Holistic Solutions for Environmental Compliance

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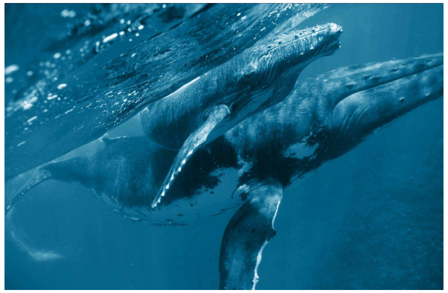
Contents



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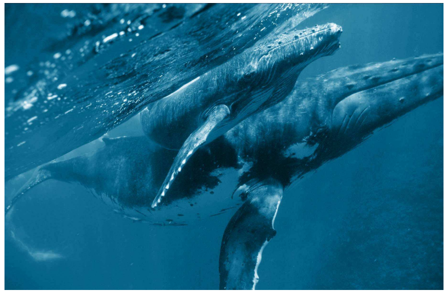
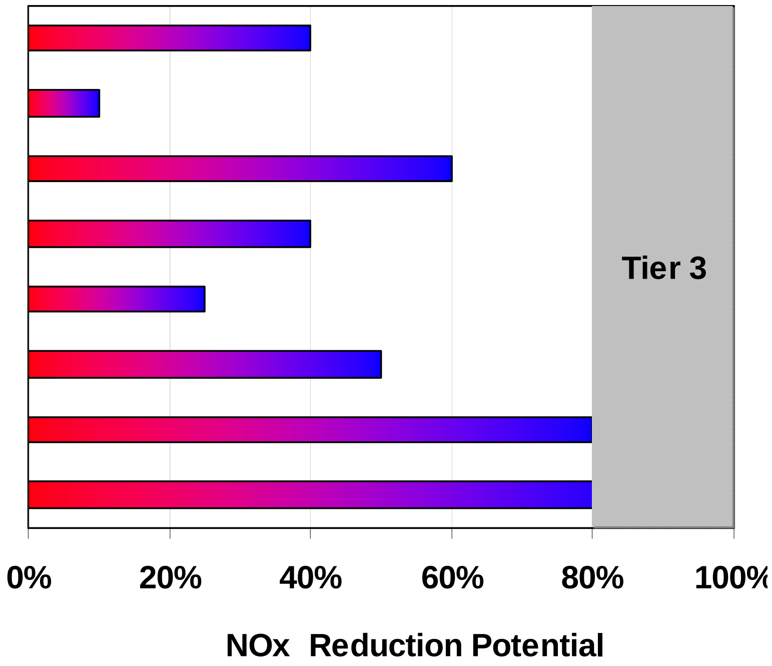
Contents



- *Overview of Emission Control Technologies and Combinations*

Available and Potential NOx Reduction Technologies

- High pressure TC sys. (2-stage) (ca. NOx -40%)
- Low NOx combustion tuning (ca. NOx -10%)
- EGR system (ca. NOx -60%)
- Wetpac H - Charge air hum. (ca. NOx -40%)
- Wetpac E - Water Fuel Emulsion (ca. NOx -25%)
- Wetpac DWI - Direct Water Inj. (ca. NOx -50%)
- NOR (SCR) system (ca. NOx -80%)
- Gas engine and Fuel conversion (ca. NOx -85%)



Available and Potential NOx Reduction Technologies: 4-stroke Solutions

CANDIADATE Tier III Combinations (4-s)	PROS (+)	CONS (-)
Nitrogen Oxide Reducer	- Known technology - Engine efficiency	- Urea handling/price - Exh.gas temp limitation
2-stage + Wetpac/EGR	- Engine efficiency - No NOR / Urea	- Water handling/price - EGR / fuel compatibility - Part load soot emission
Dual Fuel / DF + fuel conversion	- Known technology - Engine efficiency	- On board gas system - Reformer technology - Liquid mode efficiency
EGR (ext.) + Wetpac	-No 2-stage -No NOR / Urea	- Water handling/price - EGR / fuel compatibility - Part load soot emission
2-stage + NOR	- Urea consumption - Engine efficiency	- NOR operation with low gas temperature

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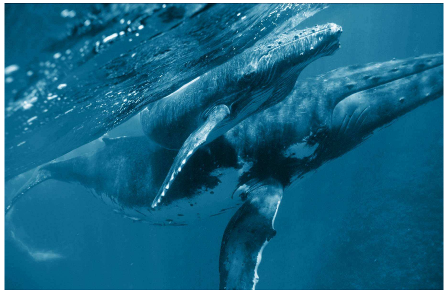
Contents



- *Wärtsilä NOR System for NOx Reduction*

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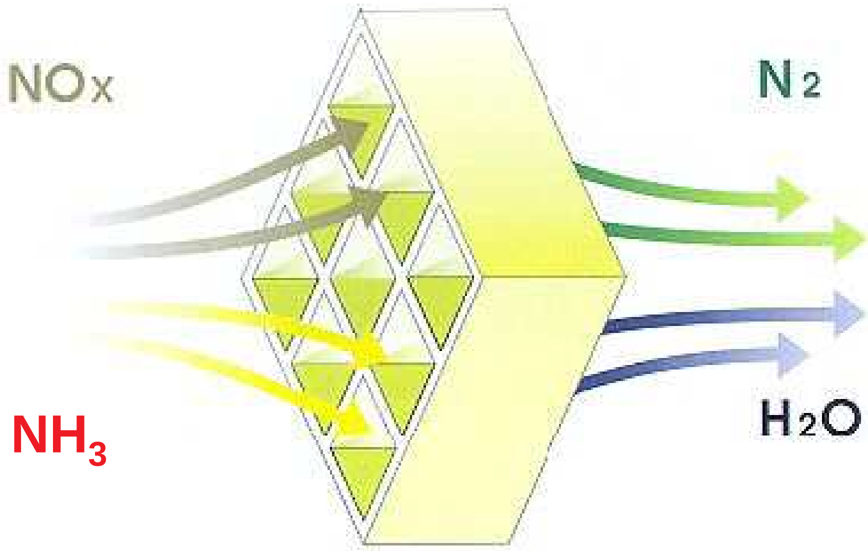
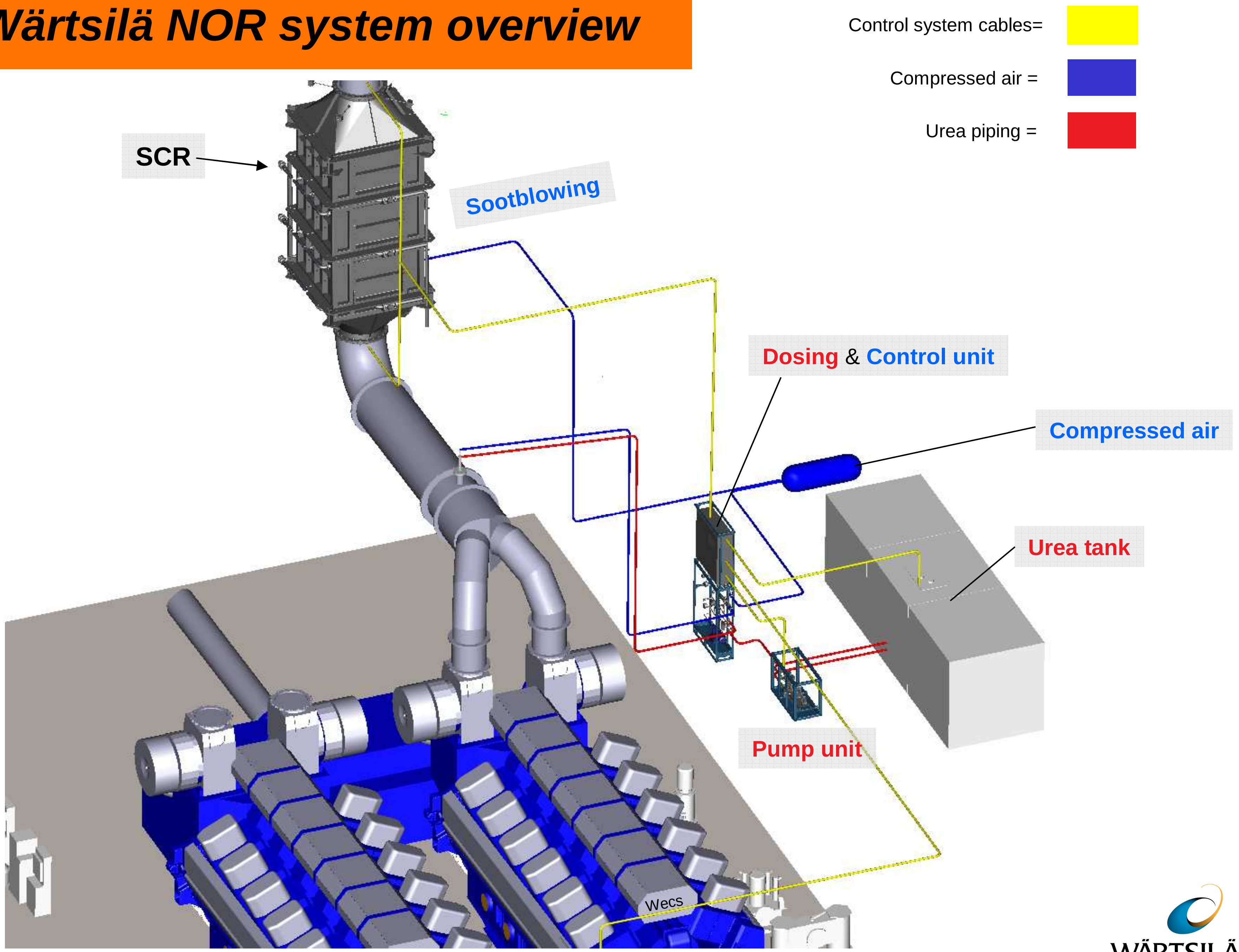
SCR catalyst operation principle



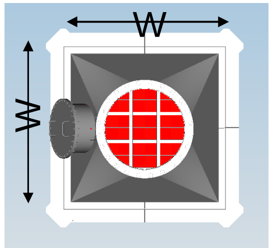
Wärtsilä NOR system overview

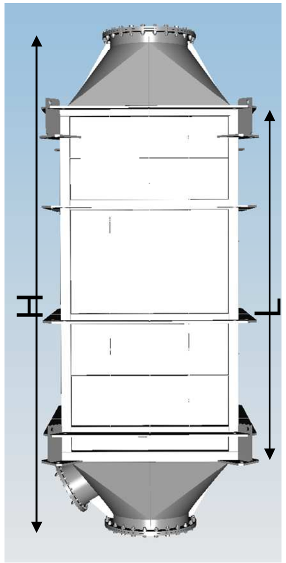


Selection of NOR Reactor for Wärtsilä Engines

WÄRTSILÄ NOR OVERALL DIMENSION TABLE

Size	Engine Power kW	Reactor W mm	Reactor H mm	Reactor L mm	Flanges DN mm	Dosing Unit Size
1	←1260	945	4505	3440	500	1
2	1261 - 2240	1260	4690	3440	700	1
3	2241 - 3500	1575	5045	3440	800	1
4	3501 - 5040	1890	5215	3440	1000	1
5	5041 - 6860	2205	5410	3440	1200	1
6	6861 - 8960	2520	5915	3440	1300	2
7	8961 - 11340	2835	6110	3440	1500	2
8	11341 - 14010	3150	6485	3440	1600	2
9	14011 - 16950	3465	6685	3440	1800	2
10	16951 - 20170	3780	6885	3440	2000	2





- NOR reactor will be selected according to engine power
- Other components will be selected according to the chosen reactor size
- The design principle is that all components are to be chosen according to exhaust gas flow

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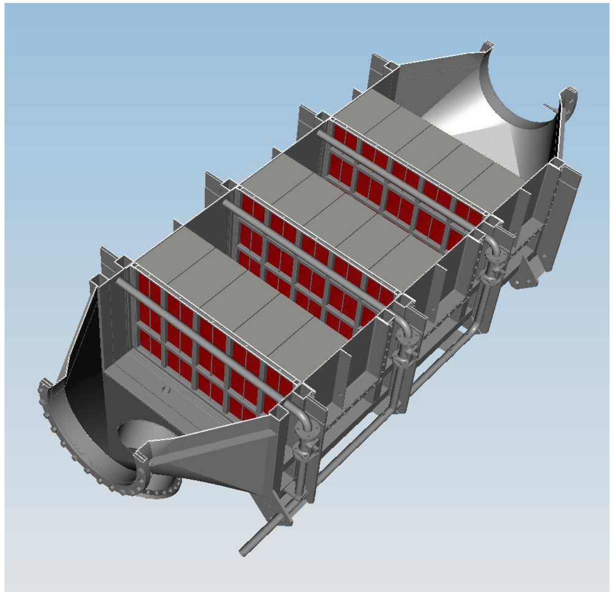
Wärtsilä NOR Performance

- High activity over a wide temperature range
- Efficient SCR process
- Durable catalyst against ageing and erosion



Performance	**NOx below IMO Tier III** NOx reduction up to 90 %
Urea consumption	Typically 15-20 l/h / MW
Operation	▫ Fuels: MGO / MDO / HFO (< 1.0 % S) ▫ Next NOR generation can operate with high sulphur fuels for combination with scrubbers ▫ NOR delivery means ensuring the compatibility of the NOR system with the engine.

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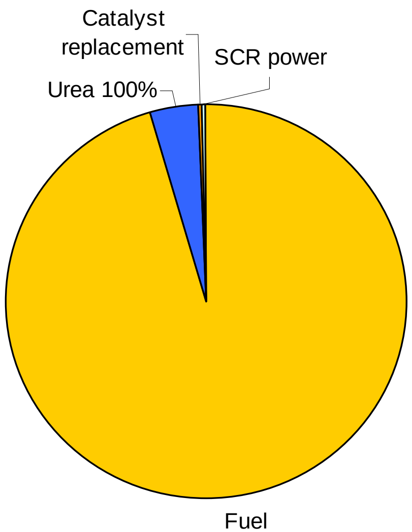
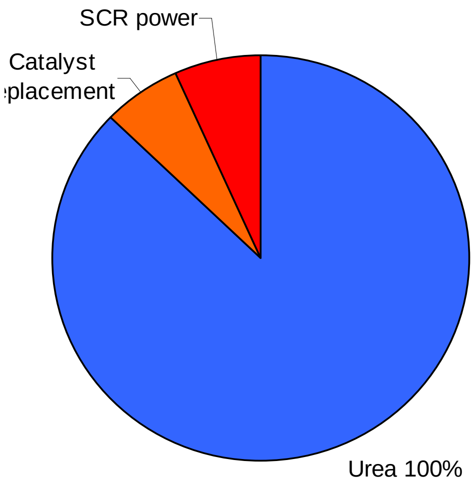
SCR System - Typical Consumables

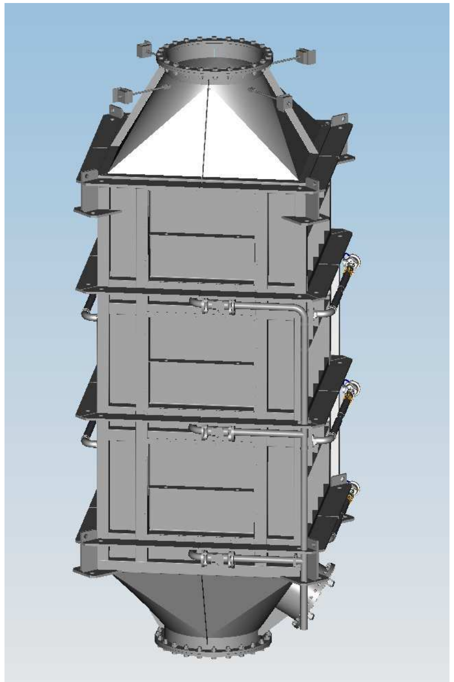
TYPICAL OPERATION COST DISTRIBUTION





1. Reducing agent
2. Compressed air for reducing agent injection
3. Compressed air for soot blowing
4. Power for NOx monitoring, if used (not in standard scope)
5. Air conditioning of cabinets
6. Catalyst element
7. Other

SCR References



- More than 200 Wärtsilä engines with SCR are in operation today, Marine and Stationary Power plants – 4-stroke and 2-stroke

SCR with 2-stroke Engines

First two-stroke Selective Catalytic Reduction
Marine Installation Worldwide:

- Engines: Main engine 1 x Sulzer 7RTA52U
  Auxiliary Engines 2 x Wärtsilä 6L20
- Vessels: M/V “Spaarneborg”
  M/V “Schieborg”
  M/V “Slingeborg”
- Type of ship: RoRo
- Owner: Wagenborg
- 1st vessel in service since December 1999

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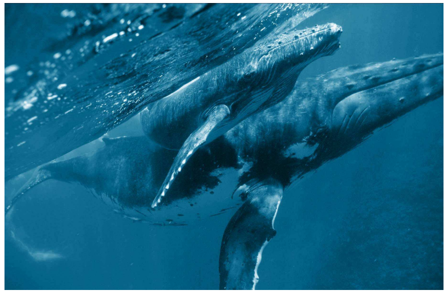
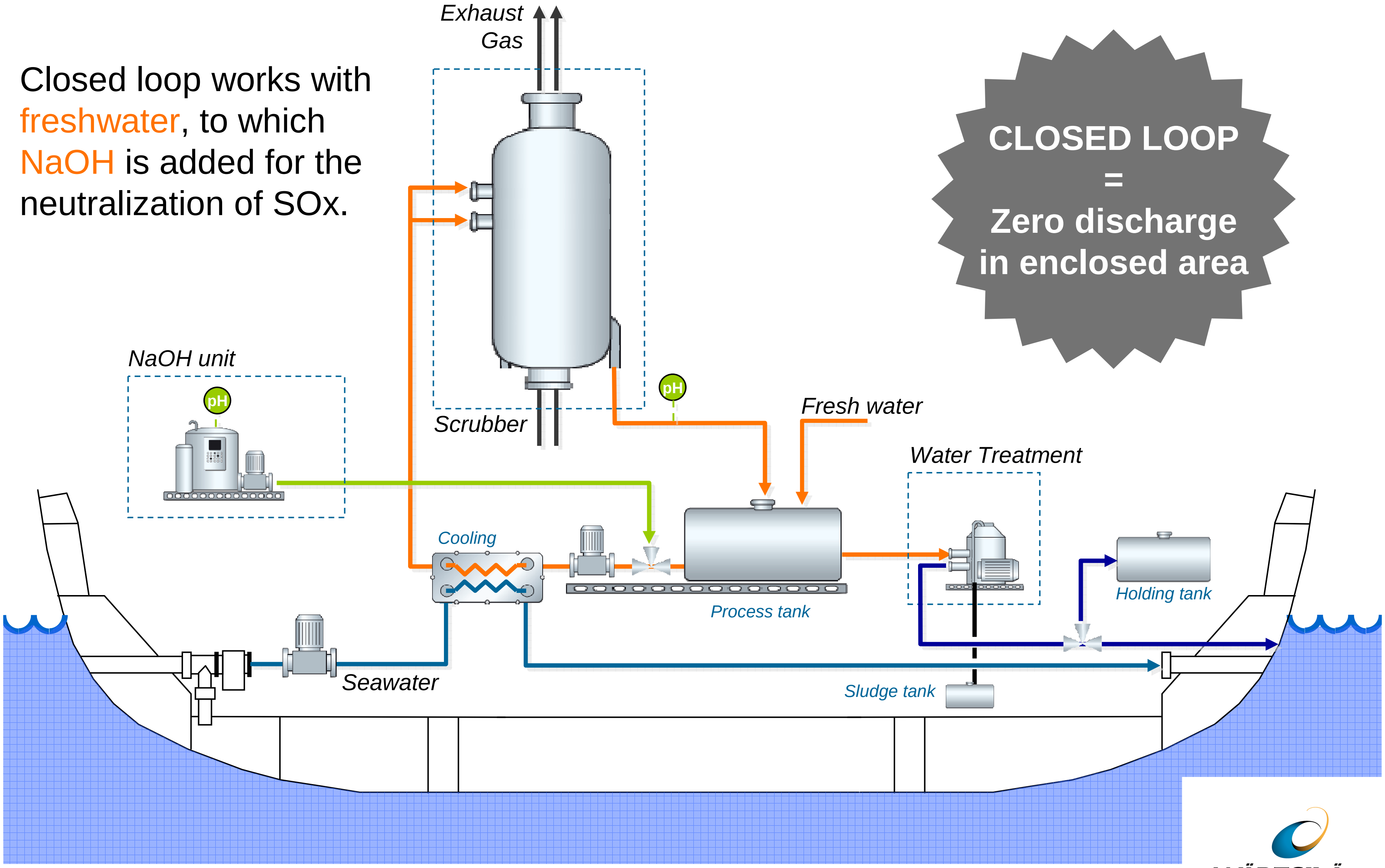
Contents



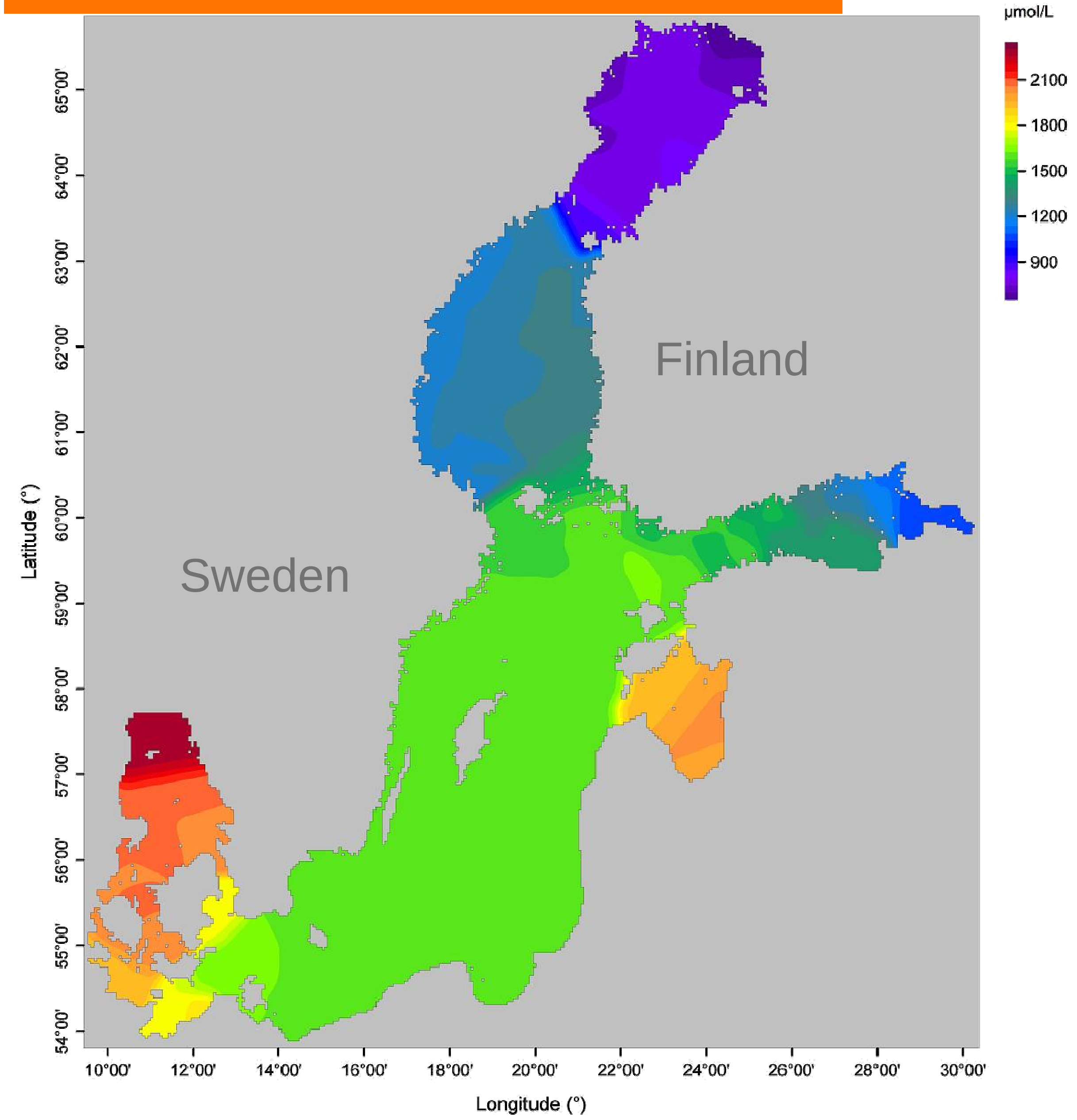
- Wärtsilä Scrubber System for SOx Reduction

After Engine - SOx Reduction with SOx Scrubber

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



Alkalinity in the Baltic Sea



Open sea alkalinity

Surface data (0… 15 m)

Data from 2001-2005

NaOH Consumption & Storage Capacity

NaOH consumption (a few % of fuel consumption) depends on:

- Fuel sulfur content
- SOx reduction

NaOH storage capacity depends on:

- Power profile
- Desired autonomy (bunkering interval)

- **10 MW** engine
- 85% MCR
- 2.7% sulphur in fuel
- Cleaning efficiency 97%
- 50% NaOH solution

- NaOH consumption 3.2 m^3/day
- (Fuel oil consumption ~48 m^3/day)

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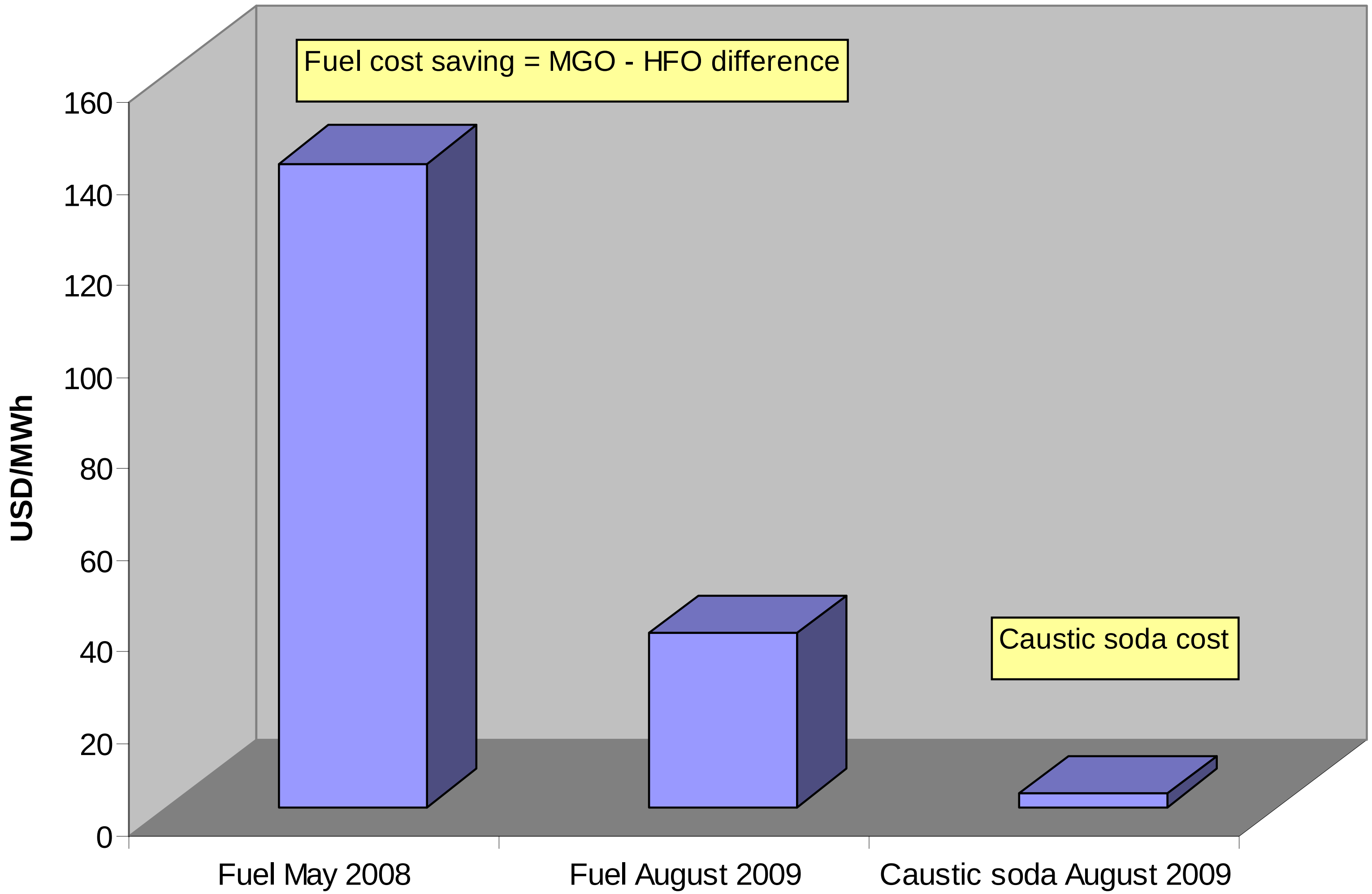
NaOH Costs Insignificant Compared with Fuel Cost Savings

Fuel cost saving versus caustic soda costs



Test Results from Wärtsilä SOx Scrubber

Wärtsilä scrubber on Neste Oil MT "Suula" with a 4R20 auxiliary engine rated at 680 kW.

• Tests in 2008-2009, including certification.
• Tests on HFO with 3.4% sulphur and HFO of 1.5% sulphur

Test results

- SOx removal > 99% in all operating conditions
- (NOx reduction: 3 – 7%)
- (Particle matter reduction: 30 – 60%)

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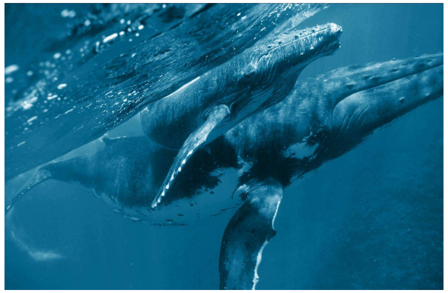
Wärtsilä Scrubber – Running on HFO June 2009

Contents



- Waste Heat Recovery for Reduction of CO_2 and Fuel Consumption

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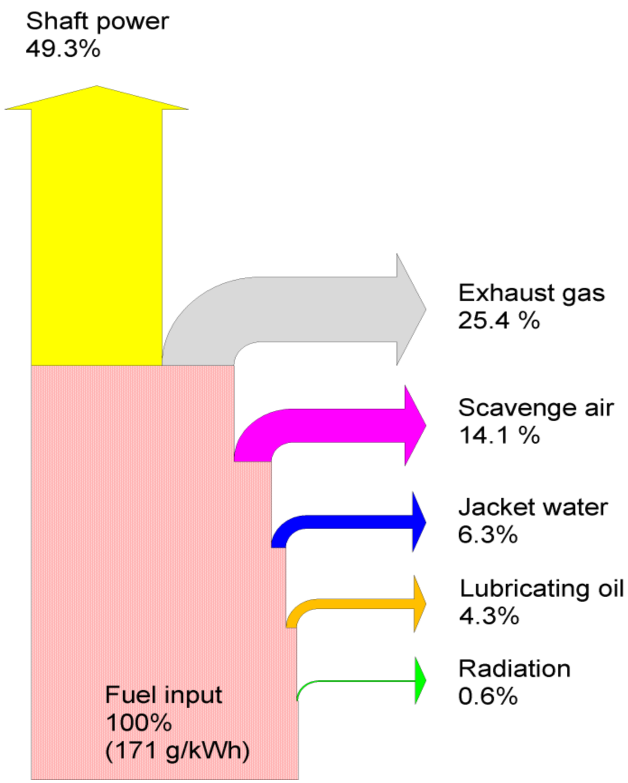
Heat Recovery Application for Marine Propulsion Engines

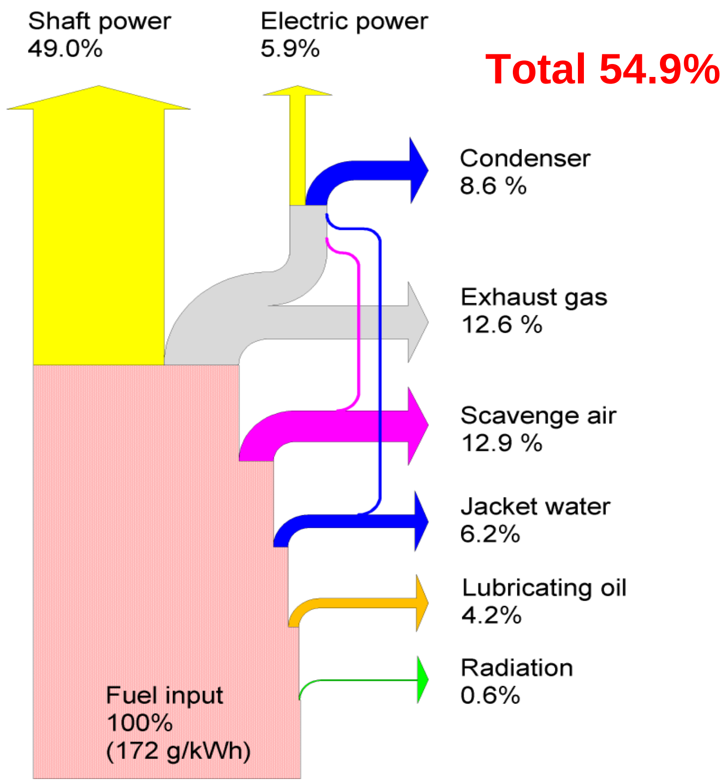
Heat Balance RTA96C Engine

ISO conditions, 100% load

Heat Balance Standard Engine

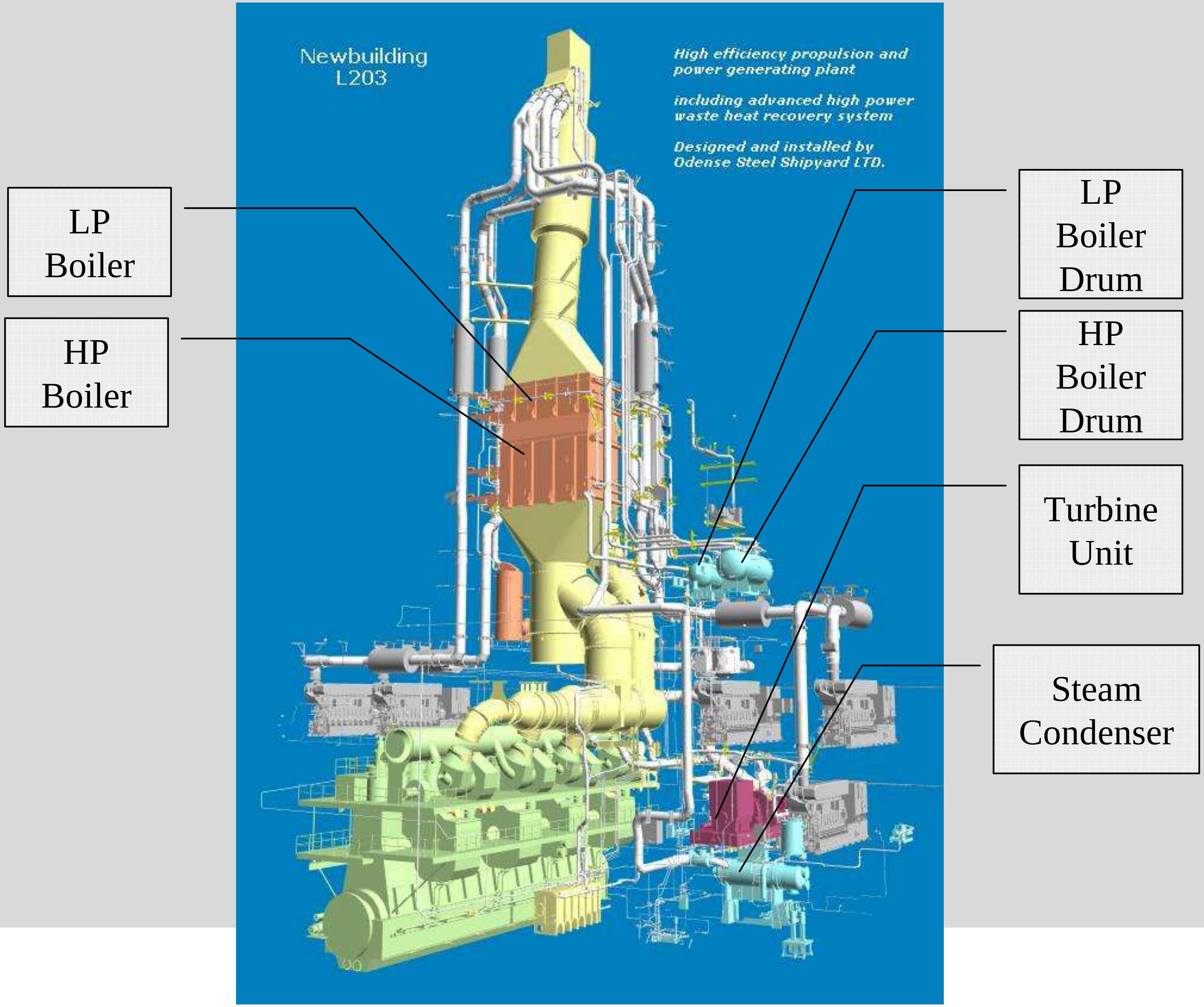


Heat Balance with Heat Recovery



Engine efficiency improvement with heat recovery = 54.9 / 49.3 = **11.4%**

Waste Heat Recovery Systems



Waste Heat Recovery

WHR system references:

6 Post-Panamax container vessels of the “Gudrun Mærsk” class for A.P.Moller with 12 RT-flex96C engines. First vessel commissioned in June 2005.

8 Post-Panamax container vessels of the “Emma Mærsk” class for A.P. Moller with 14RT-flex96C engines. First vessel commissioned in September 2006.

6 **Post-Panamax container vessels** of the “Margrethe Mærsk” class for A.P.Moller with 12RT-flex96C engines. First vessel commissioned in April 2008.

2 VLCC’s for Bergesen Worldwide with 7RTA84T-D engines. Vessel delivery in 2009.

2 VLCC’s for SAMCO with 7RT-flex82T engines. Vessel delivery in 2011.

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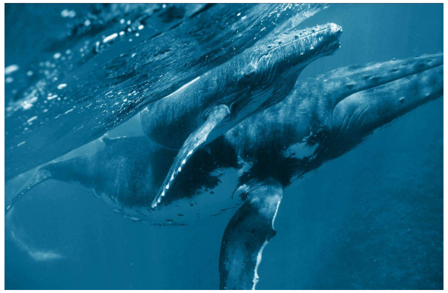
Engine Combined Cycles - ECCs

Wärtsilä Engine Combined Cycle Solutions on Stationary Power Plants

- First ECC project for Wärtsilä was in <u>1990 to Ringgold</u>, 3 x 18V32GD
- Totally <u>10 projects under delivery</u>, among them:
  - Attock Refinery, Pakistan 9 x W18V46
  - Nishat Power, Pakistan 11 x W18V46
  - Nishat Chunian Power 11 x W18V46
  - IGE (Monopoli), Italy 6 x W18V46 LBF
  - Fri-El, Italy 4 x W18V46 LBF
  - Green Energy, Italy 1 x W18V46 LBF
  - Liberty Power, Pakistan 11 x W18V46
  - Attock II, Pakistan
  - Etc.

Contents

- Gas Engine Alternative



Natural Gas as Fuel - Gas Engine Technologies

Gas-diesel (GD) engines:

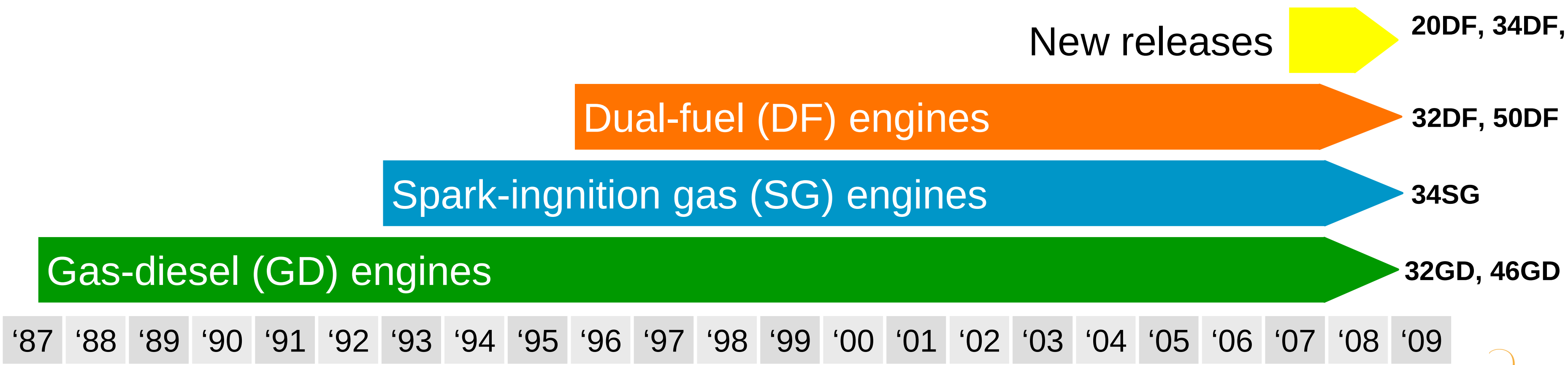
- Runs on various gas / diesel mixtures or alternatively on diesel.
- Combustion of gas, diesel and air mixture in Diesel cycle.
- High-pressure gas injection.

Spark-ignition gas (SG) engines:

- Runs only on gas.
- Combustion of gas and air mixture in Otto cycle, triggered by spark plug ignition.
- Low-pressure gas admission.

Dual-fuel (DF) engines:

- Runs on gas with 1% diesel (gas mode) or alternatively on diesel (diesel mode).
- Combustion of gas and air mixture in Otto cycle, triggered by pilot diesel injection (gas mode), or alternatively combustion of diesel and air mixture in Diesel cycle (diesel mode).
- Low-pressure gas admission.



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Gas Engine Alternative
Dual-Fuel Engine Characteristics

Wärtsilä 6L50DF

- **High efficiency**
- **Low emissions, due to:**
  - High efficiency
  - Clean fuel
  - Lean burn combustion
- **Fuel flexibility**
  - Gas mode
  - Diesel mode
- **Two engine models**
  - Wärtsilä 32DF
  - Wärtsilä 50DF

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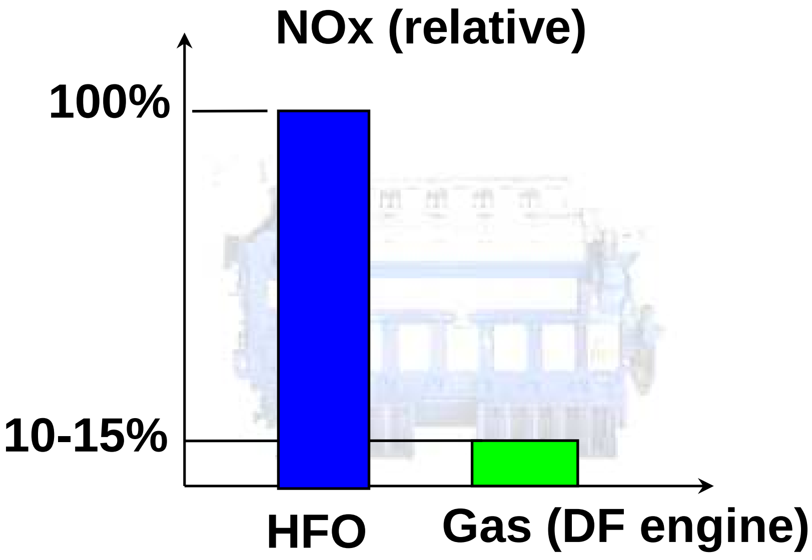
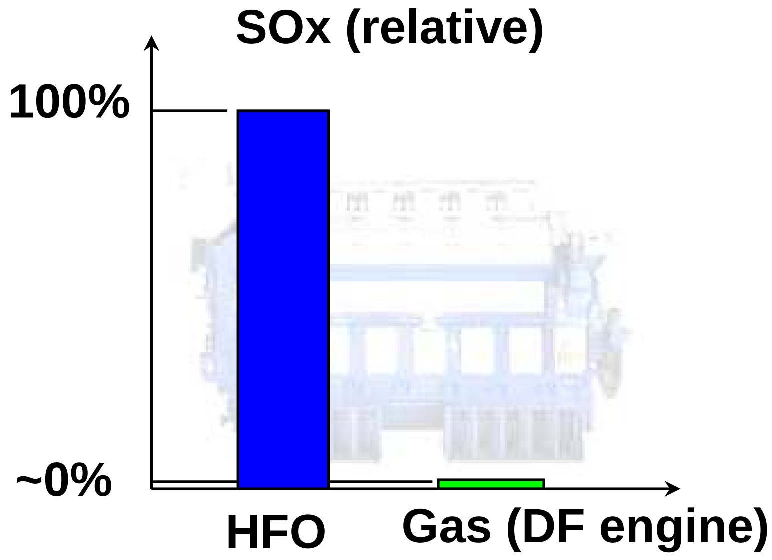
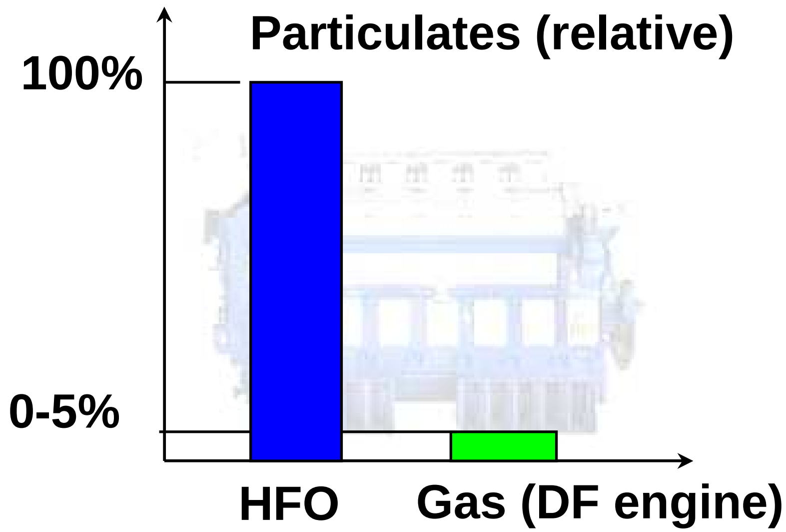
Gas Fuel Alternative – Typiacl NOx, SOx and Particulates Emissions – HFO versus Gas Fuel

In gas mode the DF engine meets the IMO Tier III regulation already today







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Examples of gas (dual-fuel) engine references

Petrojarl 1
FPSO
Petrojarl
2x 18V32DF
2x 52’000 running hours

Sendje Ceiba
FPSO
Bergesen
1x 18V32DF
38’000 running hours

Viking Energy
DF-electric offshore supply vessel
Eidesvik
Kleven Verft
4x 6R32DF
4x 49’500 running hours

Stril Pioner
DF-electric offshore supply vessel
Simon Møkster
Kleven Verft
4x 6R32DF
4x 46’500 running hours

Provalys and Gaselys
DF-electric LNG Carrier
Gaz de France
Alstom Chantiers de l’Atlantique
2x 12V50DF + 2x6L50DF
Total 92’000 running hours for 2 ships

Gaz de France energY
DF-electric LNG Carrier
Gaz de France
Alstom Chantiers de l’Atlantique
4x 6L50DF
Total 58’000 running hours

British Emerald
DF-electric LNG Carrier
BP Shipping
Hyundai Heavy Industries
2x 12V50DF + 2x9L50DF
Total 54’000 running hours

Totally 62 contracted dual-fuel engine powered LNG carriers whereof 30 delivered

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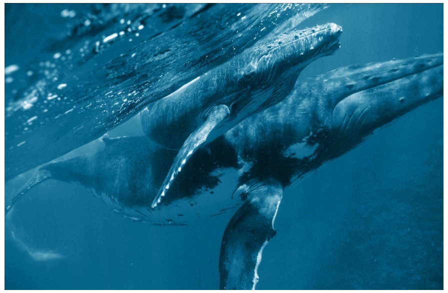
Contents



❑ Some Holistic Challenges

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Some Holistic Challenges

- ***Operation flexibility***
  - ***Switching of operational modes when crossing boarder lines of Emission Control Areas***
- ***Exhaust gas temperature from engine***
  - **High enough for NOR (SCR) operation over a broad load range.**
  - **Higher the better for waste heat recovery**
- ***Cooling water temperatures***
  - **Higher the better for waste heat recovery**
- ***Backpressure***
  - **Engine to allow higher backpressure. Often the inevitable consequence of installing several exhaust gas cleaning devices and boilers in series in the exhaust gas pipe is increased backpressure**
- ***Location of equipment***
  - **Engine + NOR (SCR) + boiler + Silences +SOx scrubber**

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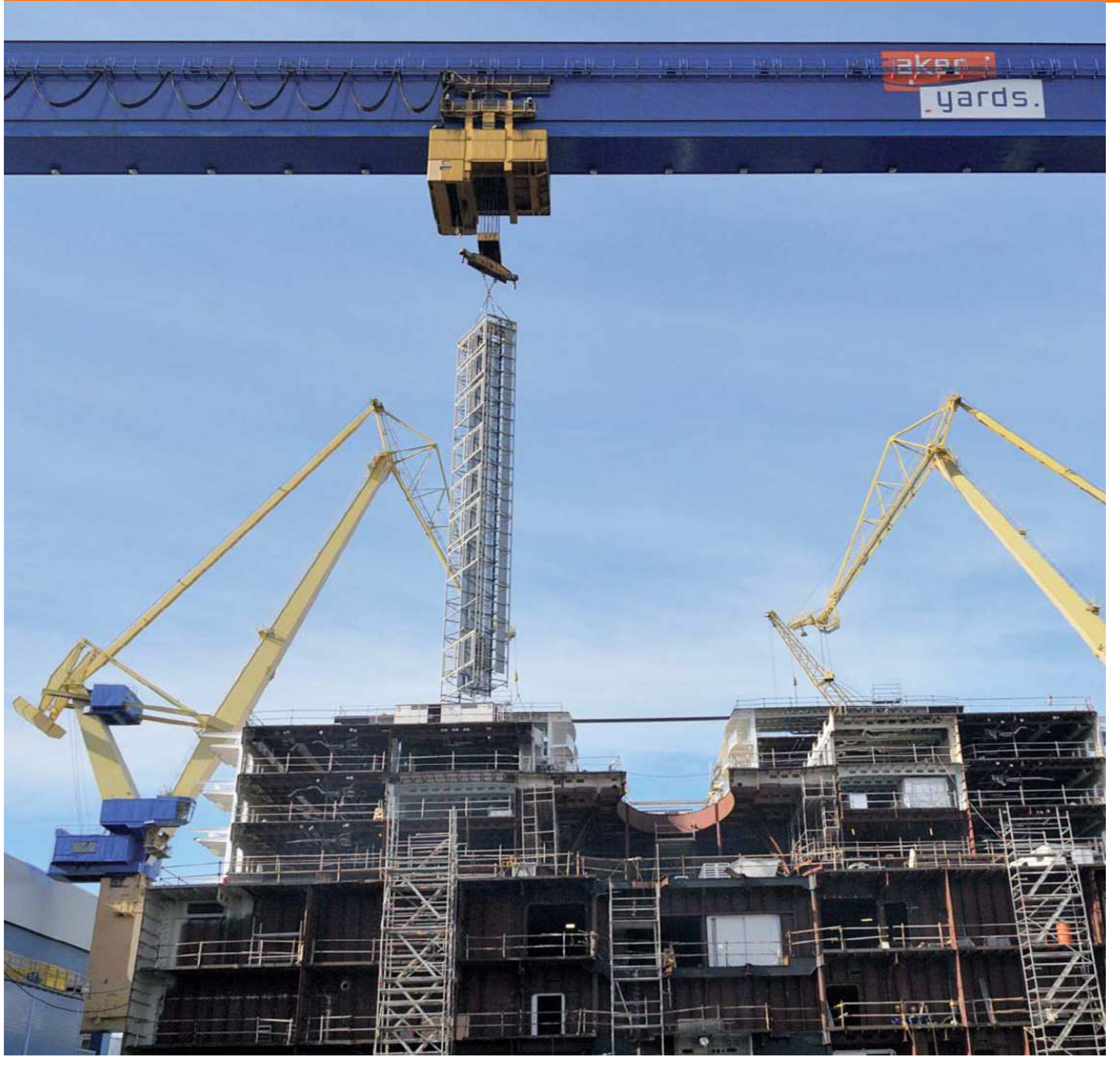
Vision: Integrated modules under Development



Wärtsilä pre-fabricated exhaust treatment module lifted into a ship at the yard.

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Thank You

for Your Attention!