on the piston topland.
  - Reduce the overall cleaning stress in the combustion chamber by introducing slide fuel valves.



# Fuel for Marine: Two Stroke Engines



## 1 Fuel – Now and in the Future

2

### Fuel challenges:

- HFO: Catalytic Fines → Wear
- DO: Viscosity: Start?
- Switch-over: HFO-DO-HFO

3

### New Fuels:

- LNG/Ethan: ME-GI
- Methanol: ME-LGI
- More?

# New Fuels & Fuel Flexibility

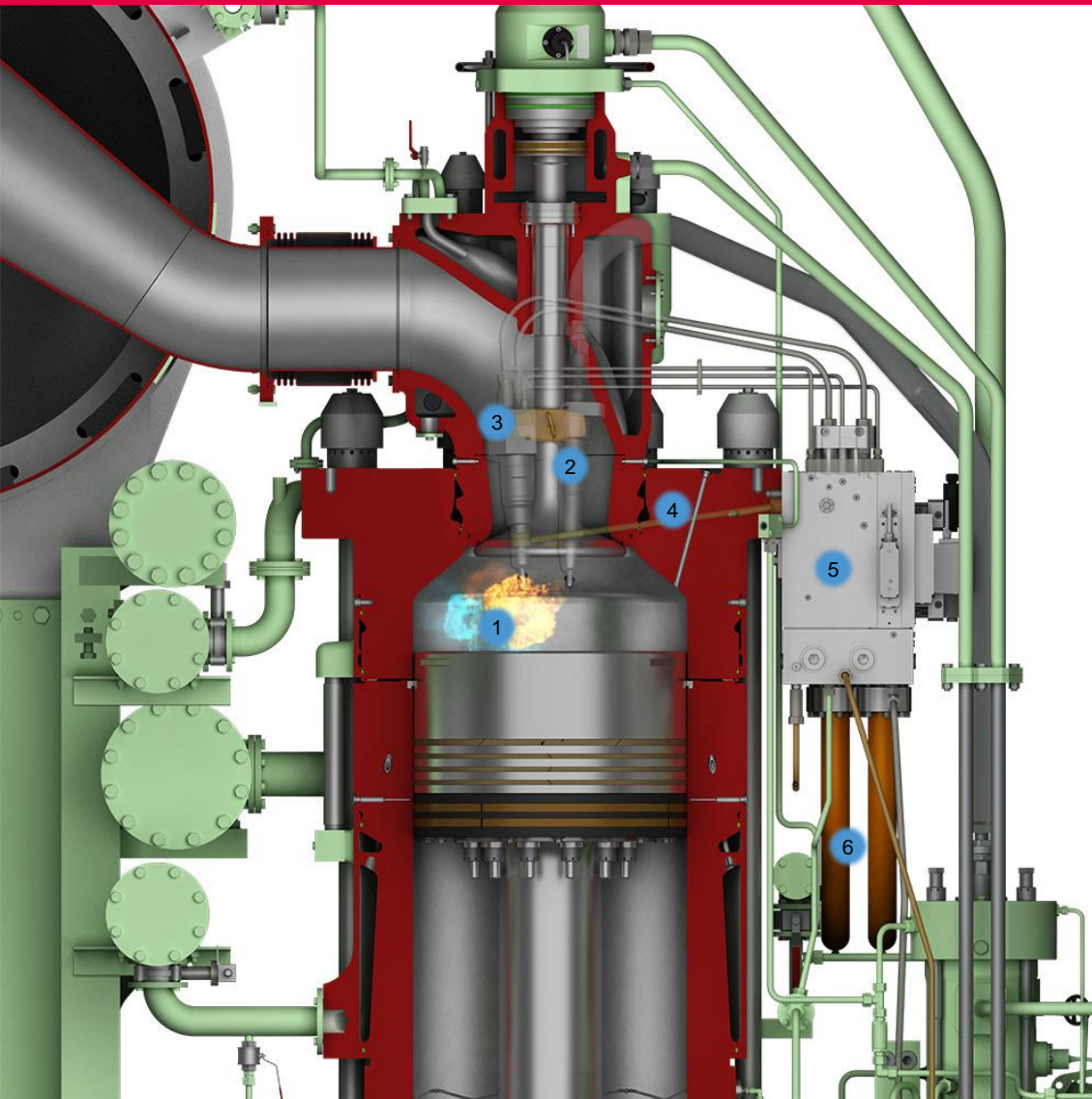


- Fuel flexibility - operation on LNG/Ethan/Methanol, HFO or MGO
- Lowest possible fuel cost
- Low GHG emission and no gas slip
- No knocking protects the engine



# ME-GI

## Combustion concept



1 From actual footage (colorized)

Yellow = pilot oil  
Blue = gas fuel

2 Conventional slide fuel valve

3 Gas fuel valve

4 Gas distribution channel (yellow)

5 Gas distributor block

6 Gas chain link double-walled pipes

[Video of ME-GI  
in action](#)

# ME-GI Gas Fuel Mode

Port to port in dual fuel mode



## Fuel oil only mode

- Operation profile as conventional engine

## Dual fuel operation mode

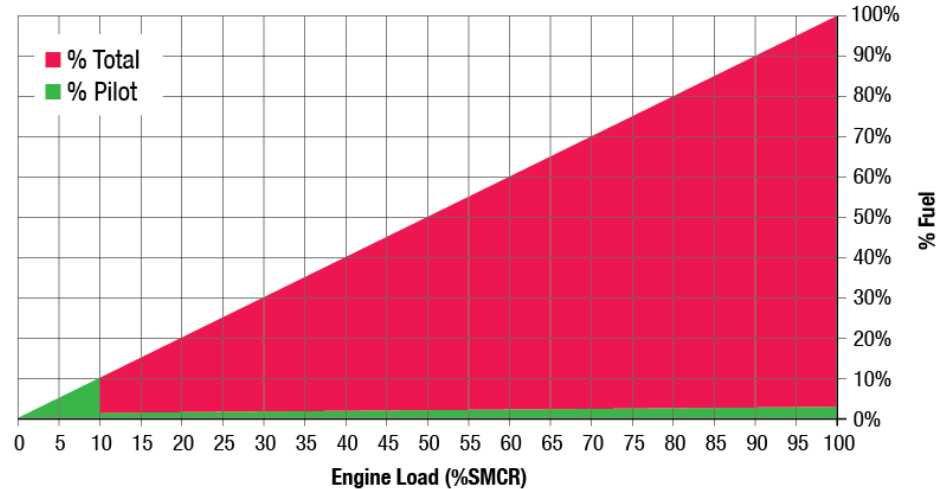
- No fuel slip
- No knocking problems
- Insensitive to gas fuel
- Unchanged load response

## News:

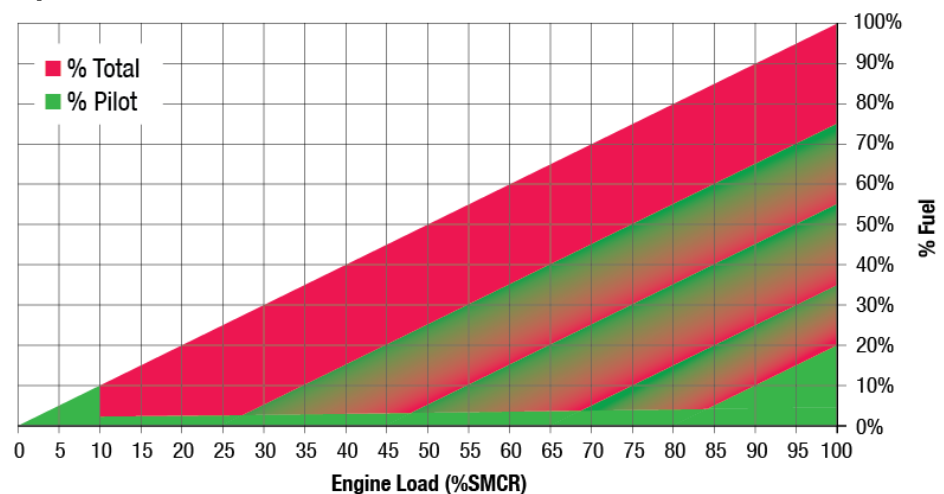
Reduced pilot oil amount 5% → 3%

Reduced load on gas → 10% load

Min. Fuel Mode

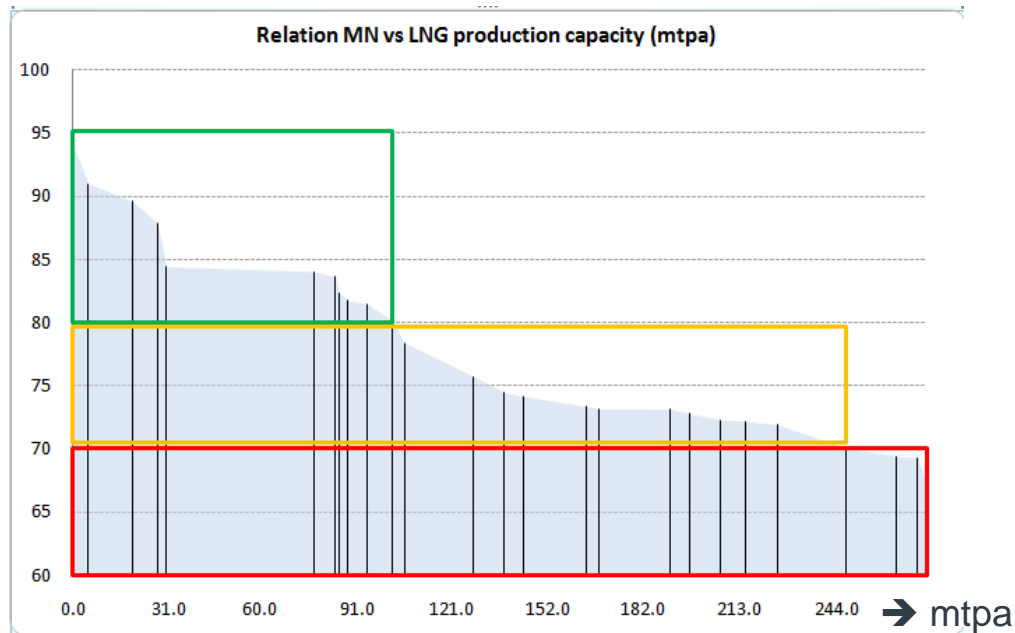


Specified dual fuel mode



# LNG Production Quality

– Variation in MN vs production capacity



MN Range (AVL)	Global LNG Production (mtpa)	% of Total LNG produced
0 - 70	26	10 %
70 - 75	118.3	43 %
75 - 80	26.1	10 %
80 - 100	102.8	38 %
0 -100	273.15	100 %

- The greatest production is seen at lower Methane Numbers
  - An engine with a min MN spec (AVL) of 80 can use only 38% of global supply
  - An engine with a min MN spec (AVL) of 70 can use 90% of global supply
- An engine with no MN requirement, like **the ME-GI can use ALL LNG qualities**

The main difference between ME-GI and ME-LGI is the gas injection and gas supply system

## ME-GI:

- High pressure supply system
- Common rail type injection
- Necessary injection pressure 300bar (Methane) - 400 bar Ethane
- Fuel types: Methane, Ethane

## ME-LGI:

- Low pressure supply system
- ME type injection, i.e concept similar to conventional HFO injectors
- Necessary injection pressure 500 – 600 bar
- Fuel types: Methanol, Ethanol, LPG, DME

# ME-LGI & ME-GI

## Fuel properties



- Below table shows the properties of some different liquid gas fuels with Diesel as a reference. Compared to Diesel the viscosity of the fuels is much lower hence lubrication, of the moving parts, will be necessary.
- In general the flash point is below 60°C except for Diesel.
- At atmospheric conditions LPG and DME is in the gas phase.

Fuel	LPG*	Methanol	Ethanol	DME	Ethane	Diesel
Liquid density (kg/m <sup>3</sup> )	455-550	796	794	670	447	860
Lower heating value (MJ/kg)	46	19.9	27	28.7	47	43
Boiling temperature(°C at 1bar)	-43-(-1)	65	78	-24.9	-890	180-360
Vapour pressure (bar at 20°C)	8.5-2.2	0.13	0.059	5.3	38.3	<1
Critical temperature (°C)	97-152	239.4	241	127	32.2	435
Kinematic viscosity (cSt at 20°C)	0.17-0.24	0.74	1.2	0.2		2.5-3.0
Bulk modulus (bar at 50°C and PSupply)	1700-3600	8200	9000	5500		15500
Engine type	ME-LGI	ME-LGI	ME-LGI	ME-LGI	ME-GI	ME-C/B

\* LPG is a mixture of primarily Propane (left) and Butane (right).

# ME-GI Fuels

Low flashpoint fuels



Common fuels	Know as	Delivery condition	Supply pressure	Supply temperature
CH <sub>4</sub>	LNG/NG Methan	Gas	300 bar	45 °C tol 10 °C
C <sub>2</sub> H <sub>6</sub>	LEG Ethan	Gas	400 bar	70 °C tol 10 °C

Additional implications when compared to CH<sub>4</sub>:

C<sub>2</sub>H<sub>6</sub>:

Higher injection pressure is required in order to subtract sufficient combustion air to the combustion. ME-GI Components has to be rated for the higher design pressure.

Bulk Modulus changed, which has an impact the size of the accumulator volume.

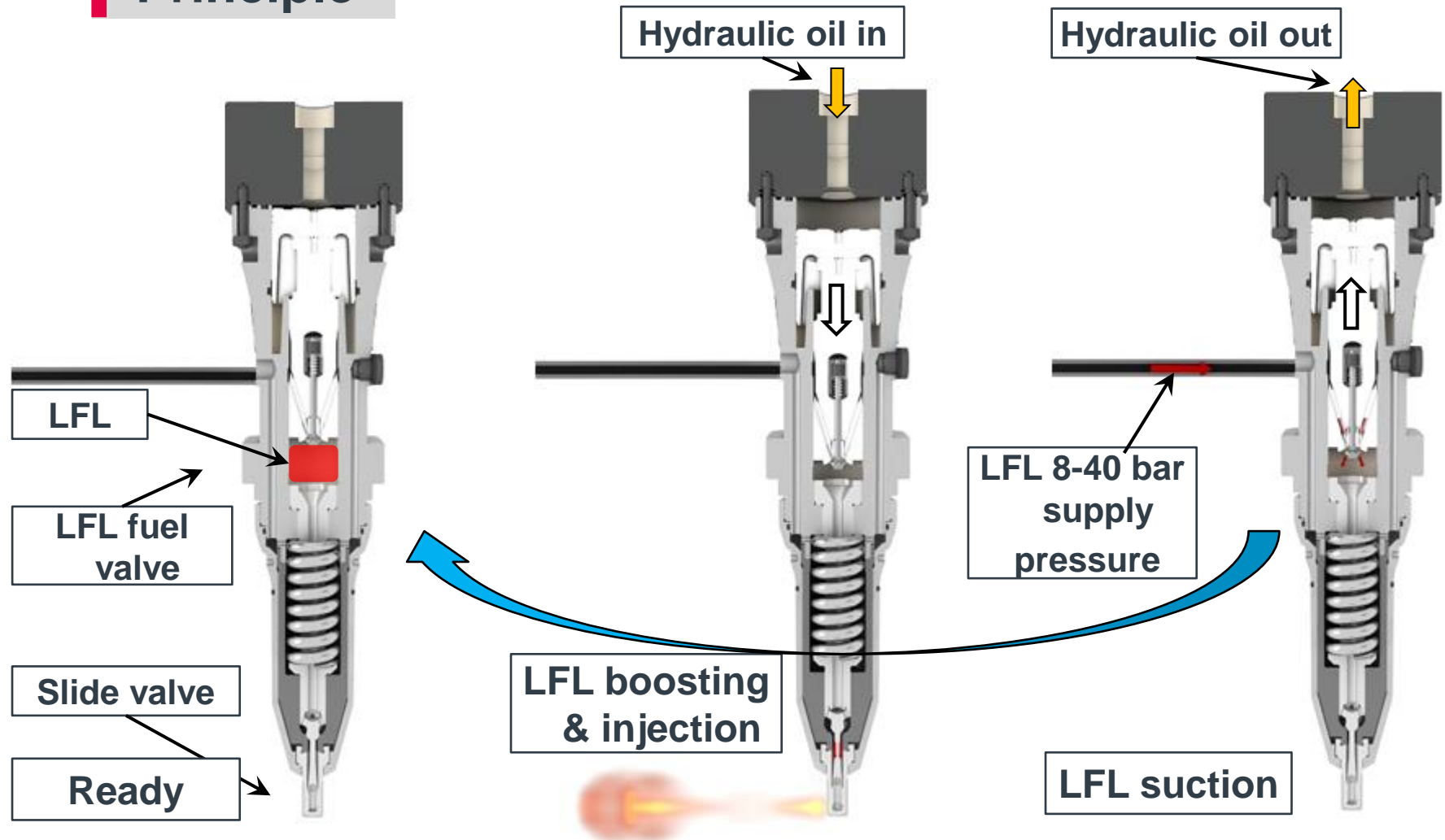
Leaks are heavier than air.

# ME-LGI

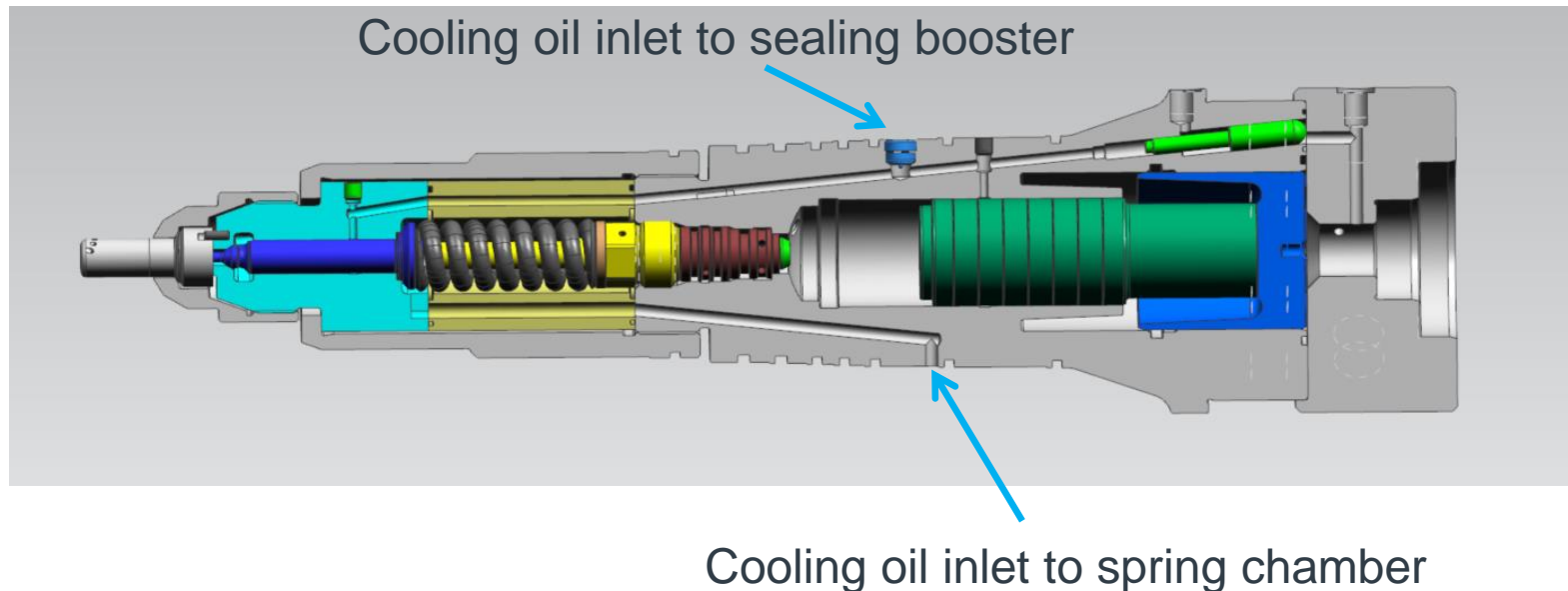
FBIV – Injection principle with LFL



## Principle



- A cooling oil circuit with hydraulic oil is necessary in order to ensure the fuel stays in the liquid phase at all times.
- A groove in the bushing will supply cooling oil to the spring chamber, sealing booster (through the non-return valve) and lubricate the suction valve spindle.

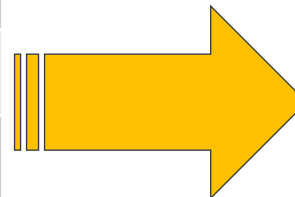


# ME-GI & ME-LGI

## Emissions



	Reduction with ME-GI*	Expected reduction with ME-LGI*
CO <sub>2</sub>	23%	10%
NO <sub>x</sub>	13%	10-15%
SO <sub>x</sub>	92%	90-95%
PM	90%	90%

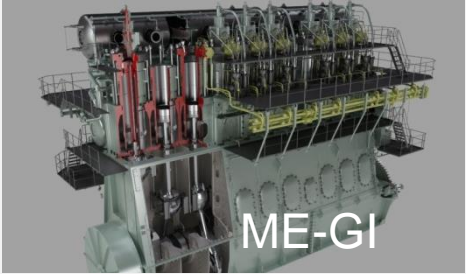

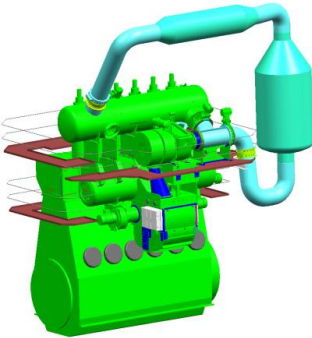



To ensure Tier III ECA operation application of EGR or SCR is necessary

\*assuming operation in gas fuel mode, and HFO pilot fuel oil

# ME-GI & ME-LGI Tier III Solutions 2016









<p>ME-GI/LGI solely for non ECA – operation on LNG/ethan, HFO and MGO</p>	<p>ECA operation on LNG/ethan and MGO 0.1% sulfur content</p>	<p>Full fuel flexibility incl. ECA operation on HFO with high sulfur content</p>
 <p>ME-GI</p>	<p>+ EGR</p>  <p>or</p> <p>+ SCR</p> 	<p>SO<sub>x</sub> scrubber</p> 



- 1 Introduction
- 2 Tier III Strategy
- 3 SCR - Selective Catalytic Reduction
- 4 EGR – Exhaust Gas Recirculation
- 5 Fuels
- 6 SO<sub>x</sub> Scrubbing**
- 7 Visit to the Test Center

# MAN Involvement



MAN involvement	Participants	Scrubber	Test results	Ship test	Ship test
Test at Holeby site	Clean Marine MDT		PM trapping: 80% SO <sub>x</sub> removal: 95%	Baru 7S50MC-C 9MW	
Service test on Ficaria Seaways	Alfa Laval Aalborg DFDS MDT		PM trapping: 79% SO <sub>x</sub> removal: 100%	Ficaria Seaways 9L60MC-C 20MW	
MAN development	APM MDT		PM trapping: 73% SO <sub>x</sub> removal : 96%	Alexander Maersk 7S50MC 9MW	

# DFDS Exhaust Gas Scrubber Project

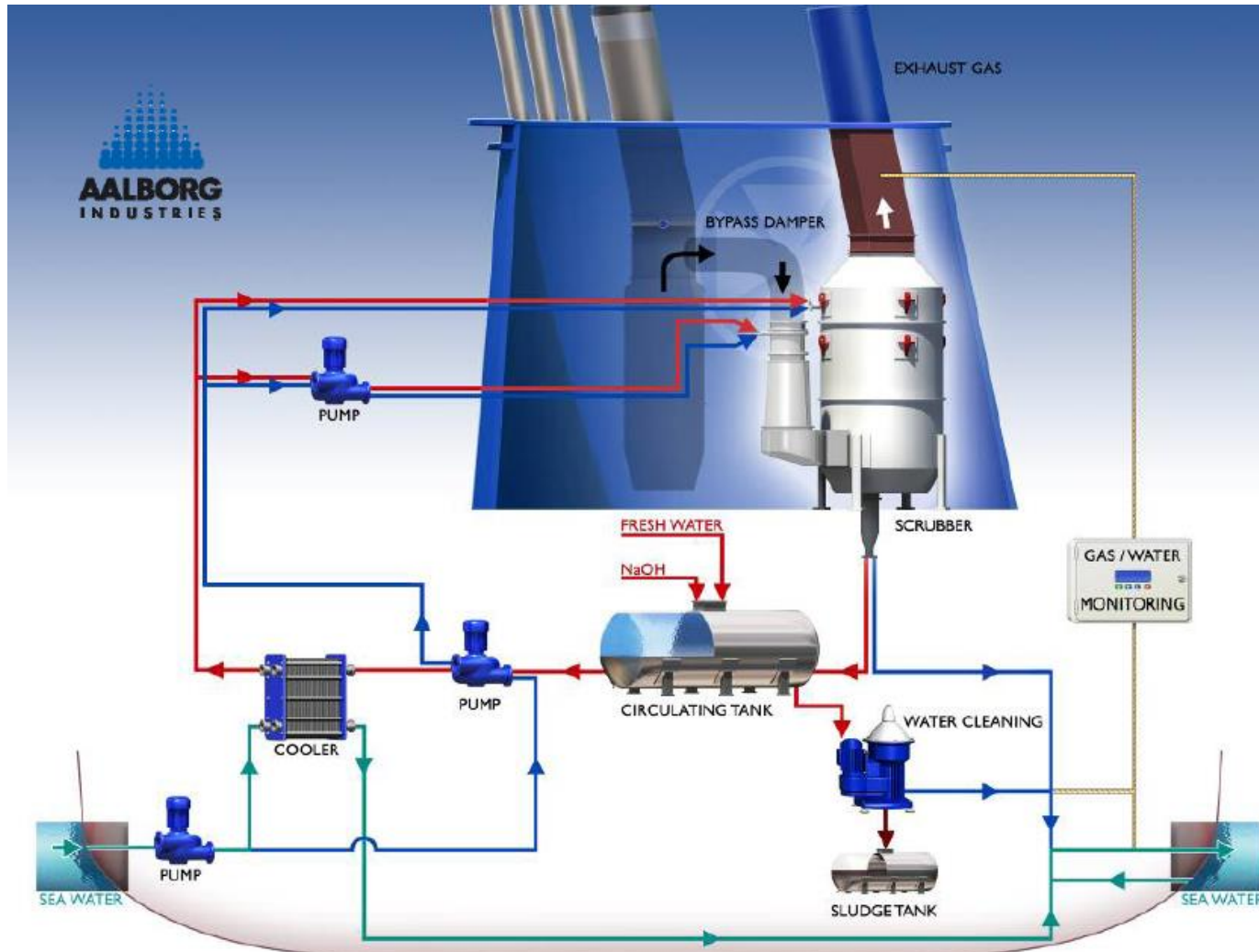


Scrubber during installation in Bremerhaven.



# DFDS Exhaust Gas Scrubber Project

Principle layout



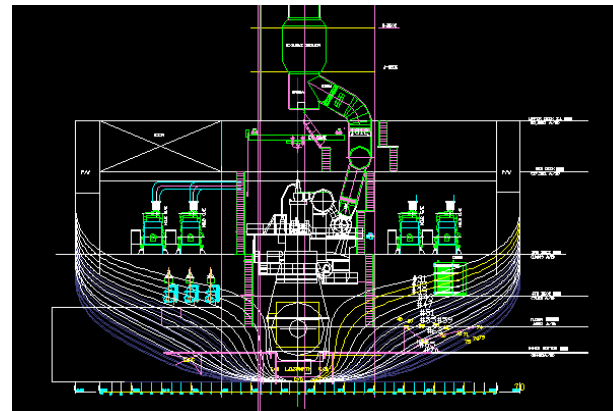
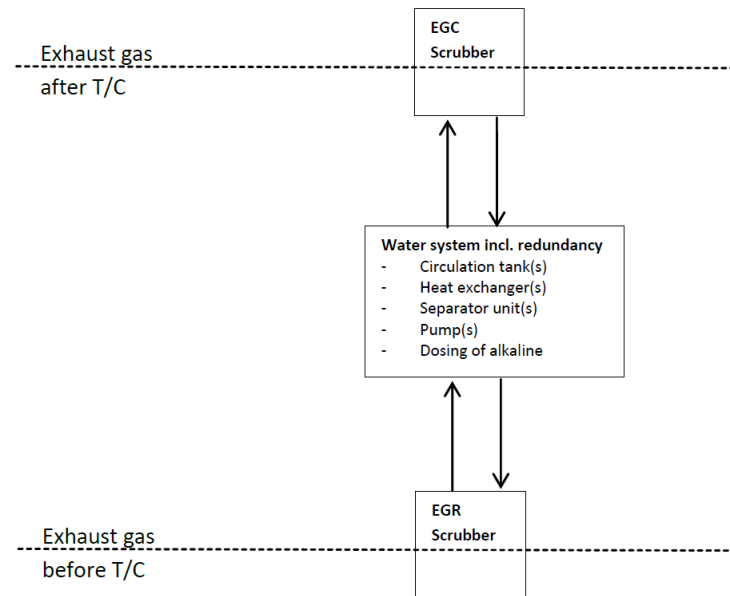
# EGR (NO<sub>x</sub>) + SO<sub>x</sub> Scrubbing



Project on combination of SO<sub>x</sub> scrubber and EGR subsidized by the Danish EPA.

Participants: Alfa Laval and MAN Diesel and Turbo.

Objective is to clarify synergy possibilities and installation aspects for shipyards.





- 1 Introduction
- 2 Tier III Strategy
- 3 SCR - Selective Catalytic Reduction
- 4 EGR – Exhaust Gas Recirculation
- 5 Fuels
- 6 SO<sub>x</sub> Scrubbing
- 7 Visit to the Test Center**

# Visit to the Test Center



- It is not allowed to take photos.
- Do not touch engine parts.
- Stiletto heels are not allowed on the gallery.
- We supply safety helmets and yellow vests.
- Respect all restricted areas!
- Please note that video cameras are used for inspection of the test plant and you might be recorded.

# Visit to the Test Center



As you are around 40 people we intend to divide you in 3 groups.

The first group (A) goes to the control room.

The second group (B) goes to the engine and EGR (Flemming will be here).

The third group (C) goes to the fuel test stand with Dorthé.

After 10-15 minutes A goes to the EGR – B goes to the fuel test and C goes to the control room. After 10-15 minutes all groups change again.

**11:15 all groups have to return the vests and helmets to the same place it was supplied.**

# Visit to the Test Center

Engine is running



As you are around 40 people we intend to divide you in 2 groups.

The first group goes to the control room – and the EGR with Flemming.

The second group goes to the fuel test stand with Dorthe.

After 15-20 minutes the groups change.

**At 11:15 all groups have to return the vests and helmets to the same place it was supplied.**

# Thank You for Your Attention!



All data provided in this document is non-binding. This data serves informational purposes only and is especially not guaranteed in any way. Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.