Developments and Perspectives of Marine Engines

Clean Combustion and Greenhouse Gases

Thursday 6 November 2008

by Paolo Tremuli

Agenda

- The Pollutants
- The Legislation
- The Abatement Methods
  - Wet Methods
  - The Selective Catalytic Reactor
  - The Scrubber
  - The Waste Heat Recovery
- A Dredging Application

WÄRTSILÄ

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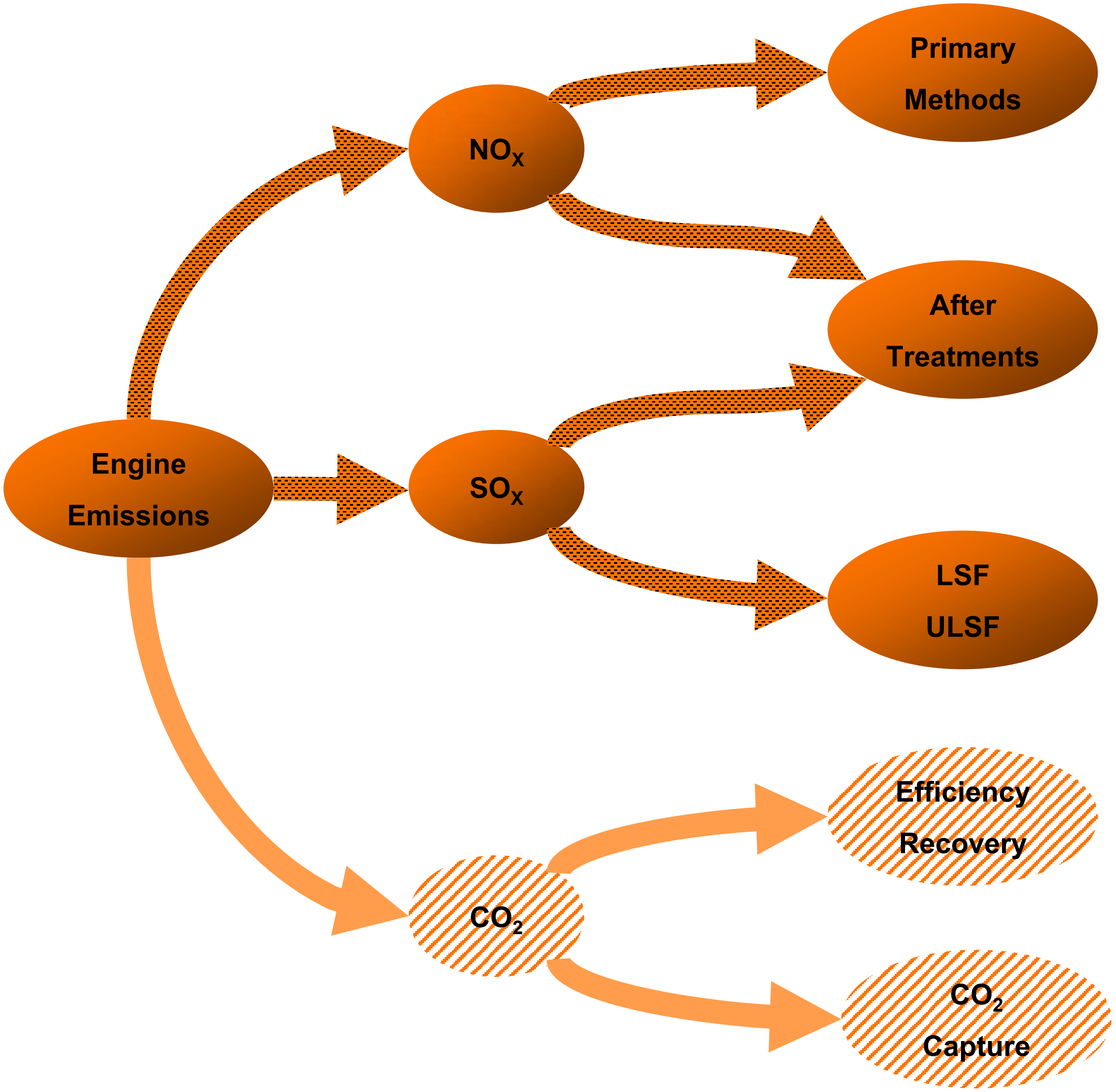
Abatement Strategies



Engine Emissions

NO_X

SO_X

CO_2

Primary Methods

After Treatments

LSF ULSF

Efficiency Recovery

CO_2 Capture

-Limited Effect on reduction

-Impact on engine efficiency

-Highest flexibility

-Highest engine efficiency

-Easy operation

-High Costs expected

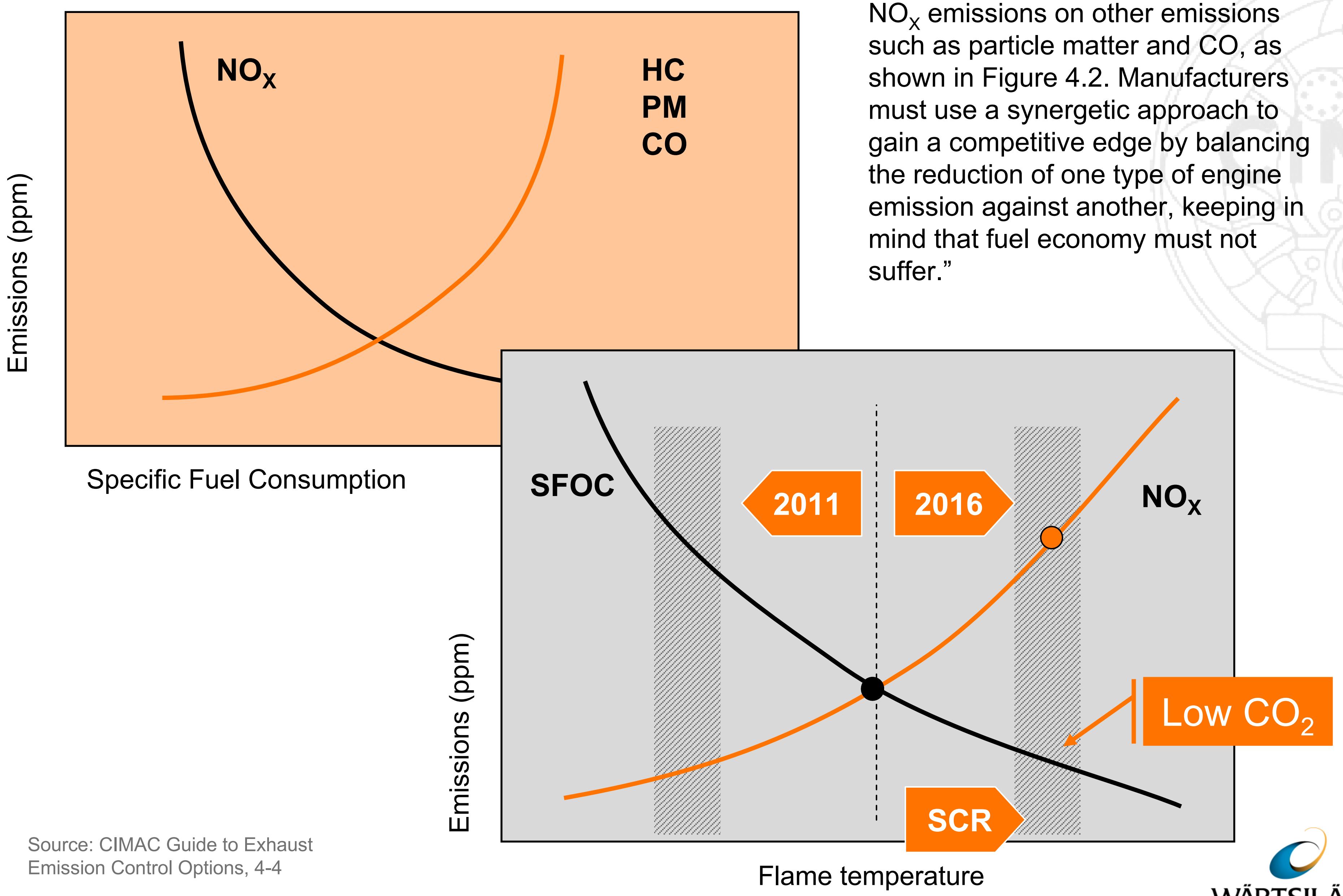
-Energy consumption equipment and Energy production shall be integrated

-Highest flexibility

-Highest engine efficiency

The NO_X trade-off

"… there are trade-offs with improving NO_X emissions on other emissions such as particle matter and CO, as shown in Figure 4.2. Manufacturers must use a synergetic approach to gain a competitive edge by balancing the reduction of one type of engine emission against another, keeping in mind that fuel economy must not suffer."



Source: CIMAC Guide to Exhaust Emission Control Options, 4-4

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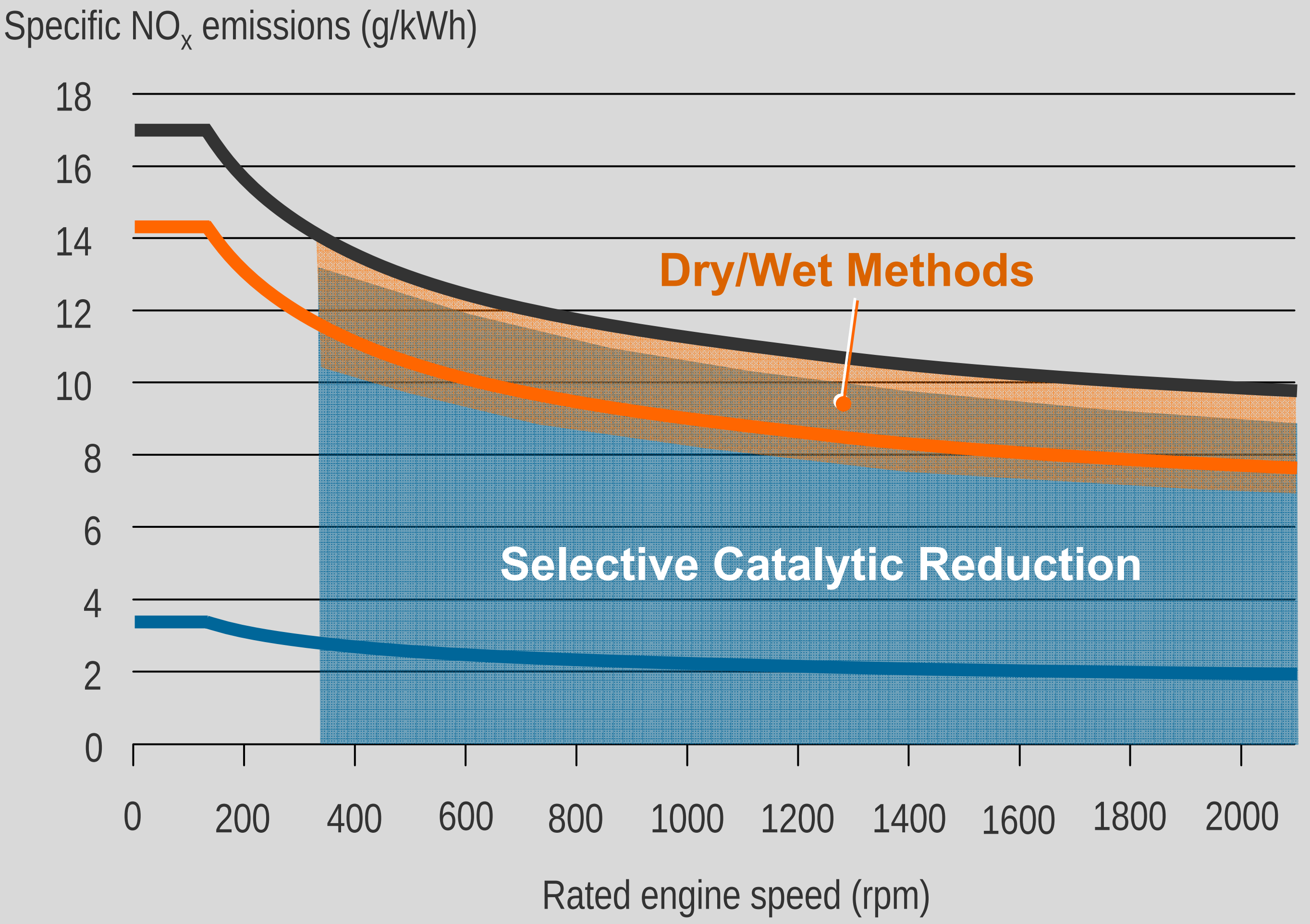
NO_x reduction – IMO requirements and methods



Tier I (present)
Ships built 2000 onwards
Engines > 130 kW

Retrofit: Ships built
1990 – 2000
Engines > 90 litres/cylinder
and > 5000 kW

Tier II (global 2011)
Ships built 2011 onwards
Engines > 130 kW

Tier III (ECAs 2016)
Ships in designated
areas, 2016 onwards
Engines > 600 kW

Revision of Marpol Annex VI

Regulation 14 - SOx and PM

Global limit sulphur %

4.50 % until 1.1.2012
3.50 % from 1.1.2012
0.50 % from 1.1.2020

Emission Control Areas sulphur %

1.50 % until 1.3.2010
1.00 % from 1.3.2010
0.10 % from 1.1.2015

Review

Shall be completed by 2018 to determine availability of fuel for compliance with global limit 0.50 % 2020, taking into account market supply and demand, trends in fuel oil market etc. Based on information from group of experts, Parties may decide to postpone date of becoming effective to 1.1.2025.

Fuel type

Not regulated = both HFO and distillate are permitted.

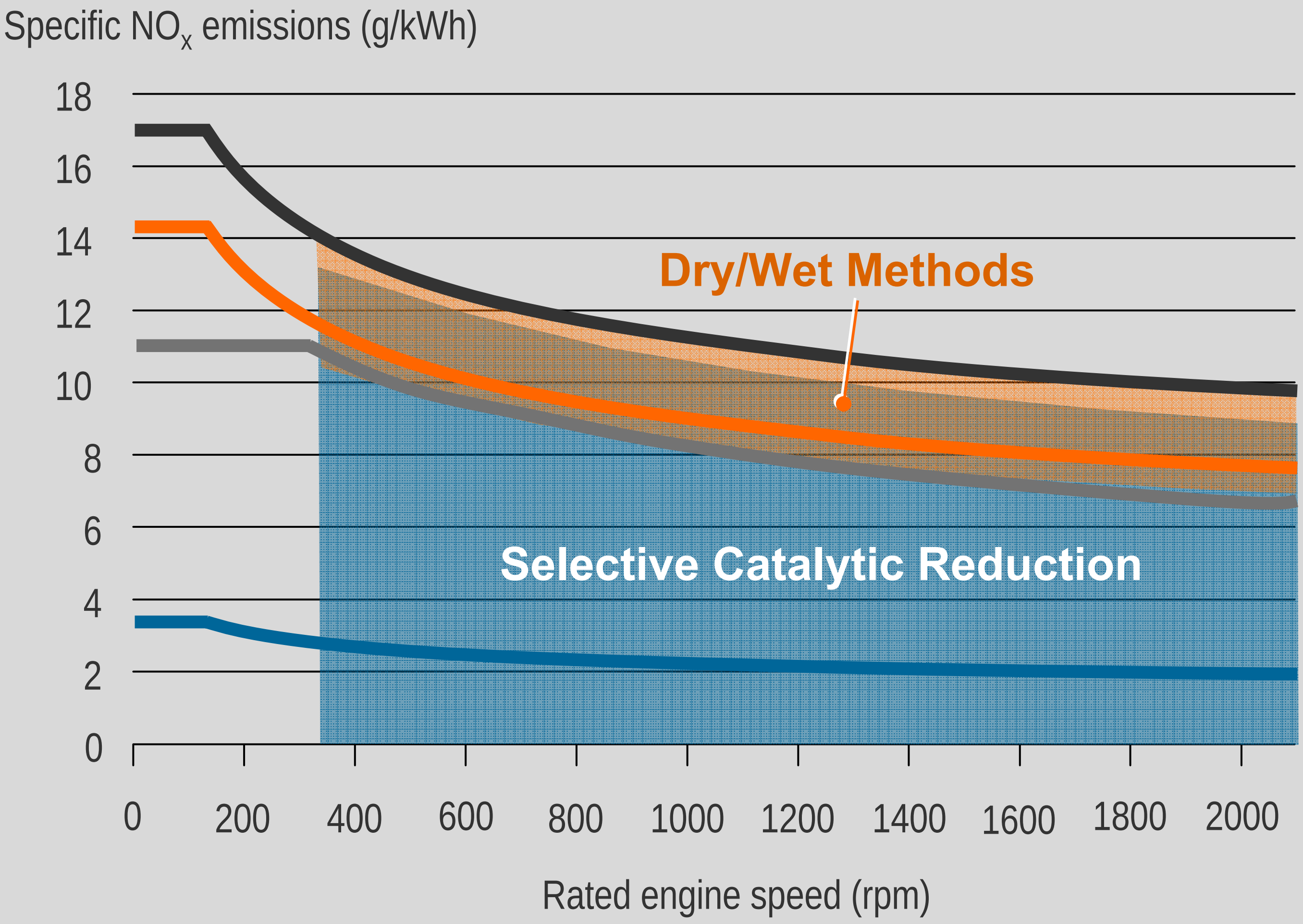
Exhaust gas cleaning

Permitted alternative under Regulation 4 to achieve any regulated limit.

Particulate Matter (PM)

No limit values.

Rhine river regulations



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Ships built 2011 onwards
Engines > 130 kW

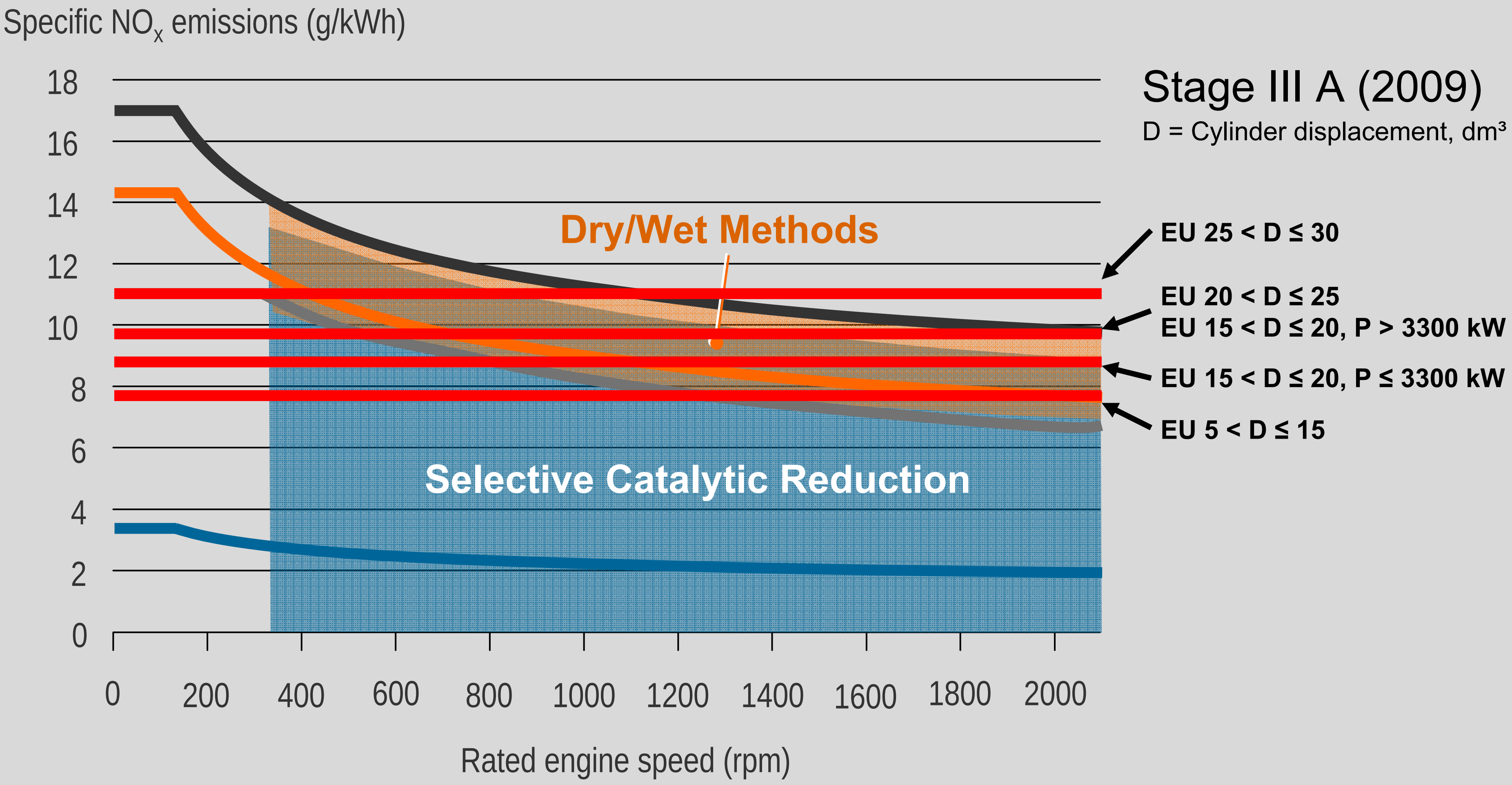
Tier III (ECAs 2016)

Ships in designated
areas, 2016 onwards
Engines > 600 kW

Rhine river regulations

In force since 1.7.2007
Engines ≥ 560 kW

…and EU regulations on inland waterways (HC+NO_x)



Plus other, national requirements

Such as

- Port and fairway dues in Sweden
- NO_x tax (and NO_x fund) in Norway
- CARB (California Air Resources Board) rules for Californian ports

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Wetpac technology alternatives

There is a considerable pressure from the markets to decrease NOx emissions for which we have the following alternatives:

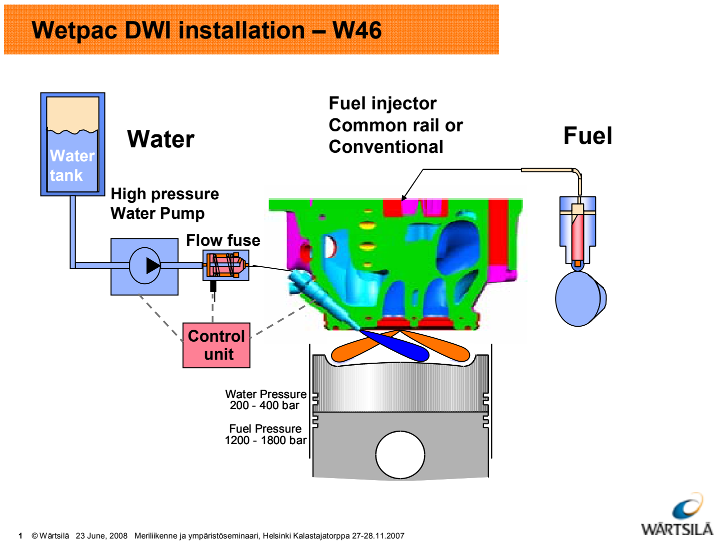
- Engine internal, so-called “dry” means
- Wetpac technologies, so-called “wet” means
- SCR – Selective Catalytic Reduction

All methods have their pros and cons of which the Wetpac technologies will be considered in this presentation

Three Wetpac technologies have been considered:

Direct Water Injection	**Humidification**	**Water-in fuel-Emulsions**
Wetpac DWI	Wetpac H	Wetpac E

Wetpac DWI (Direct Water Injection)



Wetpac DWI installation – W46

1 © Wärtsilä 23 June, 2008 Meriliikenne ja ympäristöseminaari, Helsinki Kalastajatorppa 27-28.11.2007

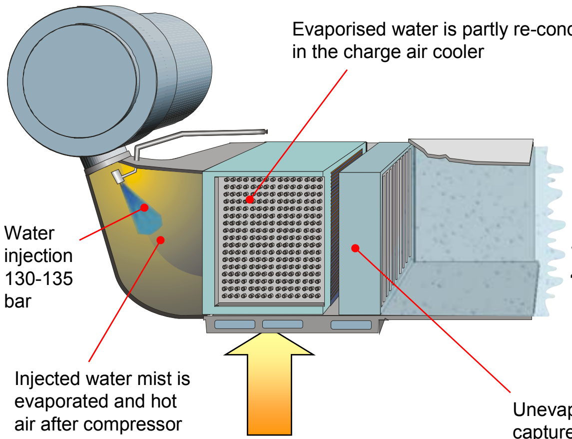
Strengths

- High NOx reduction level achievable: 50%
- Low water consumption compared to Humidification
- Water quality is less crucial compared to Humidification
- Air duct system can be left unaffected – no risk for corrosion/ fouling of CAC, etc
- Flexible system – control of water flow rate, timing, duration and switch off/on
- Less increase of turbocharger speed and less drift towards compressor surge line compared to the Humidification method due to no increase of rec. temp. and less water flow – high engine load can be achieved and high (50%) NOx reduction also at full engine load
- No major change in heat recovery possibilities
- Good long term experiences with low sulphur fuels (<1.5%)

Weaknesses

- High fuel consumption penalty
- Increased smoke formation especially at low loads
    - Remedy: switch off or less water at low load
- More complicated/expensive system compared to Humidification
- Challenges in terms of piston top and injector corrosion with high sulphur fuels (>1.5%)
    - The situation in this respect is improving

Wetpac H (Humidification)



Evaporised water is partly re-condensing in the charge air cooler

Water injection 130-135 bar

Saturated air 40…70°C

Injected water mist is evaporated and hot air after compressor is cooled to saturation point

Heat from cooling water is reducing re-condensing

Unevaporised water captured in WMC and re-circulated

Standard Wetpac H unit

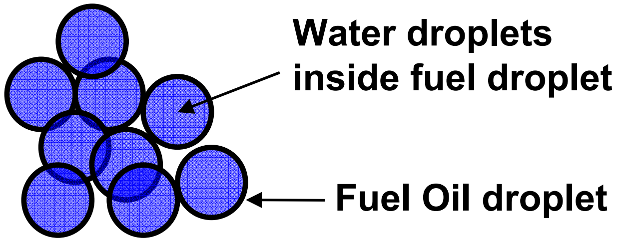
Strengths

- Only marginal increase of SFOC
- Less complicated/expensive system compared to DWI
- Flexible system – control of water flow rate and switch off/on
- Could be developed for increasing the knock-margin in gas engines

Weaknesses

- Lower NOx reduction (10-40%) compared to DWI (50%)
- High water consumption compared to DWI
  - Very clean water is required in order to avoid fouling/corrosion of CAC and air duct system
  - Major change in heat recovery possibilities - less cooling water heat available for production of clean water
- Turbocharger speed increase and drift towards compressor surge line due to increased rec. temp. and high water flow
  - By-pass is required (anti-surge device)
    - Not possible together with pulse charging systems
  - Full NOx reduction (40%) can not normally be achieved at full engine load and low loads
- Increased smoke formation especially at low loads
  - Remedy: switch off or less water at low loads
- Limited long term experience
  - Unacceptable corrosion observed in the air duct system including CAC on 500h endurance test with high sulphur fuel (3%)

Wetpac E (Water-in fuel Emulsions)



Strengths

- Only marginal increase of SFOC
- Reduced smoke formation especially at low load
- Low water consumption compared to Humidification
    - Almost similar to that of DWI, but due to low NOx reduction the water consumption is low
- Water quality is less crucial compared to Humidification
- Less increase of turbocharger speed and less drift towards compressor surge line compared to the Humidification method, due to no increase of rec. temp. and less water flow – high engine load can be achieved
- No major change in heat recovery possibilities
- Equipment can be used also for lowering viscosity of high viscosity (residual) fuels (Fuel-in-Water emulsions)

Weaknesses

- Low NOx reduction potential (15-25%)
- Limited flexibility
    - Increased smoke formation and poor engine performance due to too large nozzles in case of switching off the system
    - Increased mechanical stress on the fuel injection system in case ”standard” nozzles are used
- Limited long term experience

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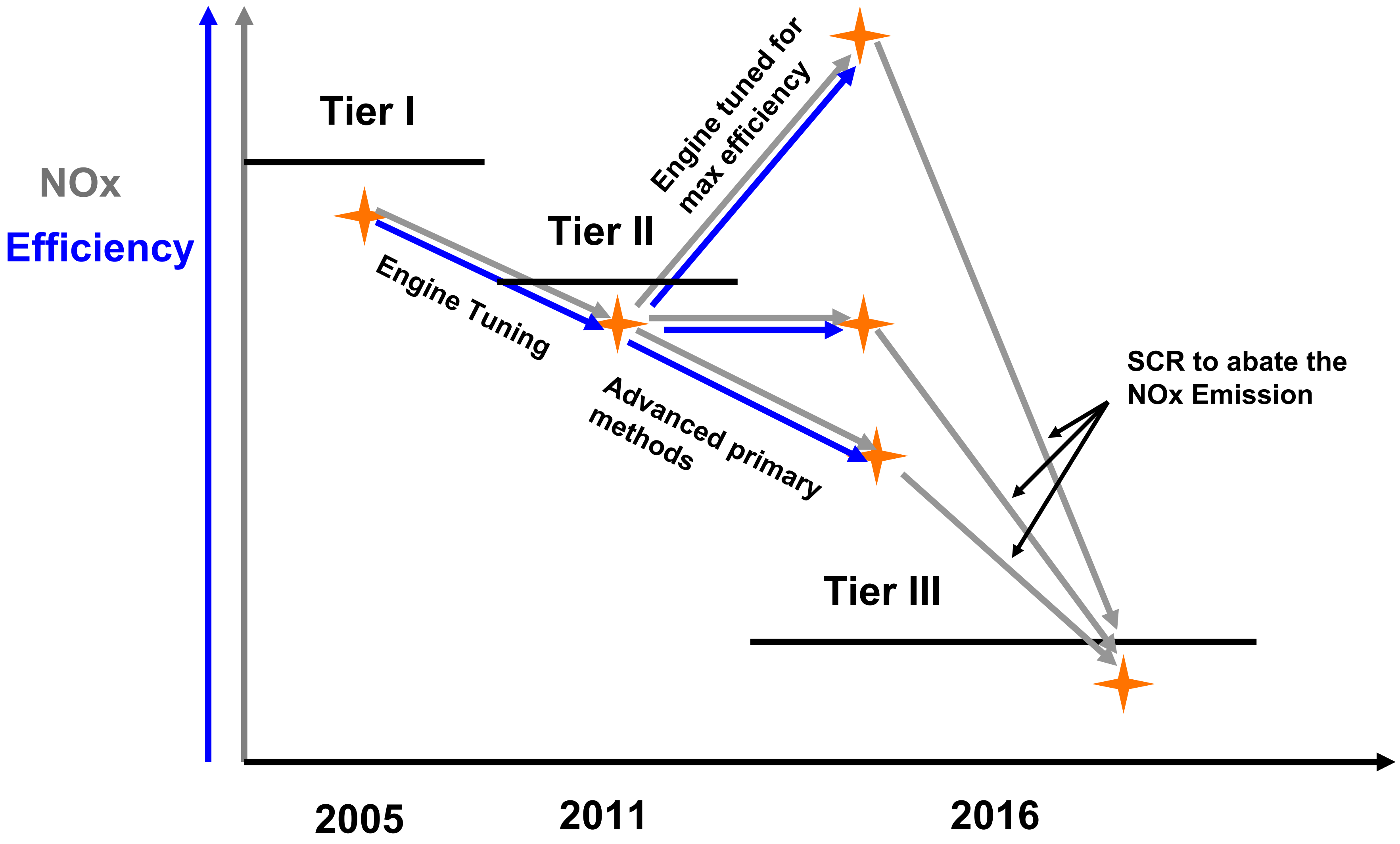
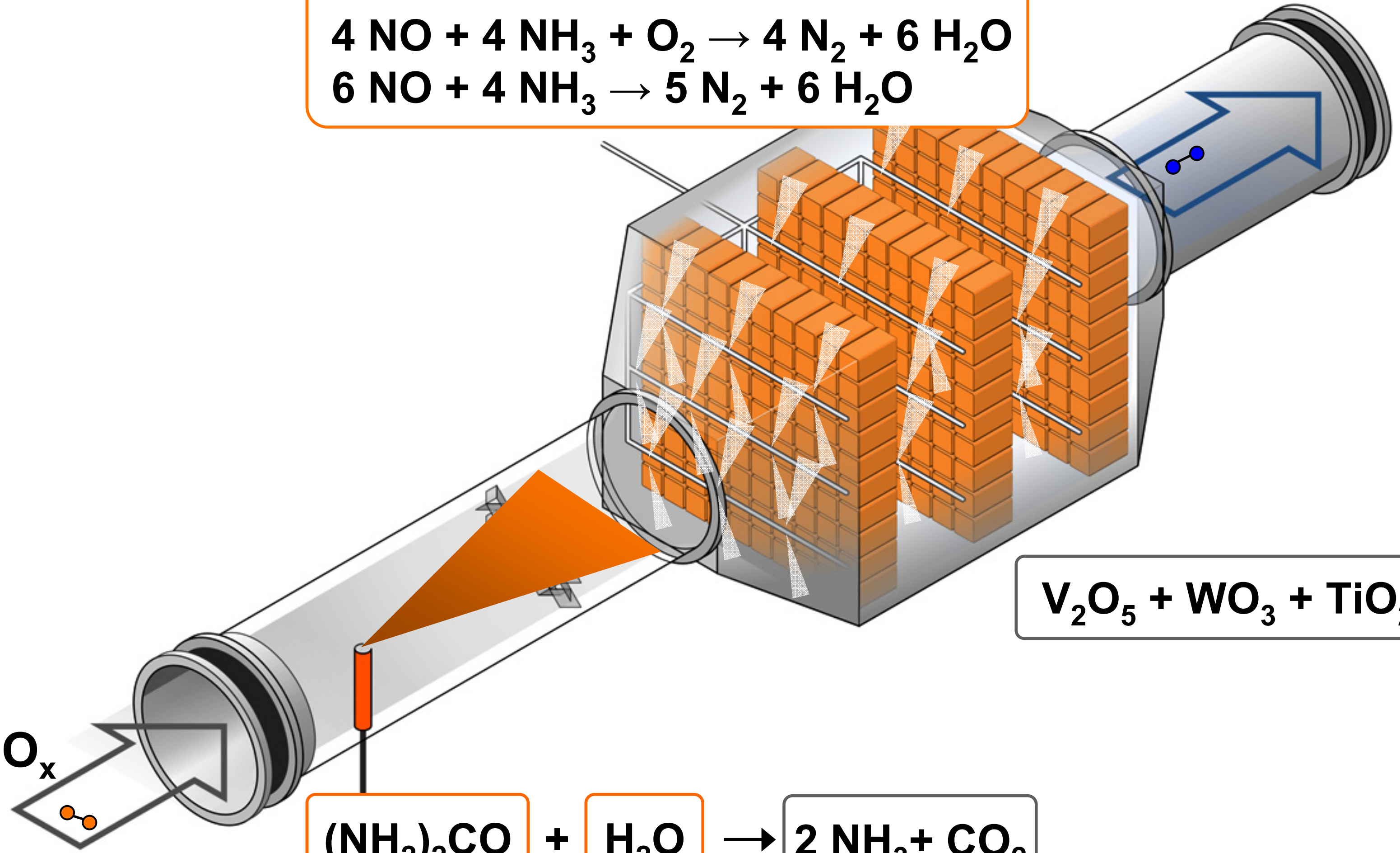
IMO Compelling Strategies



Principle of Selective Catalytic Reduction, SCR



SCR reactions:

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

$6\,NO + 4\,NH_3 \rightarrow 5\,N_2 + 6\,H_2O$

N_2 and H_2O

$V_2O_5 + WO_3 + TiO_2$

NO_x

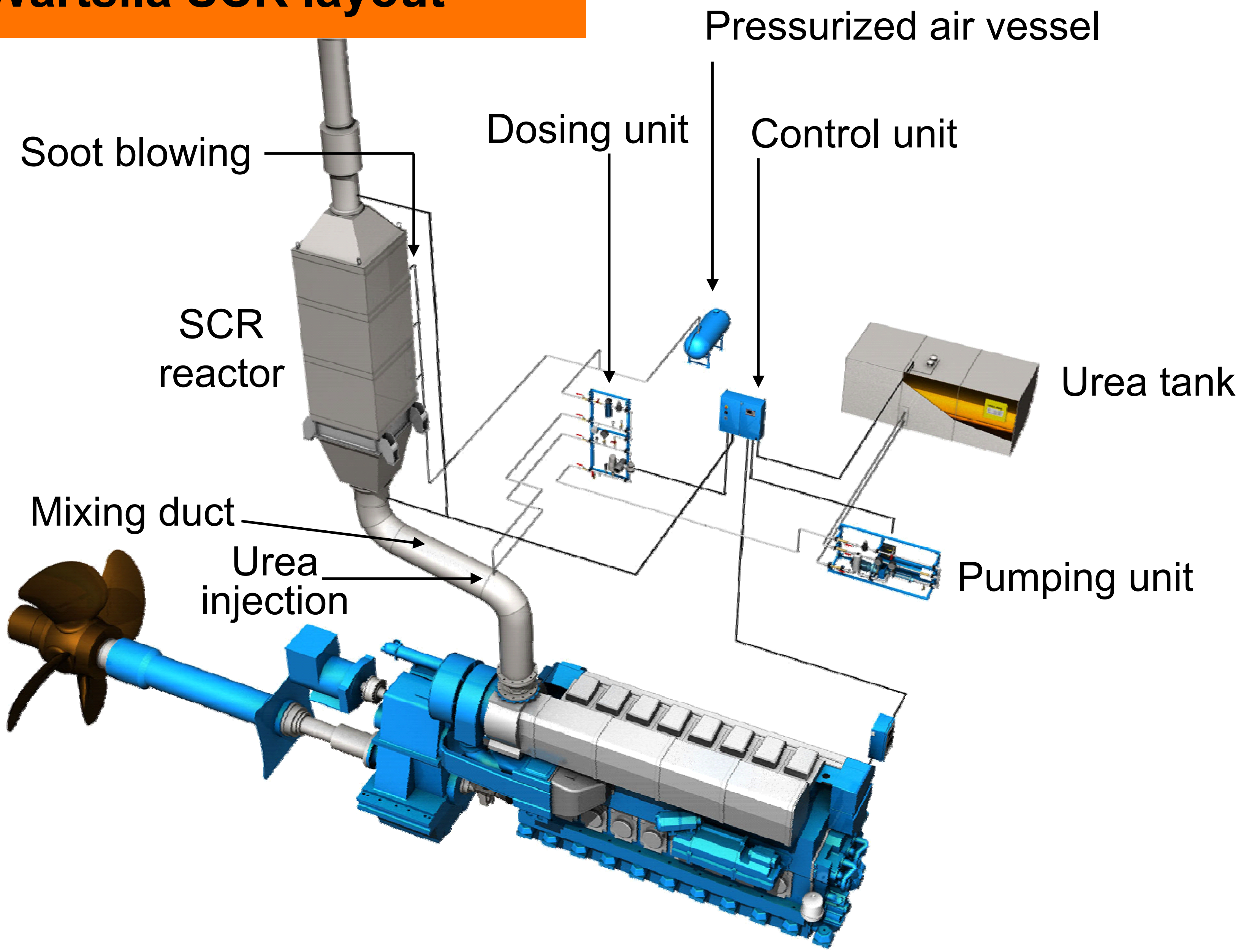
Exhaust gases

$(NH_2)_2CO + H_2O \rightarrow 2\,NH_3 + CO_2$

Urea injection

Ammonia + Carbon dioxide

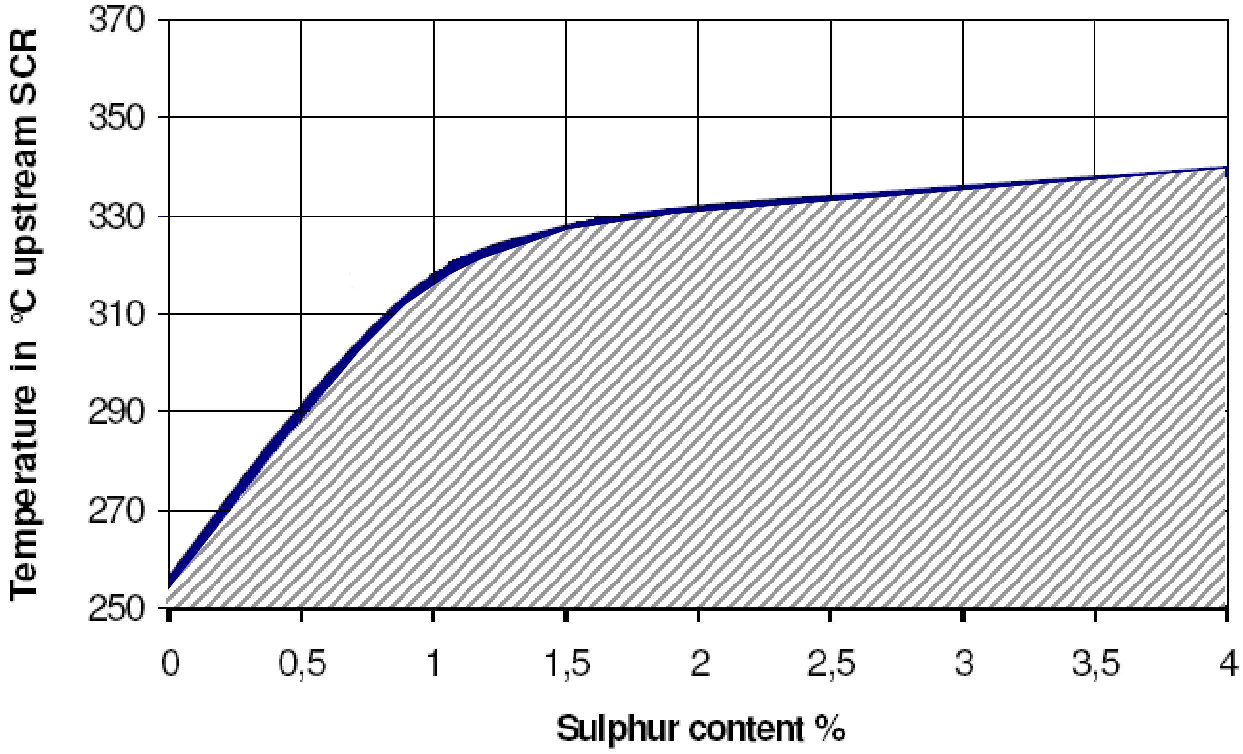
Wärtsilä SCR layout



SCR test rig

Effect of sulphur content in the fuel

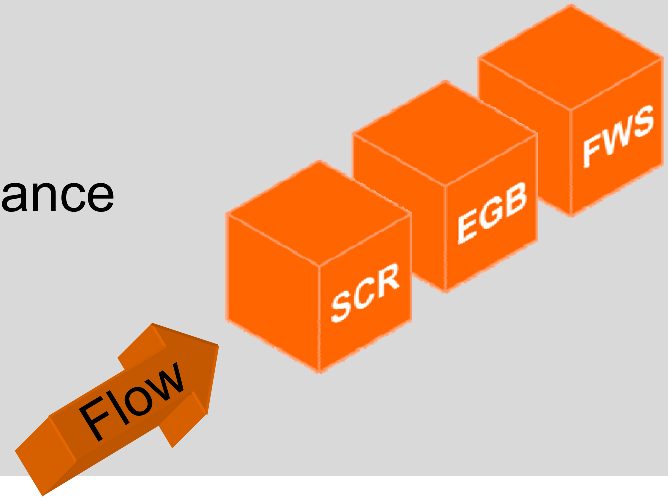
Sulphur content of the fuel has a drastic effect on the minimum temperature required for the SCR:



The lower the sulphur content, the lower the temperature needed

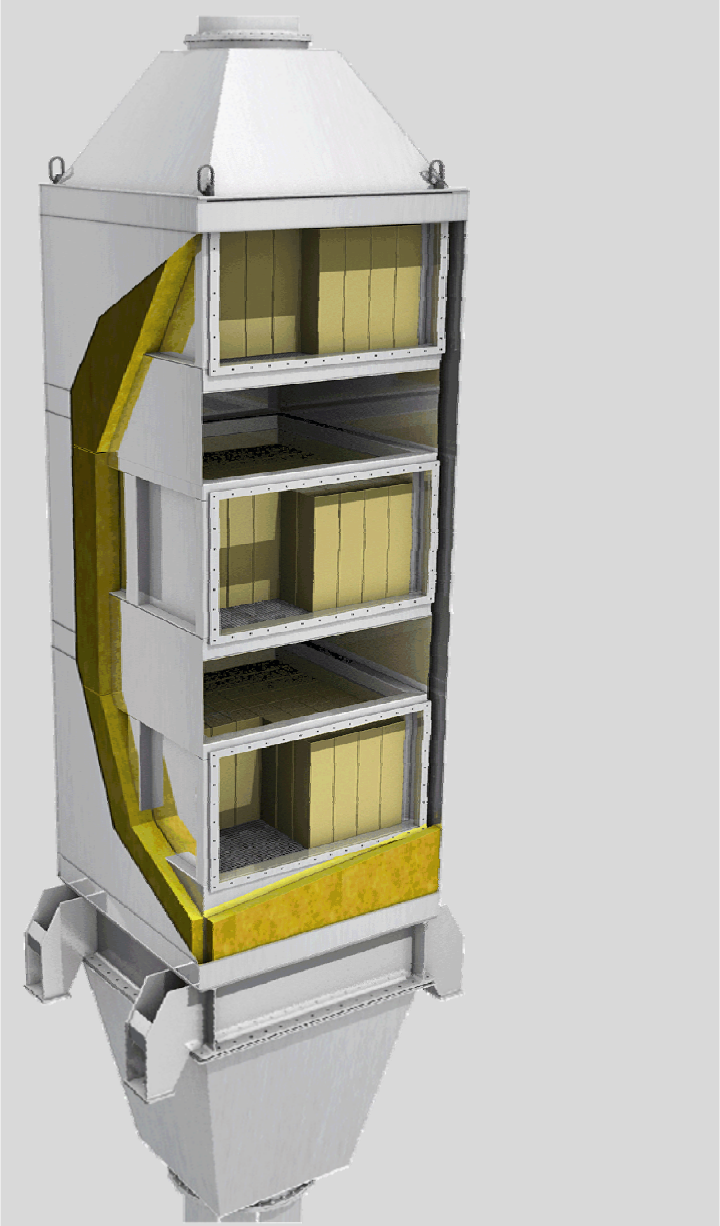
Wärtsilä SCR performance

- High NO_x conversion over a wide temperature range
- High selectivity for the SCR process
- Extremely low $SO_2 \rightarrow SO_3$ conversion rate
- High mechanical stability and chemical resistance
- Low back pressure and low risk of clogging
- One size honeycomb for all modules



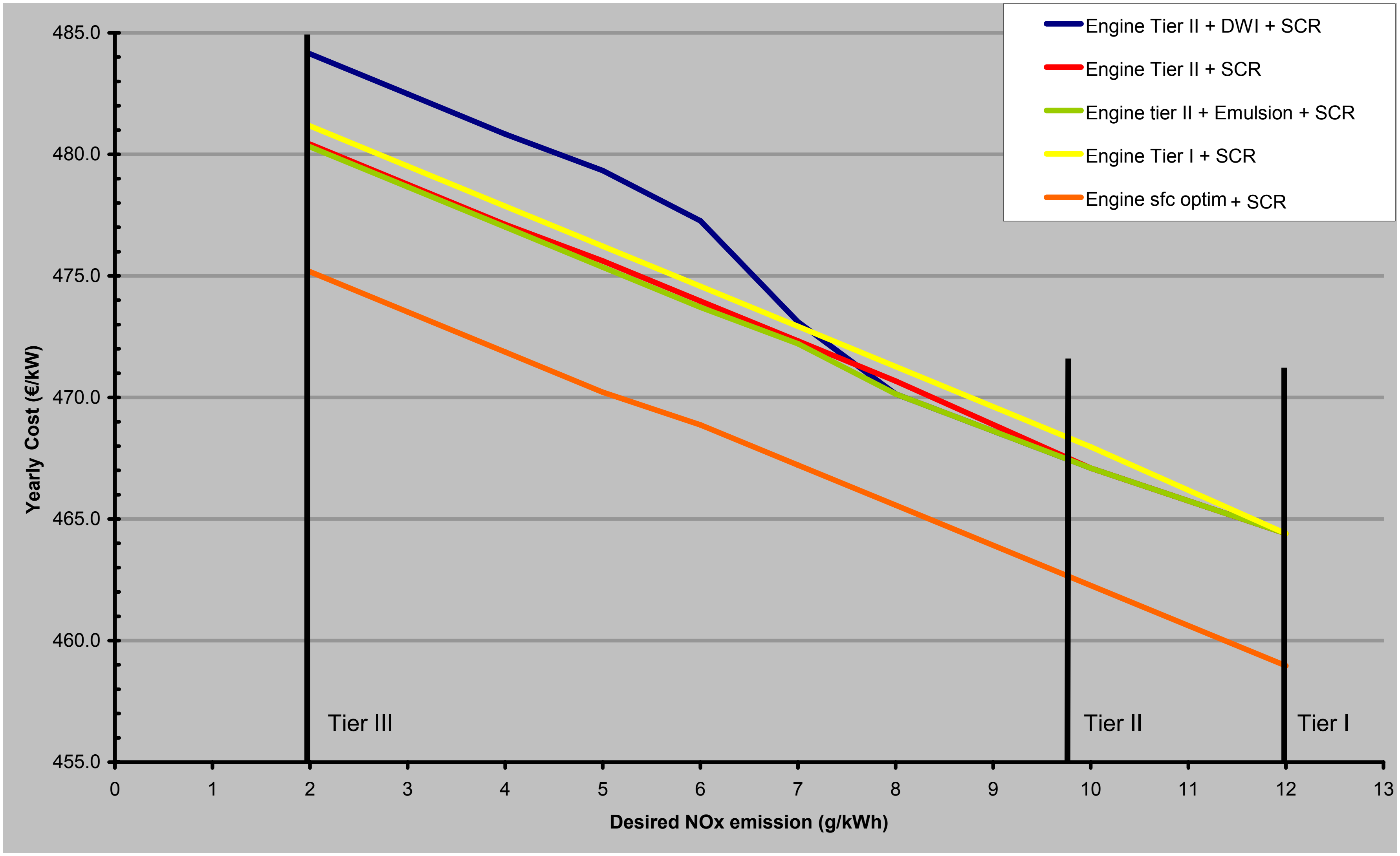
Performance	NO_x reduction	80 - 95%
	HC reduction	20 - 40%
	Soot reduction	20%
	Sound Attenuation	20 dB (A)
Operation	Temperature Span	300 - 500 °C
	Fuel	MGO/MDO/HFO/GAS

Wärtsilä SCR – Rules of thumb



- **Urea consumption about 20 L/MWh** (depending on the raw emissions)
- **Operational cost ca. 6 €/MWh** (including replacement of catalytic elements)
- **Investment cost roughly 25-50 €/kW** (equipment)

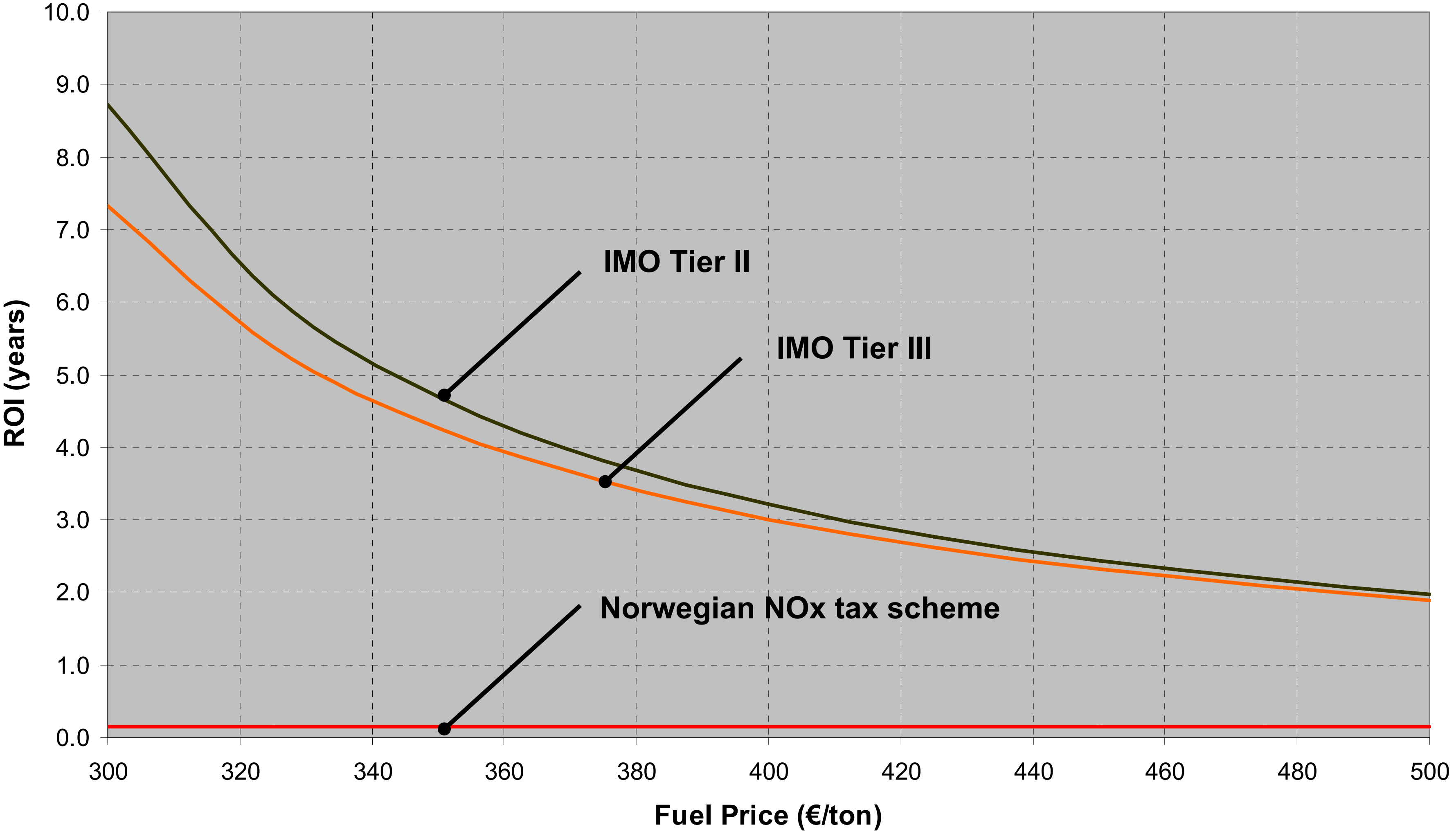
Abatement Costs



Calculation hypothesis:

- **IFO 180 price 375 €/ton**
- **Urea price 0.15 €/l**
- **Distilled Water price 5 €/ton**
- **Cost for catalyst replacement is included**

ROI for SCR


10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ROI (years)
300
320
340
360
380
400
420
440
460
480
500
Fuel Price (€/ton)
IMO Tier II
IMO Tier III
Norwegian NOx tax scheme

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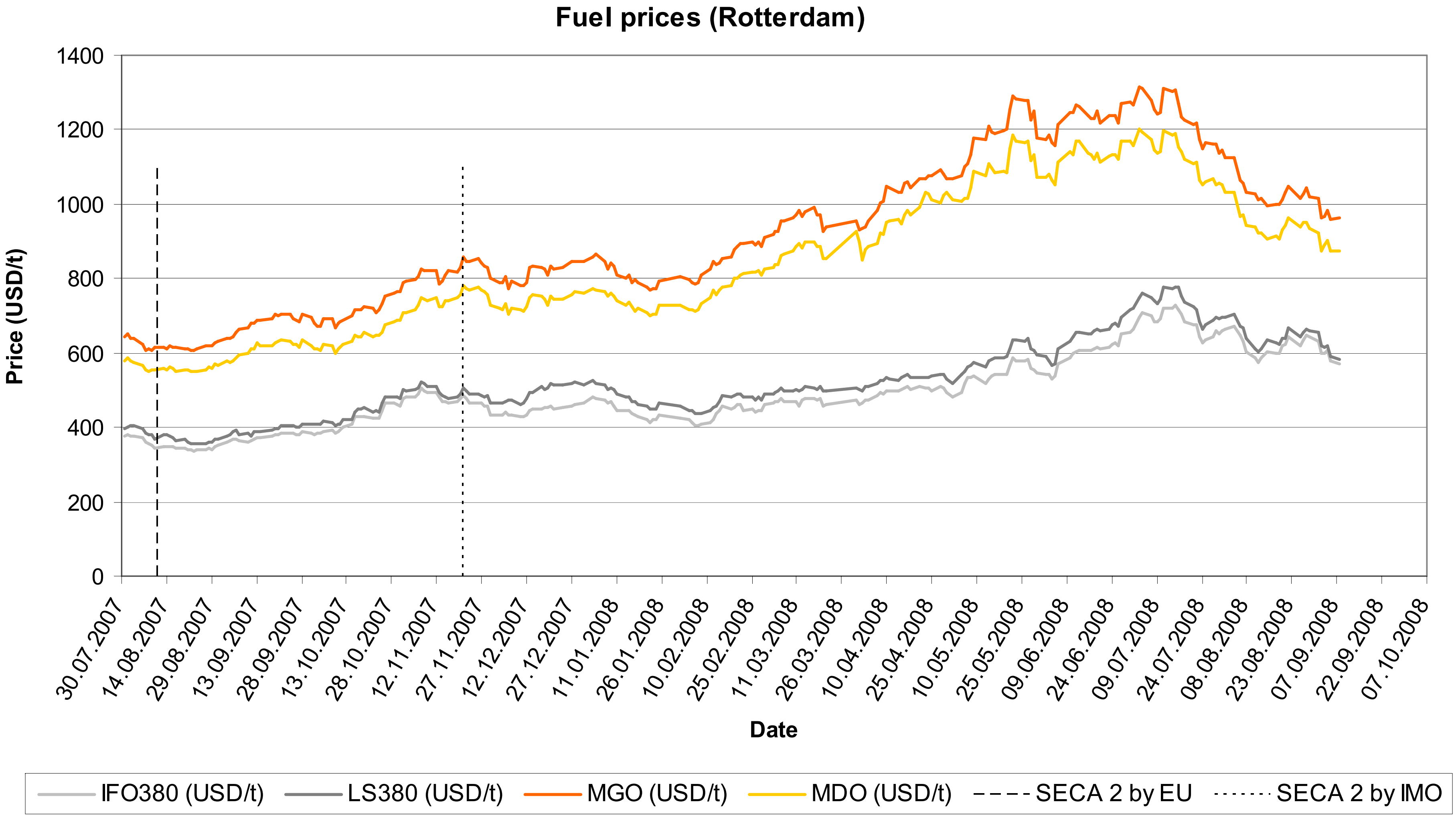
Fuel Prices, Rotterdam

Δ = 400…500 $/ton



Source: bunkerworld.com

IMO Scrubber Guideline

IMO Resolution MEPC.170(57)

SCRUBBER GUIDELINE

- Performance, certification, verification, documentation.

SCRUBBER WASH WATER

Application: ” Ports, harbours and estuaries”.

Content:

- Criteria include pH, PAH, turbidity, nitrates, additives.
- Different pH criteria for moving and stationary ships.
- Monitoring requirements.

SCRUBBER RESIDUE

Reception facilities:

- Parties undertake to ensure availability of appropriate reception facilities.
- Not to be incinerated.

SCHEDULE:

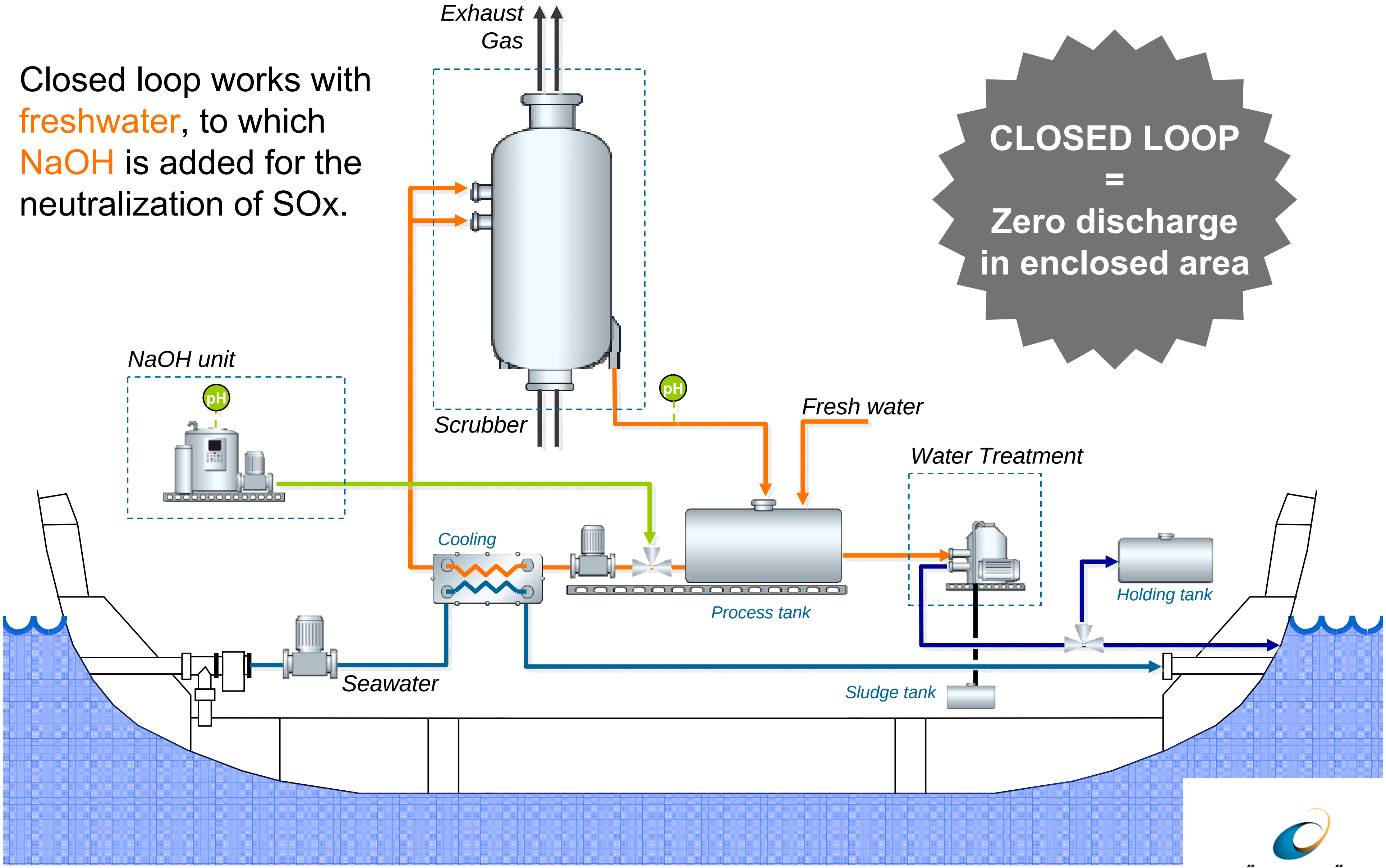
- Adopted in MEPC 57 April 2008.

Legend:
MEPC = IMO Marine Environmental Protection Committee
BLG = IMO Bulk, Liquid, Gas Subcommittee

General outlook of Marine Fresh Water Scrubber System

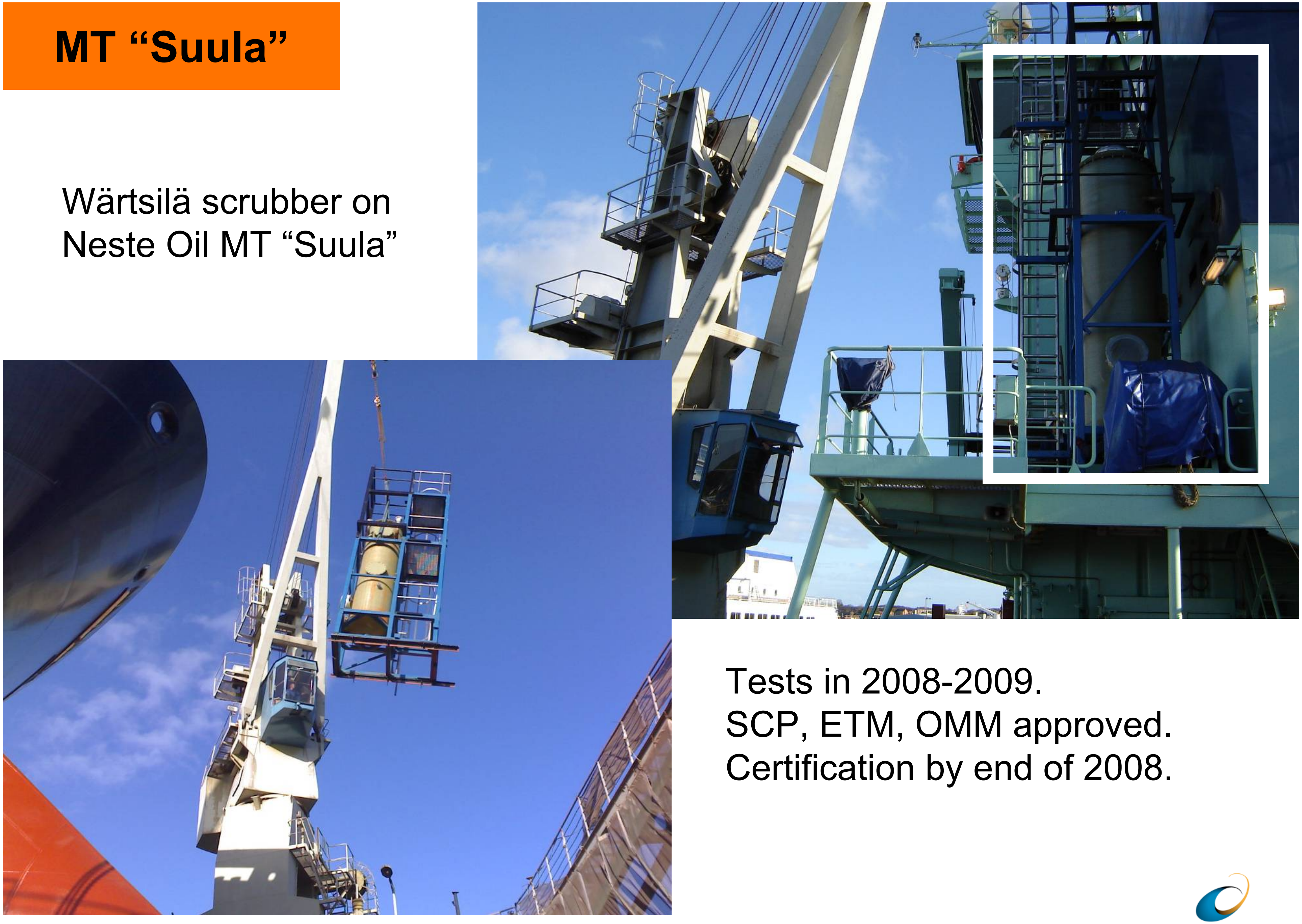
Closed loop works with freshwater, to which NaOH is added for the neutralization of SOx.

CLOSED LOOP
=
Zero discharge in enclosed area



MT “Suula”

Wärtsilä scrubber on
Neste Oil MT “Suula”



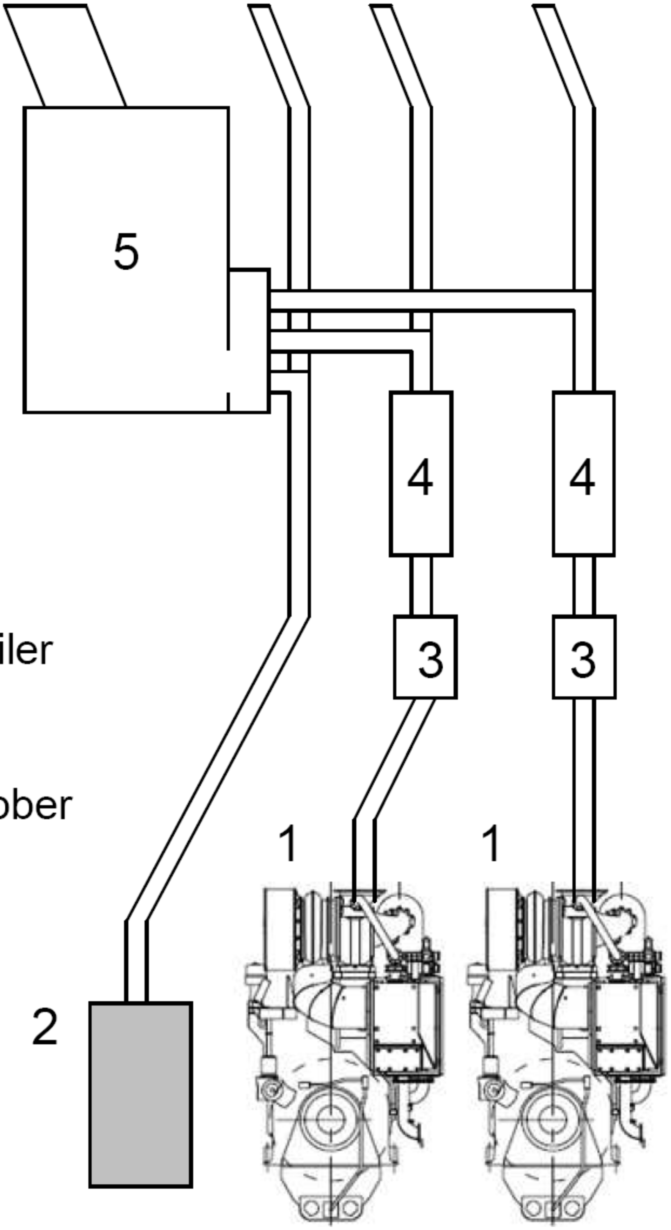
Tests in 2008-2009.
SCP, ETM, OMM approved.
Certification by end of 2008.

Wärtsilä Integrated Scrubber

BENEFITS

Avoid increased exhaust gas back pressure.

Minimize amount of equipment.



1 Diesel engine

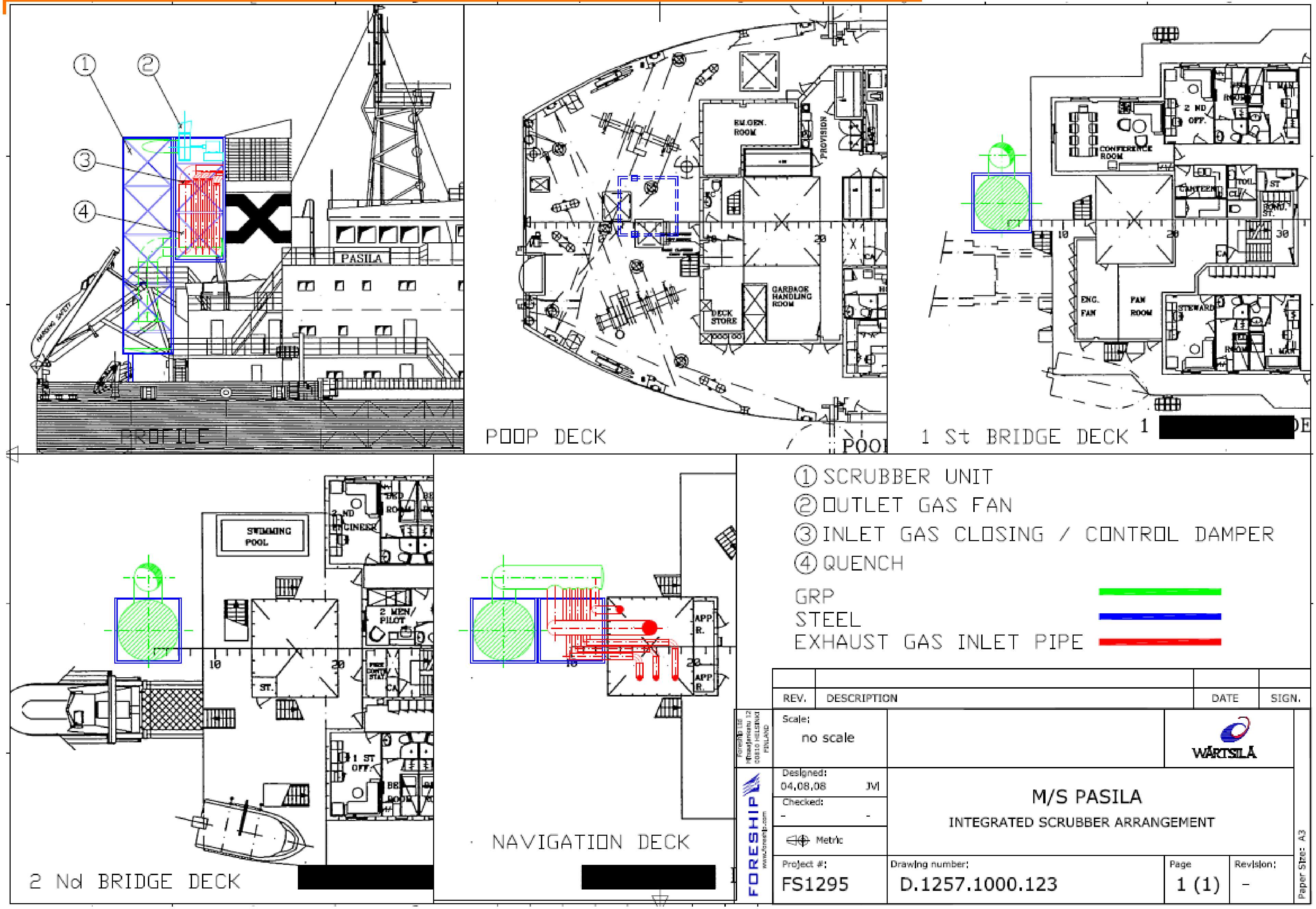
2 Oil-fired boiler

3 Exhaust gas boiler

4 Silencer

5 Integrated scrubber

Wärtsilä Integrated Scrubber - Retrofit



① SCRUBBER UNIT
② OUTLET GAS FAN
③ INLET GAS CLOSING / CONTROL DAMPER
④ QUENCH

GRP 🟩
STEEL 🟦
EXHAUST GAS INLET PIPE 🟥

REV.	DESCRIPTION	DATE	SIGN.

Scale: no scale

WÄRTSILÄ

Designed: 04.08.08 JVl
Checked: - -
Metric

M/S PASILA
INTEGRATED SCRUBBER ARRANGEMENT

Project #: FS1295
Drawing number: D.1257.1000.123
Page 1 (1)
Revision: -
Paper Size: A3

FORESHIP

NaOH consumption & storage Capacity

NaOH consumption depends on:

- Fuel sulfur content
- SOx reduction

NaOH storage capacity depends on:

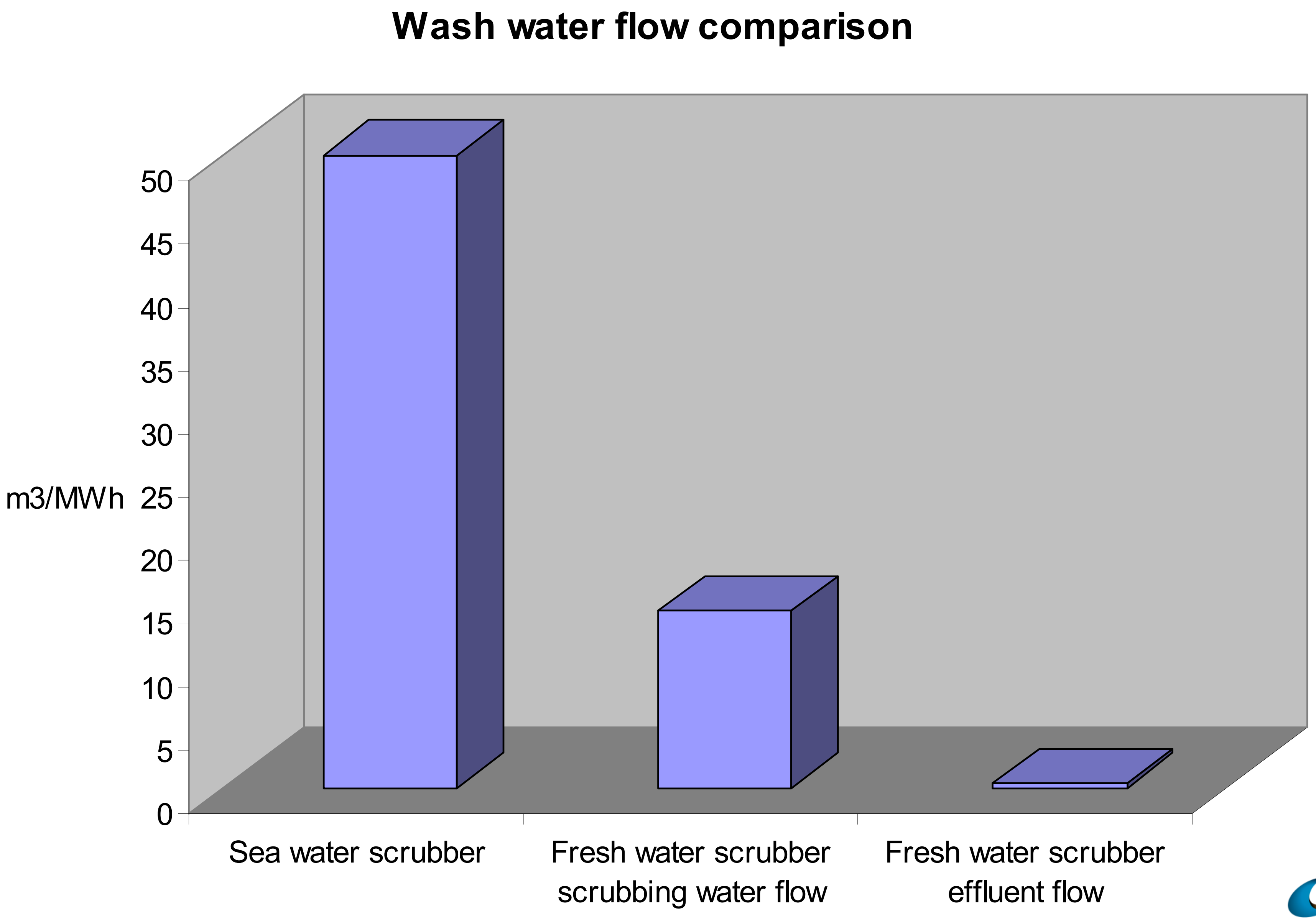
- Power profile
- Desired autonomy (bunkering interval)

10 MW plant, 85% MCR load

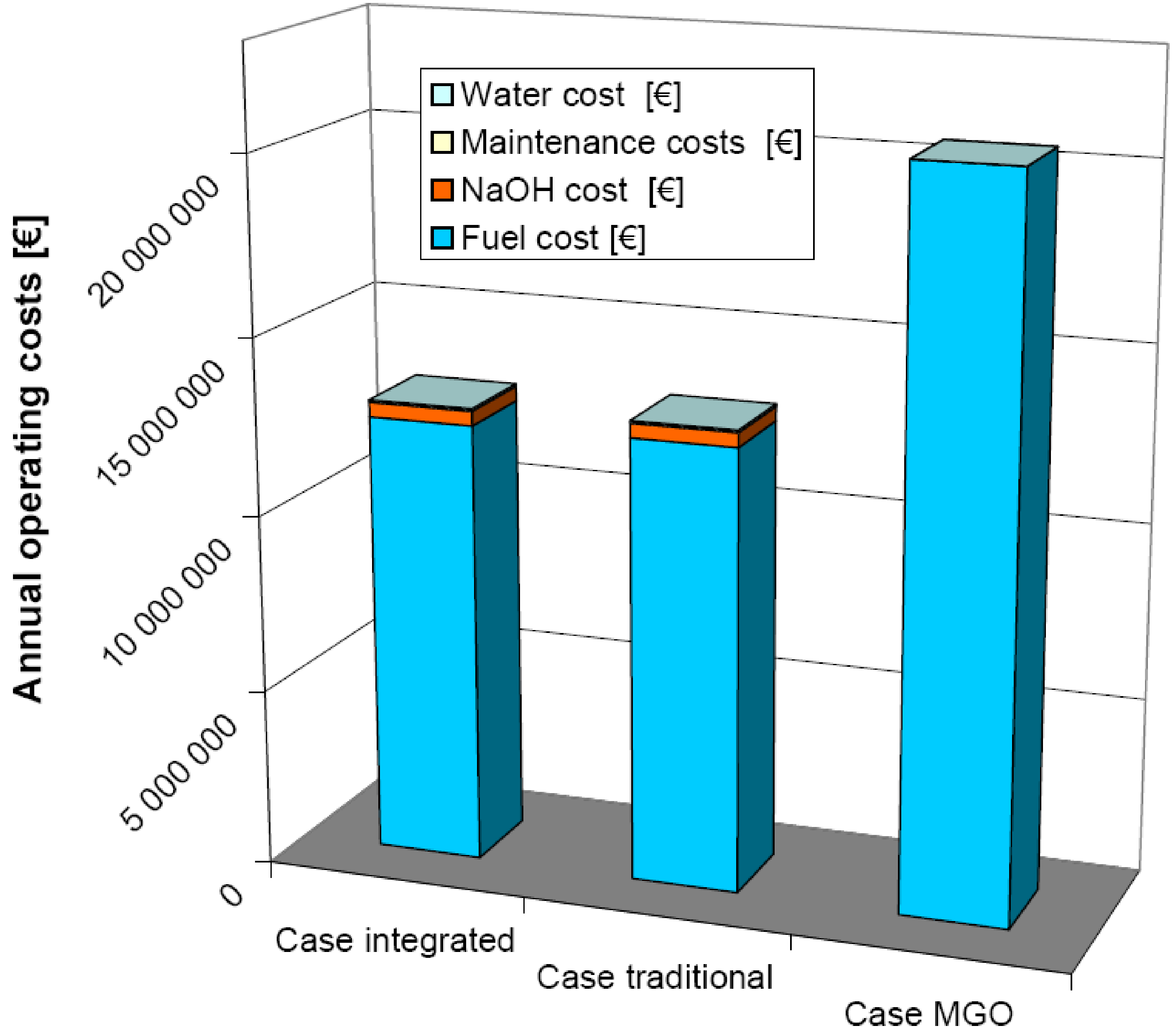
- Caustic soda in 50% solution

%S in fuel	2,7%	2,7%	2,7%	3,5%	
IMO limit	1,5%	0,5%	0,1%	0,1%	
NaOH cons.	1,5	2,7	3,2	4,2	[m^3/day]

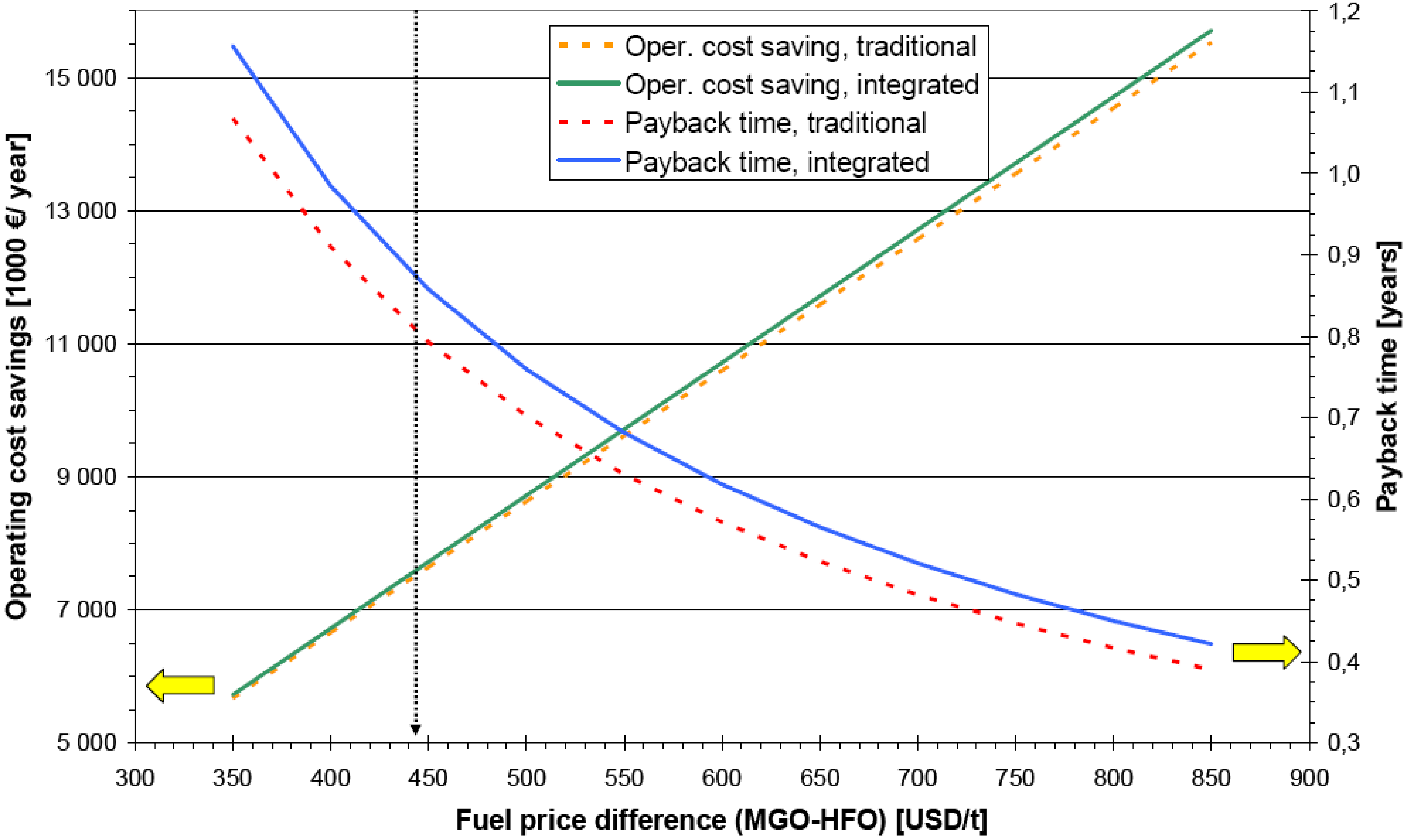
Wash water flow



Scrubber economy



Scrubber economy



Summary

1. With more stringent IMO and EU regulations, SOx-scrubbing is an increasingly attractive way of minimising operational costs by using HFO in an environmentally friendly way.
2. In **SOx Emission Control Areas** the cost saving is immediate, increasing in March 2010 when the price premium for low-sulphur fuel is expected to increase. In 2015 the cost savings will be dramatic, with ROI often below one year.
3. In **global operation** outside SECAs drastic savings in 2020 are evident. Already from 2012 savings are possible when using cheaper HFO with higher sulphur content than the global limit 3.5 %, where available.
4. In **EU ports** from 1.1.2010 significant savings can be achieved with scrubbers for diesel-generators and oil-fired boilers.
5. All these savings apply to **all ships regardless of age**.

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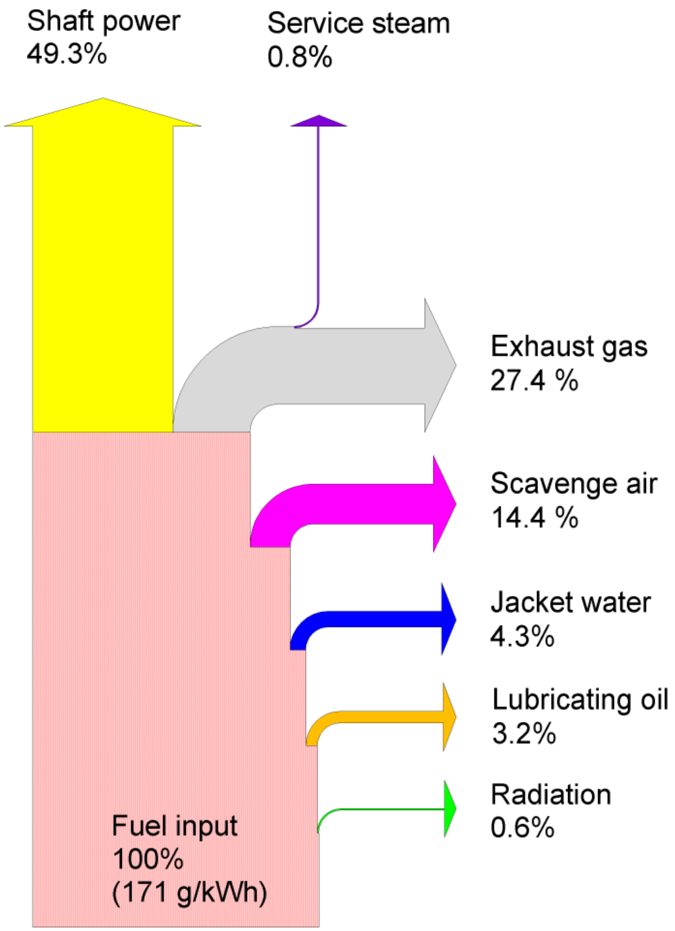
Waste Heat Recovery

Why waste heat recovery?



About 50% of the fuel input energy is not being put to productive use.

Recovering part of the wasted energy provides the vessel with:

- lower fuel consumption
- less emissions

Waste Heat Recovery

How to recover wasted energy?

- Using exhaust gas energy to generate steam to operate a steam turbine.

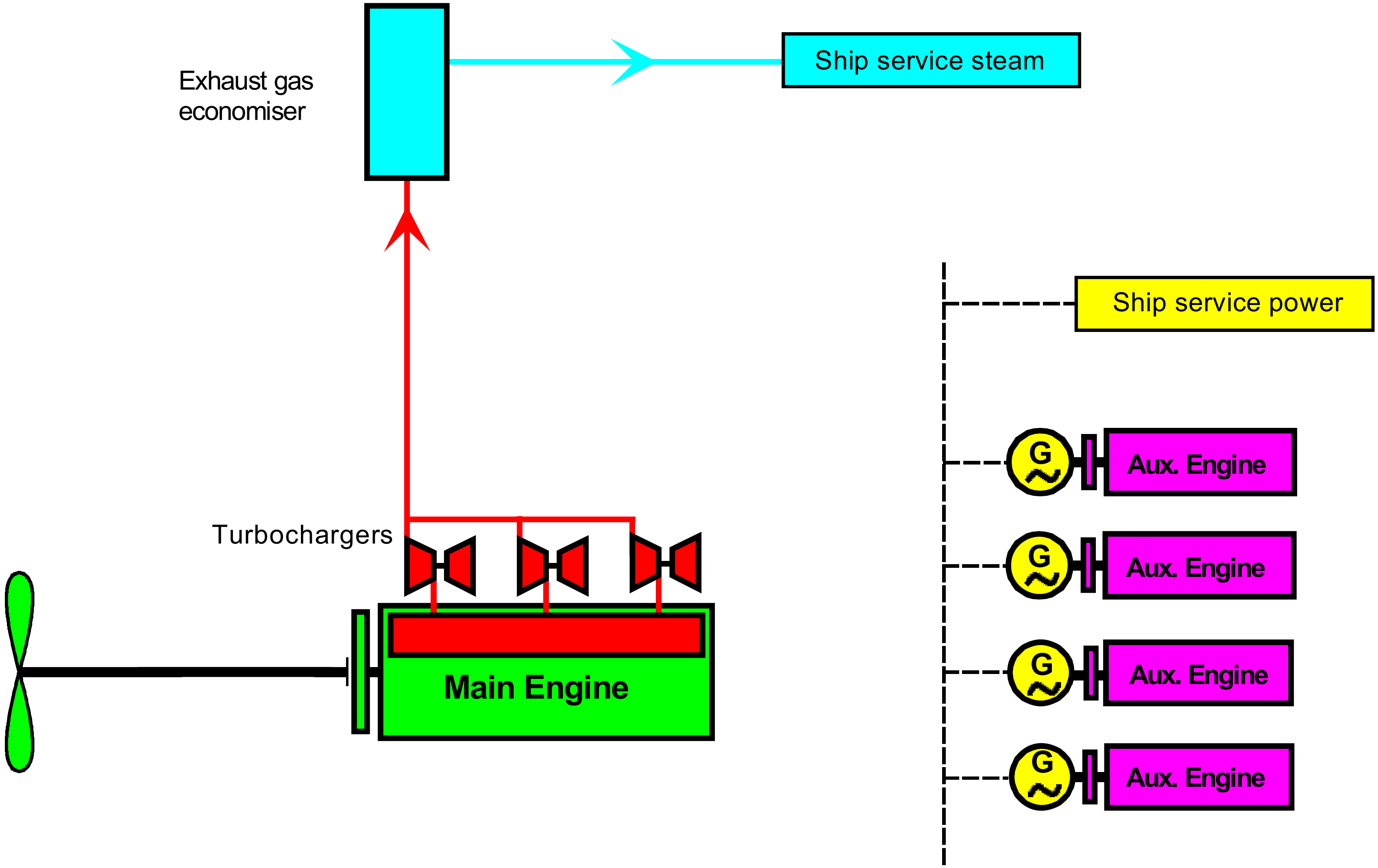
  The special engine tuning in combination with direct ambient scavenge air suction allows to achieve an elevated exhaust gas temperature.

- Using jacket cooling energy and scavenge air cooling energy to heat up feed water.

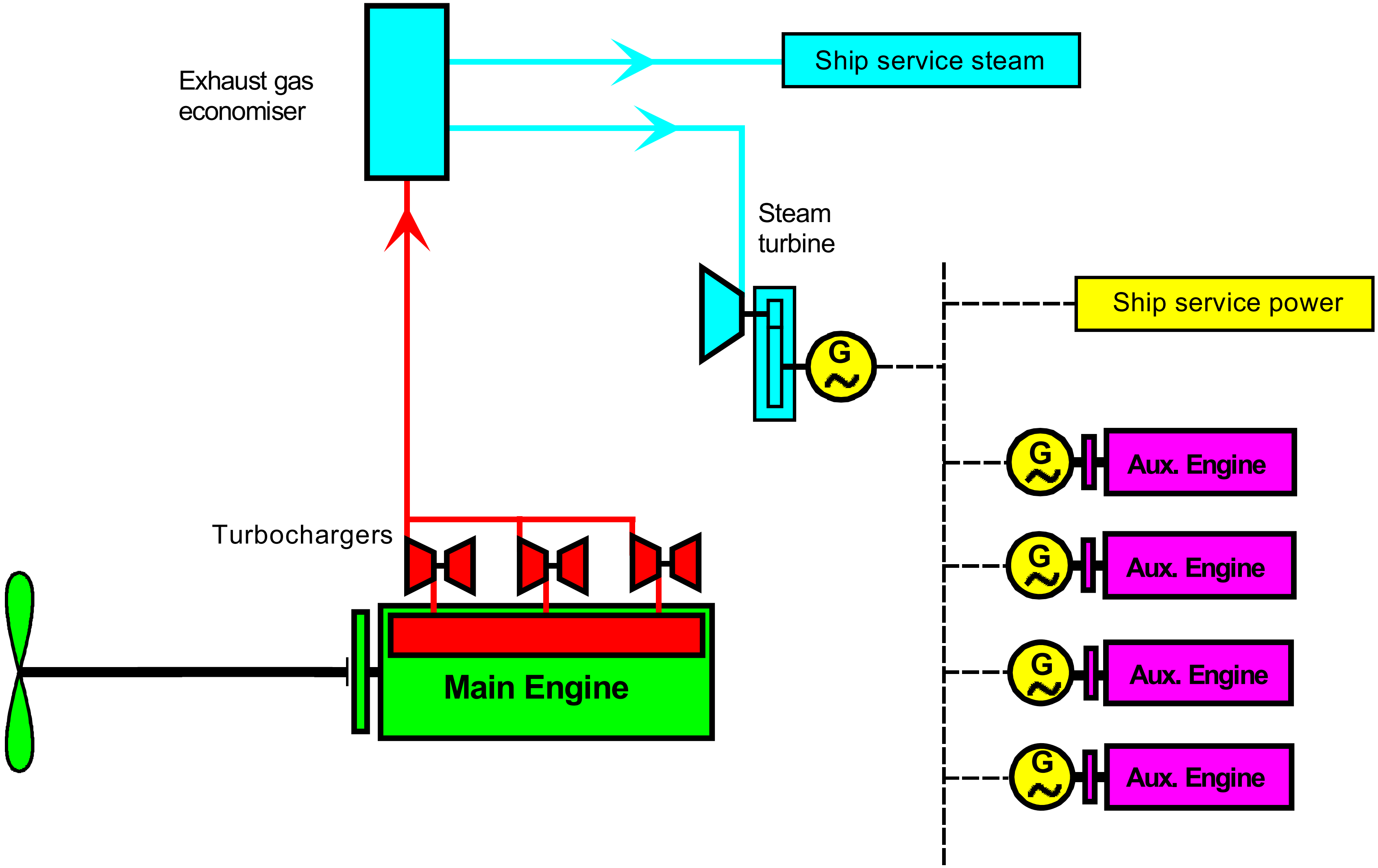
- Using exhaust gas energy after cylinders to operate a gas turbine.

  Today’s modern high efficiency turbochargers have a surplus in efficiency in the upper load range. This allows to branch-off exhaust gas before turbocharger to operate gas turbine.

Waste Heat Recovery



Waste Heat Recovery



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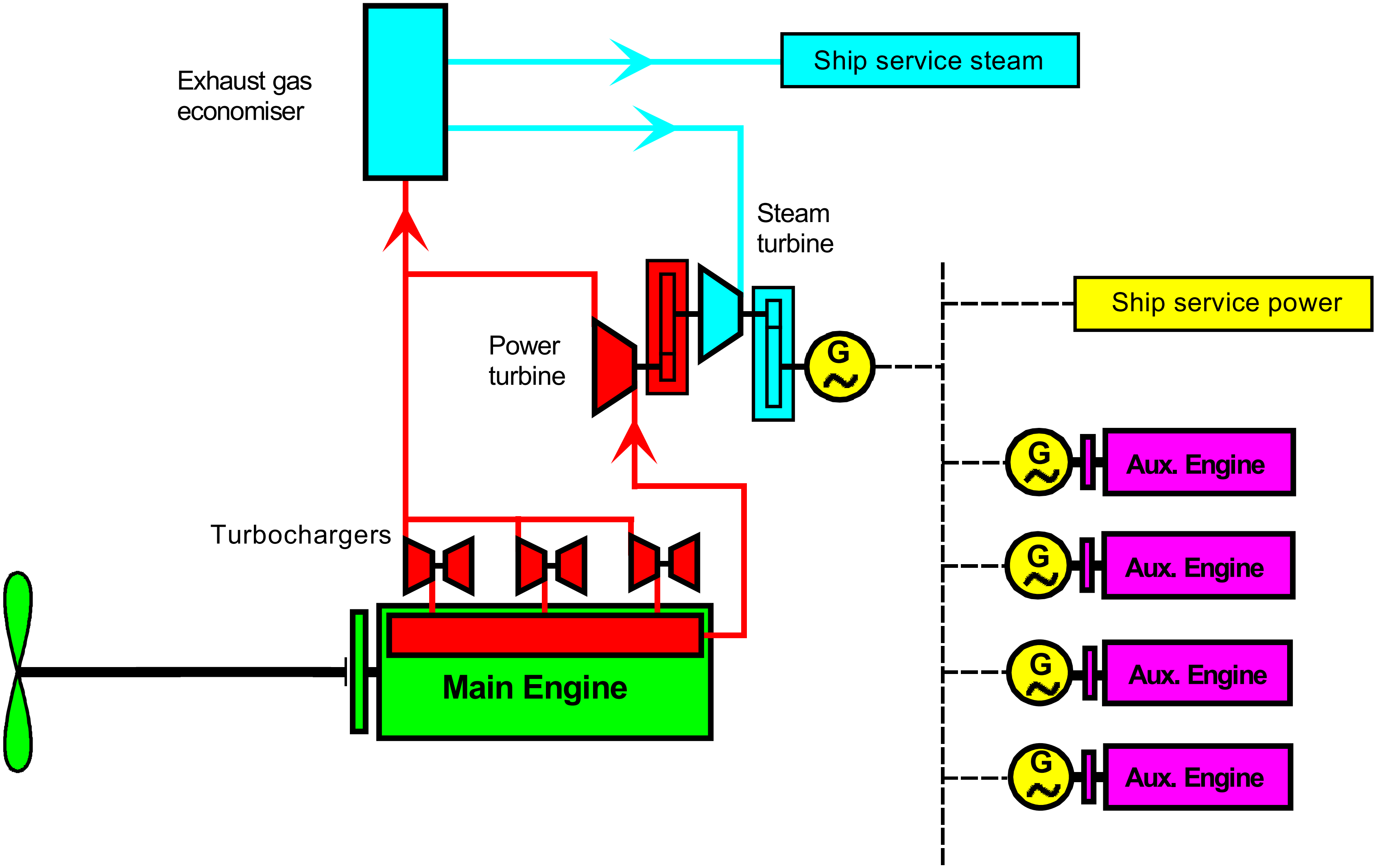

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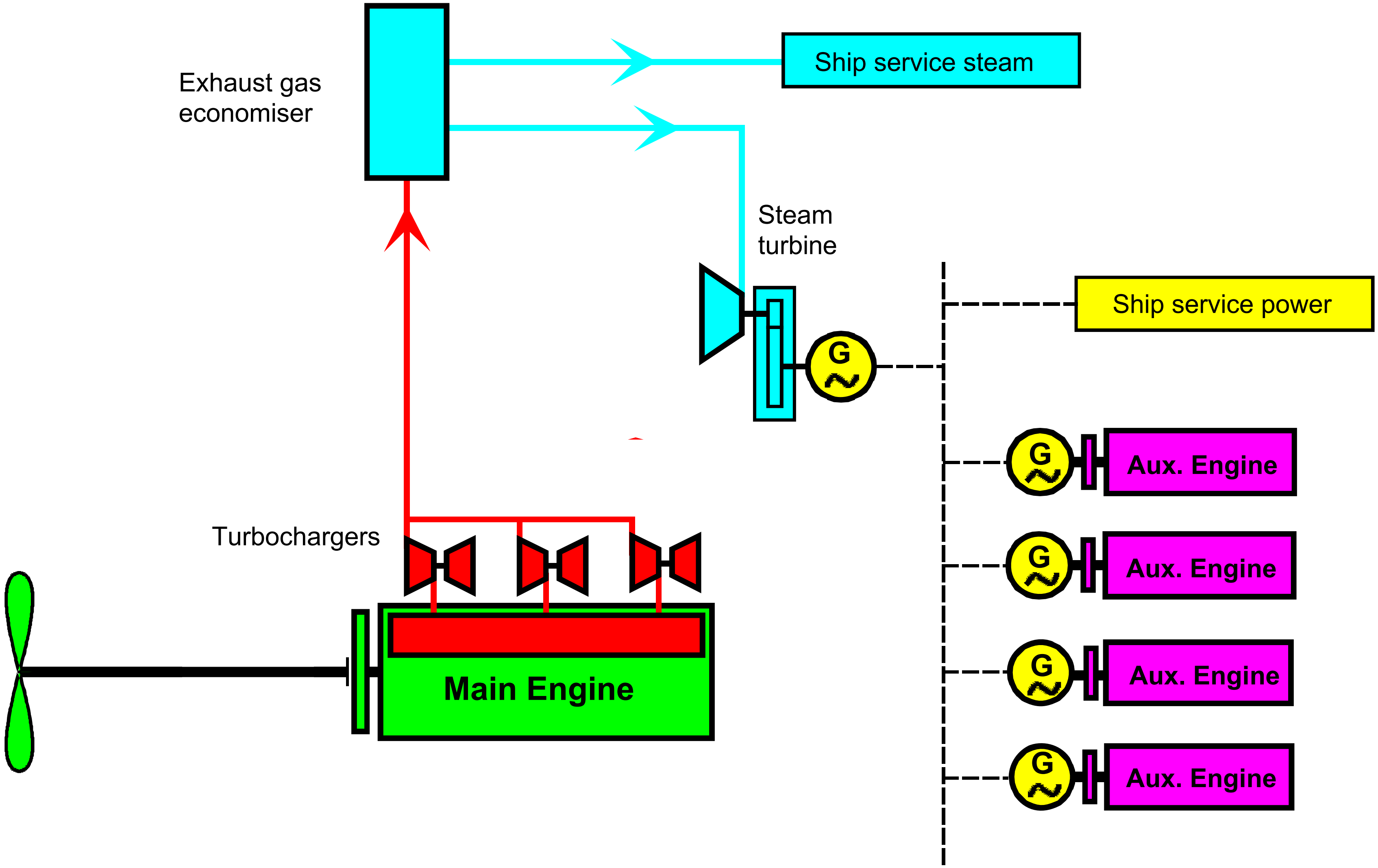
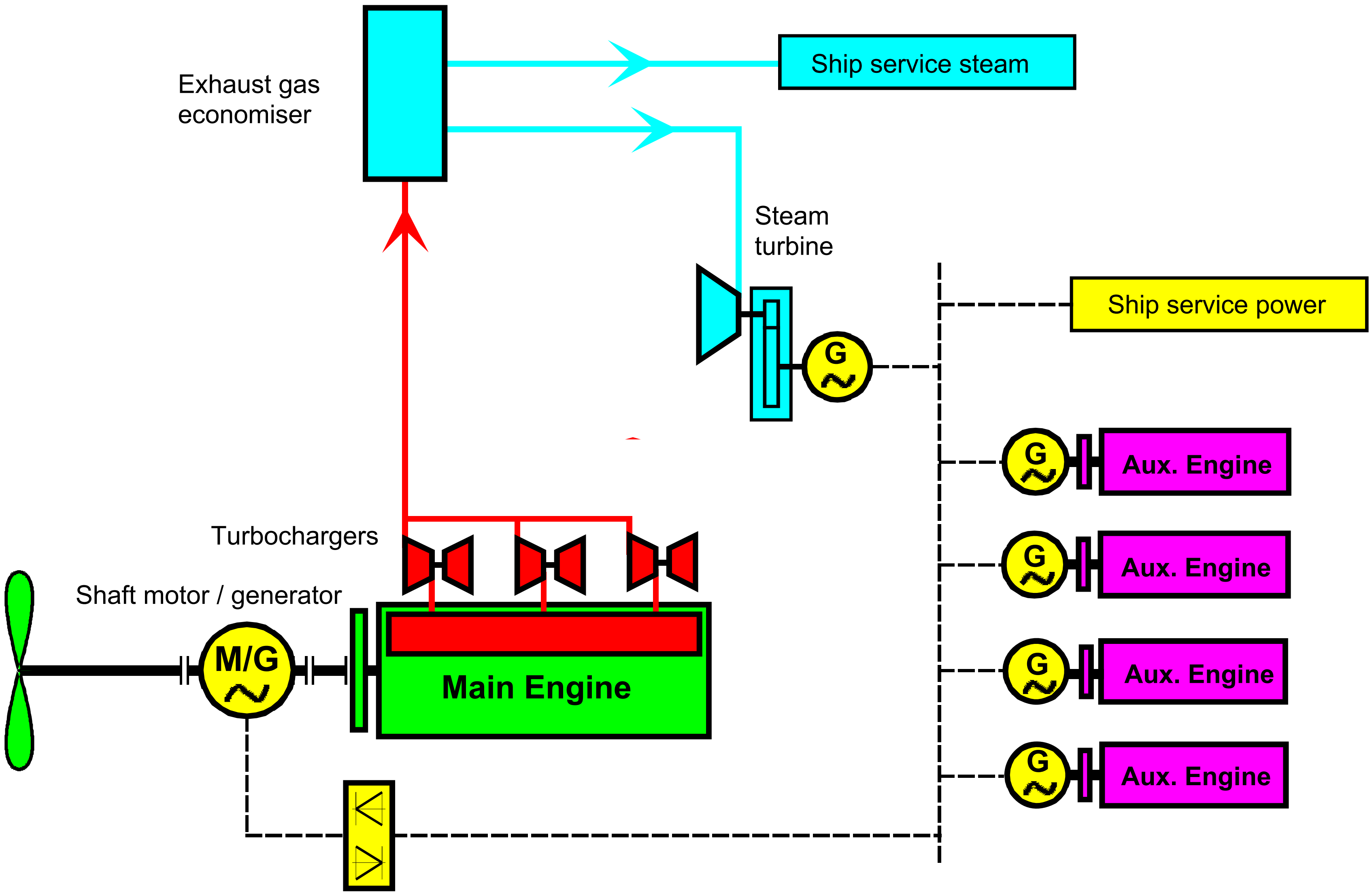


Waste Heat Recovery



Exhaust gas economiser

Ship service steam

Steam turbine

G

Ship service power

G

Aux. Engine

G

Aux. Engine

G

Aux. Engine

G

Aux. Engine

Turbochargers

Shaft motor / generator

M/G

Main Engine

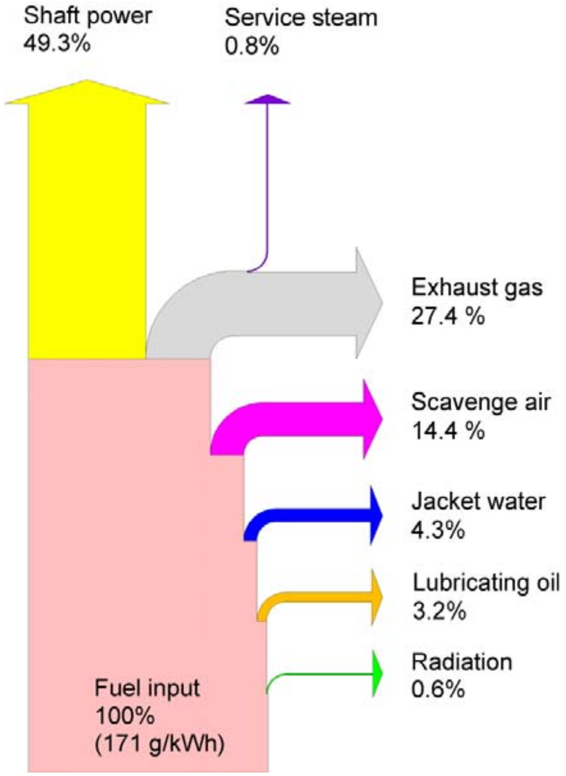
Frequency control system

Waste Heat Recovery

Heat Balance RTA96C Engine

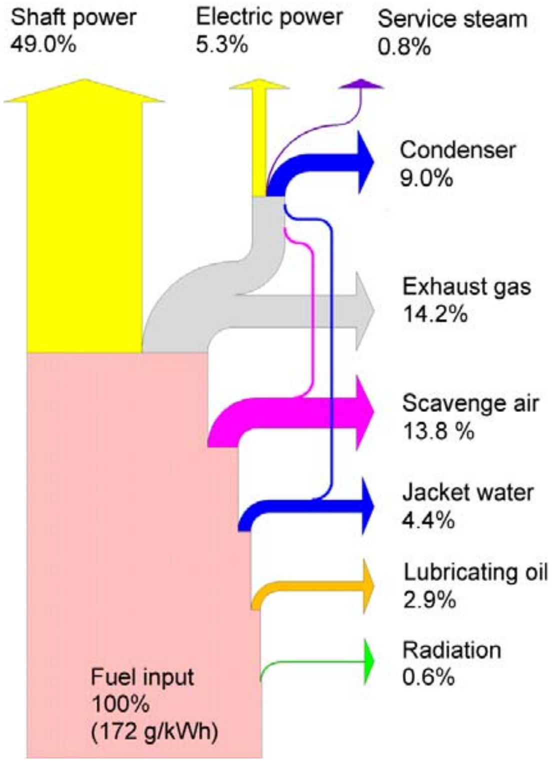
ISO conditions, shop trial conditions, 100% load

Heat Balance Standard Engine



Heat Balance with Heat Recovery

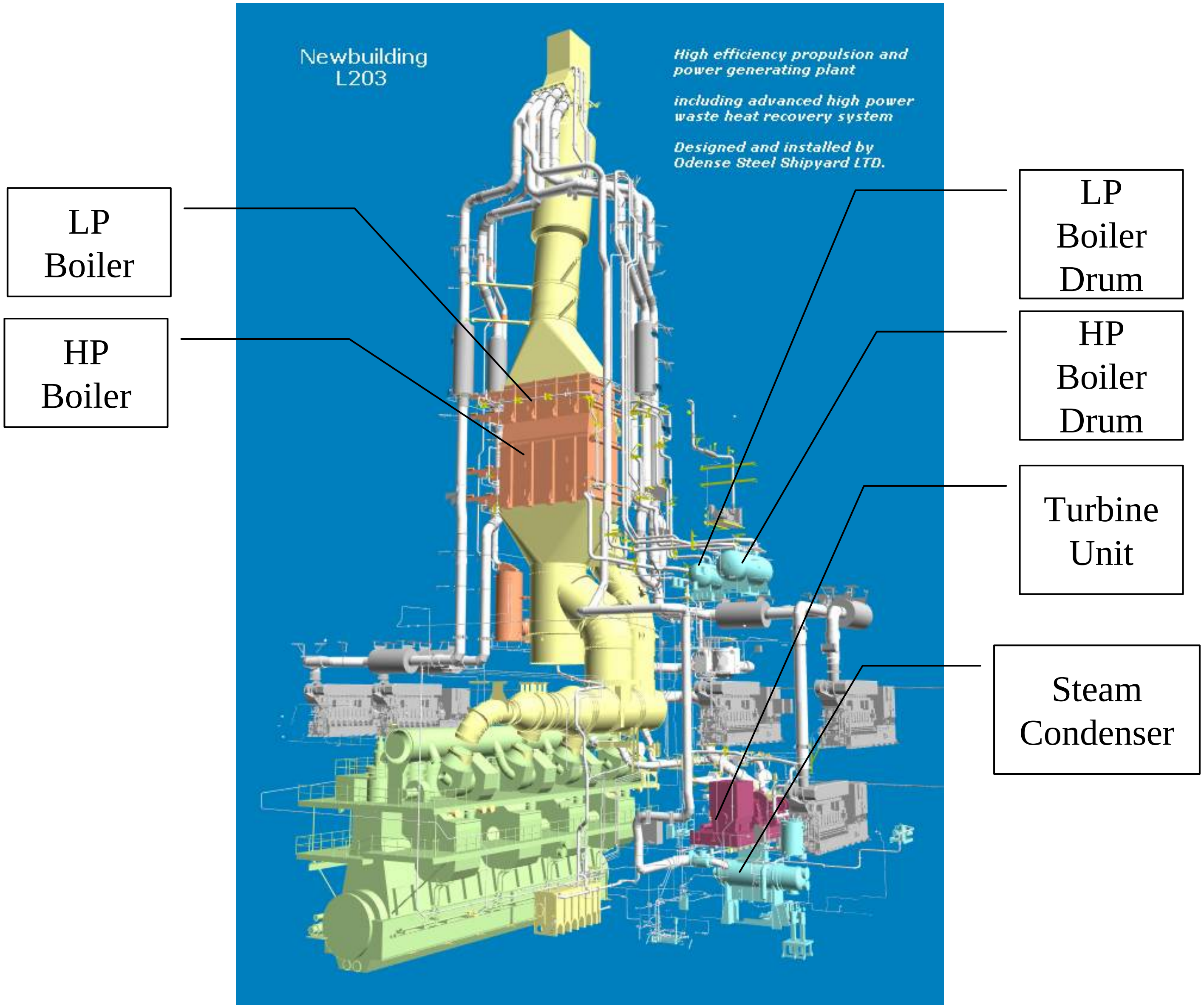
Total 54.3%



Engine efficiency improvement with heat recovery = 54.3 / 49.3 = **10.1%**

Recovered power = **10.8%**

Waste Heat Recovery



Savings with Heat Recovery

		Main	Aux	Main	Aux	Heat recovery
Power (W6L64 + 2*W4L20)	kW	10251	1000	10251	0	1025.1
annual Operating hours	h	6500	6500	6500	6500	6500
Fuel						
Daily F.C. HFO	ton/day	42.9	4.8	42.9	0.0	0.0
Fuel price	$/ton	536	536	536	536	536
Total annual F.C.	$	6,225,035	696,800	6,225,035	-	-
Lube Oil						
Annual consumption	ton	33.3	9.8	33.3	0.0	0.0
Total annual cost	$	66,632	19,500	66,632	-	-
Maintanance costs						
Specific cost	$/MWh	5	6	5	6	1
Annual cost	$	333,158	39,000	333,158	-	6,663
Total Annual Operating Cost	$	**7,380,124**		**6,631,487**		
Saving	$	**-748,637**				

Emission Reduction Benefit from Heat Recovery

Additional Power 10% from the same burned fuel

CO_2 -10%	43600 ton/year	→	39260 ton/year	-4340 ton/year
NO_X -10%	1112 ton/year	→	844 ton/year	-268 ton/year
SO_X -10%	383 ton/year	→	309 ton/year	-74 ton/year

Agenda

- The Pollutants
- The Legislation
- The Abatement Methods
  - Wet Methods
  - The Selective Catalytic Reactor
  - The Scrubber
  - The Waste Heat Recovery
- **A Dredging Application**

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Ship Case

Trailing suction hopper dredgers

Standard

Installed power:

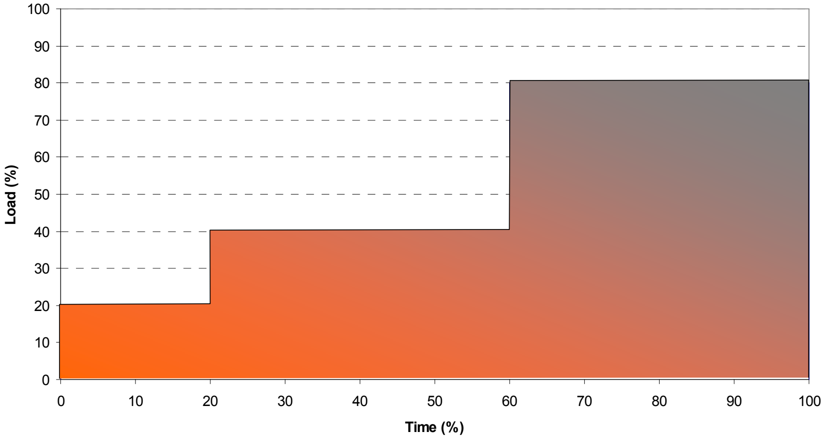
- Main Engines
  - 2 x W12V46C 12600 kW
- Auxiliary power
  - 1 x W6L26A 1860 kW
  - 1 x High speed engine 1200 kW
- Total Installed power 28240 kW

Hybrid

Installed power:

- Main Engines
  - 2 x W9L50DF 8550 kW
- Auxiliary power
  - 1 x W6L50DF 7600 kW
  - 2 x Fuel Cell 500 kW
  - 4 x WHR units 1500 kW
  - Batteries 3200 kW
- Total Installed power 28900 kW

Calculation Assumption



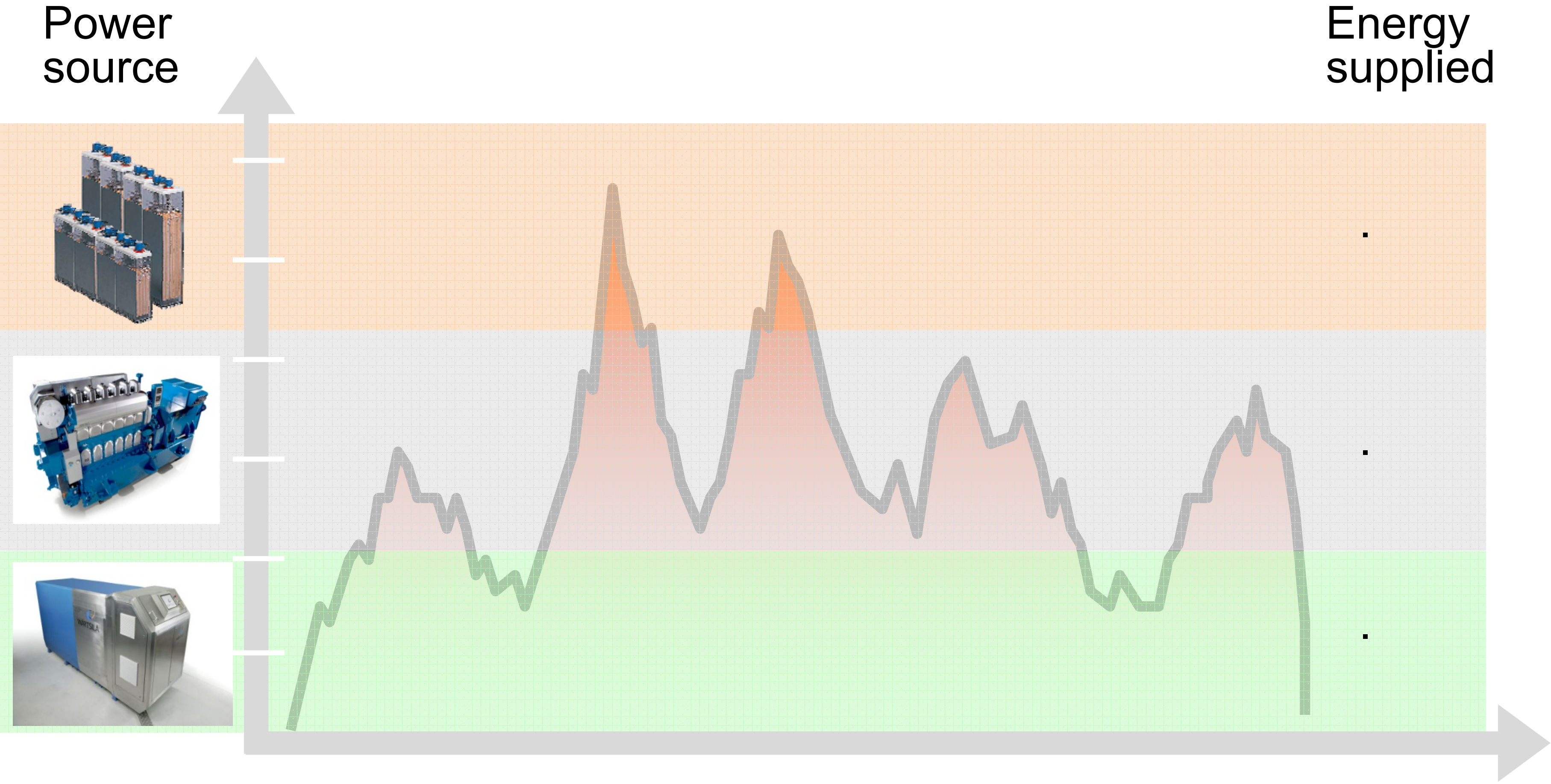
HFO Price	345 US$/ton
LFO Price	690 US$/ton
Gas Price	455 US$/kg

Sulphur cap	2.7 %
SECA limit	0.5 %

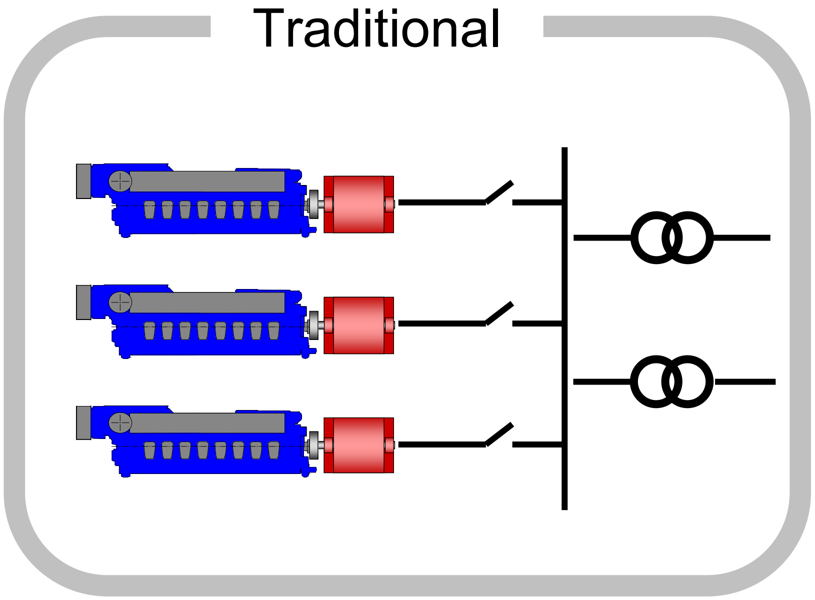
NOx abatement at IMO tier III

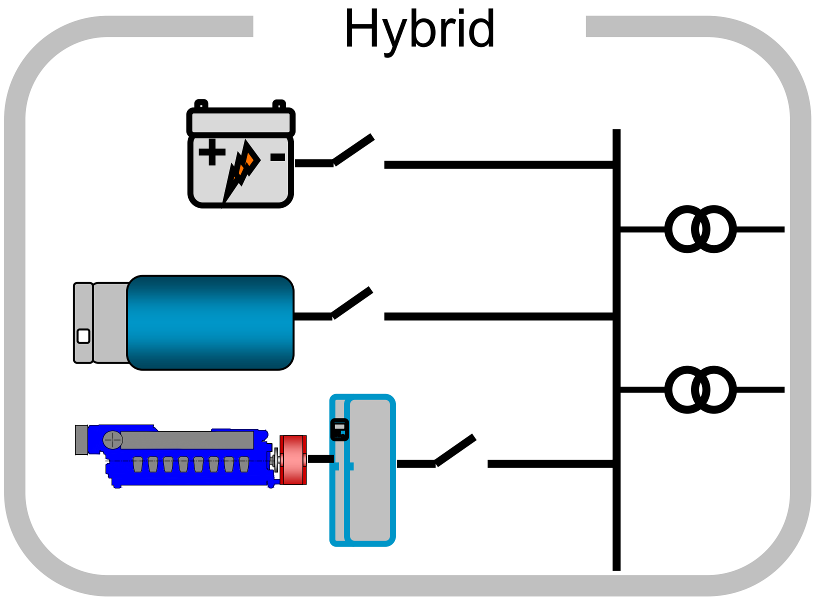
Taxation or fairway dues not taken into account

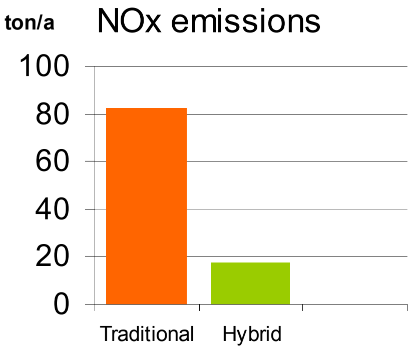
TYPICAL AUXILIARY POWER LOAD PROFILE

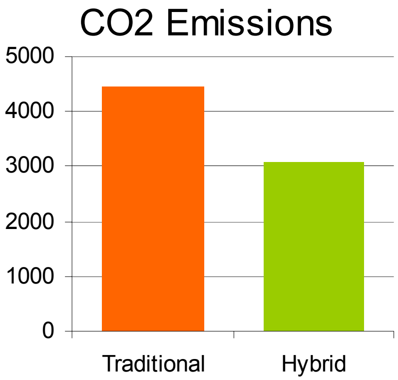


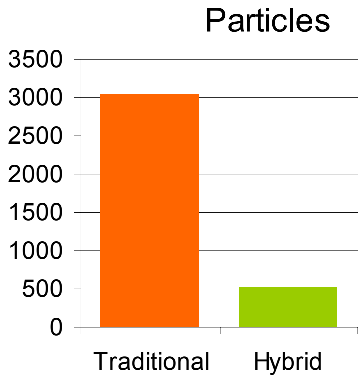
GENERATED EMISSIONS


Traditional

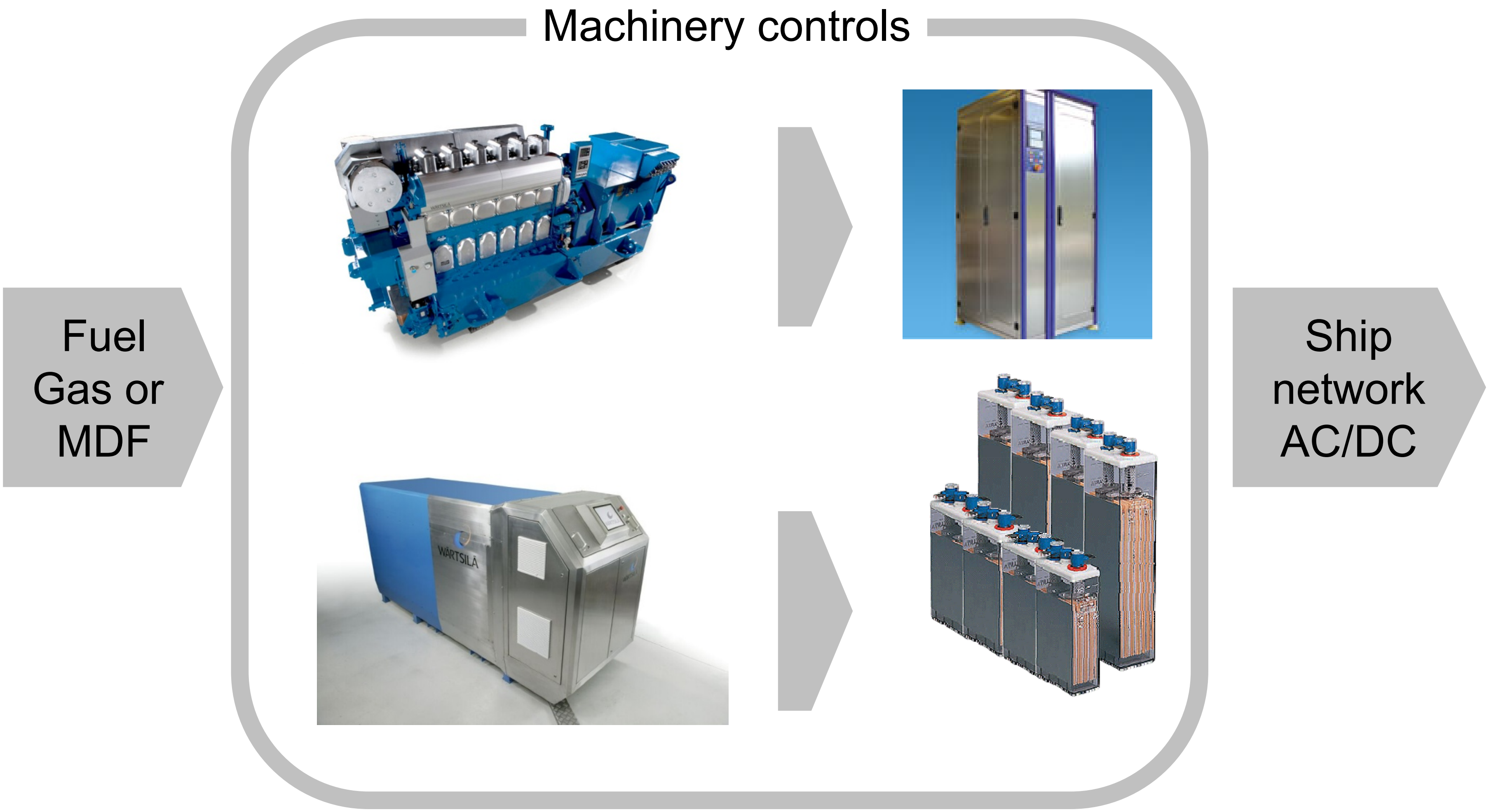

Hybrid


NOx emissions


CO2 Emissions


Particles

MAJOR COMPONENTS

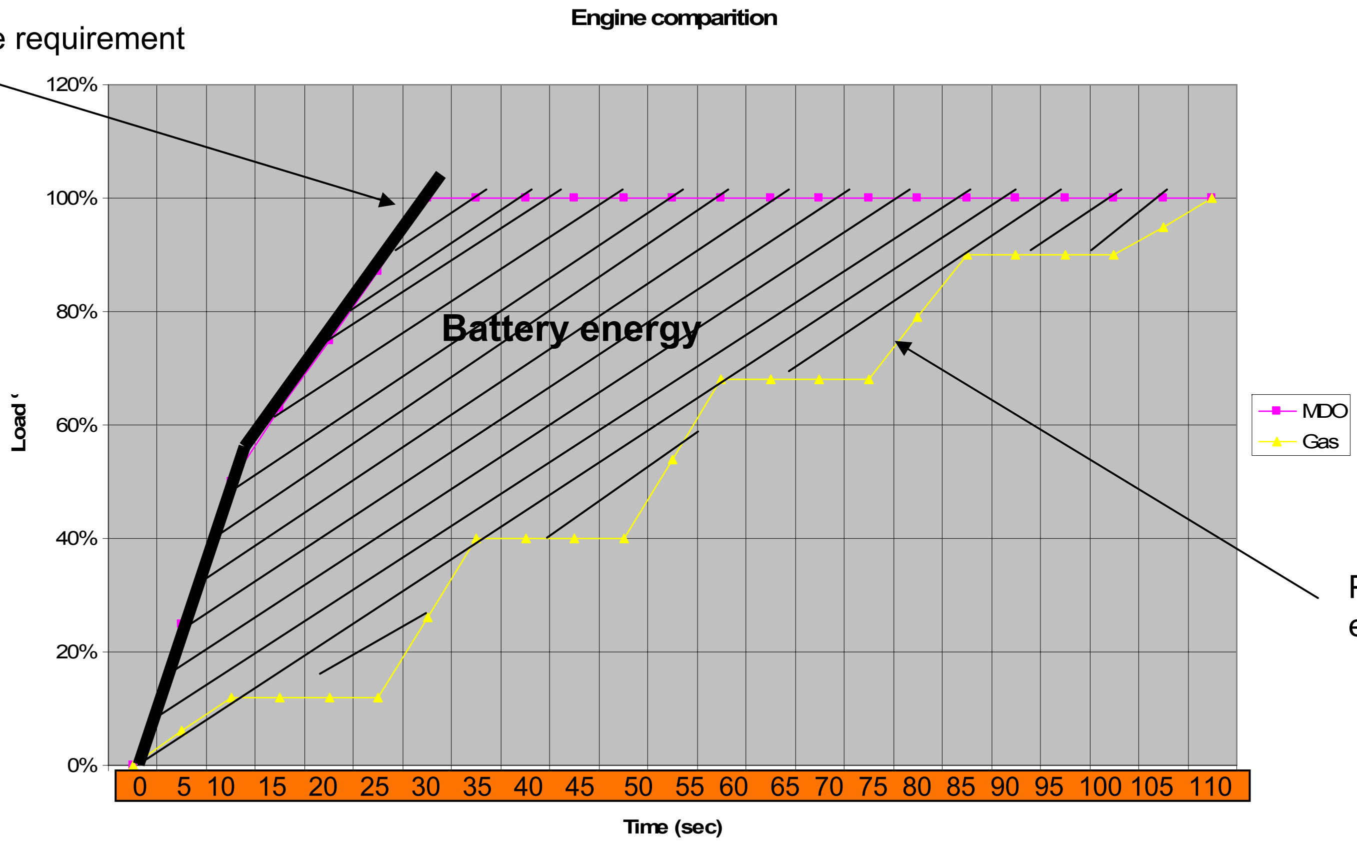


Machinery controls

Fuel
Gas or
MDF

Ship
network
AC/DC

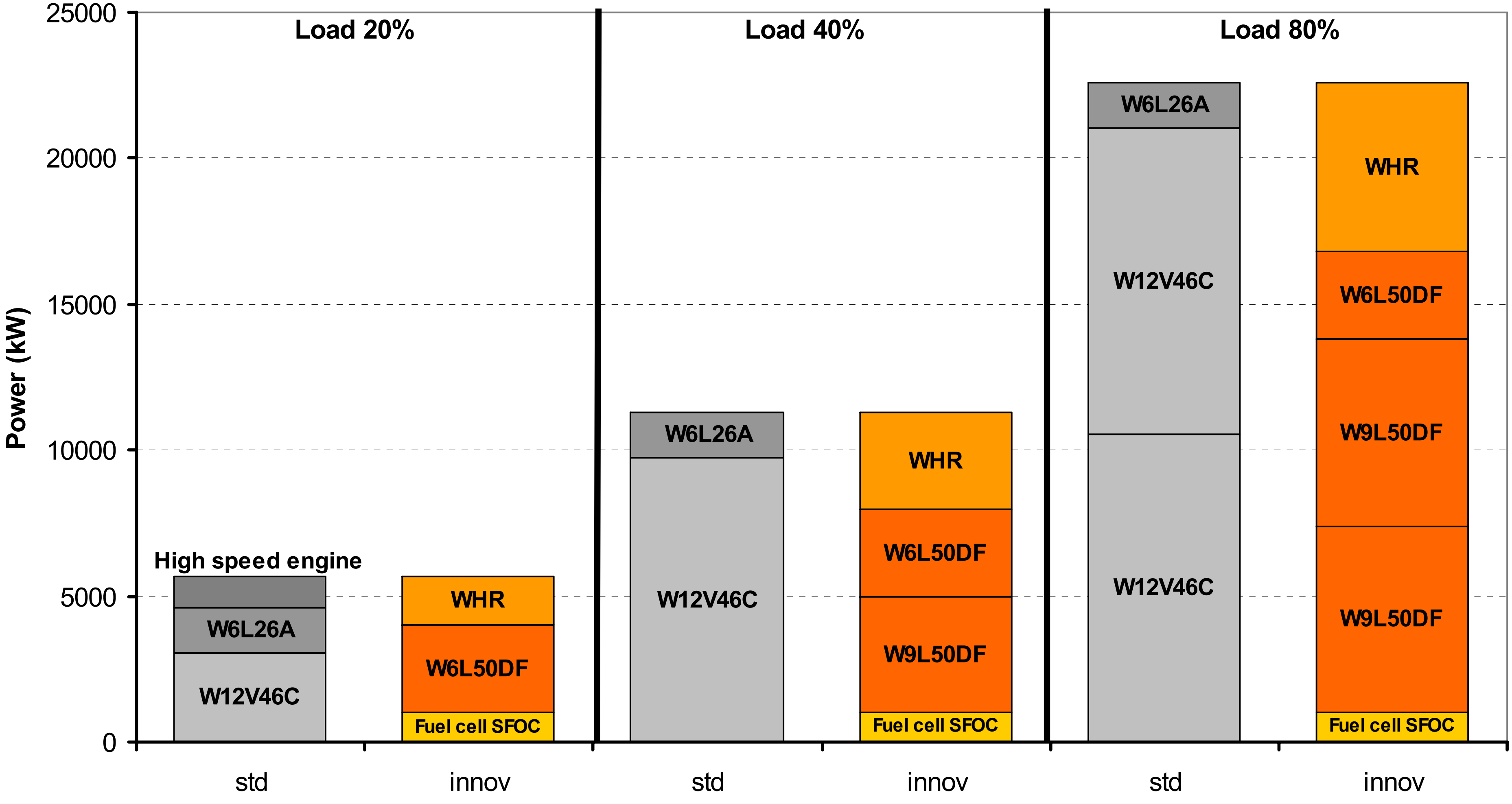
Application example



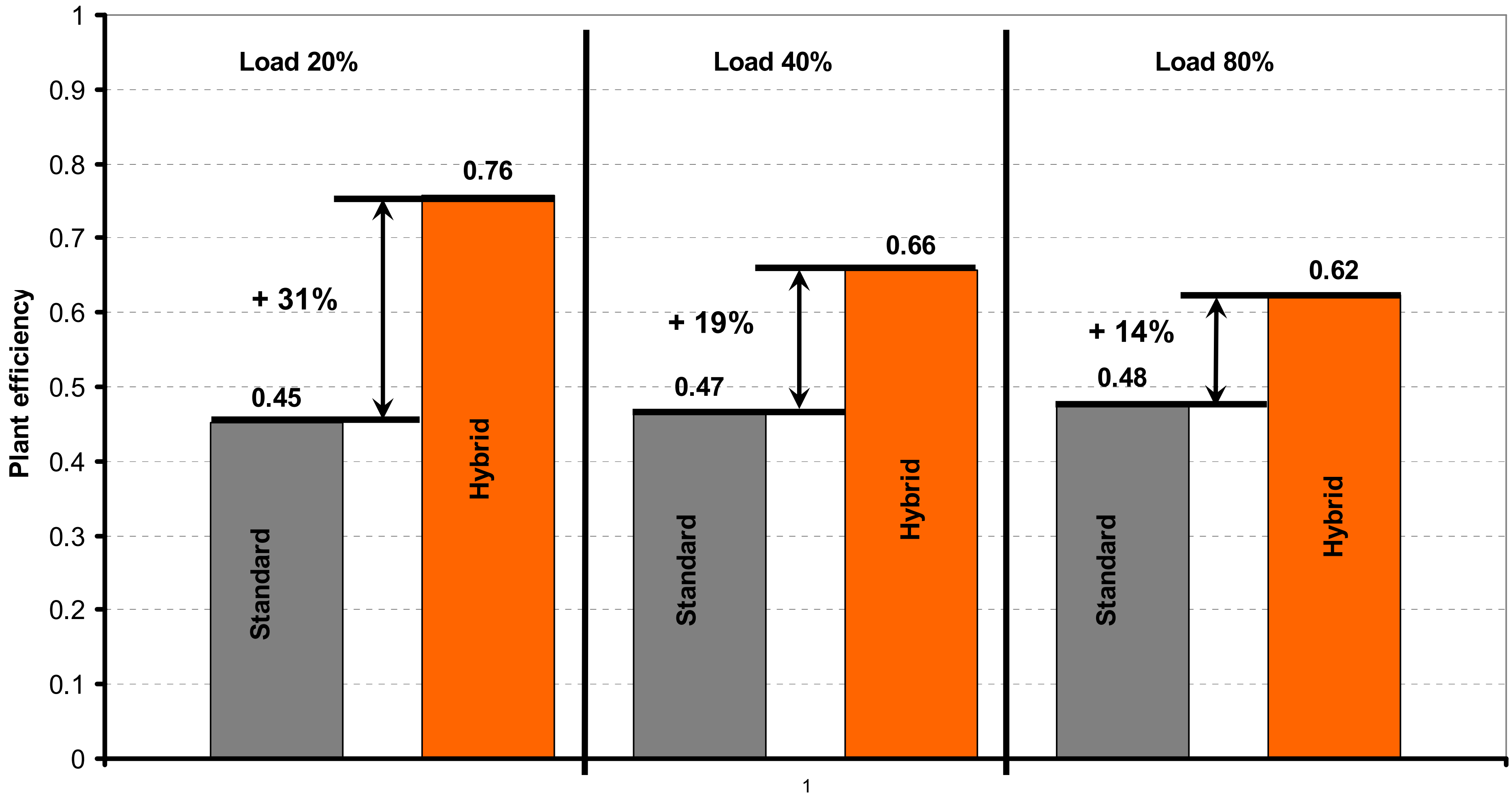
Load response requirement

Present engine dynamics

Load Sharing



Efficiency Comparison



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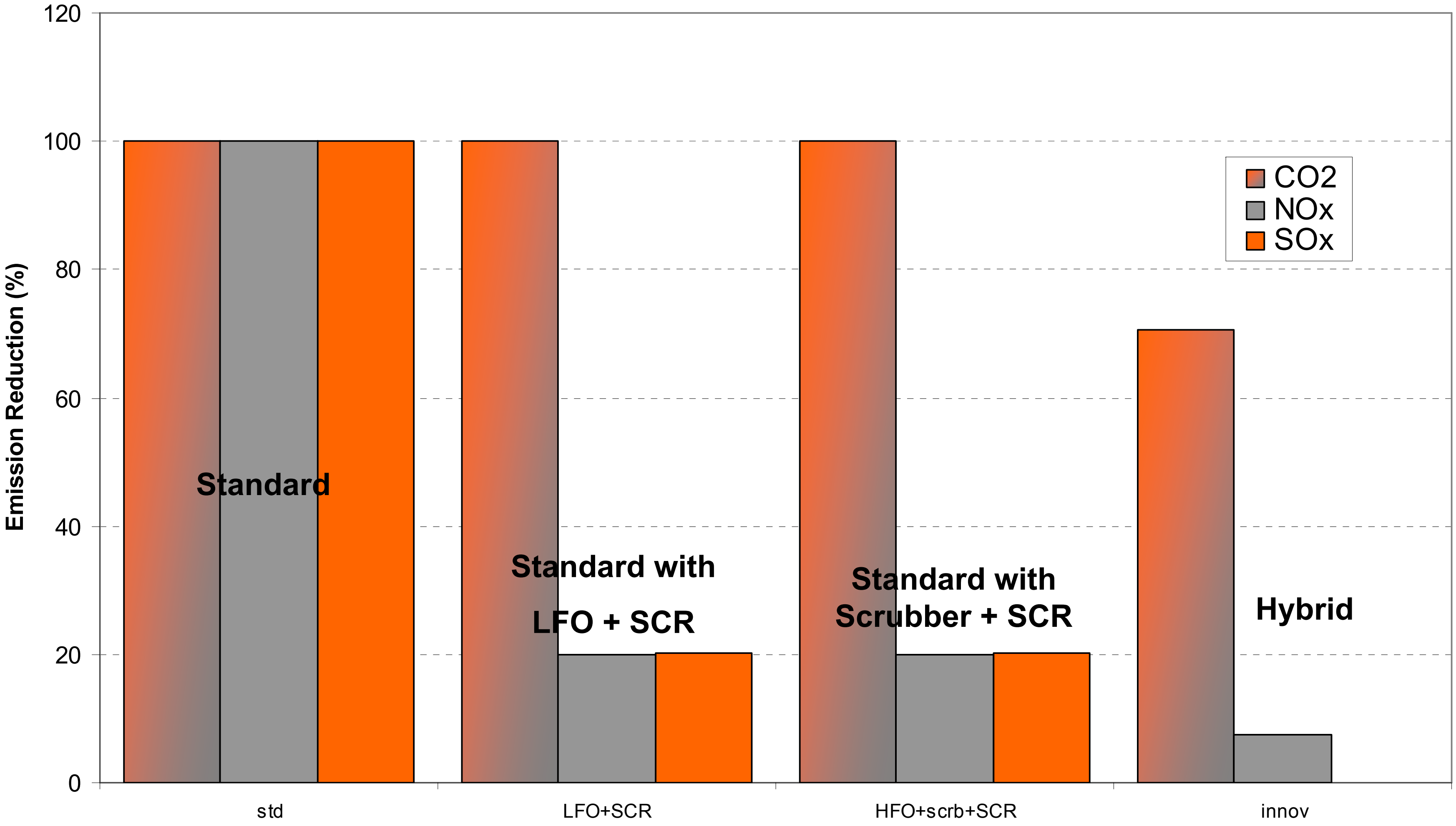
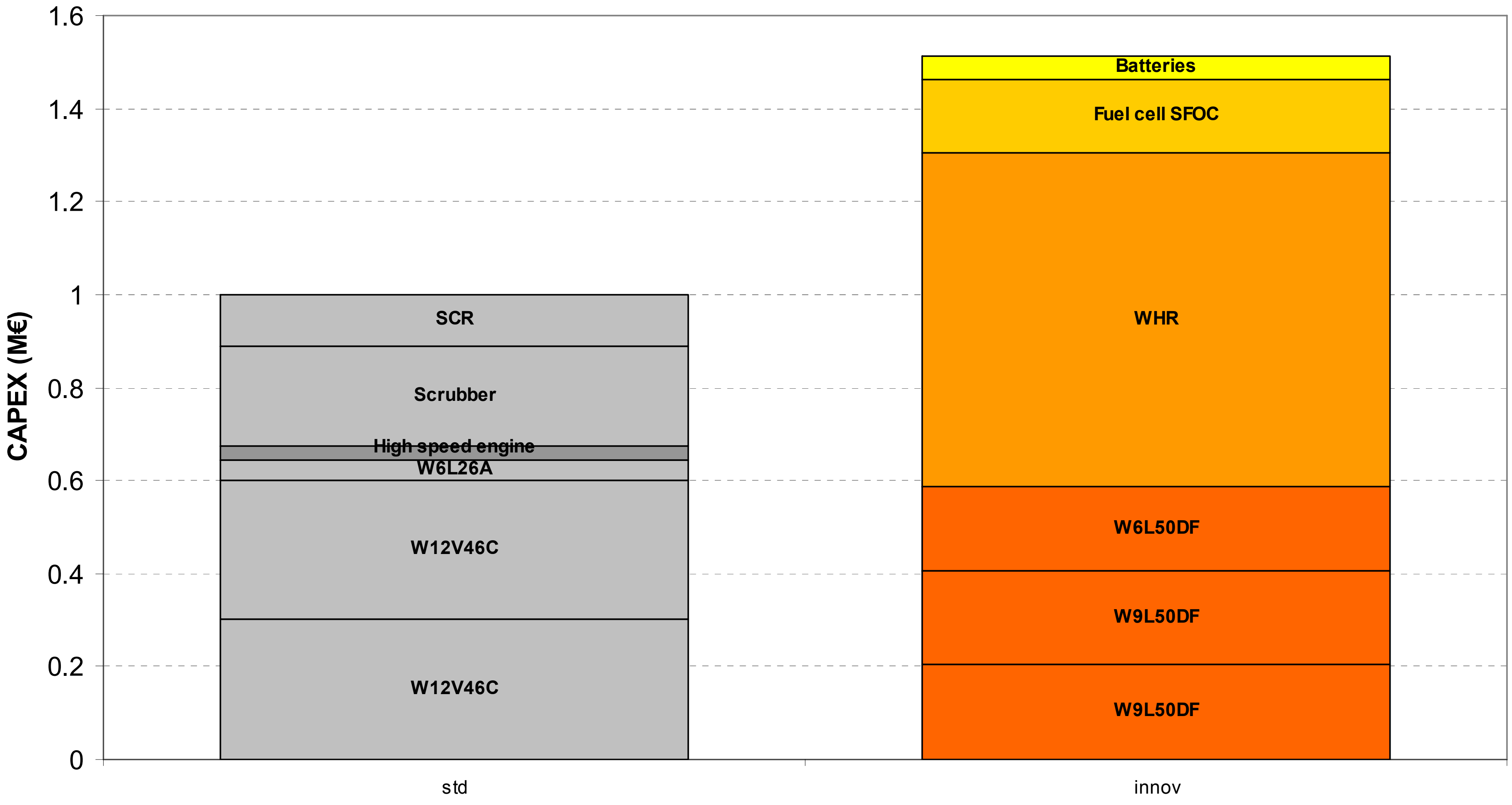
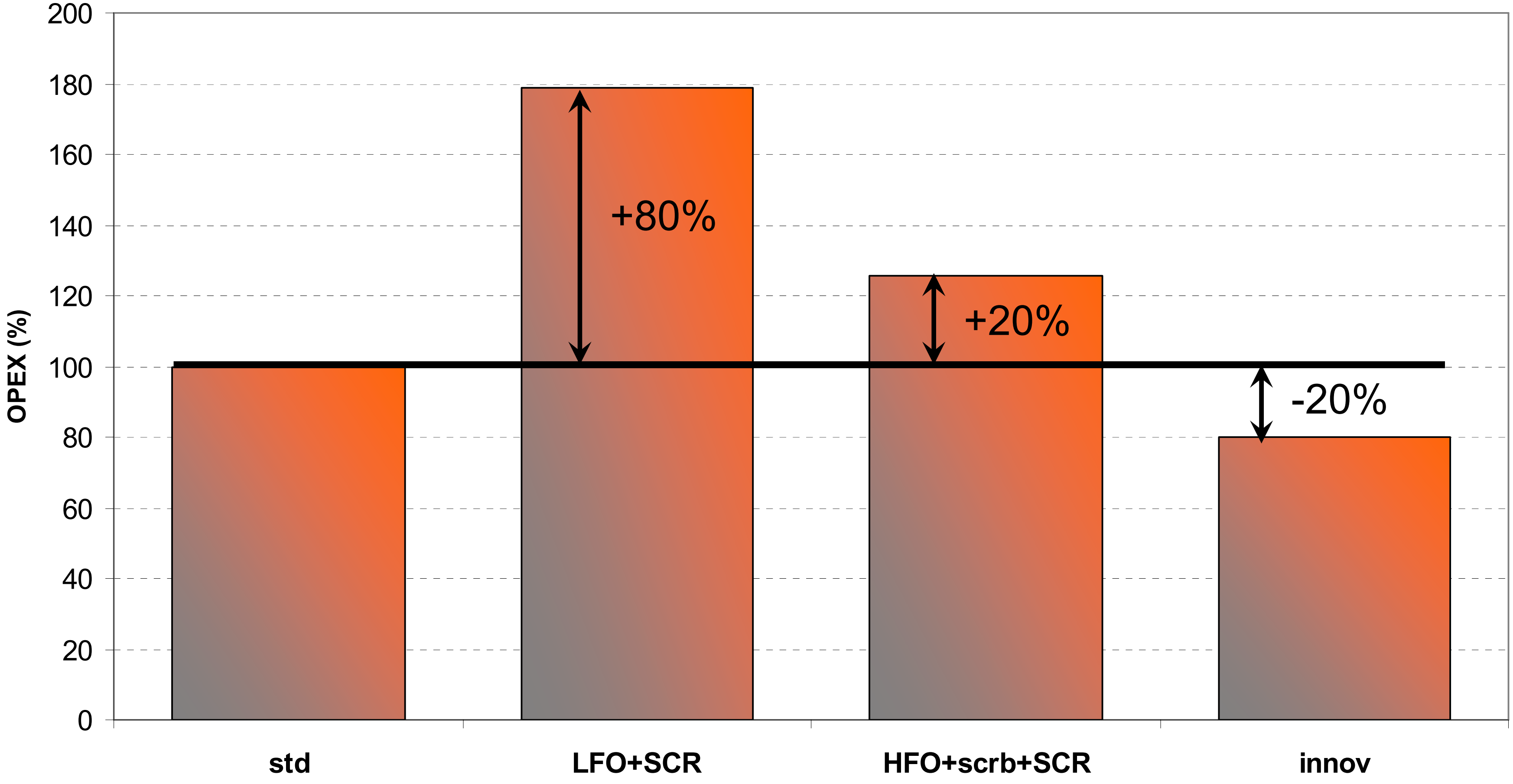
Emission Reduction



CAPEX


CAPEX (M€)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
SCR
Scrubber
High speed engine
W6L26A
W12V46C
W12V46C
Batteries
Fuel cell SFOC
WHR
W6L50DF
W9L50DF
W9L50DF
std
innov

OPEX



200
180
160
140
120
100
80
60
40
20
0
OPEX (%)
+80%
+20%
-20%
std
LFO+SCR
HFO+scrb+SCR
innov

Conclusions

- Higher efficiency + 14 – 31 %
- Lower OPEX - 20 %
- Lower emissions
  - NOx - 92 %
  - SOx - 99%
  - CO2 - 30%
- Higher CAPEX + 51 %
- ROI 5.8 years

DREADGING INTO A CLEANER FUTURE

Thank you for your attention

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