DUAL FUEL ENGINES
LATEST DEVELOPMENTS

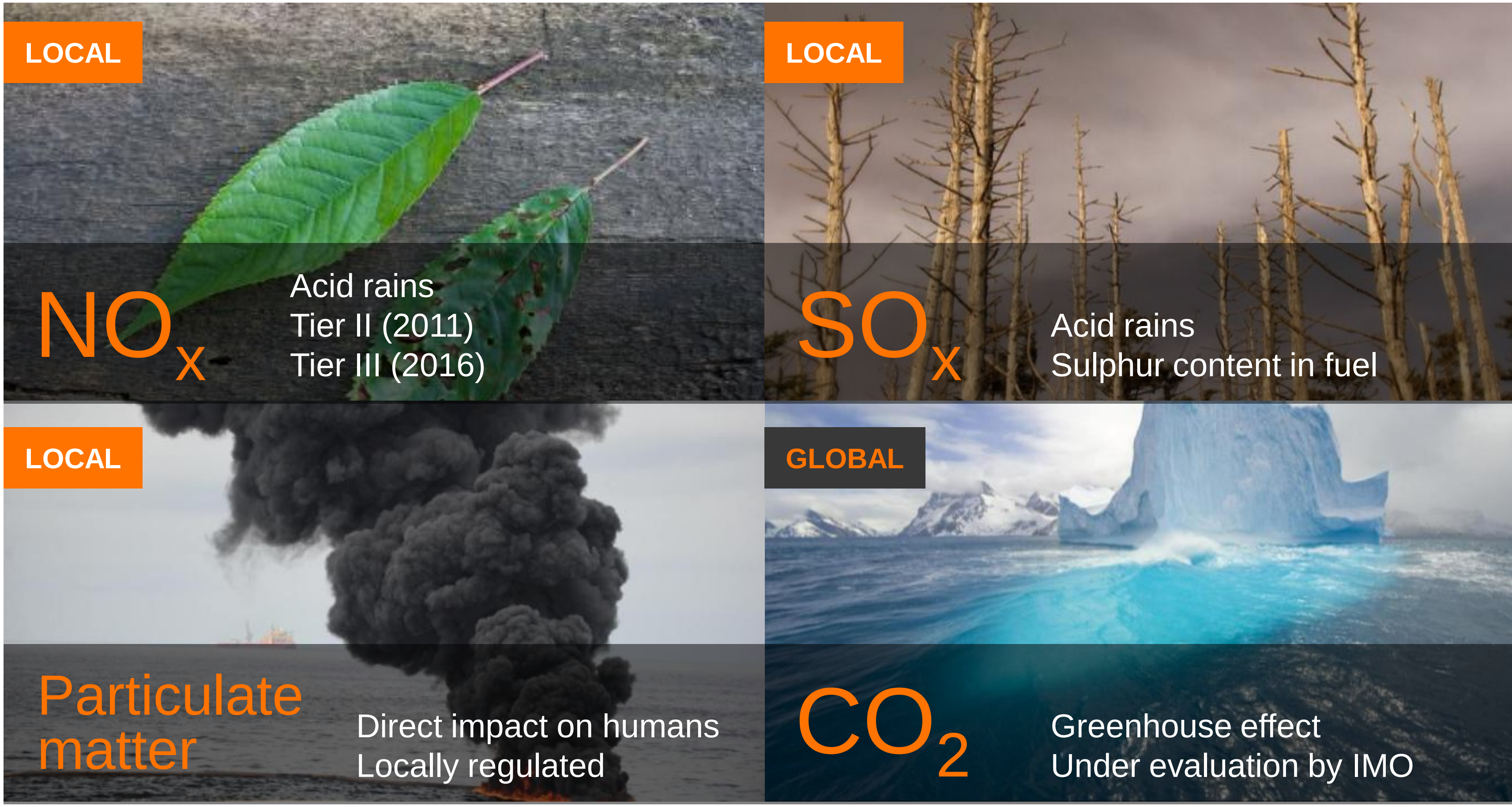
Oskar Levander, Director, Concept design, MLS

HAMBURG, 27.9.2011

Content

- Environmental and market drivers
- LNG as a marine fuel
- DF engines
- RoRo concept design
- Machinery and fuel comparison
- Conclusions

Factor trends: Environment



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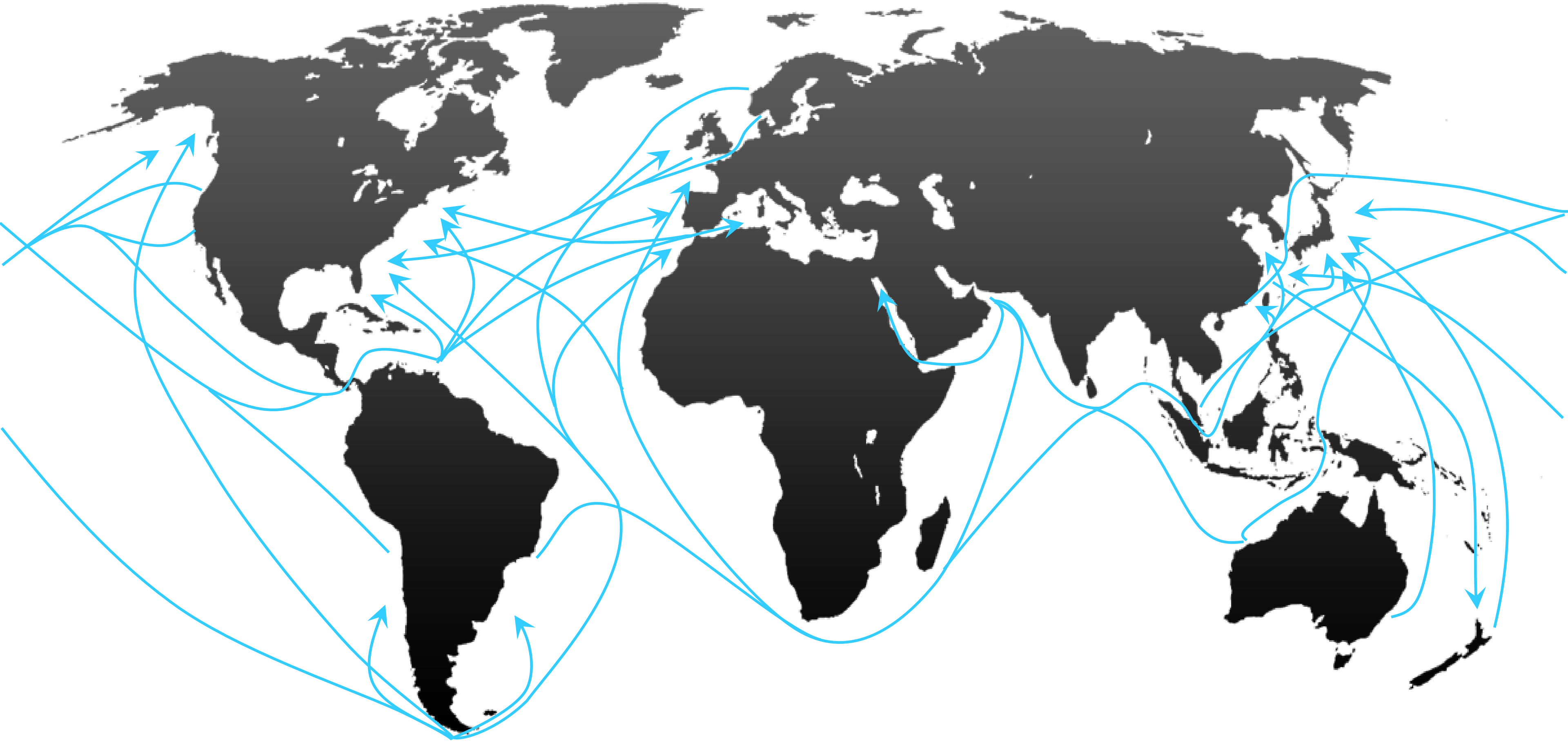
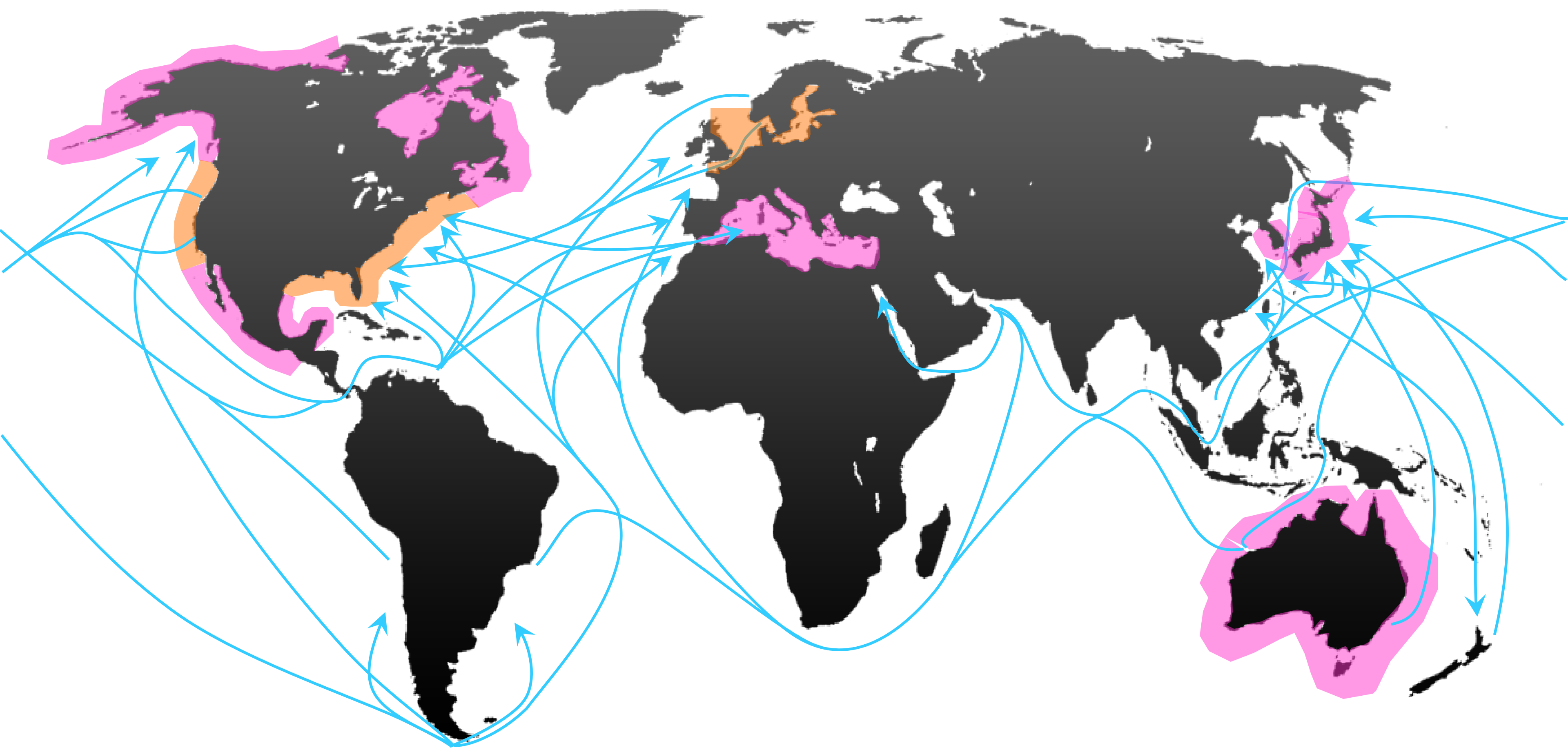
Until now…..



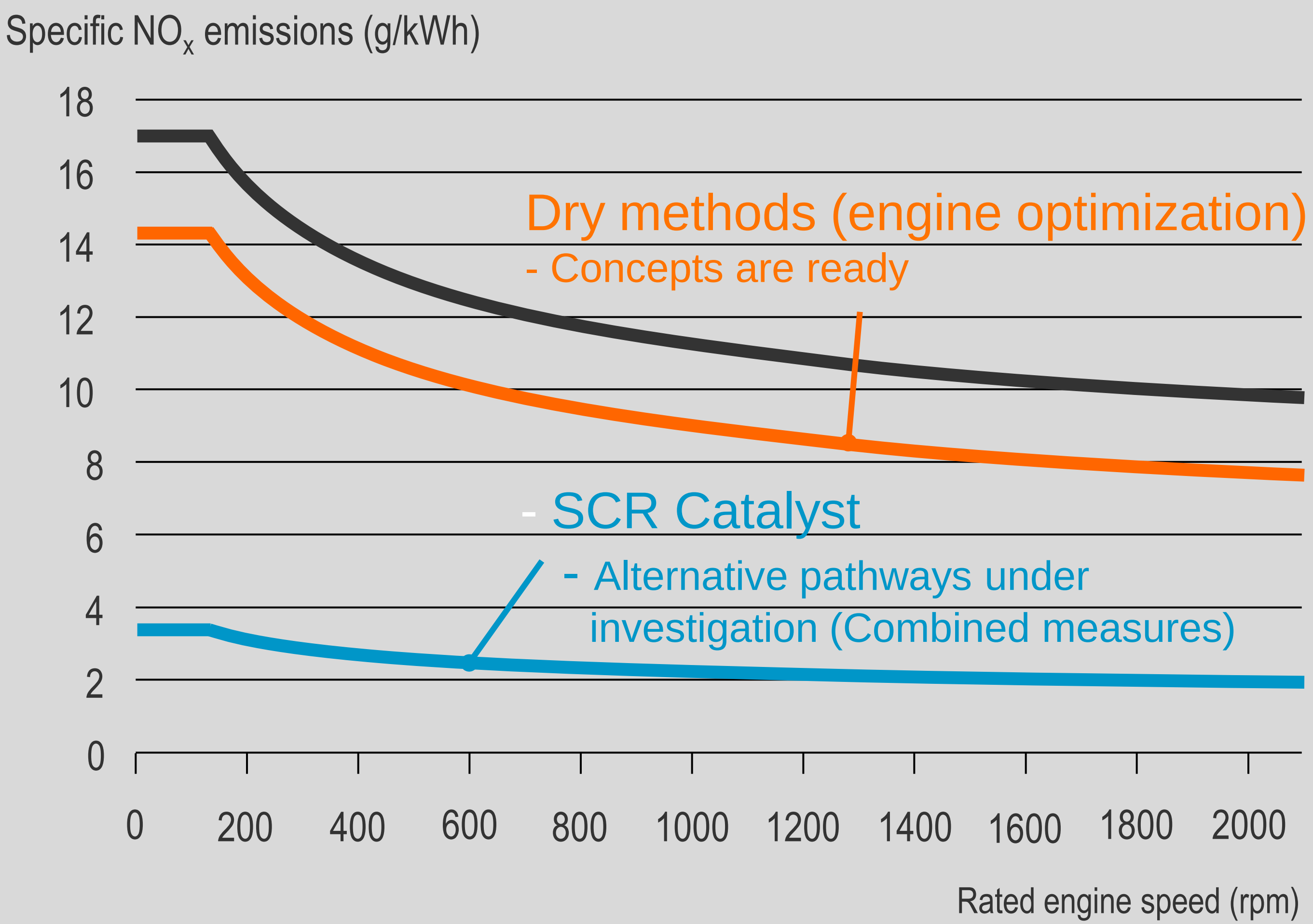
From now on….



Established Emissions Controlled Areas

Emissions Controlled Areas under consideration

NOx 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
Wärtsilä: RTA, W46, W64

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

Tier III (ECAs 2016)
Ships in designated areas, keel laid 2016 onwards
Engines > 130 kW

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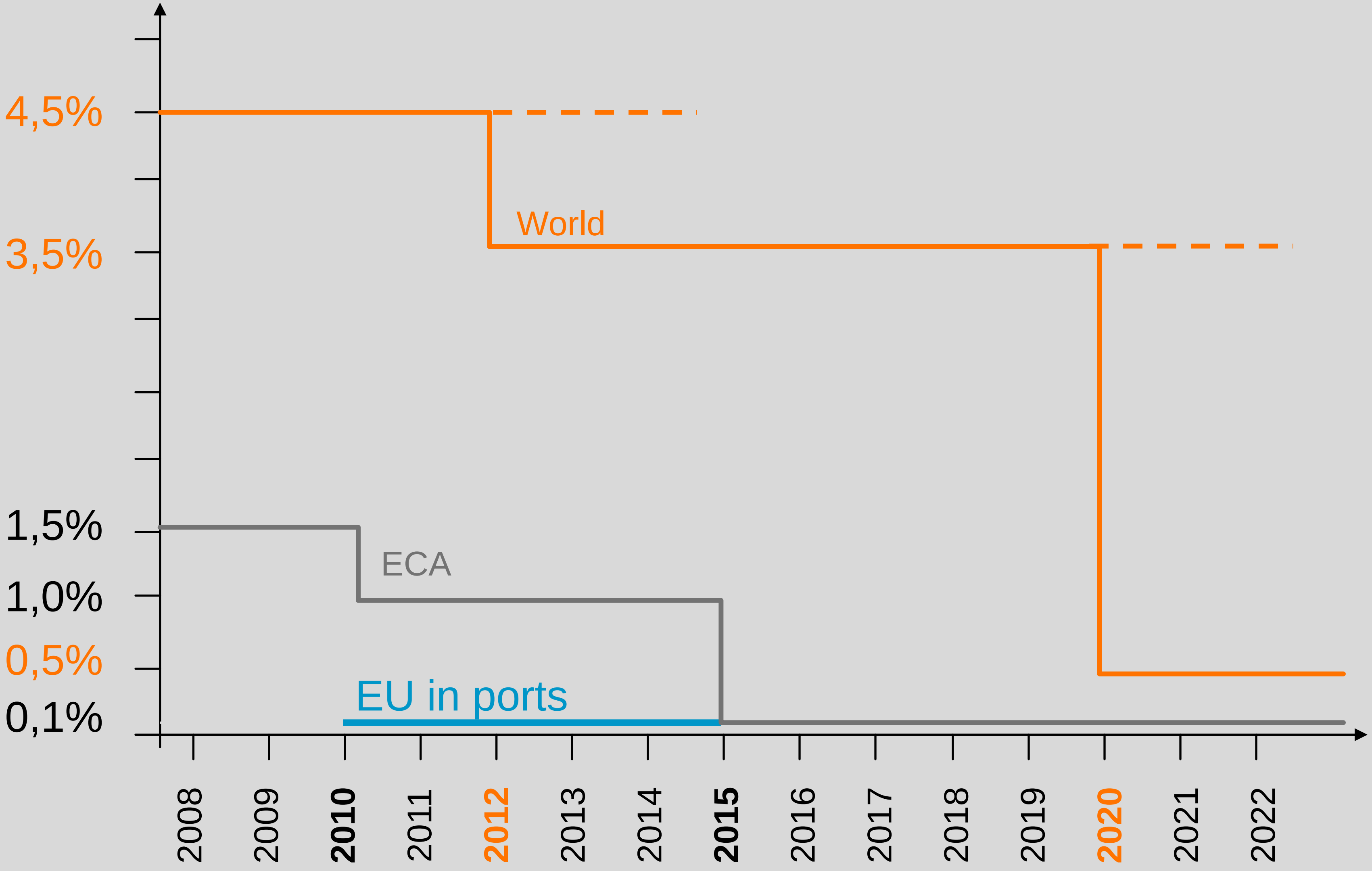
IMO Sulphur Limits



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Machinery options

Main options for operations inside ECA

- **MGO + SCR**
- **HFO + Scrubber + SCR**
- **LNG**

Greenhouse emission reductions

The society is demanding lower CO_2 emissions from ships

IMO is trying to respond the demand by introducing guidelines for:

- Energy Efficiency Design Index (**EEDI**)
- Energy Efficiency Operational Index (**EEOI**)
- Market based instruments
- …

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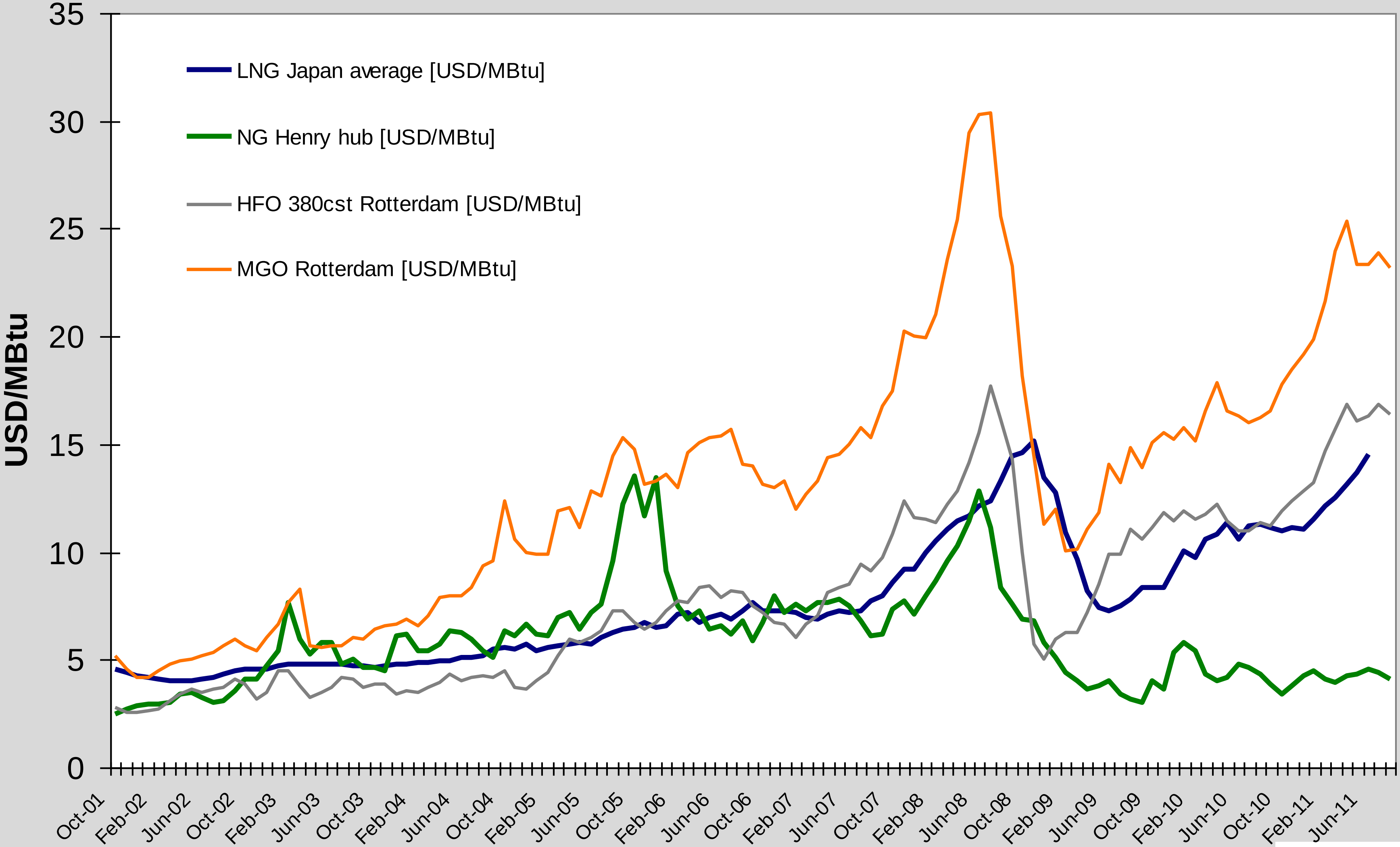
Fuel prices



Sources: www.lngoneworld.com, www.bunkerworld.com, LR Fairplay

Cleaner Exhaust Emissions with LNG

- 25-30% lower CO_2
  - Thanks to low carbon to hydrogen ratio of fuel
- 85% lower NO_X
  - Lean burn concept (high air-fuel ratio)
- No SO_X emissions
  - Sulphur is removed from fuel when liquefied
- Very low particulate emissions
- No visible smoke
- No sludge deposits

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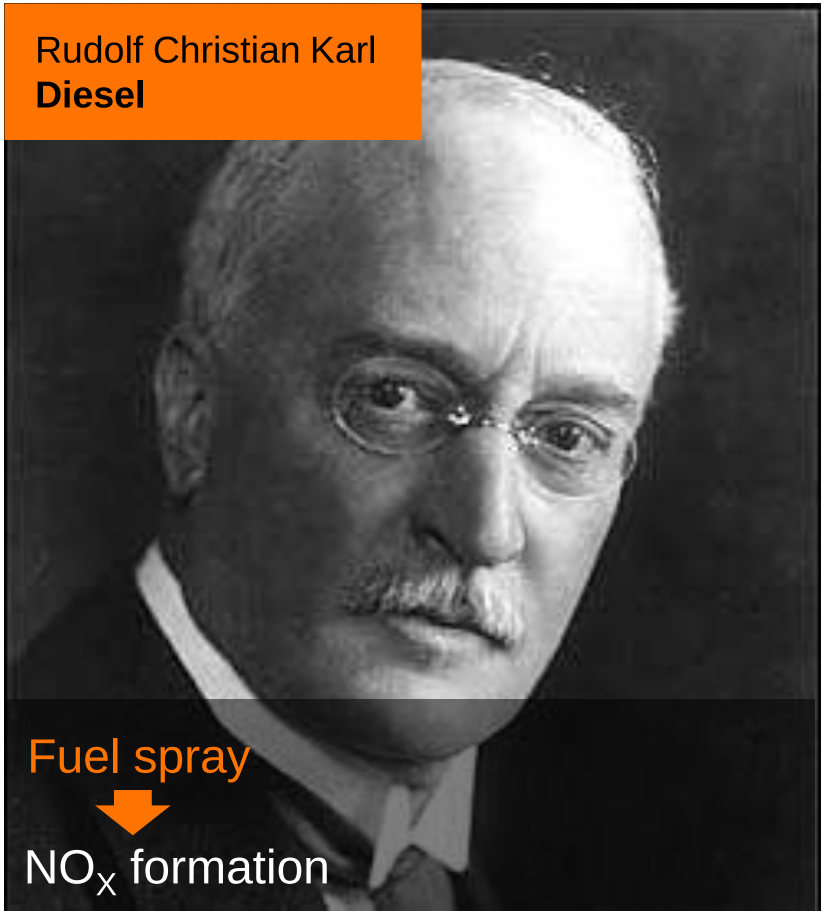
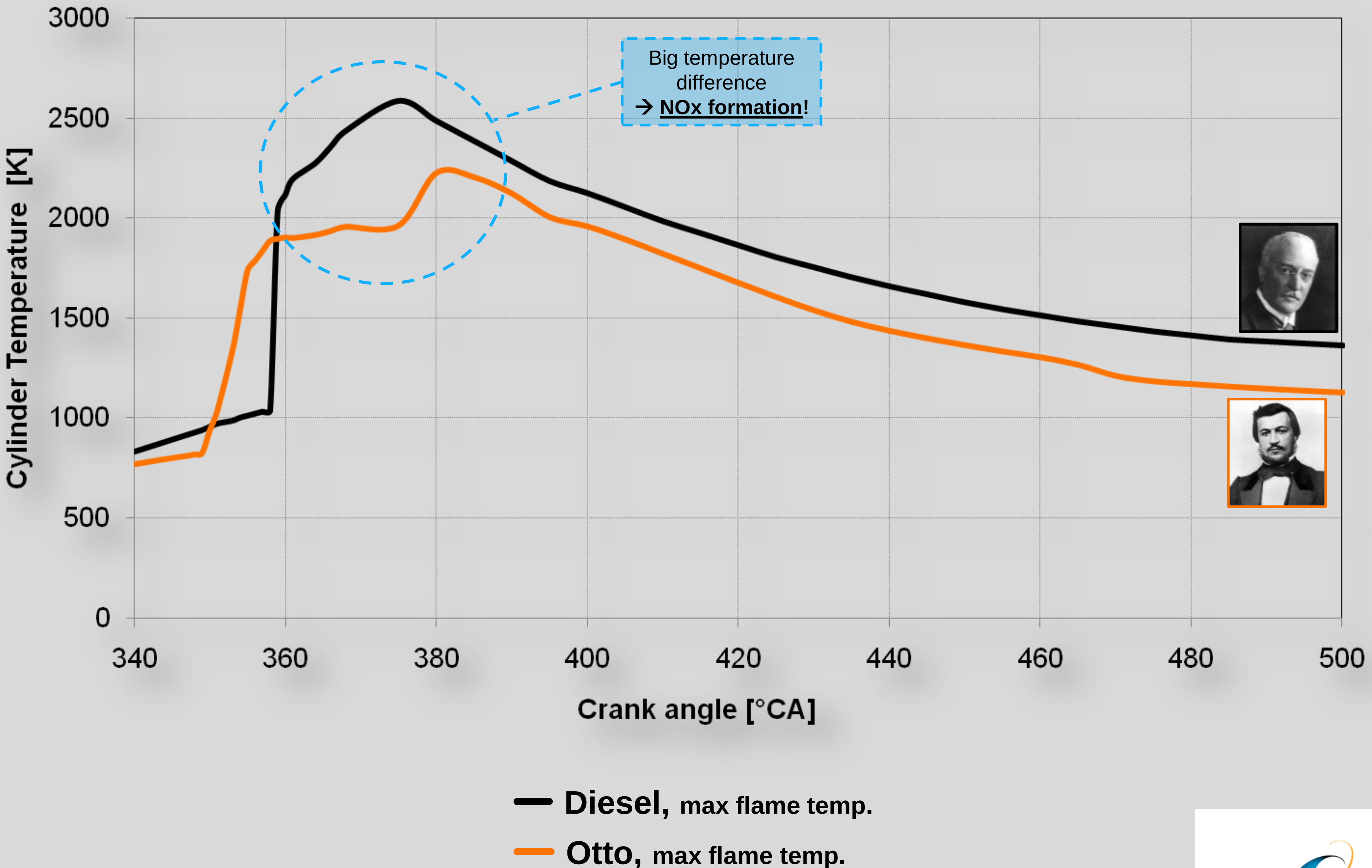
DF ENGINES

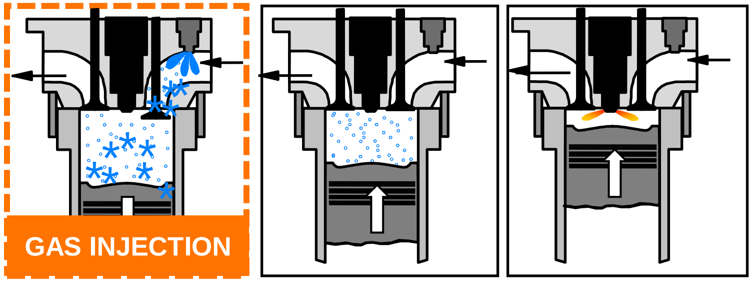
Otto or Diesel cycles: effects on NO_X



Otto or Diesel cycles: effects on NO_X

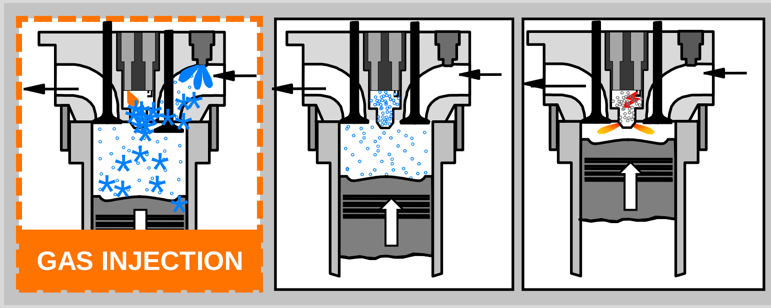


Select the right technology



DUAL-FUEL (DF)

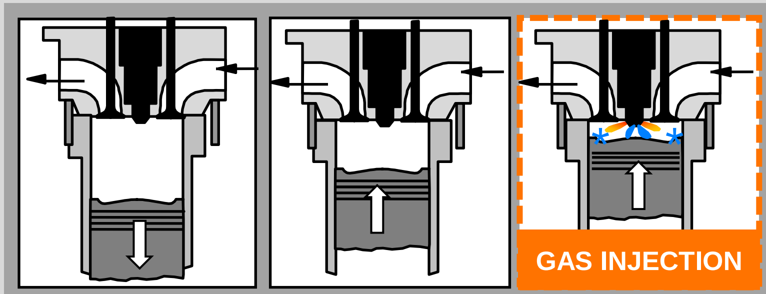
Meets IMO Tier III



SPARK-IGNITION GAS (SG)

Meets IMO Tier III

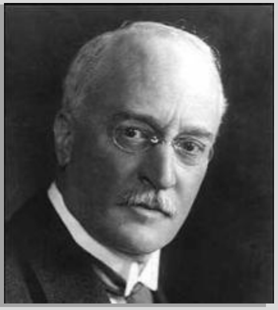
No redundancy
No HFO flexibility



GAS-DIESEL (GD)

Does NOT meet IMO Tier III

High gas pressure



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Gas burning technologies

GAS-DIESEL (GD)

DUAL-FUEL (DF)

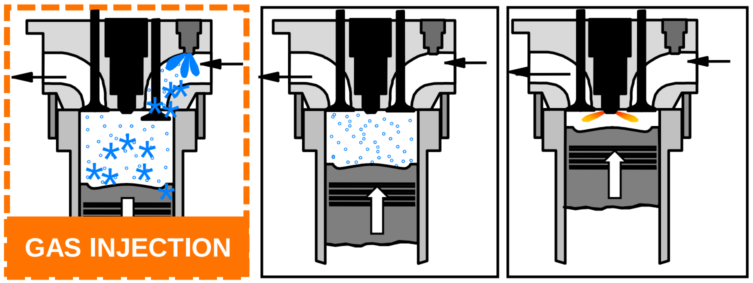
1987

1992

1995

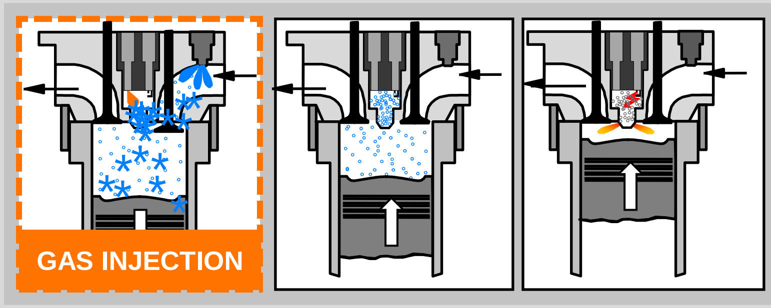
SPARK-IGNITION GAS (SG)

The marine favourite technology?



DUAL-FUEL (DF)

Meets IMO Tier III



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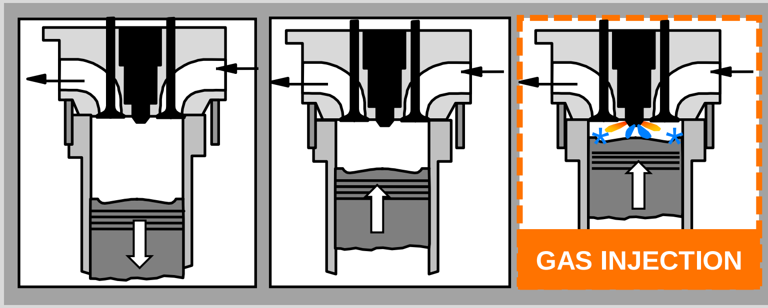
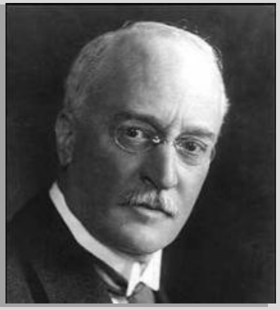


GAS-DIESEL (GD)

Does NOT meet IMO Tier III

High gas pressure



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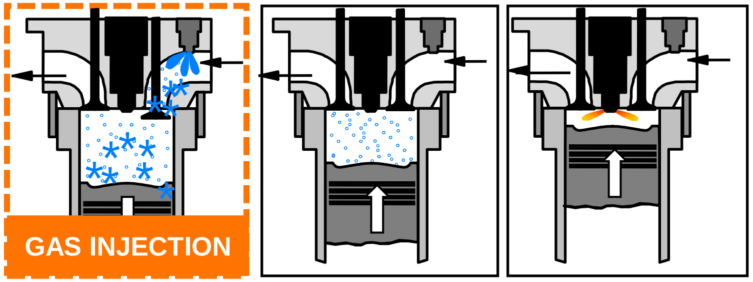
Wärtsilä's choice



DUAL-FUEL (DF)
Meets IMO Tier III

1 **IMO Tier III compliant**

2 **Low pressure gas**

3 **Fuel flexibility; GAS, MDO and HFO**

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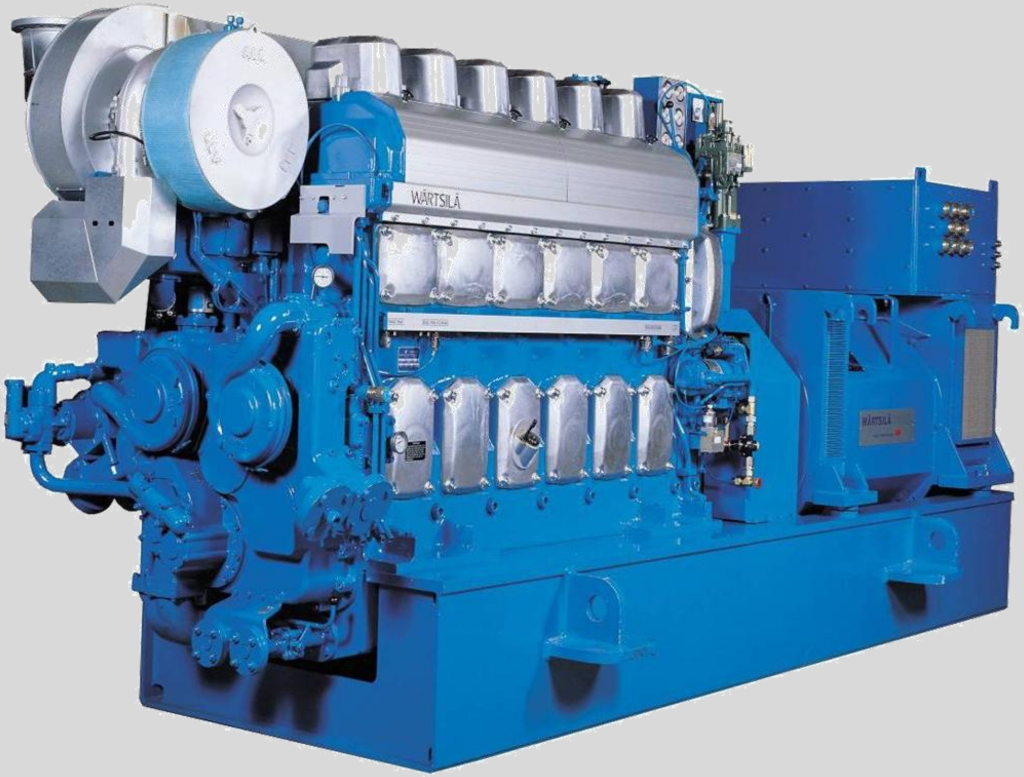
Dual-fuel engine characteristics

- High efficiency
- Low gas pressure
- Low emissions, due to:
  - High efficiency
  - Clean fuel
  - Lean burn combustion
- Fuel flexibility
  - Gas mode
  - Diesel mode
- Three engine models
  - Wärtsilä 20DF
  - Wärtsilä 34DF
  - Wärtsilä 50DF



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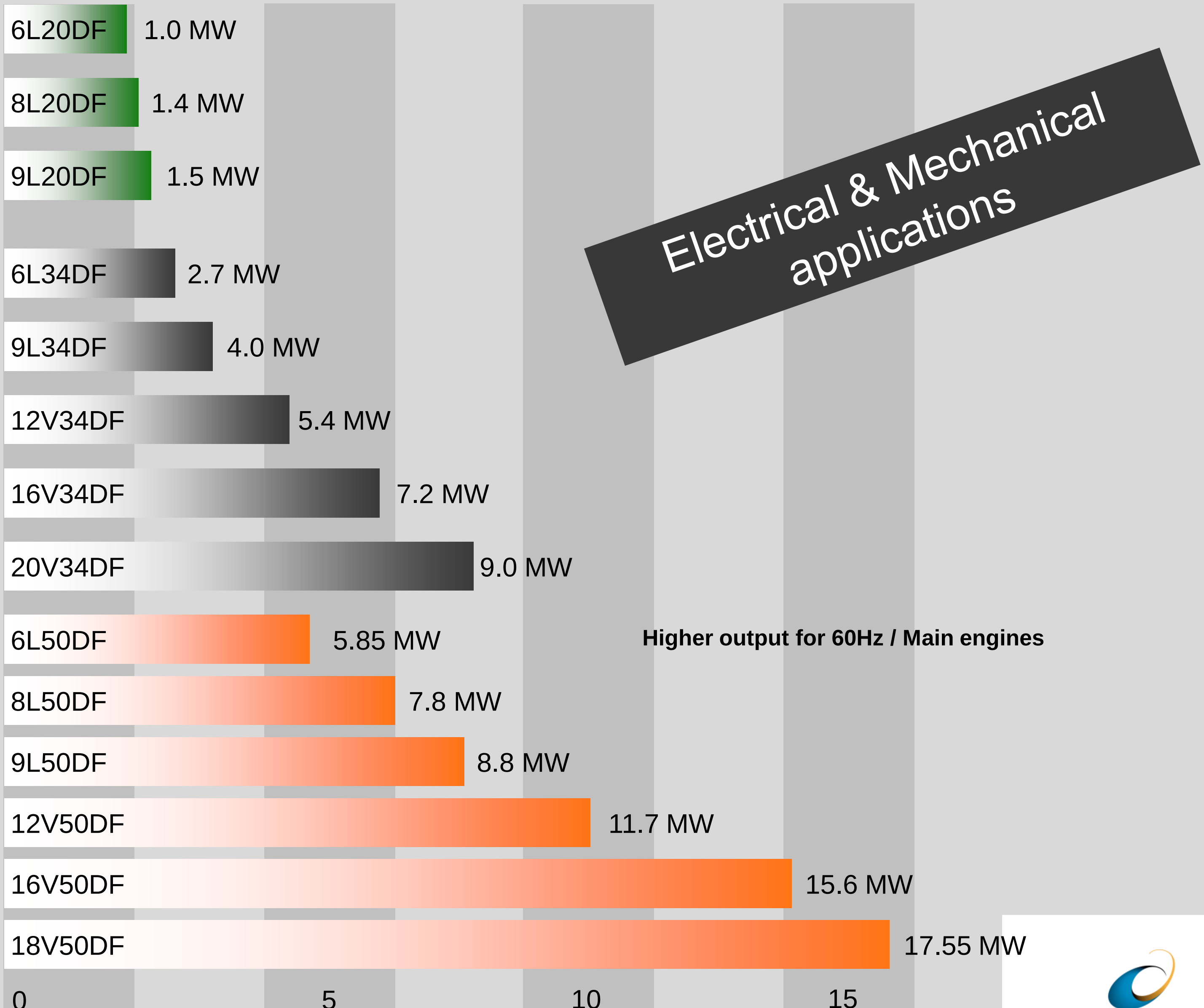
Dual-fuel engine range

WÄRTSILÄ 20DF

WÄRTSILÄ 34DF

WÄRTSILÄ 50DF



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Wärtsilä successfully tests new 2-stroke dual-fuel gas engine technology

Wärtsilä Corporation, Trade & Technical press release, 23 September 2011:

“Wärtsilä successfully tests new 2-stroke dual-fuel gas engine technology to comply with IMO Tier III emission limits“

“The on-going tests show that the Wärtsilä 2-stroke gas engine performance is in compliance with the upcoming IMO Tier III NOx emission limits, thereby setting a new benchmark for low-speed engines running on gas.”

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Dual-Fuel advantages

Main advantages of the Dual-Fuel 4-stroke engine compared to SG:

- Redundancy, backup without interruptions in power or speed.
- Able to operate on liquid fuel outside ECA-area (incl HFO)
- Simple system, no PTI/"take me home" or double gas system needed.
- Vessel re-routing possible, gas supply not a limitation

Dual-Fuel applications – References

Power Plants

DF Power Plant
- 49 installations
- 155 engines
- Online since1997

Merchant

LNGC
- 68 vessels
- 254 engines
- 950'000 rh

Conversion
- 1 Chem. Tanker
- 2 engines conv.
- Complete gas train
- Complete design

Offshore

PSVs/FPSOs
- 22 vessels
- 78 engines
- Online from 1994

Cruise and Ferry

LNG ferries
- 1+1 vessels
- 4 engines per vessels
- Complete gas train
- 2800 passengers
- In service in 2013

Navy

Costal Patrol
- Coming…

→ 4 segments → 140 installations → > 3'000'000 running hours

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Viking Line 2800 Pax Cruise Ferry

The industry's most environmentally sound and energy efficient large passenger vessel to date.

Main particulars:

Overall length:	**214.0** m
Breadth, moulded:	**31.8** m
Cruising speed	**22** knots
Passengers:	**2800**
Class:	**LR**
Ice class:	**1A**
In service:	**2013**
Shipyard:	**STX Finland Oy**
Ship Owner:	**Viking Line**

Machinery:

Main Engines:	4 x Wärtsilä 8L50DF
Output:	4 x 7600 kW

LNGPac 200	2 x 200 m3

Integrated tank – and aux. rooms

Bunkering system, Safety systems

GVU in enclosure

Cold recovery for HVAC

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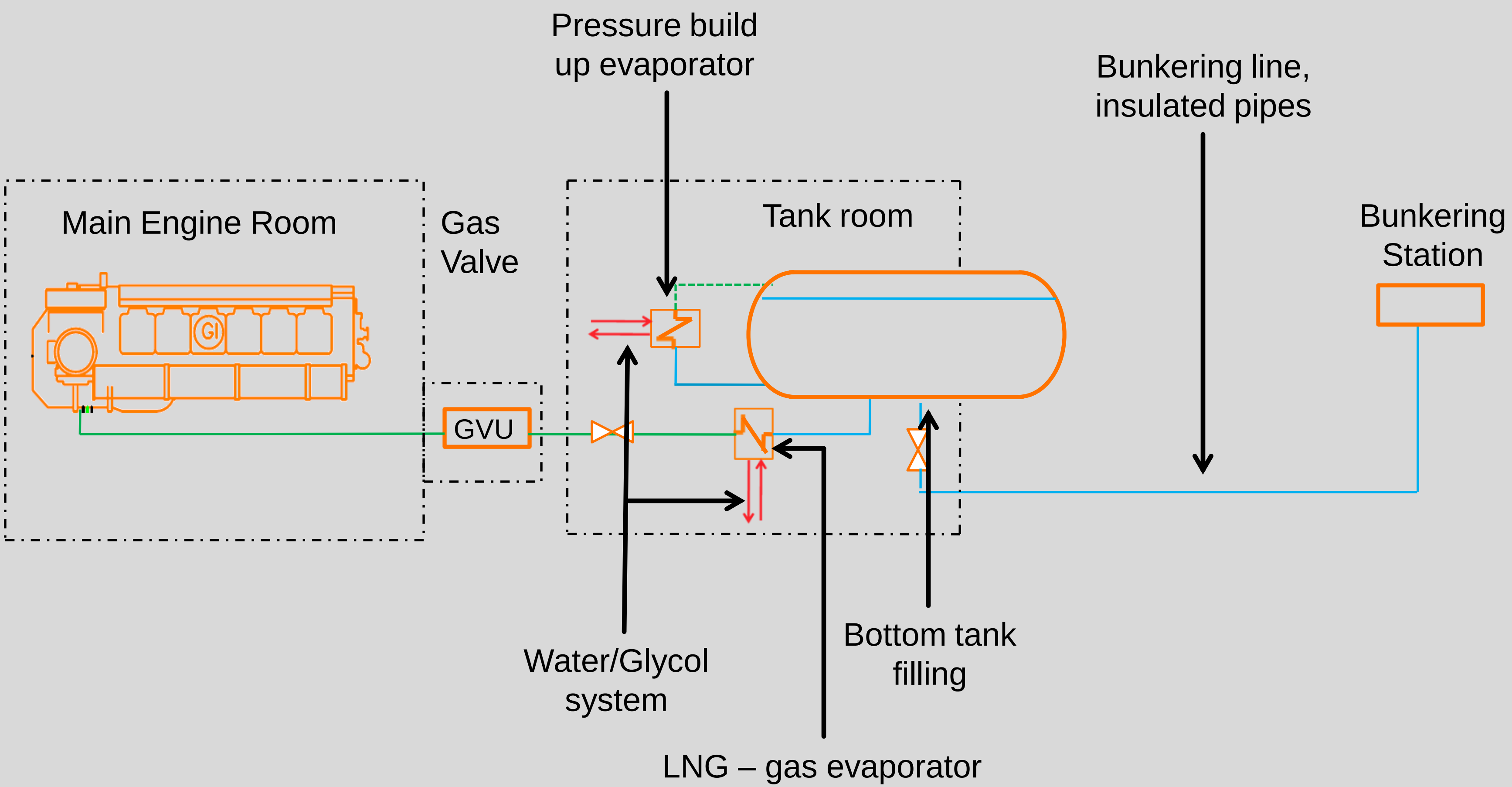
Conversion of Bit Viking

Conversion of Bit Viking

LNGpac Main Components



  27 September 2011 Oskar Levander

Gas Valve Unit in enclosure

Main features

- Can be located in the same engine room, dedicated compartment not needed
- Compact design and easy installation (plug-and-play concept)
- Integrated ventilation system when combined with LNGPac

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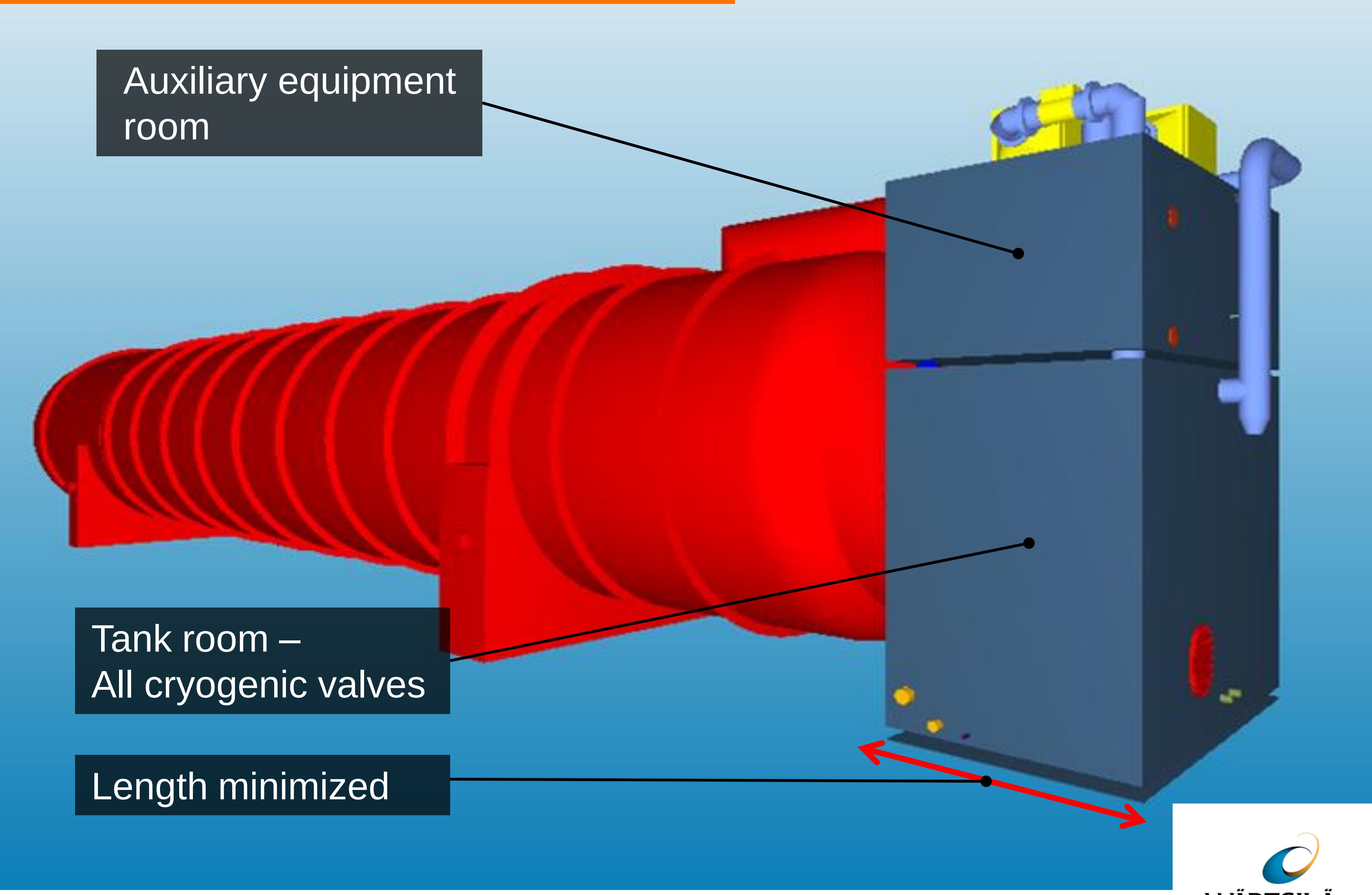
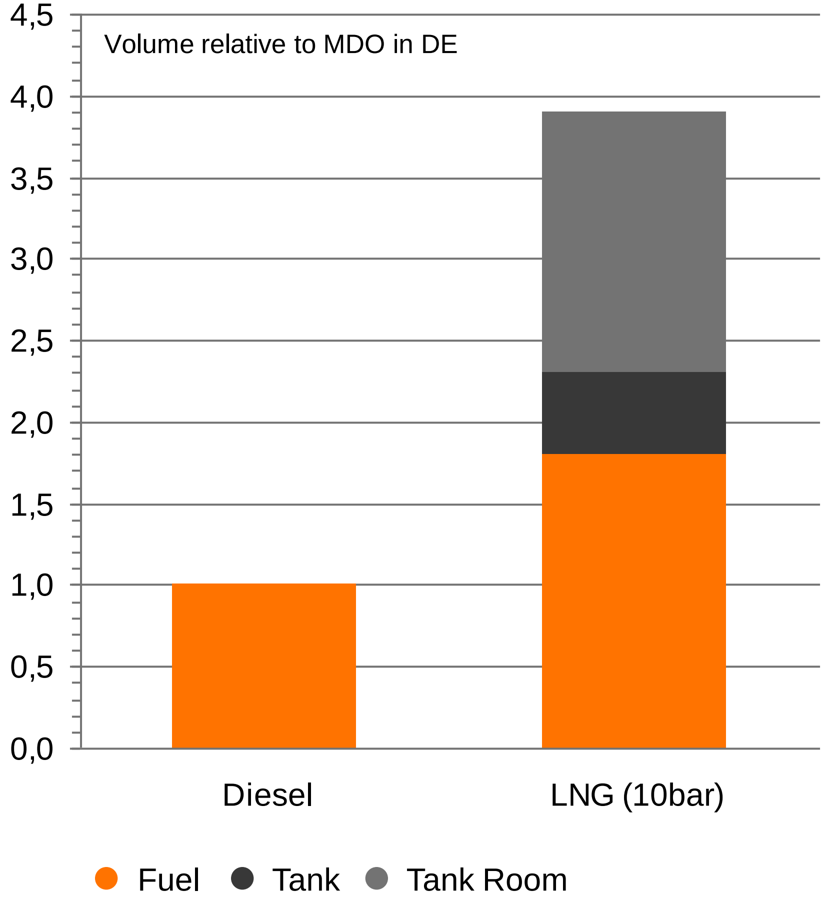
LNGPac: A turn key solution



LNGPac

LNG storage

Storage volume (Relative)



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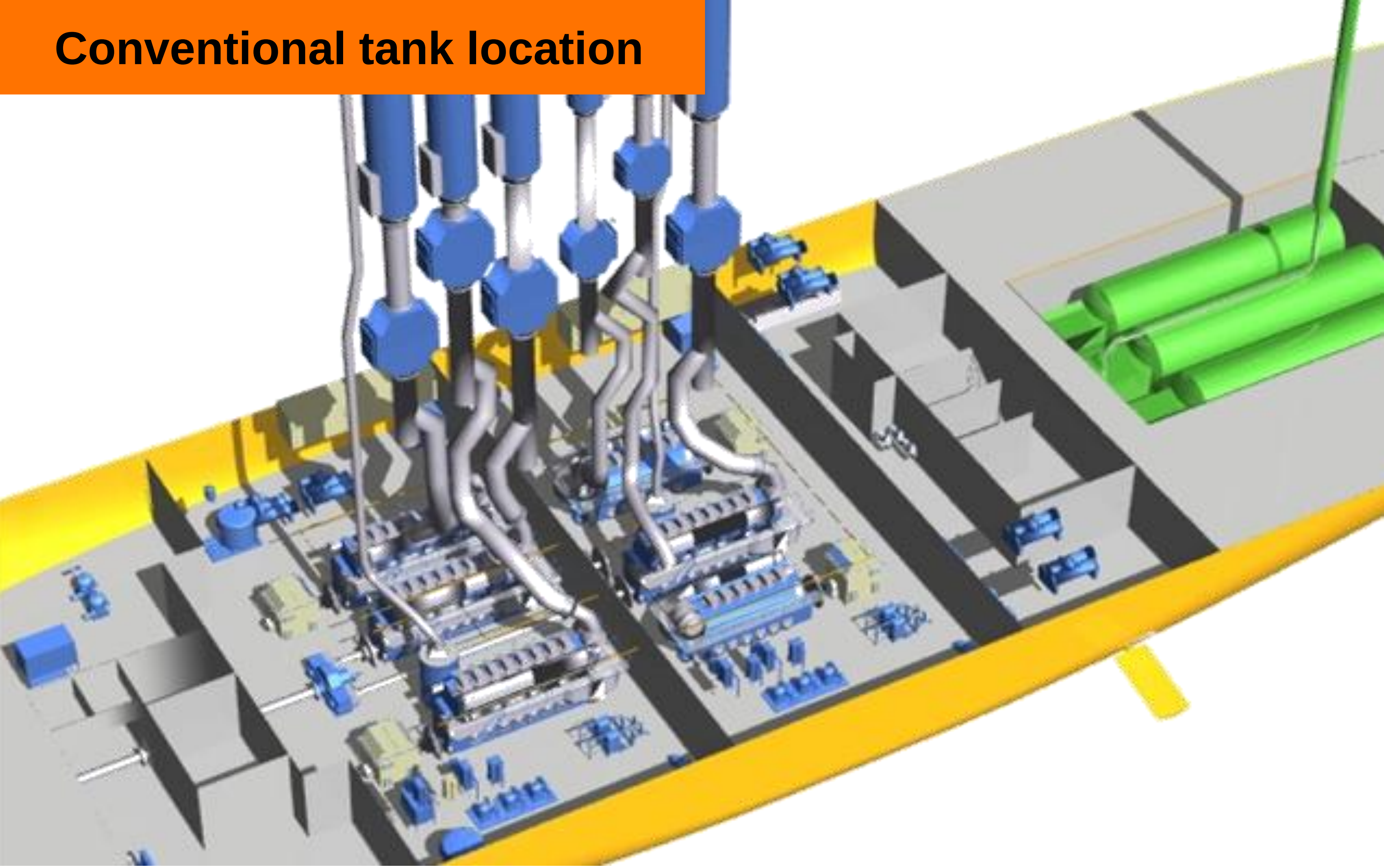
Conventional tank location



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LNG tanks located outside

The LNG tanks can be located outside

- Does not take up space inside ship
- Good ventilation
- No ventilation casing needed trough accommodation
- Visible location for good PR

LNG storage in trailers

LNG distribution chain

LNG logistics is a key question for introduction of LNG as a marine fuel

LNG Terminal

LNG Feeder

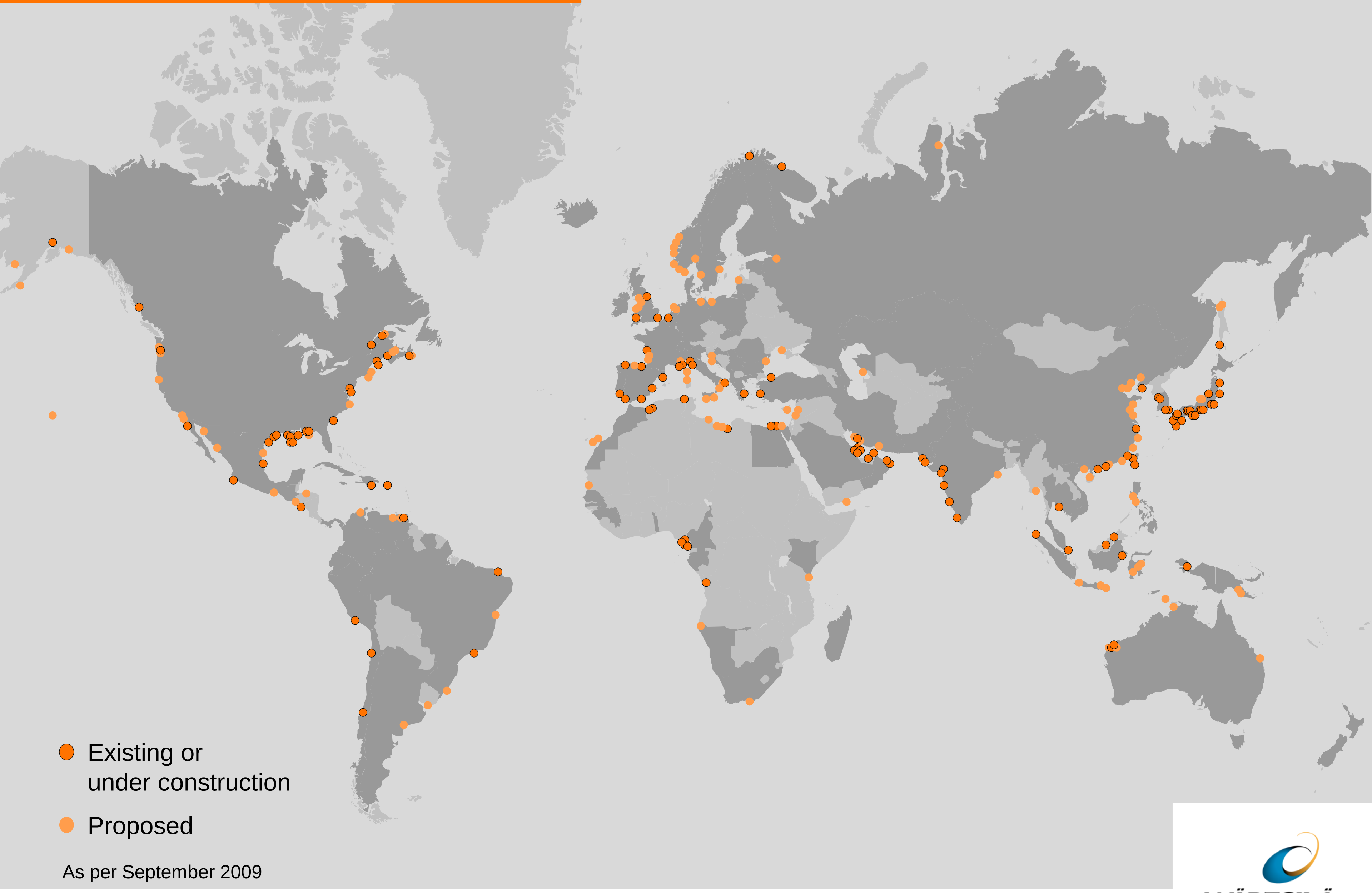
LNG Container feeder

LNG Ferry

LNG Ro-Lo

LNG Tug

Marine LNG terminals



As per September 2009

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Bunkering from LNG truck

LNG bunker barge/tanker

LNG barge carrier – operation principle

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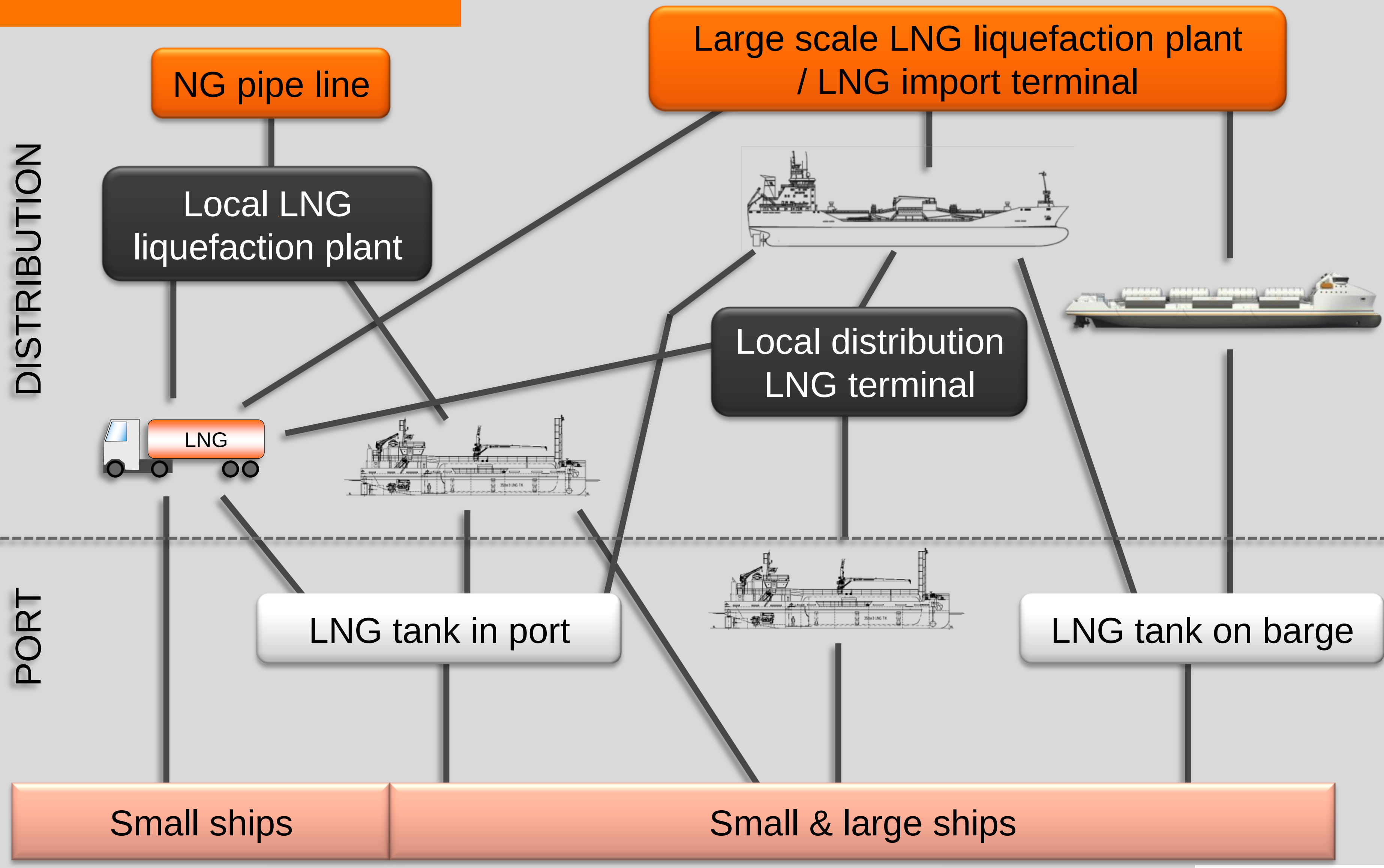
LNG barge carrier – operation principle

LNG distribution



Total Concept Optimization

Wärtsilä engineers solutions for LNG delivery, storage, transportation and utilization onboard.

RORO CONCEPT FOR ECA

RoRo trends

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RoRo trends

- Growing capacity
  - Efficiency of scale
- Slowing down
  - Reducing fuel costs
- Flexible cargo intake
- Designed for operation inside ECA areas

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RoRo concept

RoRo vessel for European routes in ECA

- Operation area: European SECA area
- RoRo cargos
  - Double stack containers on main deck
  - Trailers and mafis on upper deck and in lower hold
  - Containers on upper deck
- Focus on environmental and economical performance
  - Operation inside SECA area
  - IMO tier III NOx compliant

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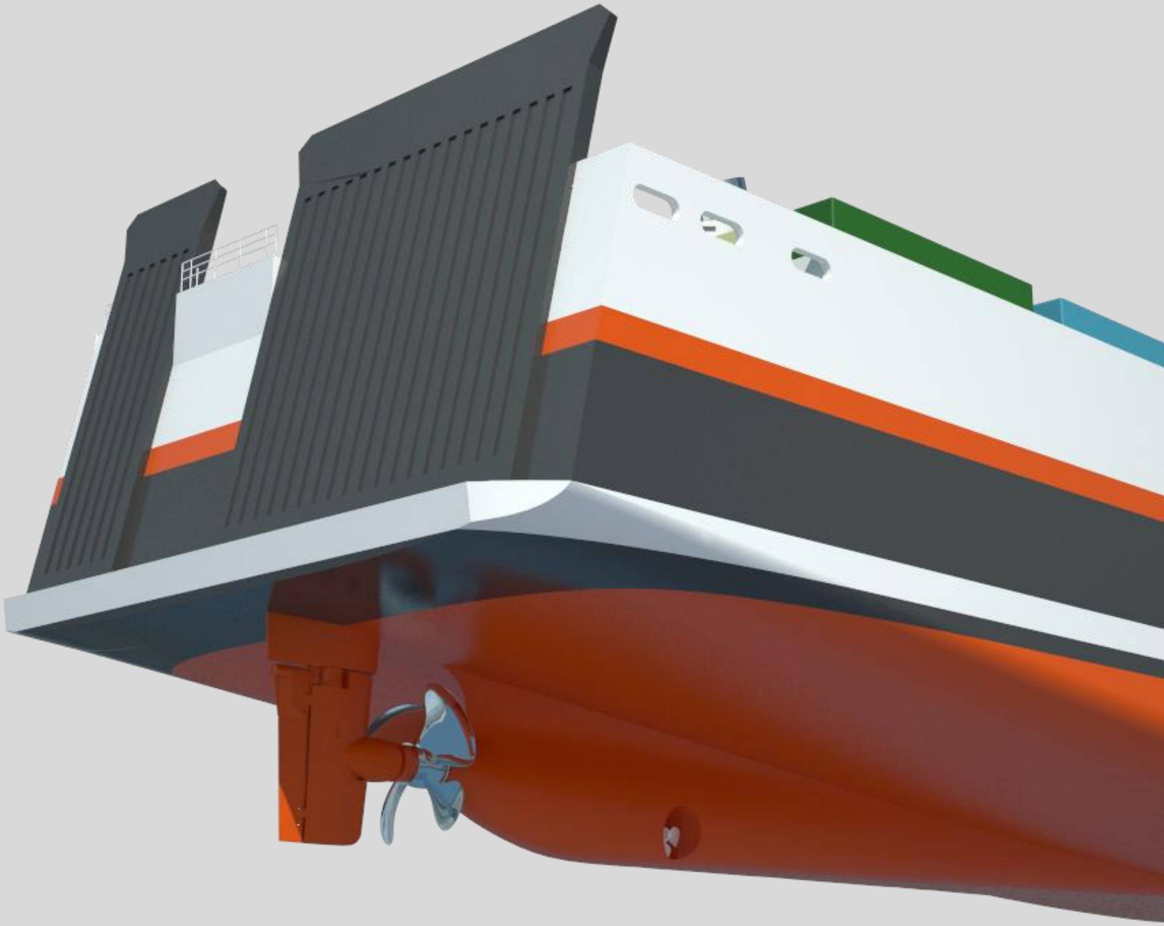
RoRo main particulars

Size	22 000	GT
Length	190.0	m
Length, bp	180.0	m
Beam, wl	26.6	m
Draft (design)	6.5	m
Depth, main deck	8.3	m
Speed, service	~19	knots (incl. 15% SM)
Lane meters	2 800	m
Deadweight (desgin)	10 500	tons
Propulsion power	10 800 – 11 400	kW (installed)
Aux power	~2 100	kW (installed)
Drivers	12	pax

Propulsion

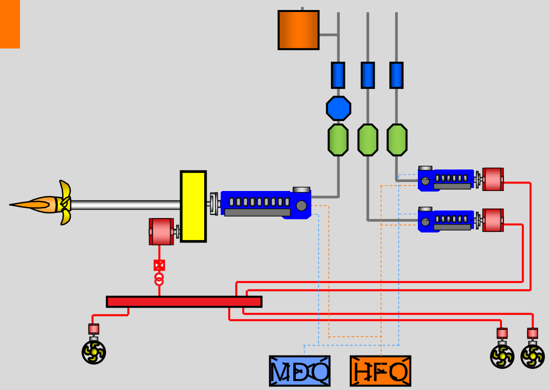
- Single screw
  - Simple and well proven
  - Good ice performance
  - Low cost

- Energopac rudder

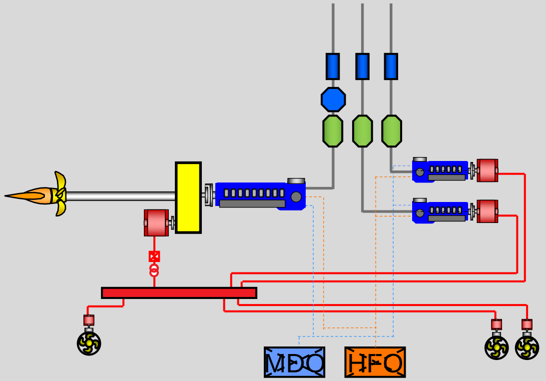


Machinery alternatives for comparison

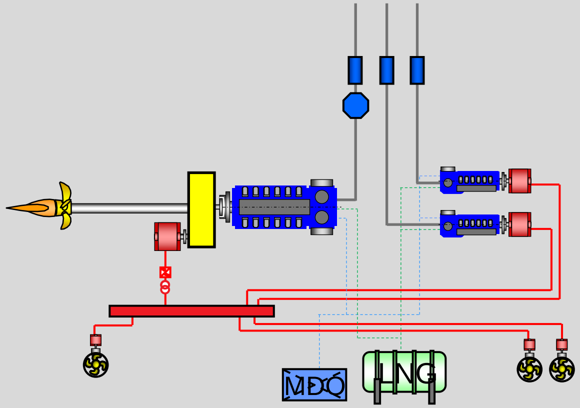
1. **MGO**
   - Operates on MGO
   - SCR to reduce NOx to tier III limit



2. **HFO + Scrubber**
   - Operates on HFO
   - Scrubber removes SOx
   - SCR to reduce NOx to tier III limit

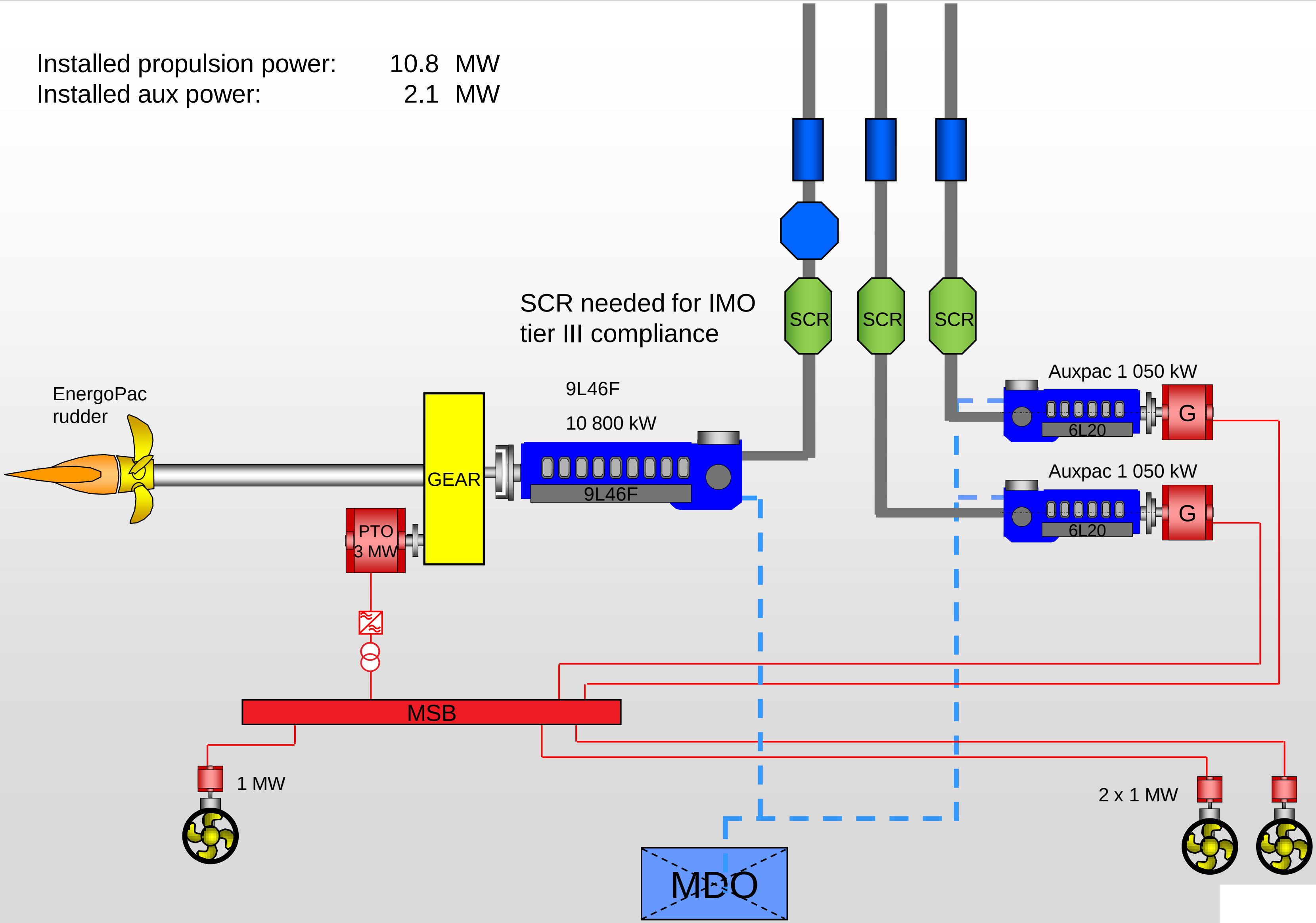


3. **DF - LNG**
   - Operates on LNG
   - No exhaust cleaning needed



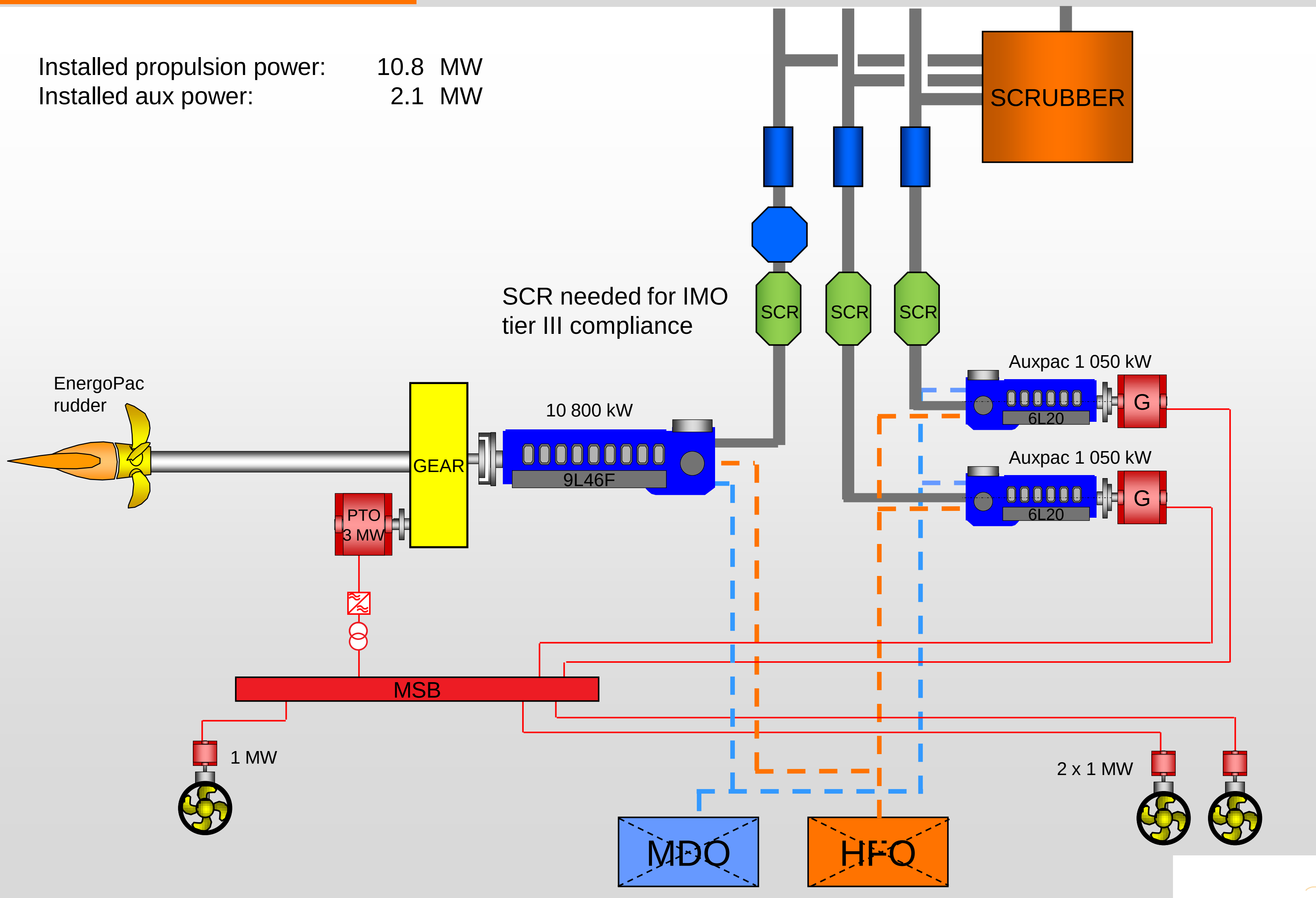
MGO

Installed propulsion power: 10.8 MW
Installed aux power: 2.1 MW



HFO + Scrubber

Installed propulsion power: 10.8 MW
Installed aux power: 2.1 MW



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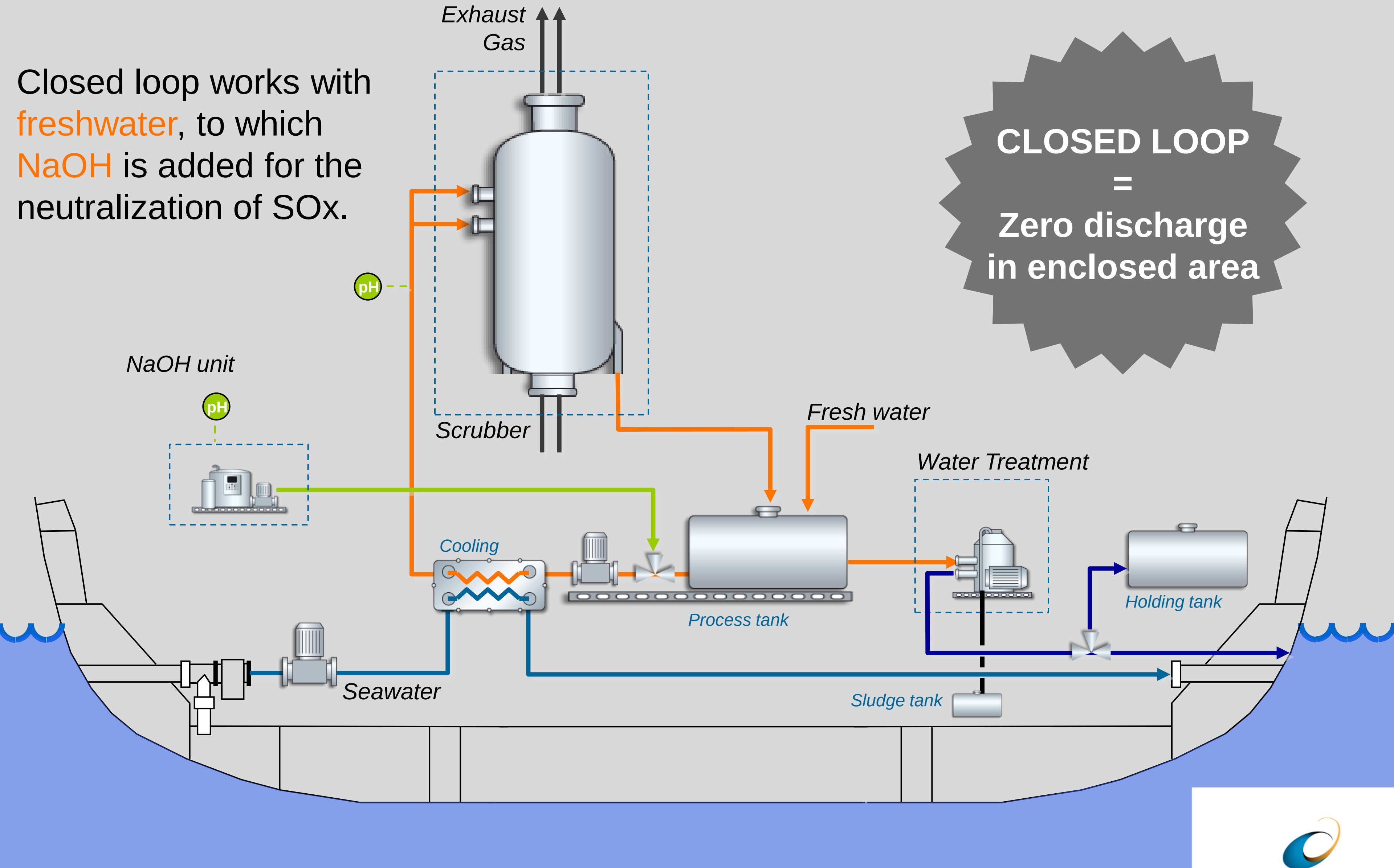
Marine Fresh Water Scrubber System

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



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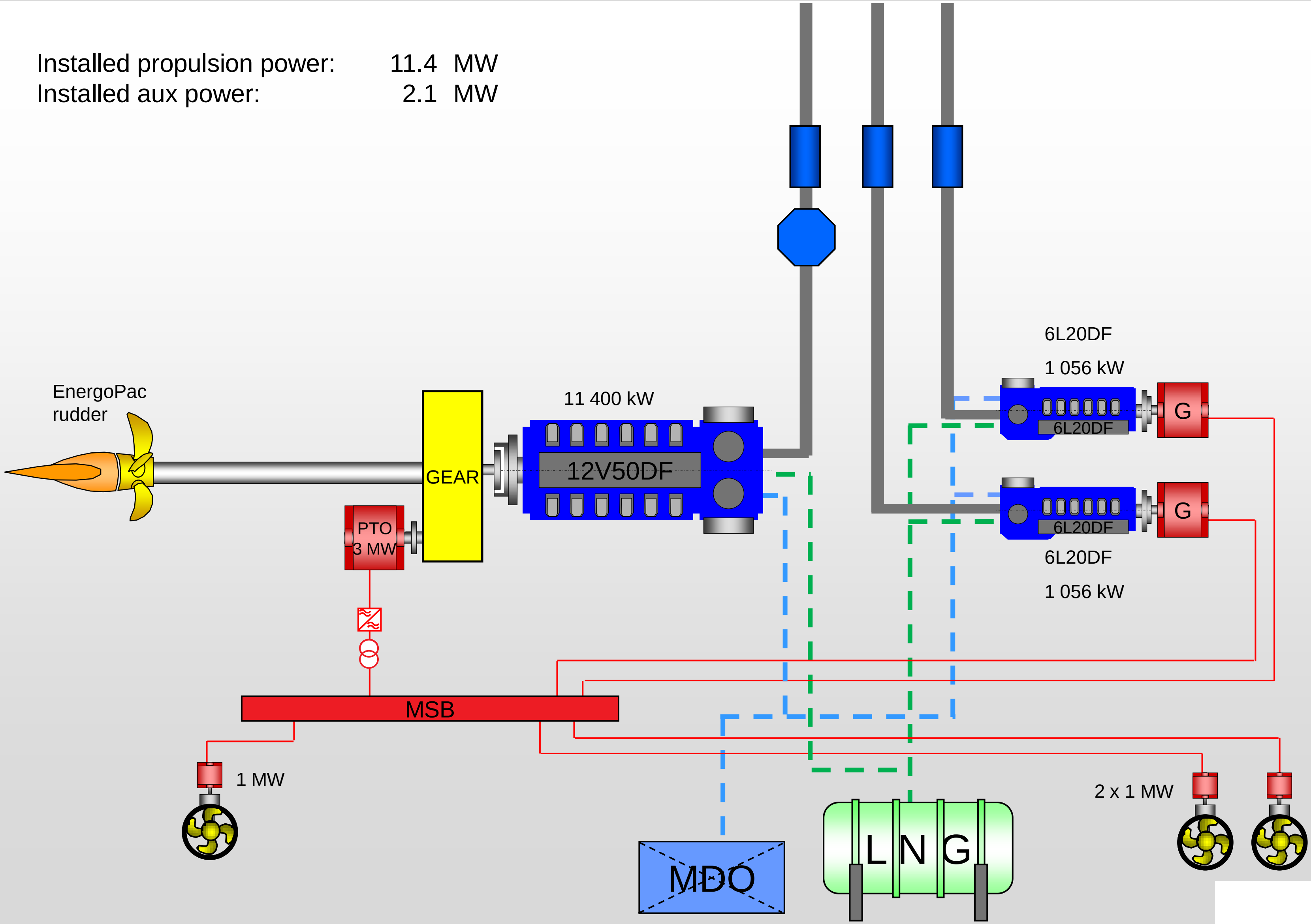
Containerships VII - scrubber installation

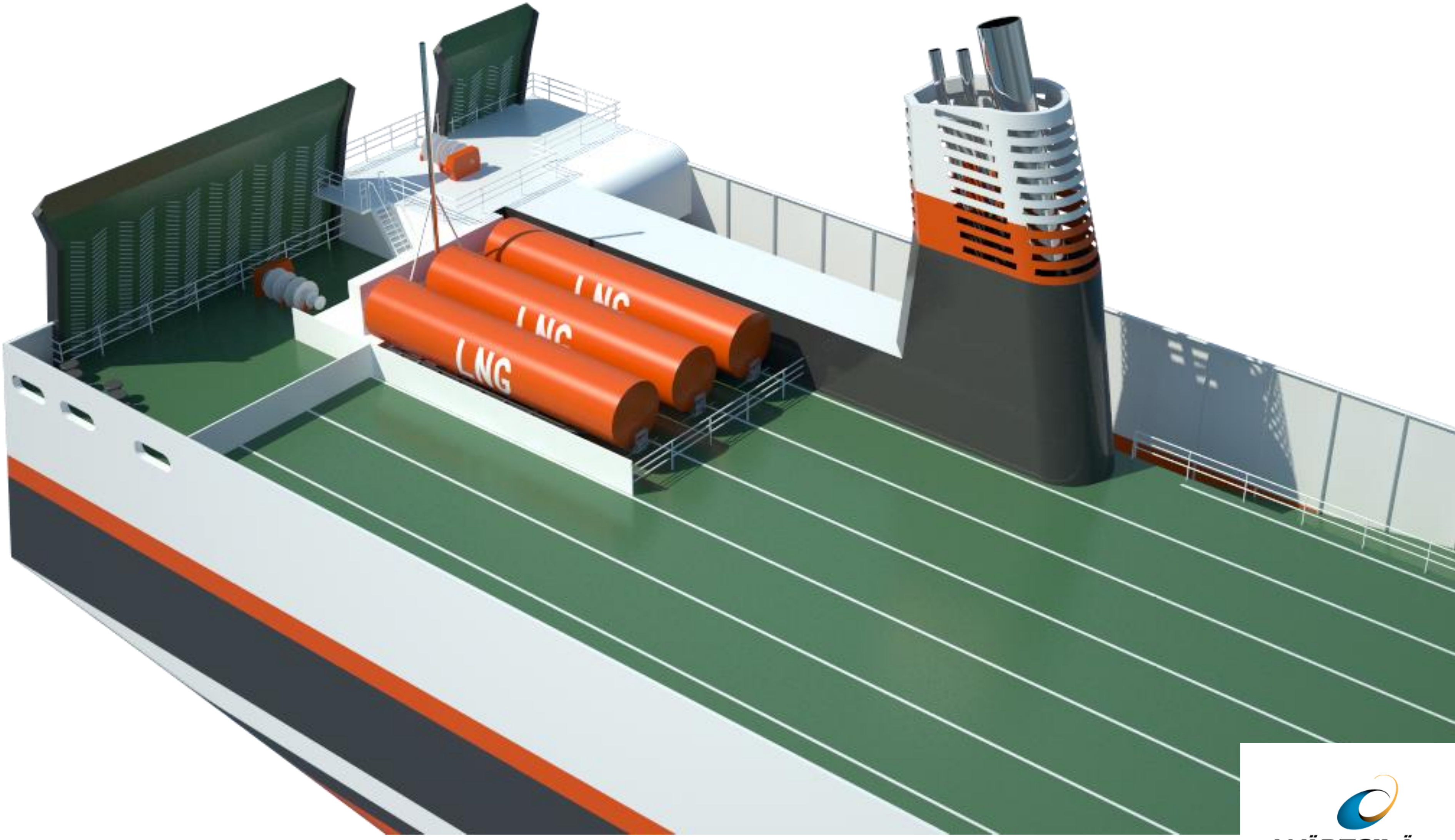
DF - LNG

Installed propulsion power: 11.4 MW
Installed aux power: 2.1 MW



LNG storage in trailers

3 x LNG trailers = 150 m3 of LNG



LNG tank capacity (LNG trucks on deck)

• Target for autonomy	2	days
• Daily consumption (acc. to profile)	19	tons
• Total consumption	38	tons
	84	m^3
• + 15% Margin	+ 13	m^3
• Total tank capacity demand	97	m^3
• Volume capacity of one truck	50	m^3

→ **Two LNG trucks loaded every second day**

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LNG storage in trailer

Assumed fuel prices

	USD/ton	EUR/ton	USD/MBtu
HFO	635	455	16.5
MGO	950	680	23.4
LNG	740	530	16.0

For reference: NG market price in US: <5 $/MBTU

Source: www.bunkerworld.com (September 2011), LNG price estimated

1 EUR = 1.4 USD

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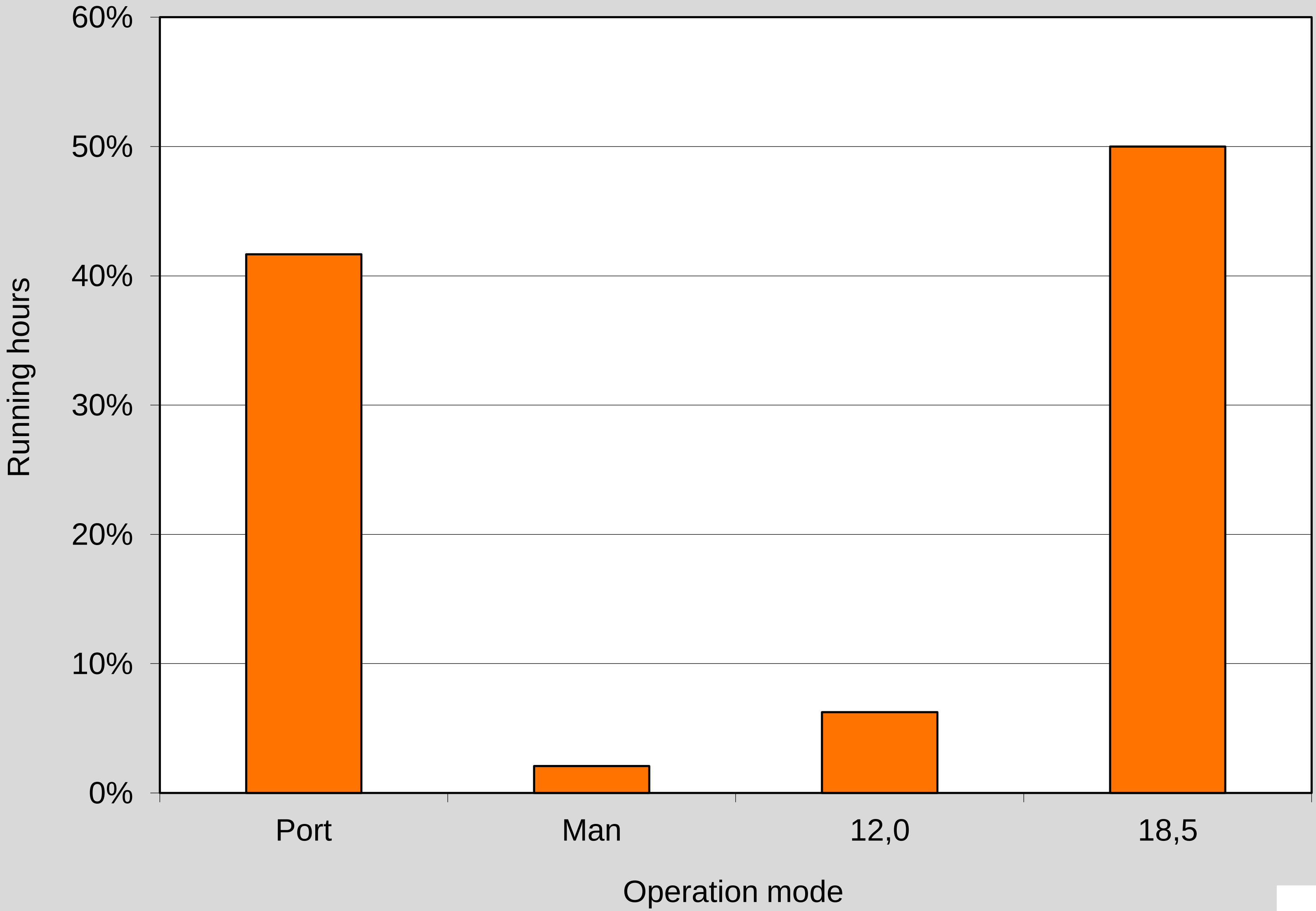
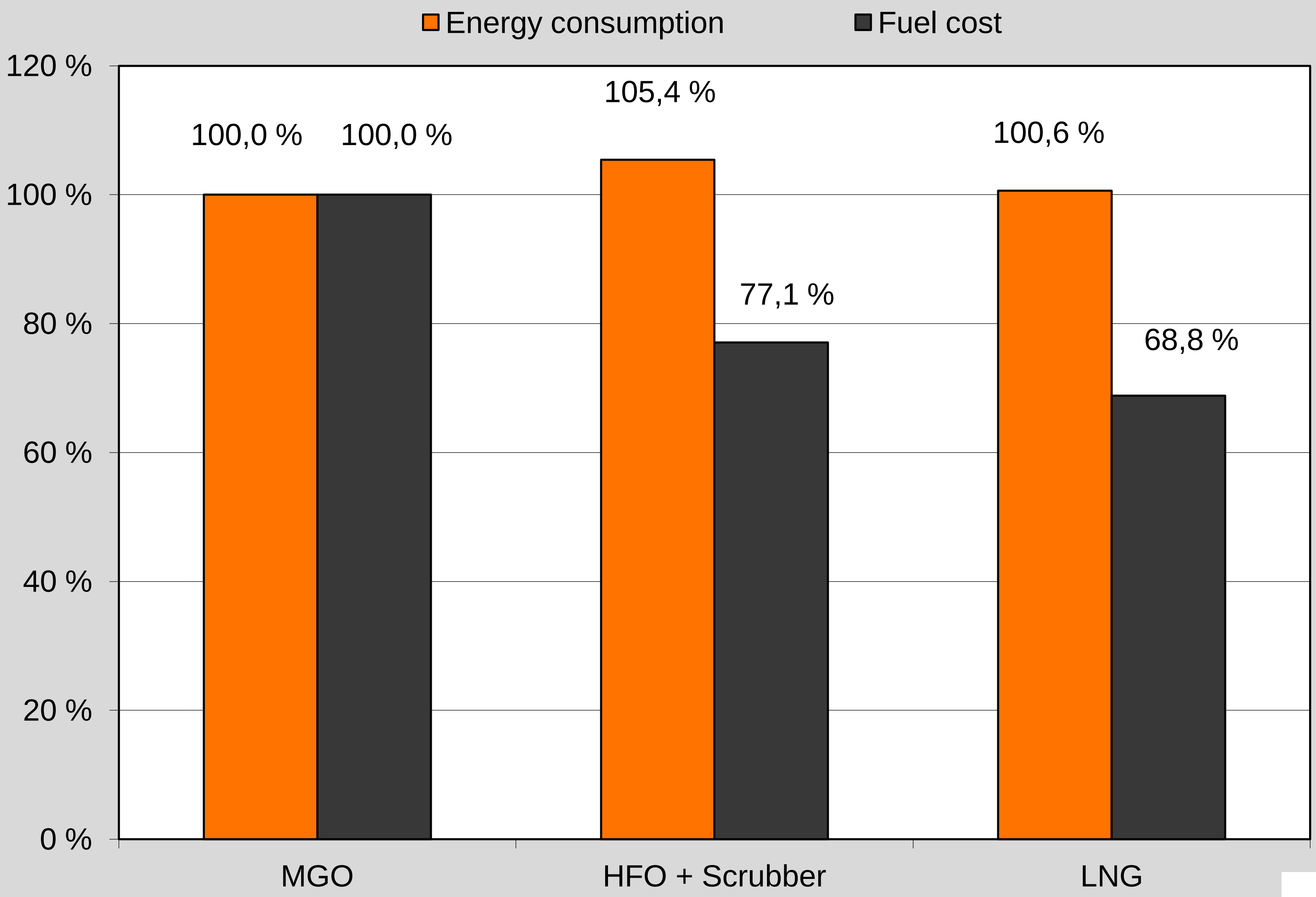
Operation profile

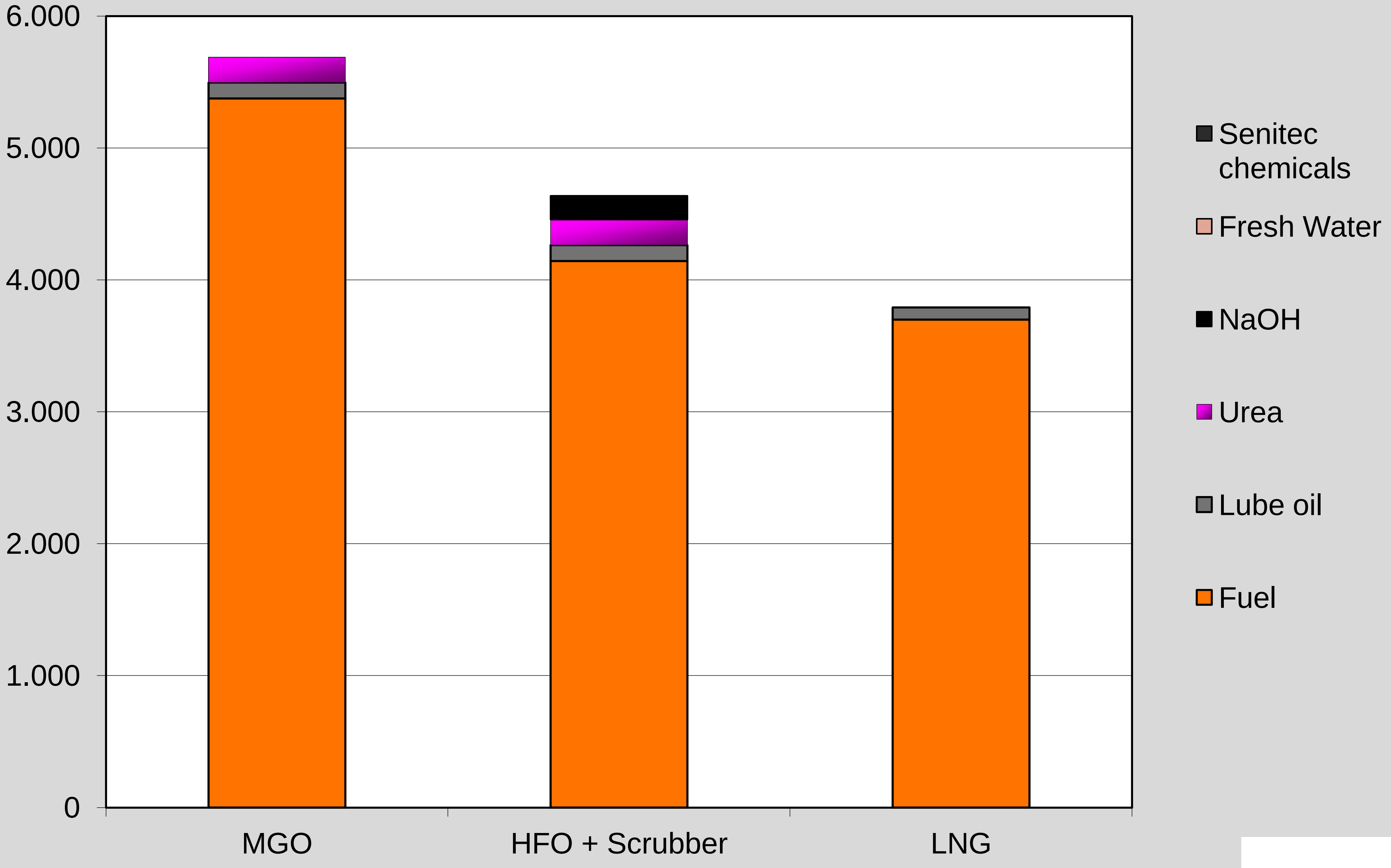


Annual fuel consumption and cost (relative)

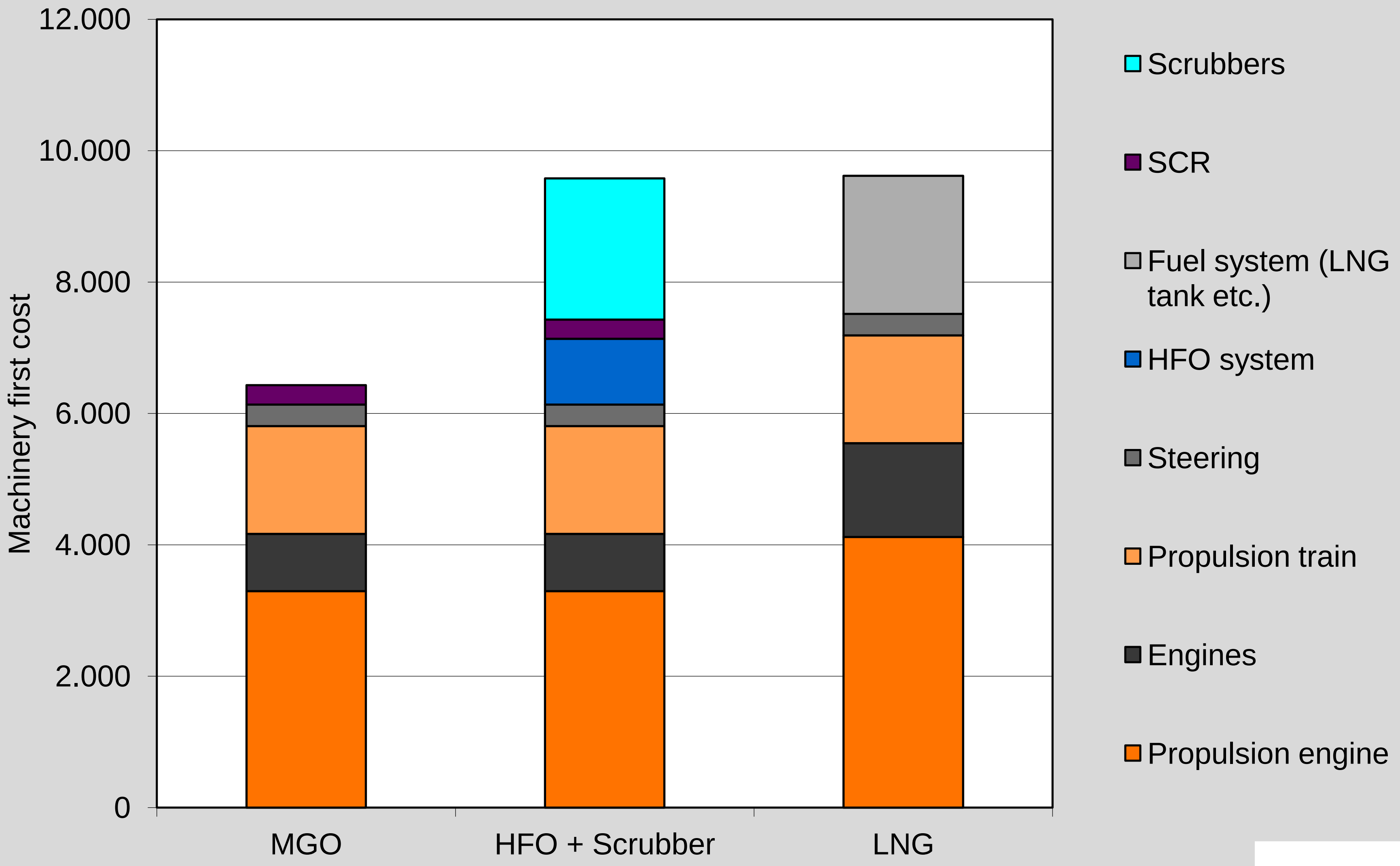


Annual fuel, lube oil and consumables cost (k€)

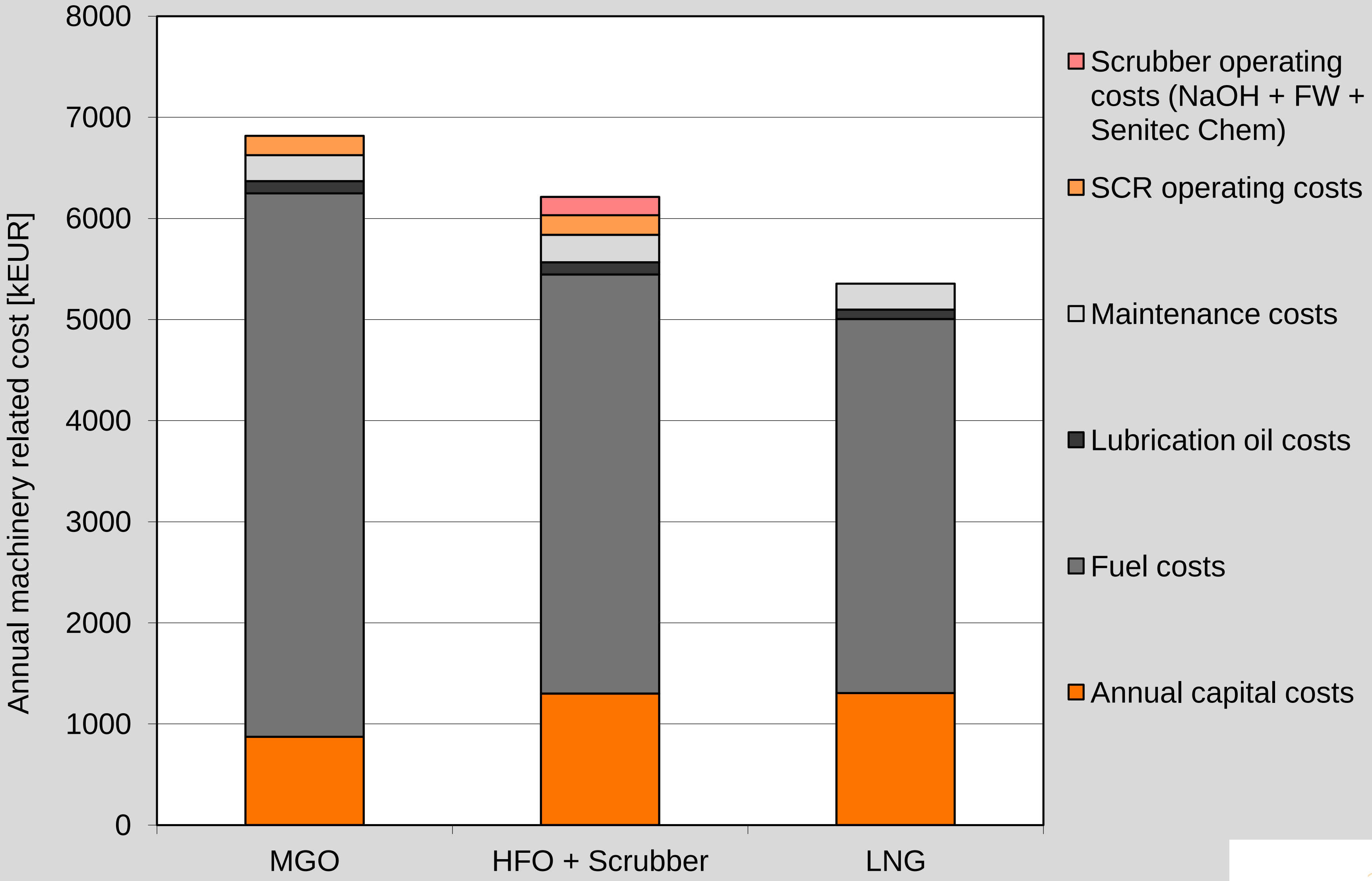
10 years
6% interest



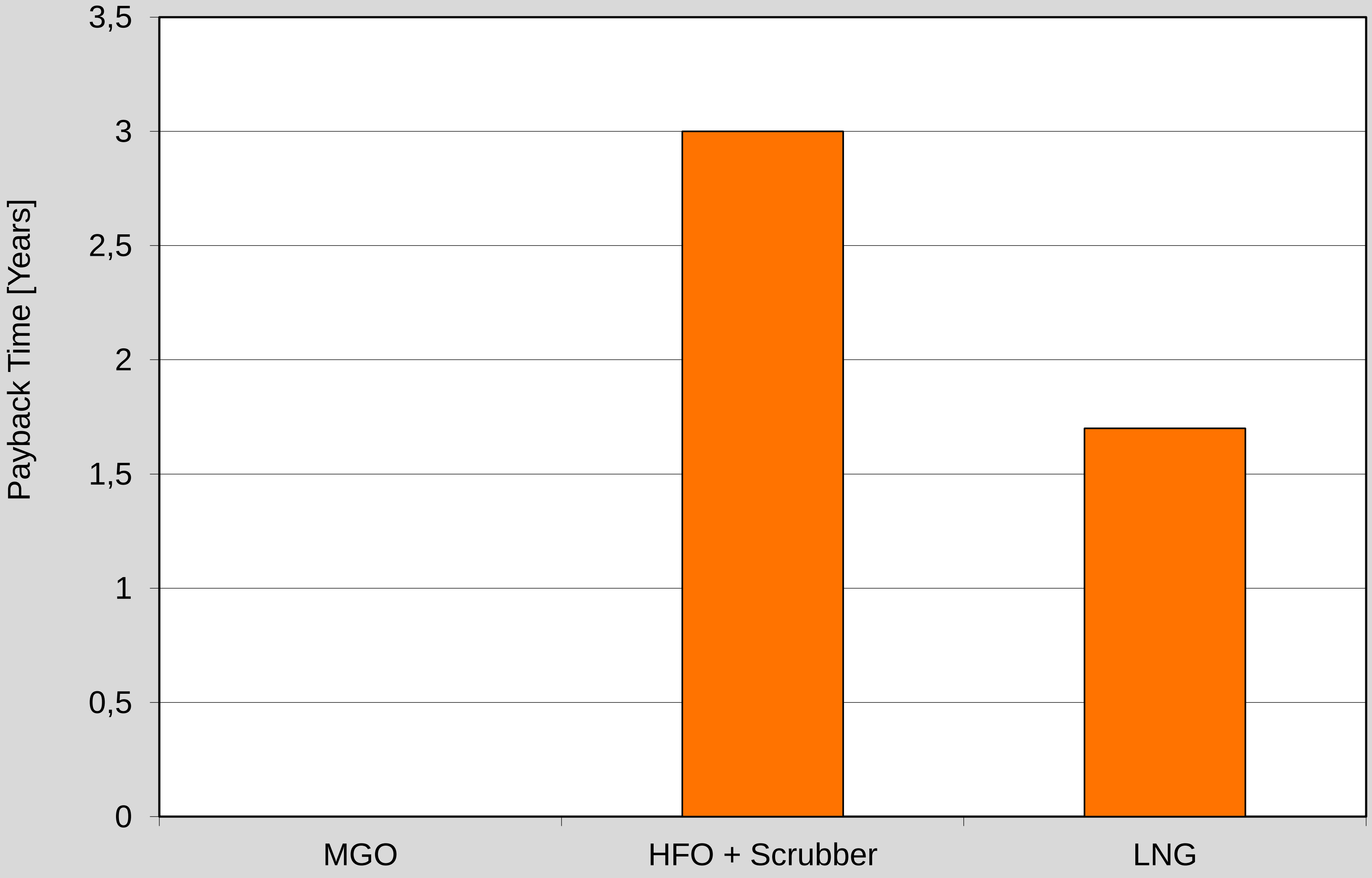
Machinery Investment cost



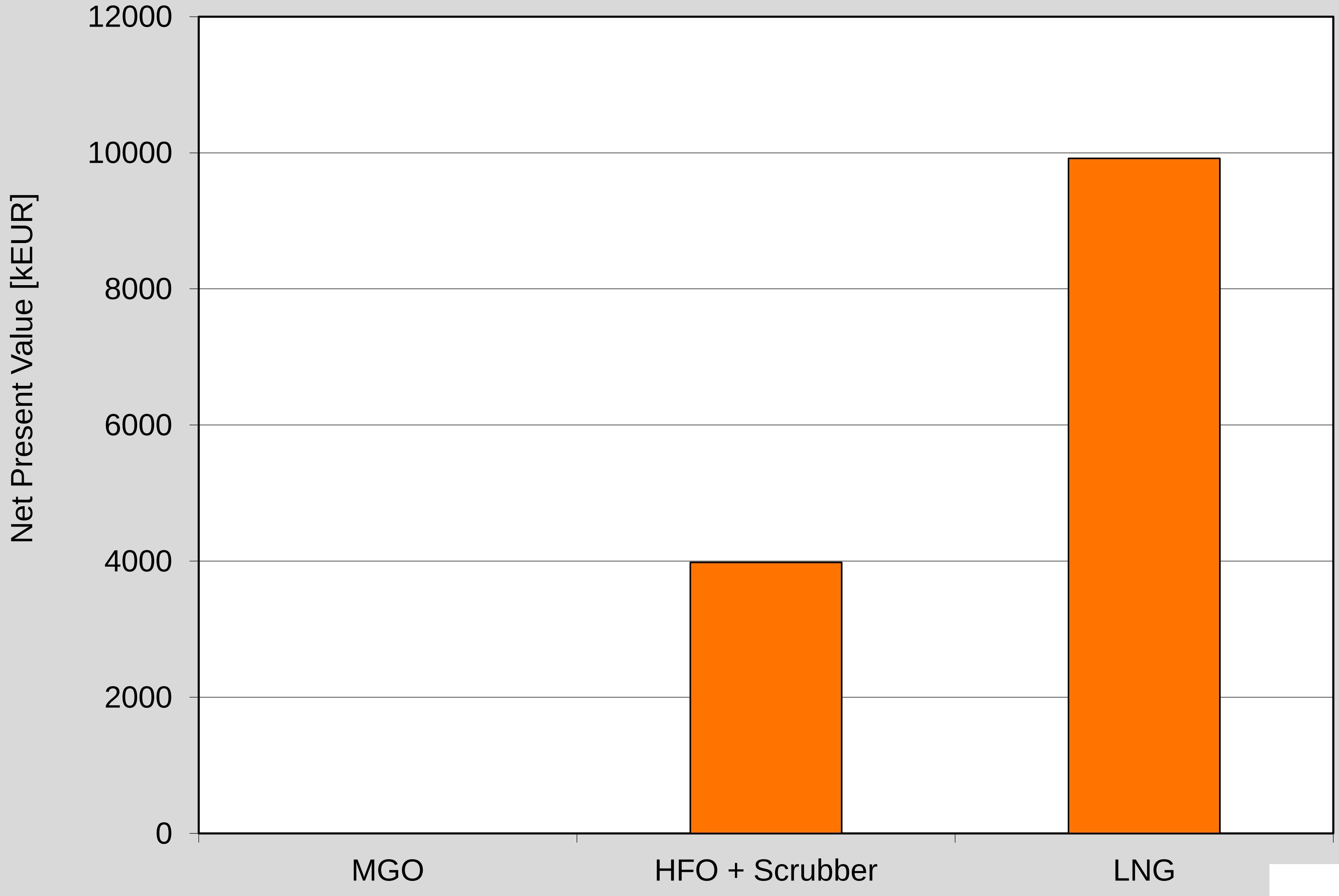
Annual machinery cost



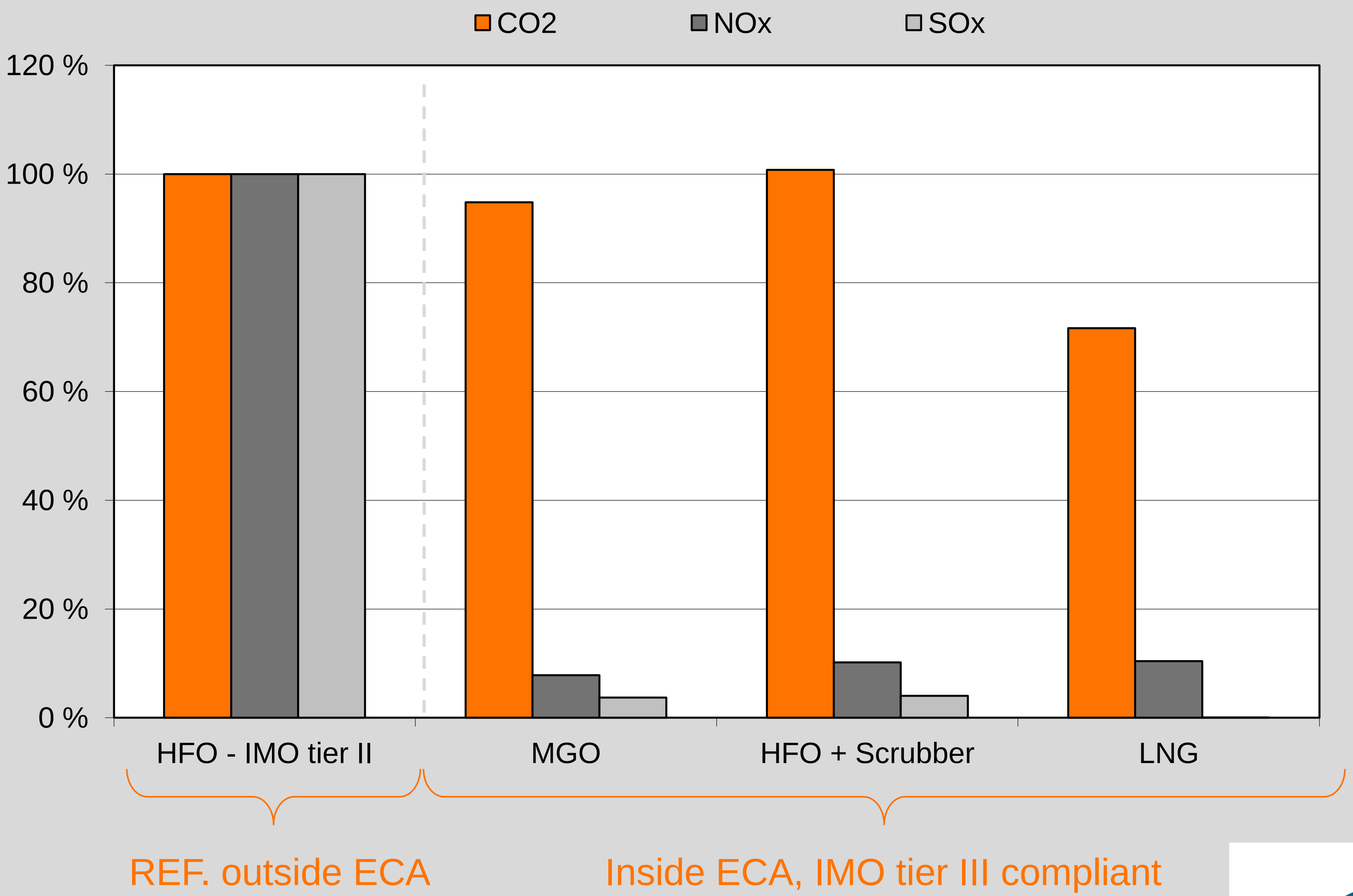
Concept payback time (compared to MGO)



Net present value (NPV) – 10 years of operation



Exhaust emissions



IMO Energy Efficiency Design Index (EEDI)

$$\text{EEDI} = \frac{CO_2 \; from \; propulsion \; + CO_2 \; from \; Auxiliaries \; - Efficent \; use \; of \; energy}{f_i \cdot Capacity \cdot V_{ref} \cdot f_W}$$

$$\text{EEDI} = \frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

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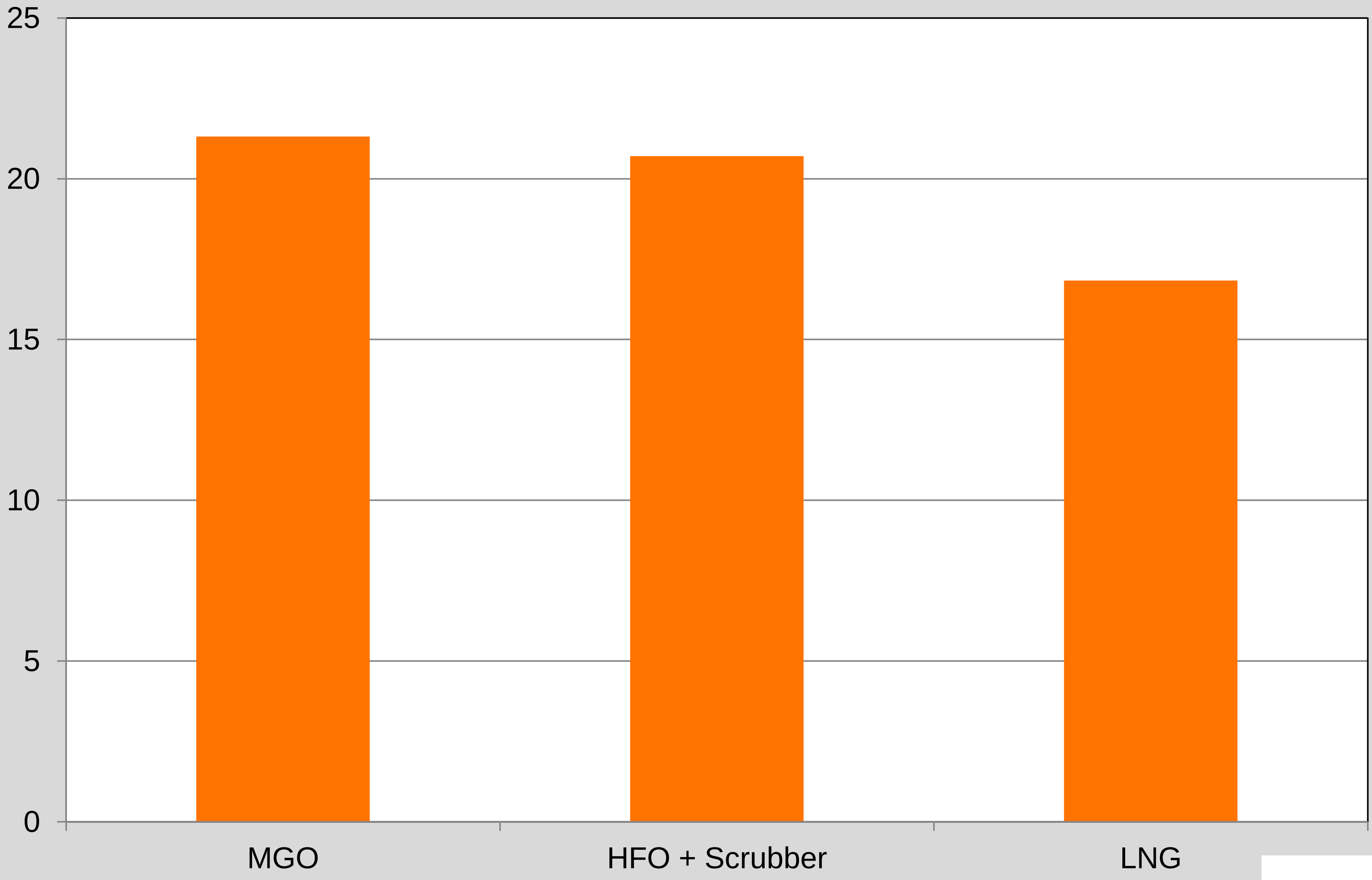
EEDI



Operating part time in SECA

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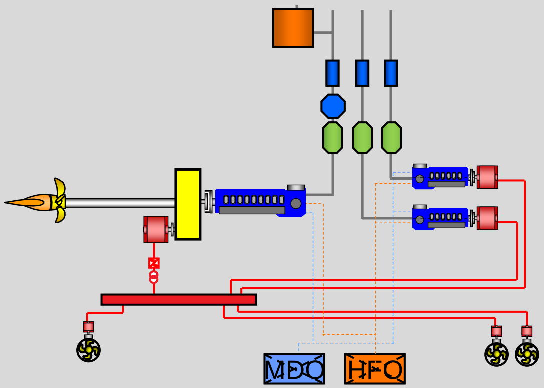
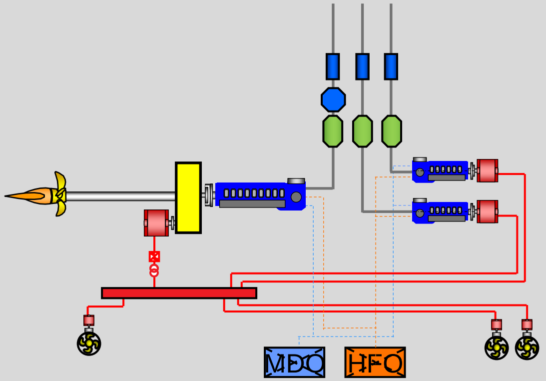
Machinery alternatives for comparison – part time in ECA

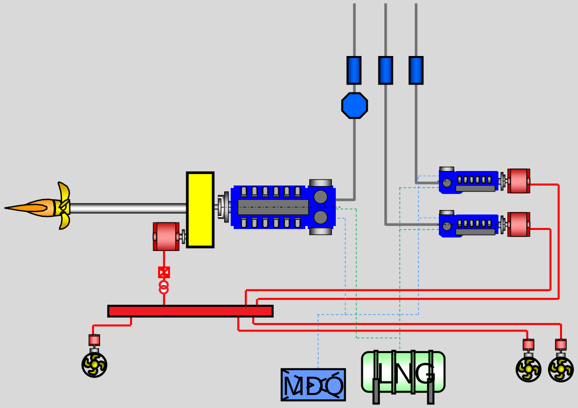
1. **MGO - HFO**
   - Operates on MGO inside SECA
   - and *HFO outside SECA*
   - SCR used only in port and inside NECA



2. **HFO + Scrubber**
   - Operates on HFO
   - Scrubber only used inside SECA
   - SCR used only in port and inside NECA

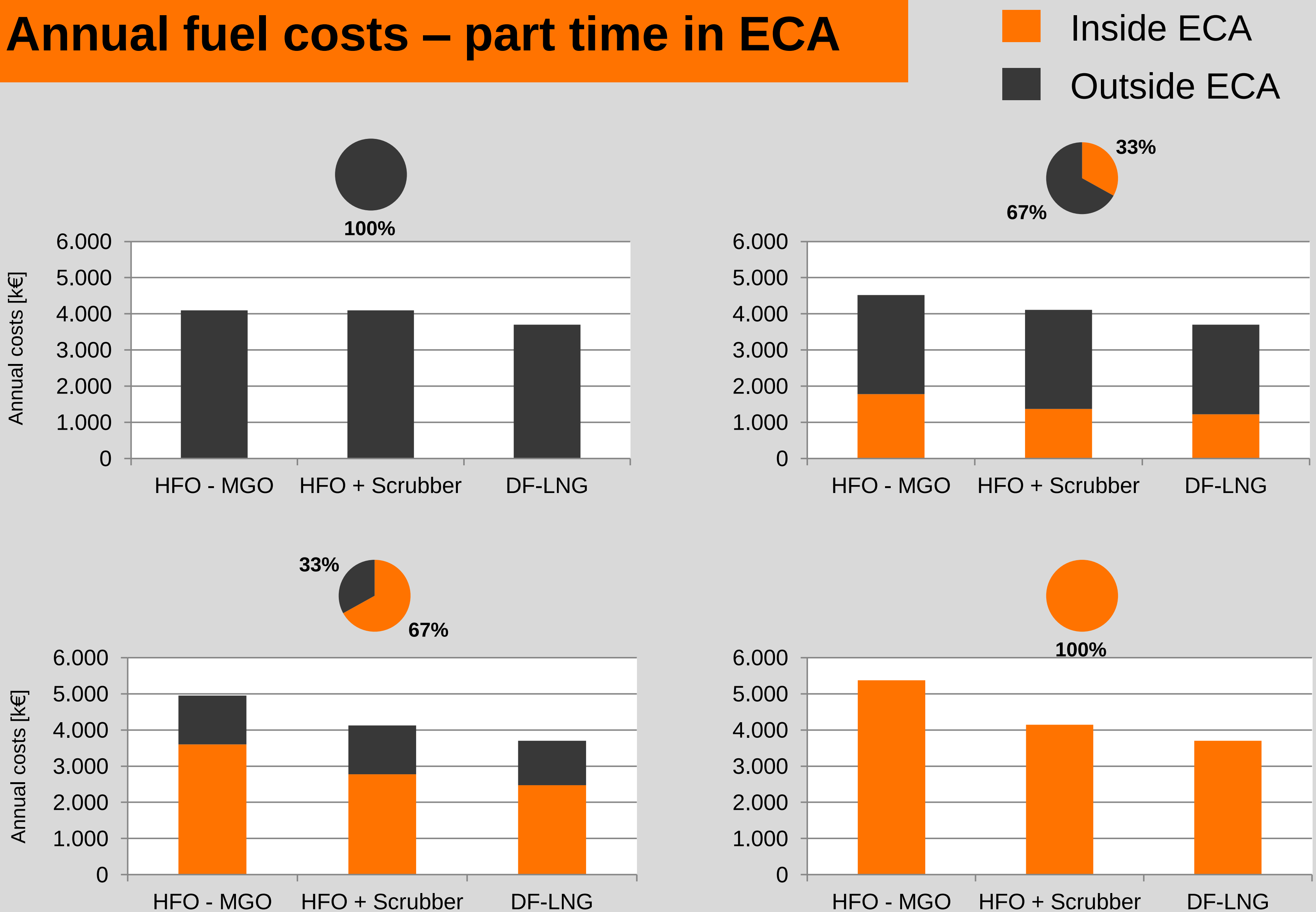


3. **DF - LNG**
   - Operates on LNG all the time
   - No exhaust cleaning needed



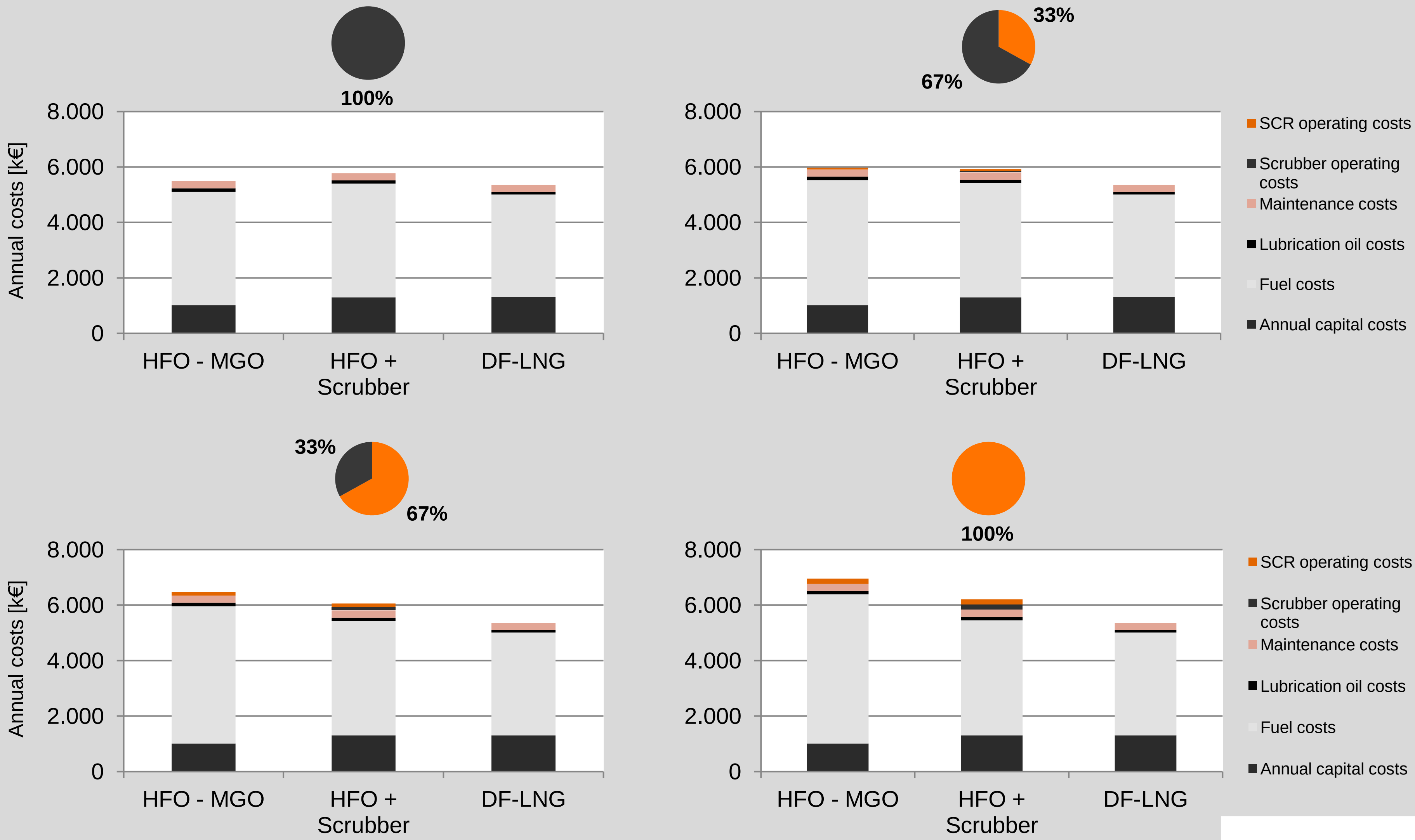
WÄRTSILÄ

Annual fuel costs – part time in ECA



Annual costs – part time in ECA

Inside ECA
Outside ECA



Conclusions

DF engines – a well proven technology

DF engines running on LNG has great potential

- Best NPV
- Lowest emissions
- Short payback time