Hitachi Zosen
Technology and Business Innovator

NOx Reduction Technologies for 2-stroke Diesel Engines to Meet IMO Tier III

6th Asian Shipbuilding Expert's Forum, Guangzhou, November 22, 2012

Takahiro Fujibayashi
Hitachi Zosen Corporation, Japan

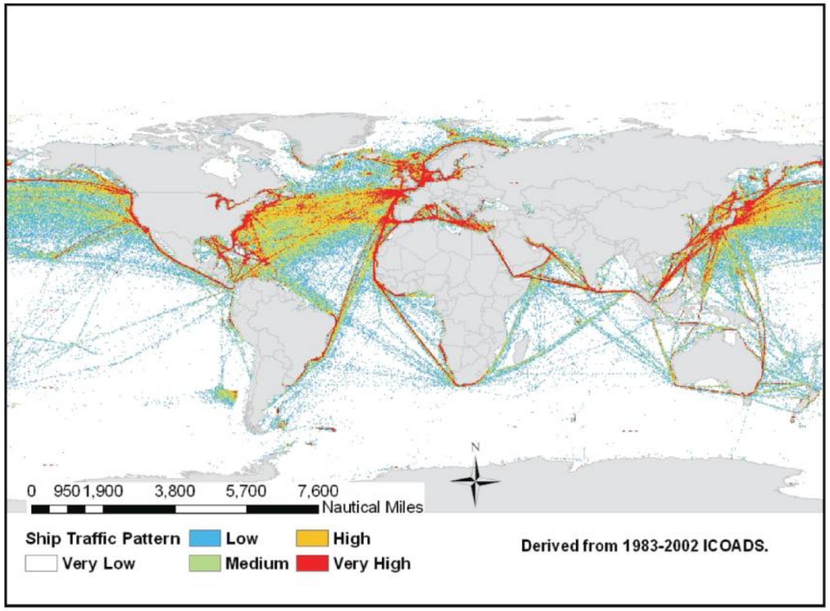
Topics

1. ***Regulation – IMO NOx Tier III***
2. ***Exhaust gas recirculation***
3. ***Selective catalytic reduction***
4. ***Summary***

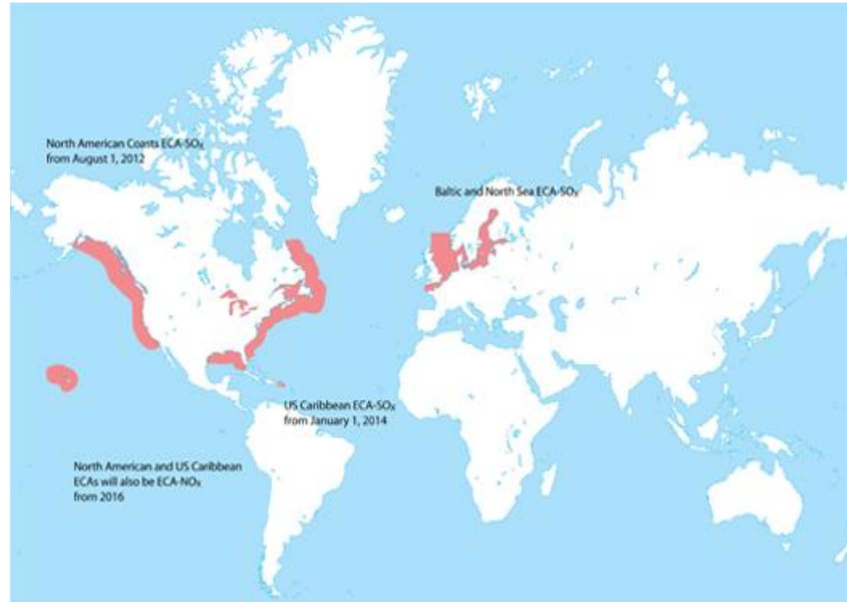
Regulation

Emission Control Areas

- **High traffic areas**



- **Map – ECAs fixed**



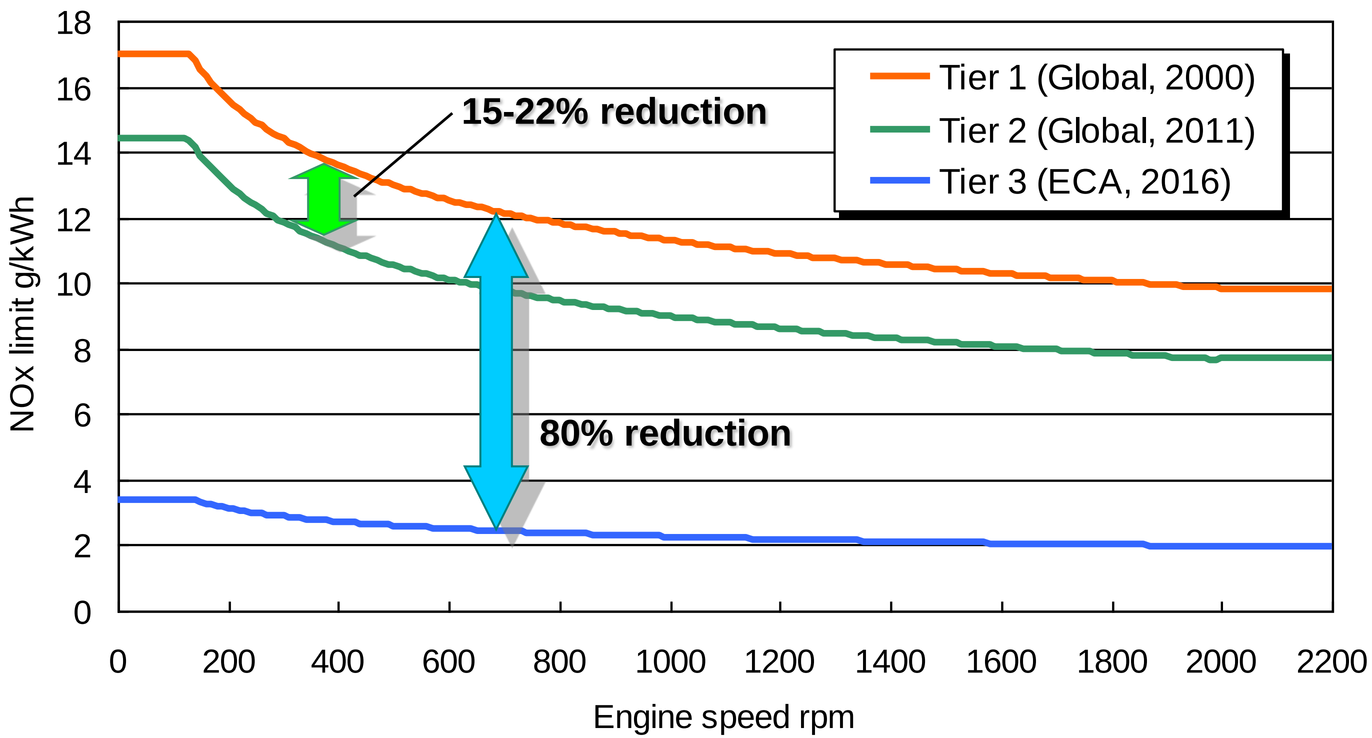
Source: "Understanding exhaust gas treatment systems", LRS

- **ECAs fixed (existing and coming)**

ECA (Annex VI: Prevention of air pollution by ships)	In Effect From
Baltic Sea (SOx)	**19 May 2006**
North Sea (SOx)	**22 Nov 2007**
North America (SOx and NOx)	**1 Aug 2012 (NOx from 2016)**
United States Caribbean Sea ECA (SOx and NOx)	**1 Jan 2014 (NOx from 2016)**

IMO NOx Regulation Tier III

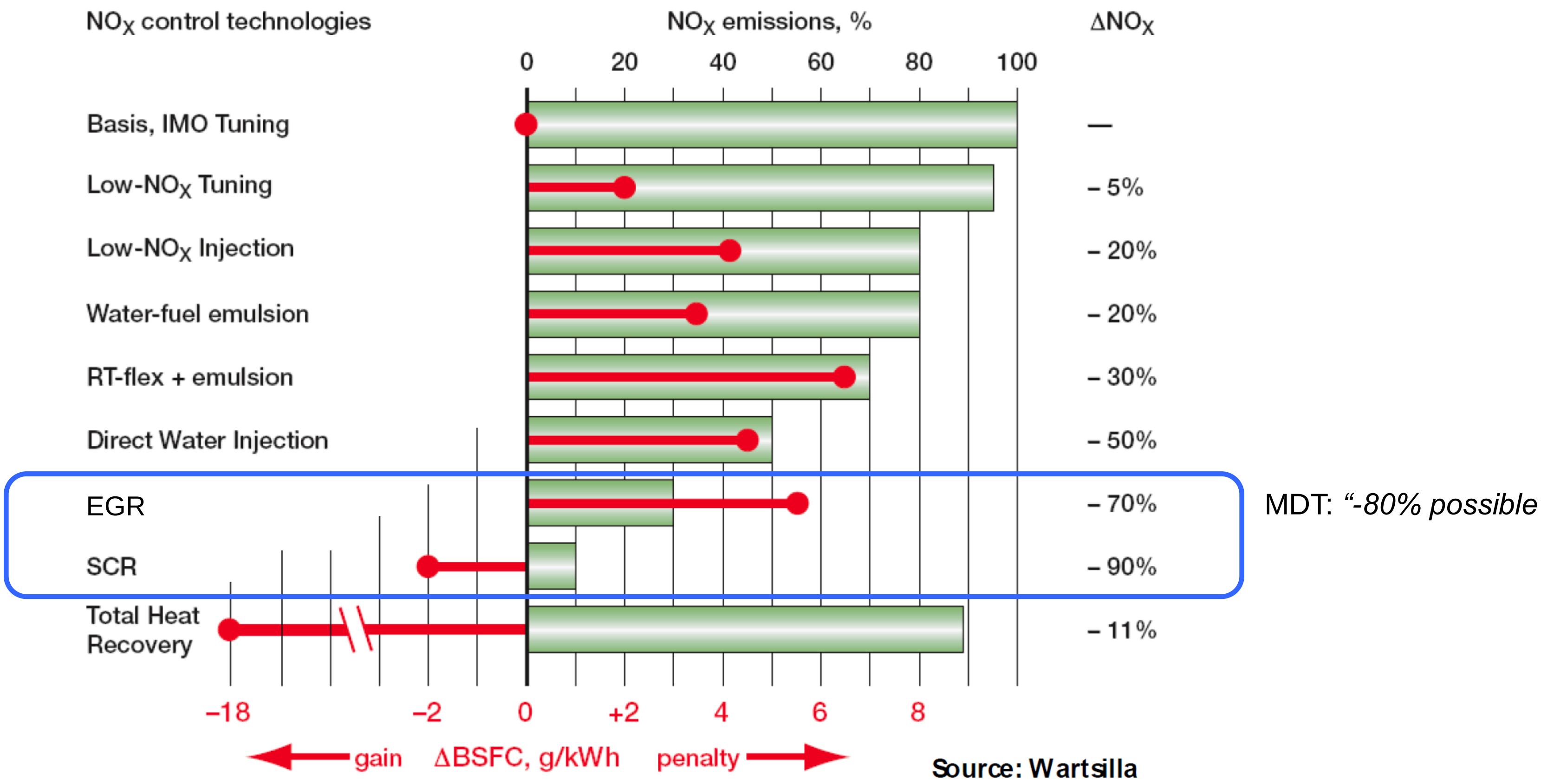
NOx limit - MARPOL Annex VI, Reg 13



- Tier 1: Low NOx atomizer, injection retard,,,
- Tier 2: Miller cycle,,,
- Tier 3: ***???*** *(Existing engine technology **not enough**)*

Techniques to reduce NOx

- Candidates, for example:



Source: 'Global: Understanding MARPOL Annex VI – the international requirements for the control of NOx and SOx emissions from ships operating globally and in Emission Control Areas' by IMO at SAE 2012, Emission Control from Large Ships

- **EGR and SCR seem able to meet Tier 3**

Consider other requirements

- Besides NOx, consider also...

EEDI (less CO_2, i.e. less FOC)

Fuel flexibility (High S with SOx scrubber)

Cost (CAPEX and OPEX)

Less space

Availability of consumables

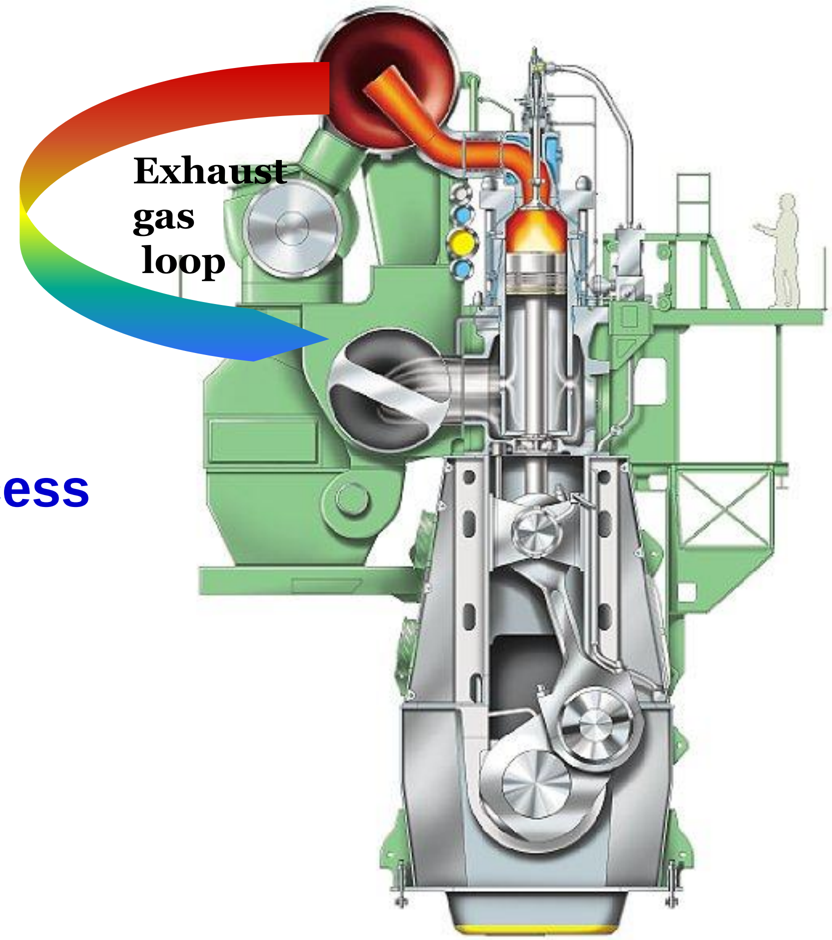
What is used for aux. engines?

EGR

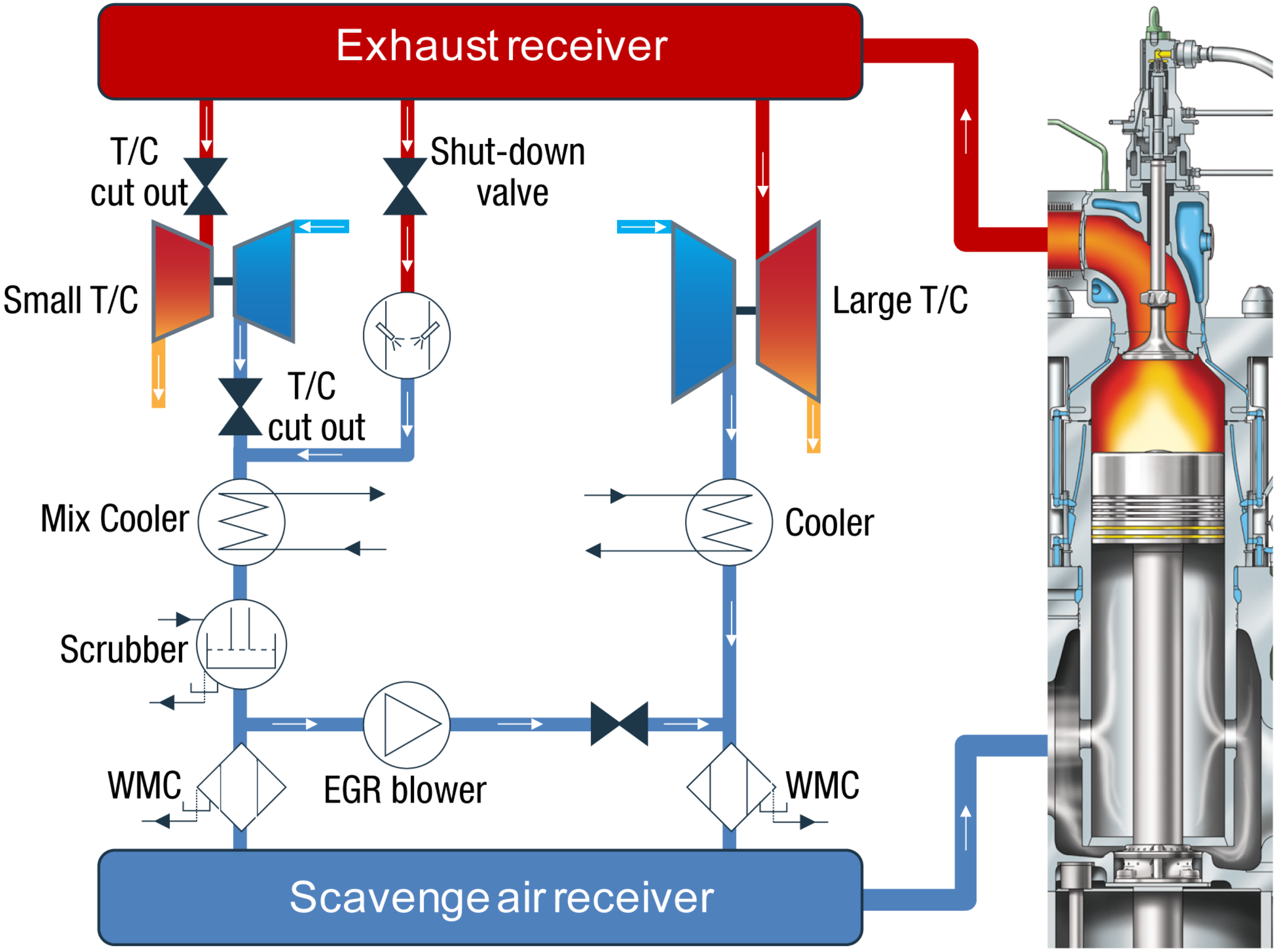
Exhaust Gas Recirculation

What is EGR?

- Recirculating a part of exh. gas as scav. air
  - More CO_2 - higher specific heat capacity
  - Less O_2 - slower combustion
  - Lower combustion temperature - less NOx
- A method **related with combustion process**



EGR system layout



Source: MDT

EGR system layout – EGR not in use

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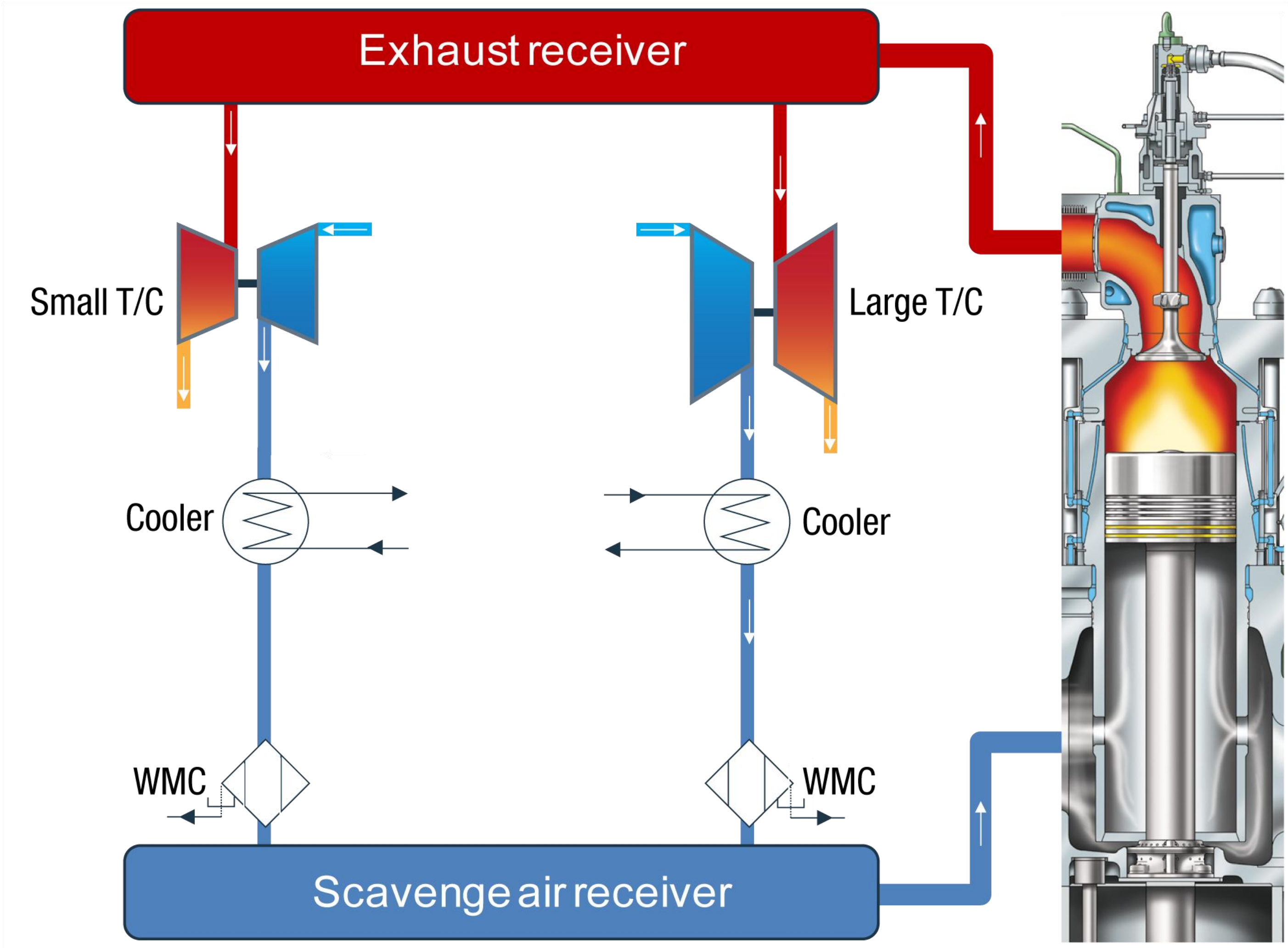
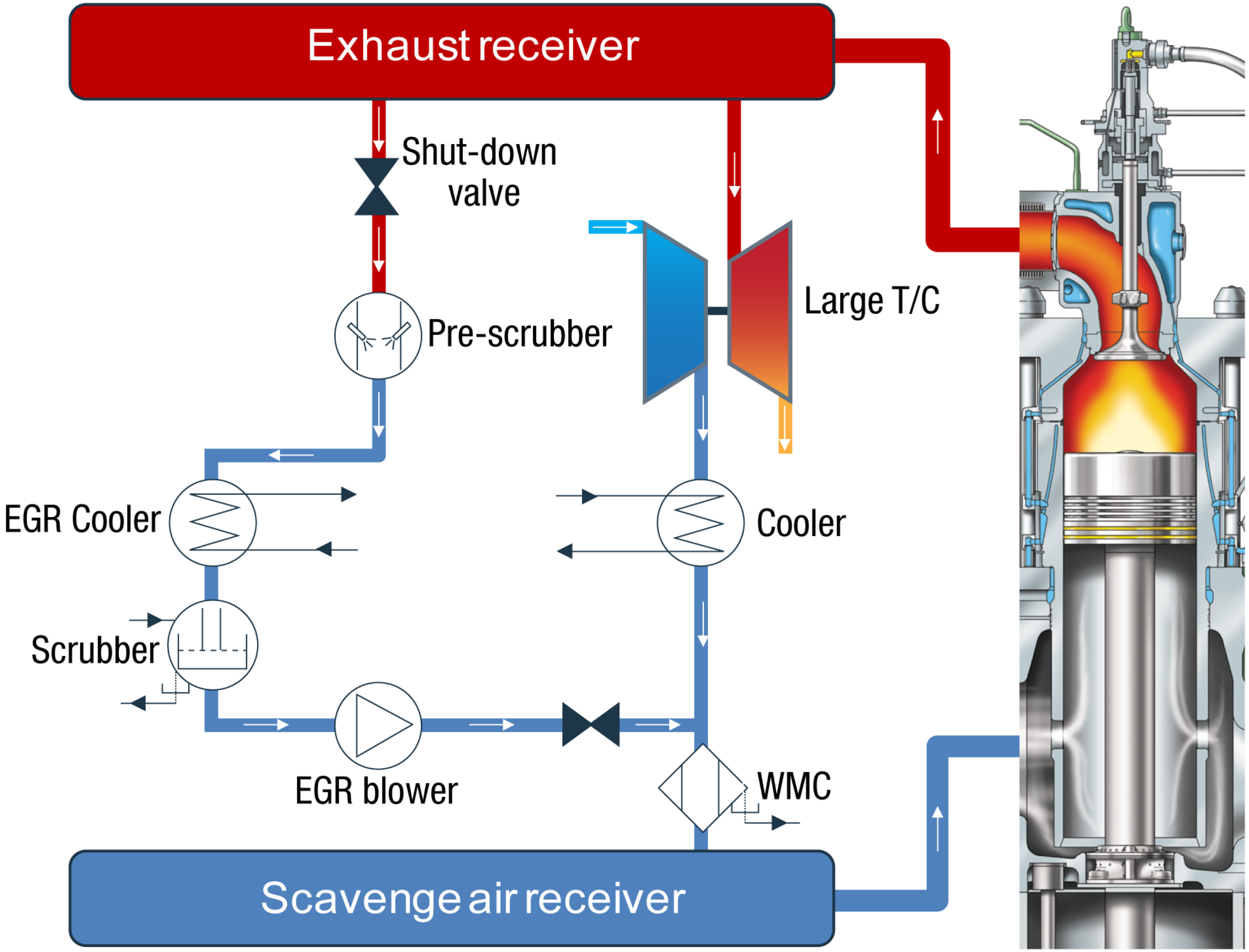


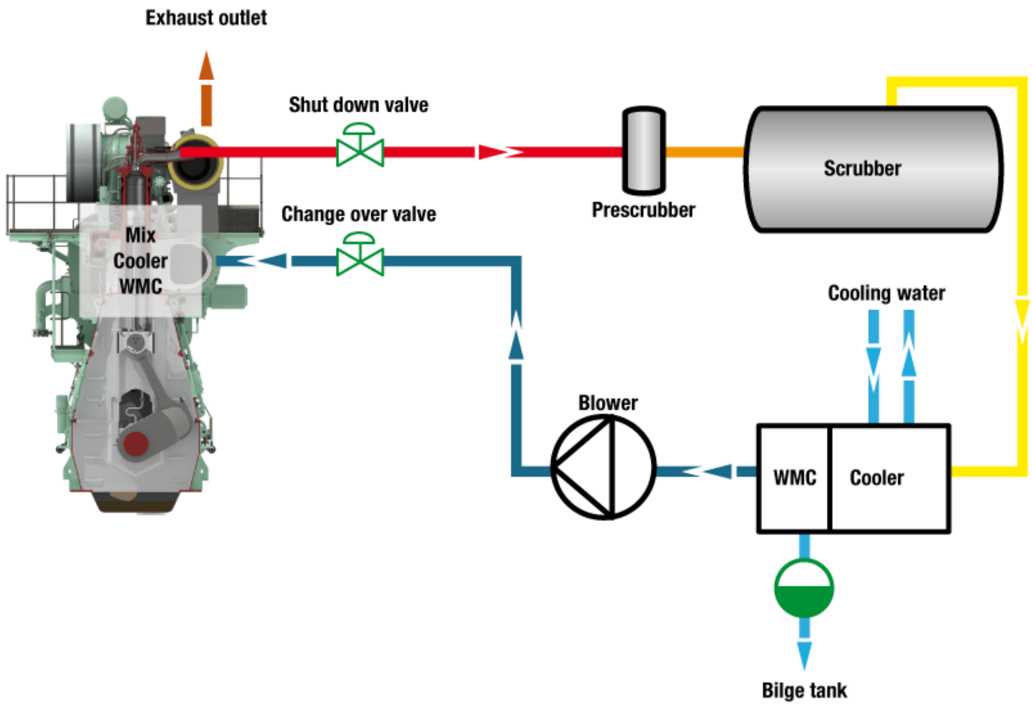
Source: MDT

EGR system layout – EGR in use



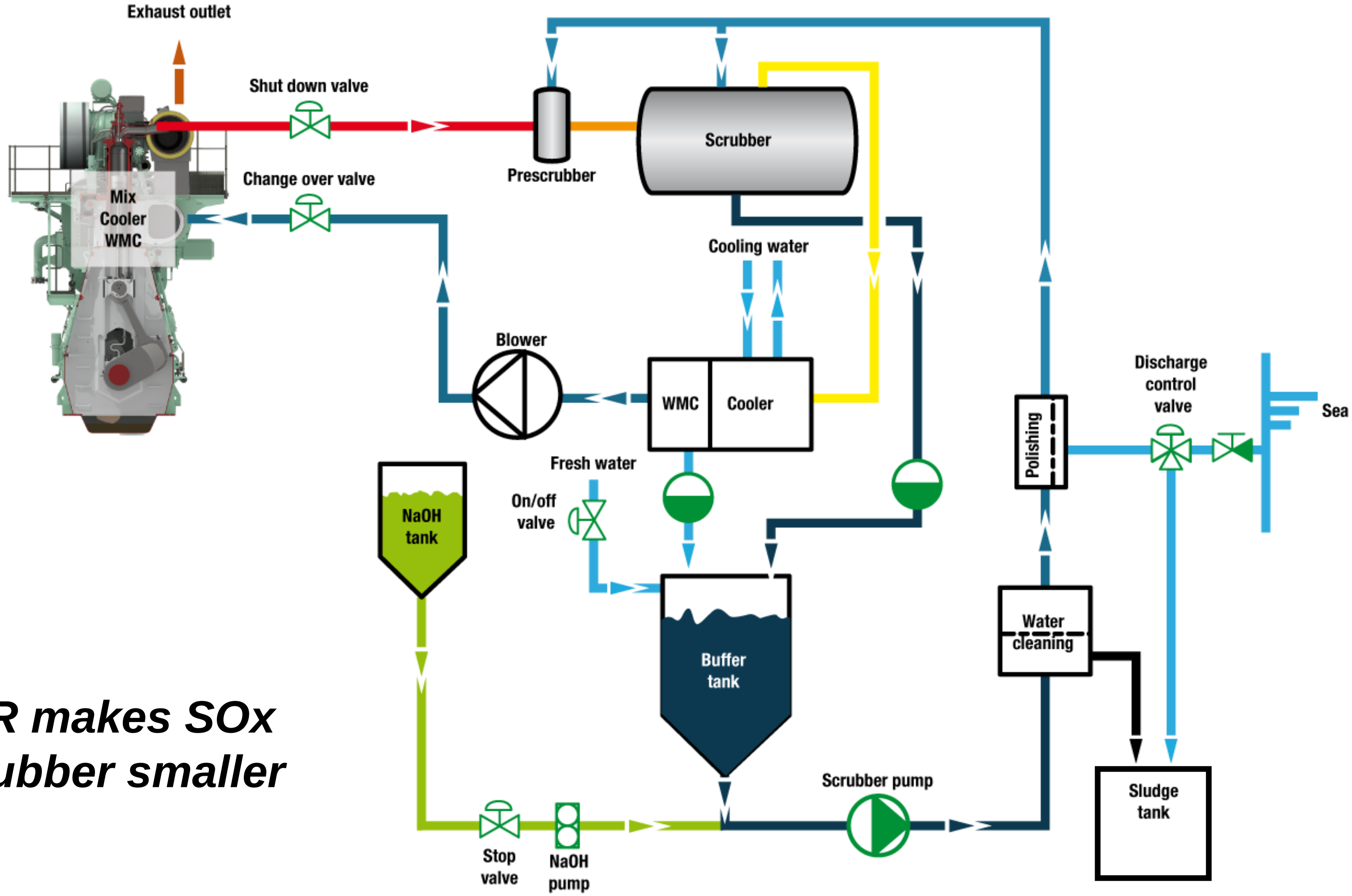
Source: MDT

EGR system layout



Source: MDT

EGR system layout with auxiliary systems

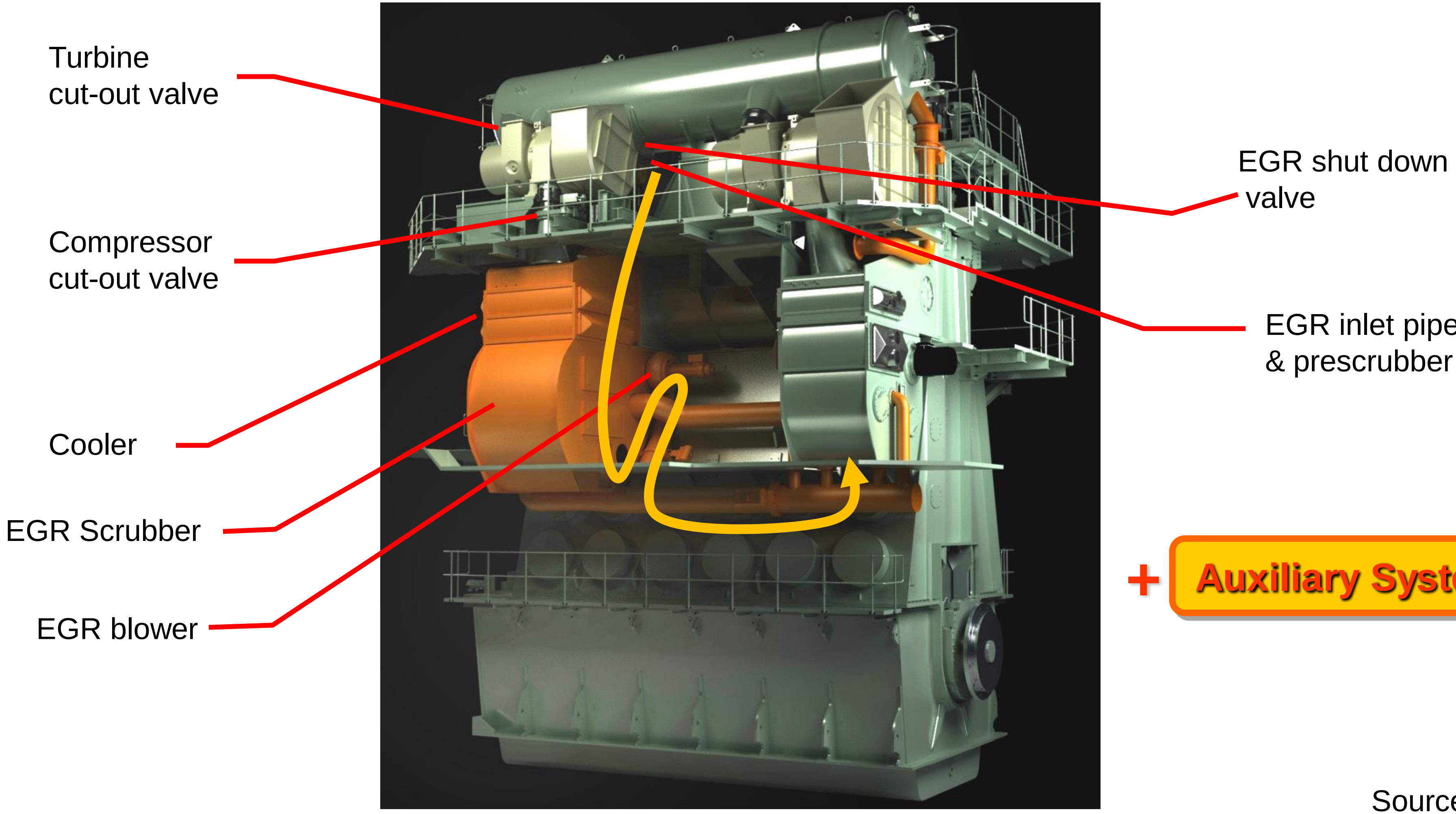


- ✓ ***EGR makes SOx scrubber smaller***

Source: MDT

Integrated EGR - MDT

S80ME-C with EGR2



+ **Auxiliary Systems**

Source: MDT

Performance of 4T50ME-X with EGR1 - MDT

	NO_x (g/kWh)	dSFOC (g/kWh)	CO (g/kWh)	Pmax (bara)	EGR rate (%)
No EGR	17.8	0	0.65	152	0
Max. EGR	2.3	+4.9	4.17	151	39
EGR ref.	3.7	+3.0	2.57	151	36
Incr. Pcomp/ Pscav	4.0	+2.5	2.18	156	36
Incr. Phyd	4.2	+2.8	1.83	151	37
Incr. Pscav	3.6	+1.9	2.12	156	37
Incr. Tscav	3.9	+3.6	2.82	156	34
Tier III setup	3.4	+0.6	1.34	157	41

Source: MDT

Tier III operation cost of 4T50ME-X with EGR1 - MDT

What does it cost:

SFOC penalty:	0.5 – 1.0 % (1 - 4 g/kWh for S80ME-C-EGR2) with fuel-saving measures
Additionally aux. power:	1.0 – 1.5 % of M/E power
NaOH consumption:	5 l/MWh in case of 3%S fuel and 50% solution

Source: MDT

SCR

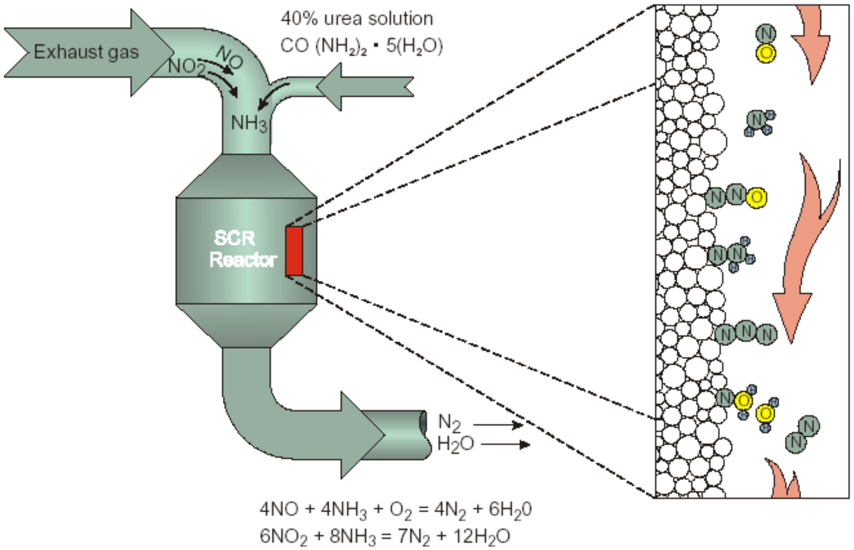
Selective Catalytic Reduction

What is SCR?

- A **conventional/proven** method for stationary plants
- More than **90%** NOx reduction possible
- Not conventional for ships, especially for 2-strokes

- **After-treatment**, regardless of combustion process
  i.e. **free from 'Diesel Dilemma'**

- NOx --> **nitrogen and water**:
  - 4NO + 4NH3 + O2 --> 4N2 + 6H2O (Major)
  - 6NO2 + 8NH3 --> 7N2 + 12H2O (Minor)
  - NO + NO2 + 2NH3 --> 2N2 + 3H2O (Fast)



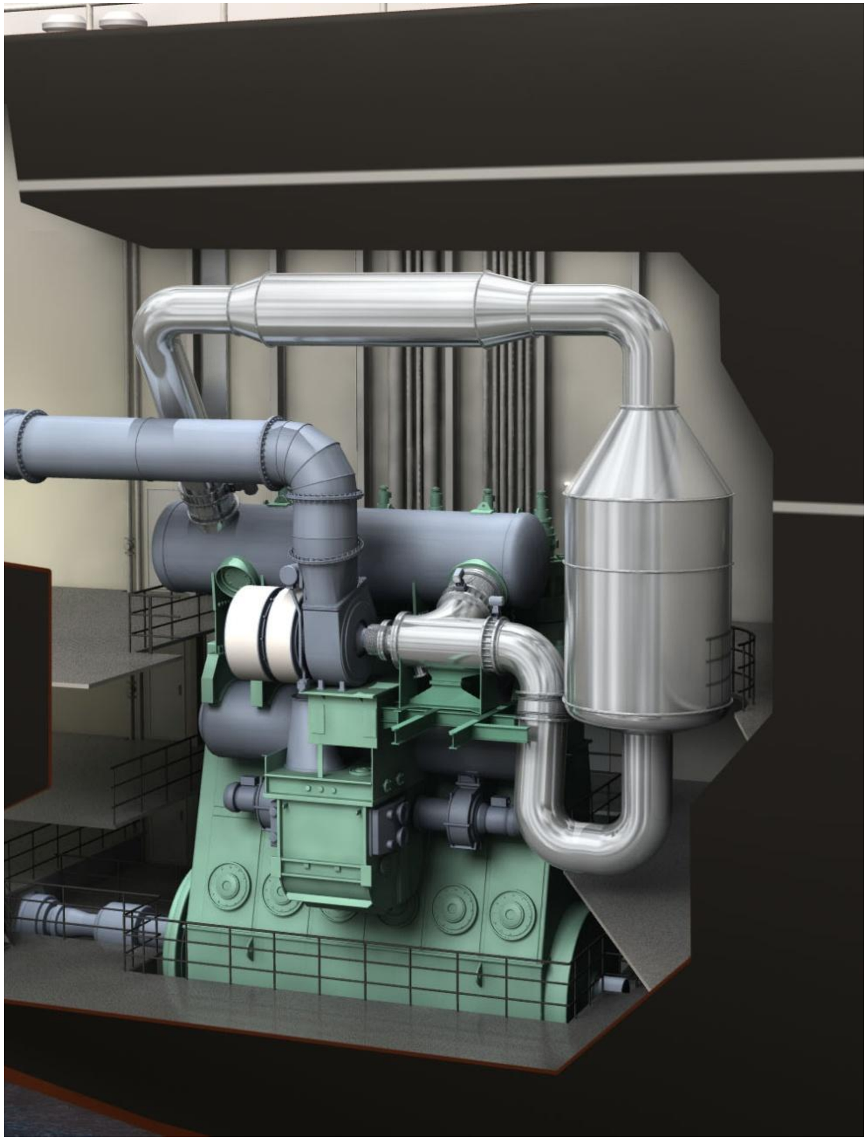
- **Urea** as reducing agent
  - (NH2)2CO --> NH3 + HCNO
  - HCNO + H2O --> NH3 + CO2

FAQ: "SCR before or after?"

SCR after turbine 'Low Press SCR'	SCR before turbine 'High Press SCR'
Low pressure	**High pressure**
	● More active --> Compact
Low temp	**High temp**
● Gas temp: 210 - 280 degC ● SCR needs: 300 - 350 degC Heat up with burner	● Gas temp: 290 - 430 degC --> No heating, low CO2

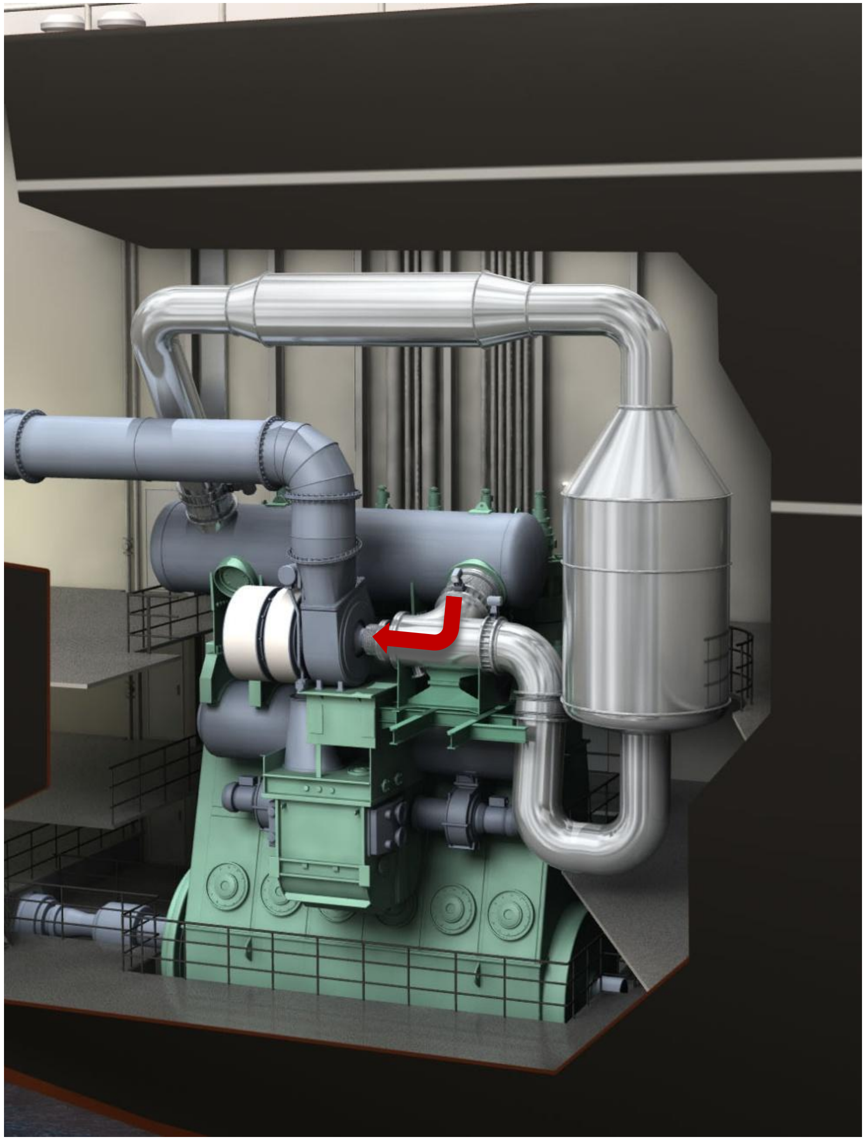
e.g. Burner = 100 C x 1 kJ/kg K x 10 kg/kWh / 42700 kJ/kg = 23 g/kWh !?

SCR-engine



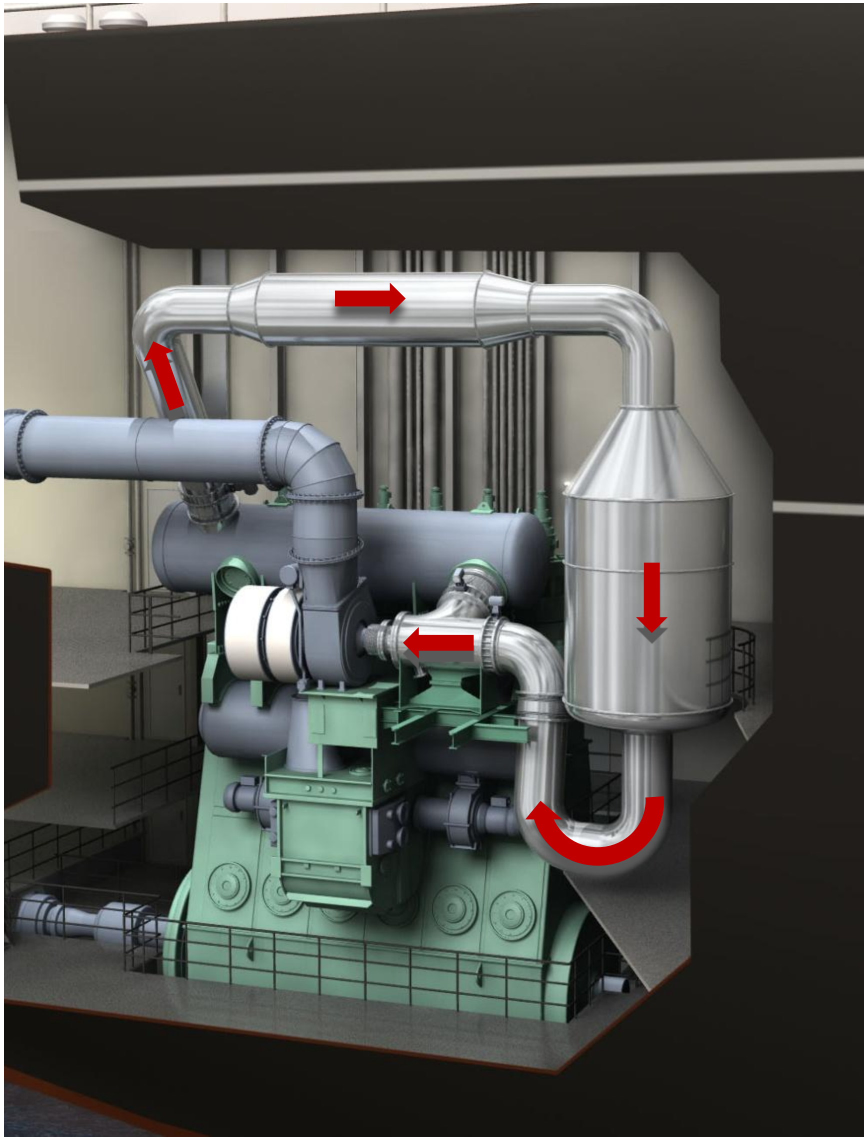
SCR-engine – SCR not in use

- **Exhaust gas flows directly to the turbine**



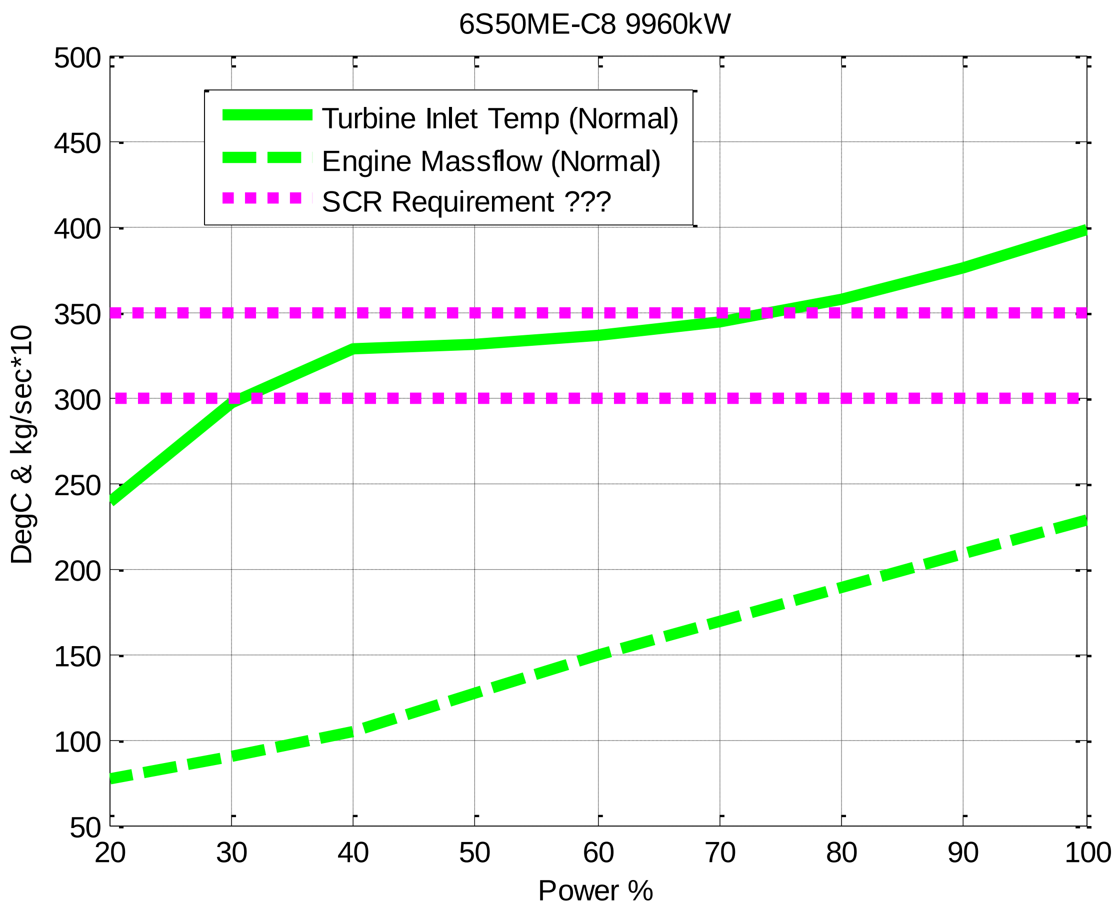
SCR-engine – SCR in use

- **Exhaust gas flows to the SCR reactor**

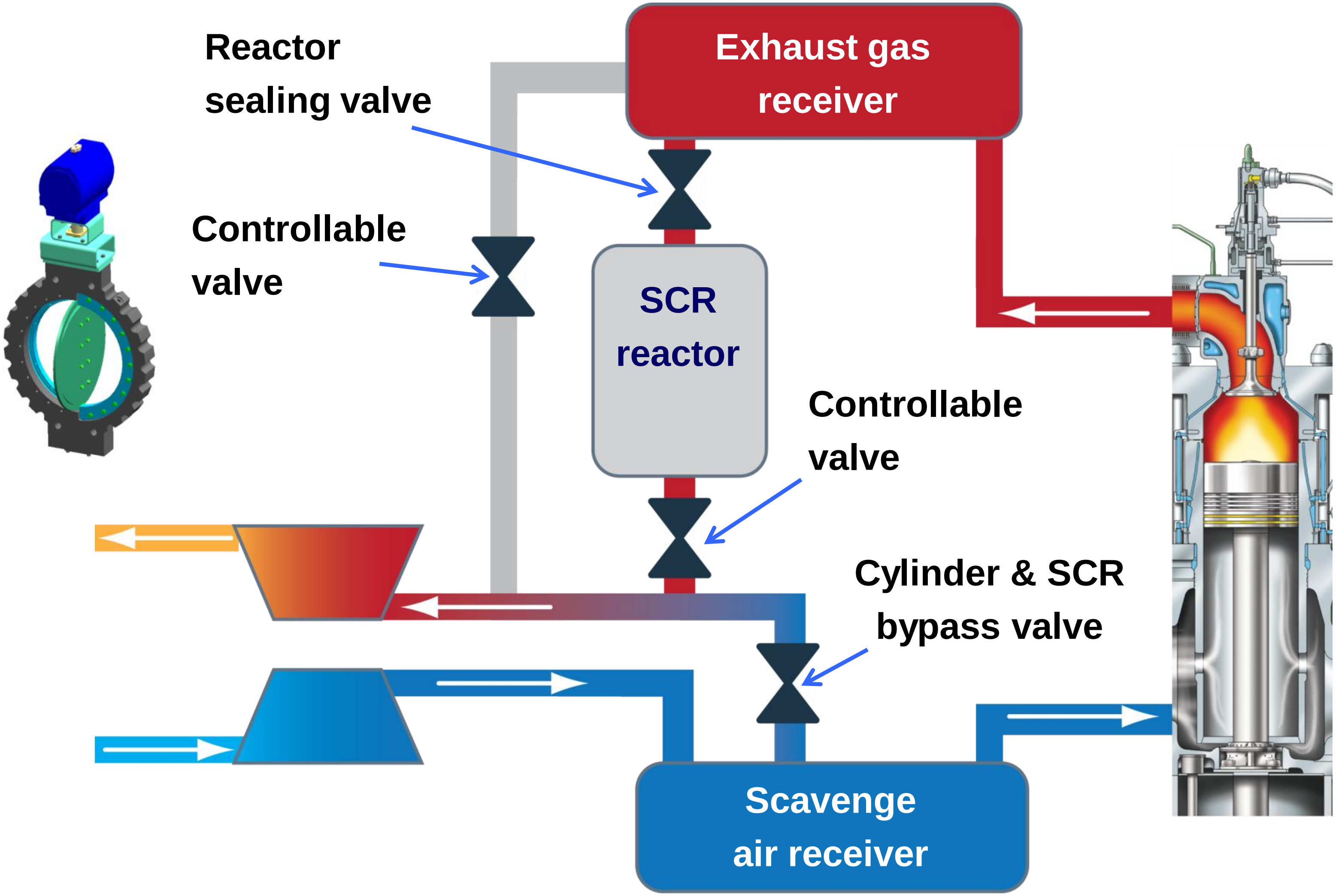


Temperature issue for 2-stroke

- The current temperature requirement for continuous operation on high S fuel is **300C (lower) and 350C (sweet)**



Low Load Method and valve control



6S46MC-C-SCR on testbed

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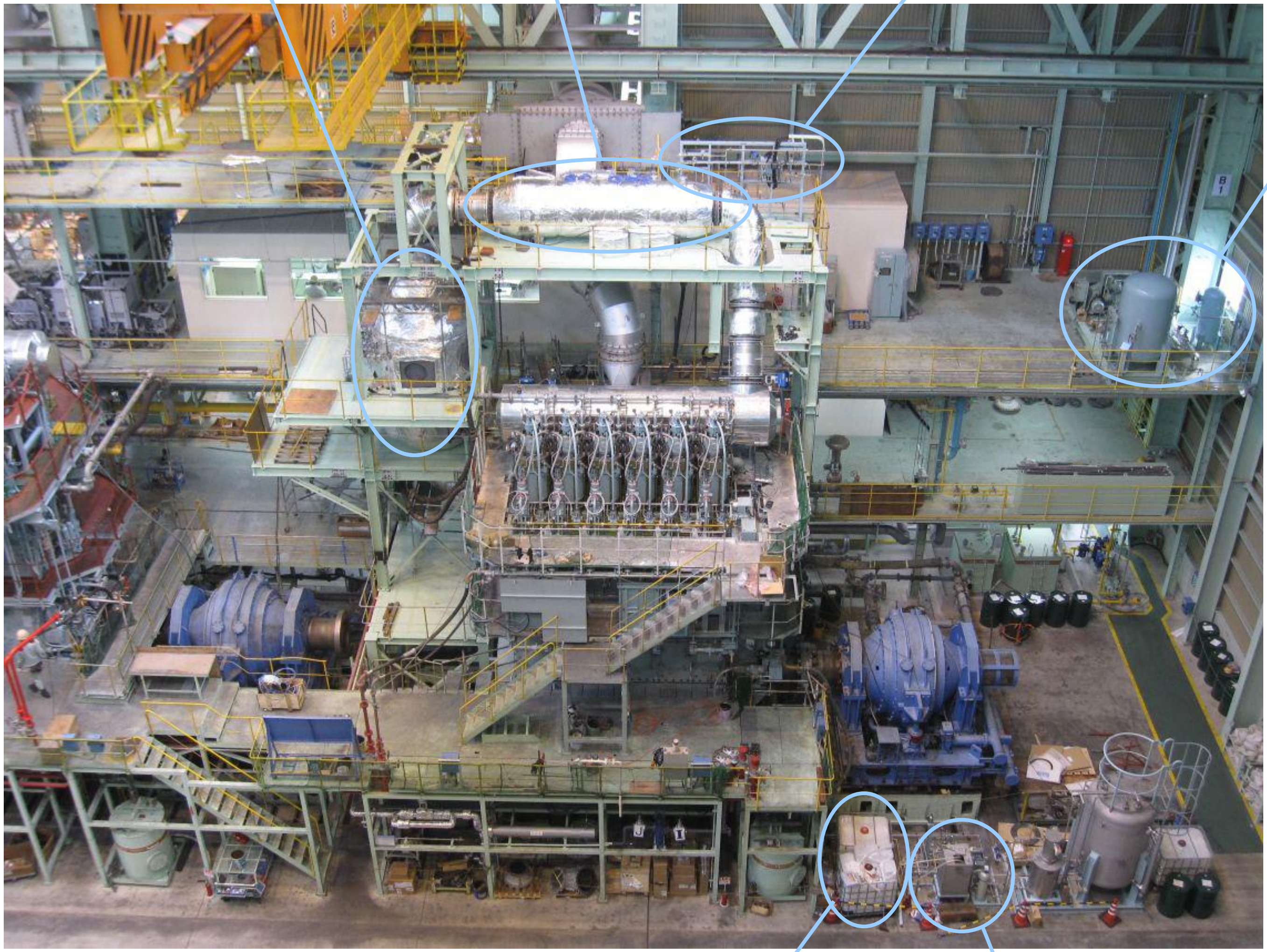


Form 130

NIPPON KAIJI KYOKAI

STATEMNT OF FACT

No. KB11MM00001 Date: 1 November 2011

Engine Manufacture	Model Number	Serial Number	Test Cycle(s)	Rated Power (kW) and Speed (RPM)	NOx Reducing Device
Hitachi Zosen Corporation	6S46MC-C7	4506	E3	6780 kW 111 RPM	Selective Catalytic Reduction fitted

THIS IS TO CERTIFY:

1. That, at the request of Hitachi Zosen Corporation, Japan, NOx measurement for the above-mentioned marine diesel engine fitted with Selective Catalytic Reduction (SCR) was surveyed in accordance with Chapter 5 of NOx Technical Code 2008 at Hitachi Zosen Corporation, Japan, on 26 April 2011; and
2. That the NOx measurement result shows the following value less than the NOx Tier III emission limit of 3.4 g/kWh specified in paragraph 5.1, Regulation 13, MARPOL ANNEX VI.

NOx emission value: 2.8 (g/kWh)

Specification of the above-mentioned marine diesel engine fitted with SCR is as per the document "Technical File for NOx Certification", Drawing No. E5036111, examined on 1 November 2011.

Remarks:
The following items are outside the scope of this certification.
a. Aged deterioration of SCR performance.
b. SCR bypass operations when the engine is under heating operation, low load operation, and transient speed change operation.

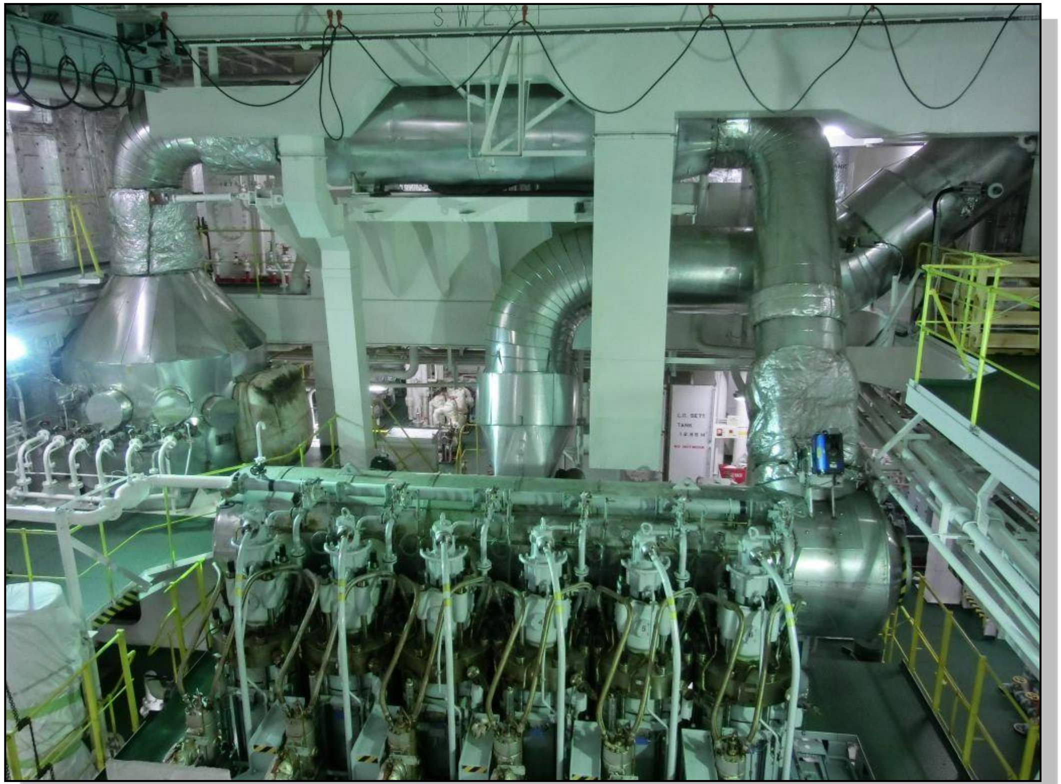
T. Narisawa
General Manager
Machinery Department
NIPPON KAIJI KYOKAI

Installation in engine room

- The same arrangement - engine, reactor, vaporizer, duct, fixation, …
  - ➢ Proved on the test-bed
  - ➢ Made the sea trial trouble-less

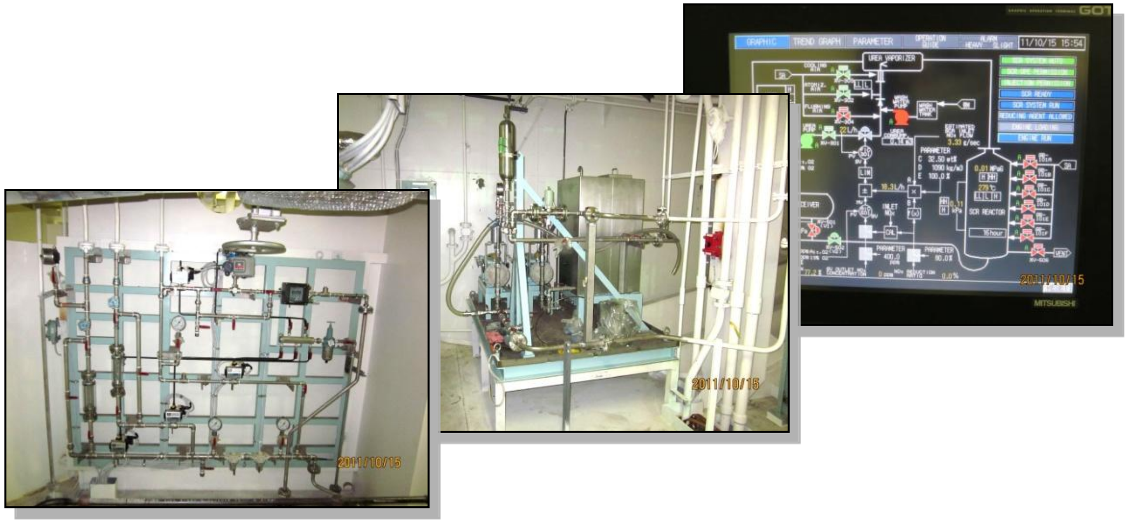
SCR on test-bed

SCR in engine room



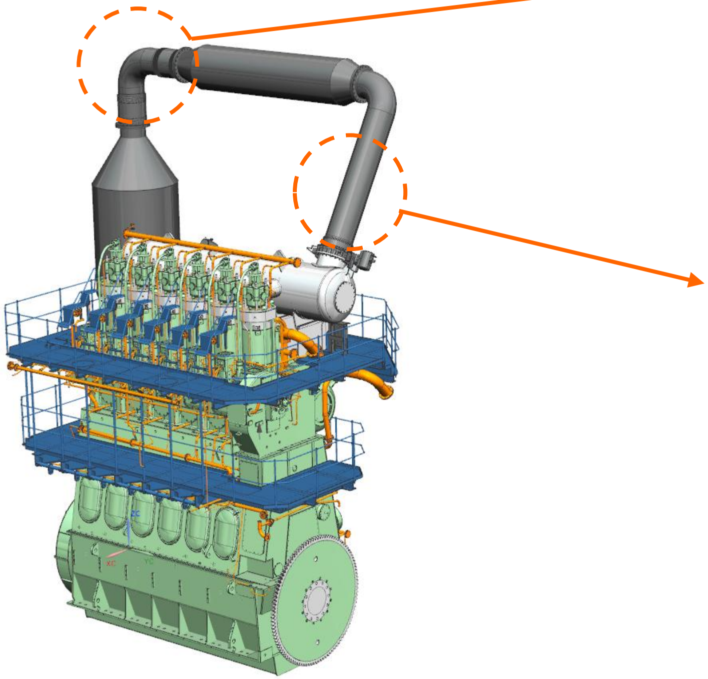
Installation in engine room

- Enough maintenance space reserved
  - Piston overhauling
  - Reactor maintenance
- Safe SCR
  - Urea-SCR for safety
  - Fulfilling class requirements on safety



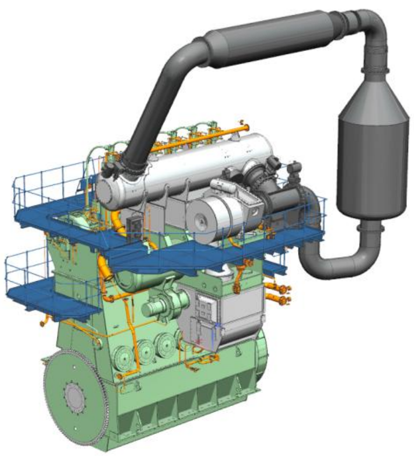
Fixation of vessels and ducts

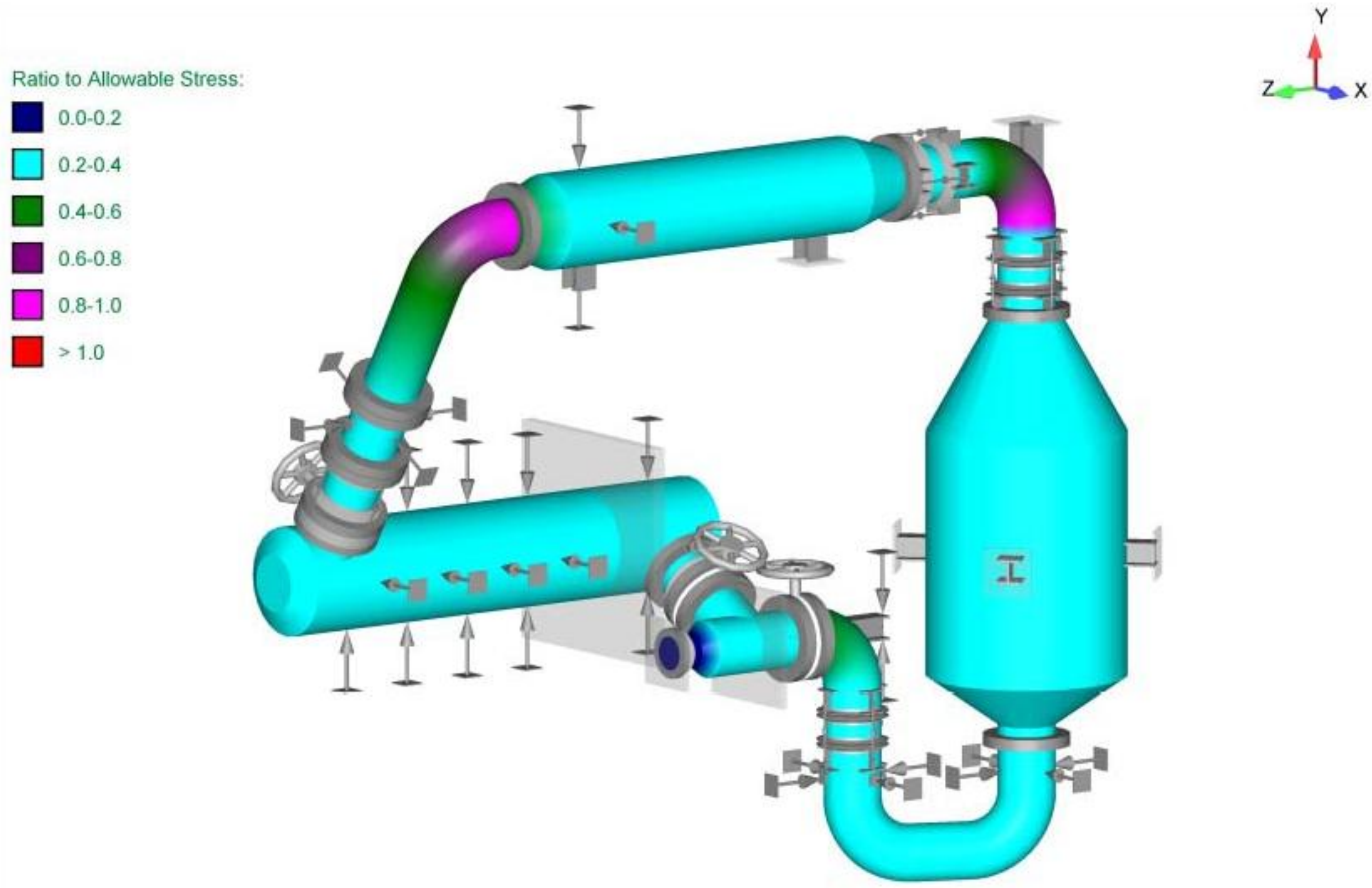
- SCR located at high pressure side
  - Gas forces - e.g. Ø600 * 2.5 barG = 7.2 tf
  - Thermal expansions
    e.g. 0.01 mm/m/K * 4 m * 400 K = 16 mm
  - Compensators necessary - almost free end
  - Vibrations



Fixation of vessels and ducts

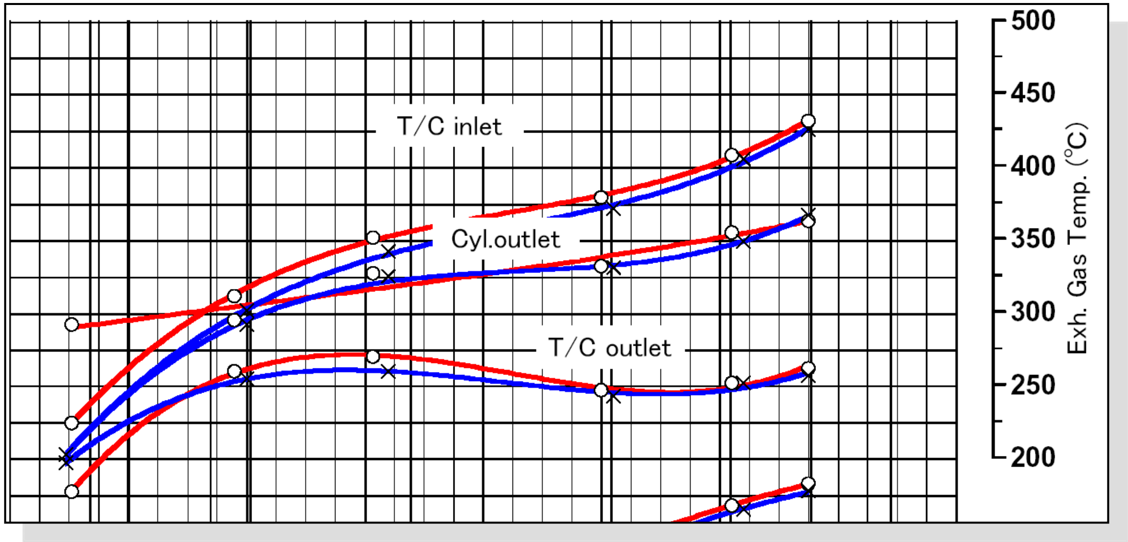
- Stress evaluated before installation

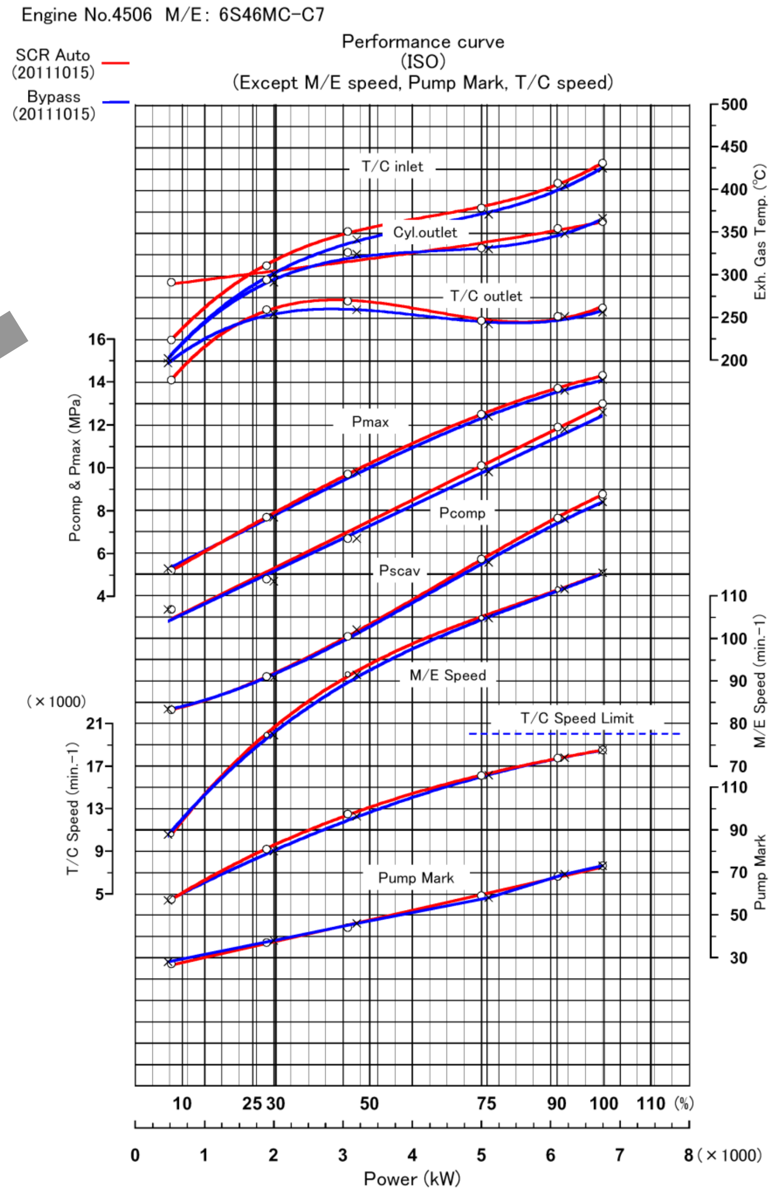




Engine performance – sea trial

- Almost same performance between SCR and Bypass
- Higher cylinder outlet gas temp. at low load due to CBV

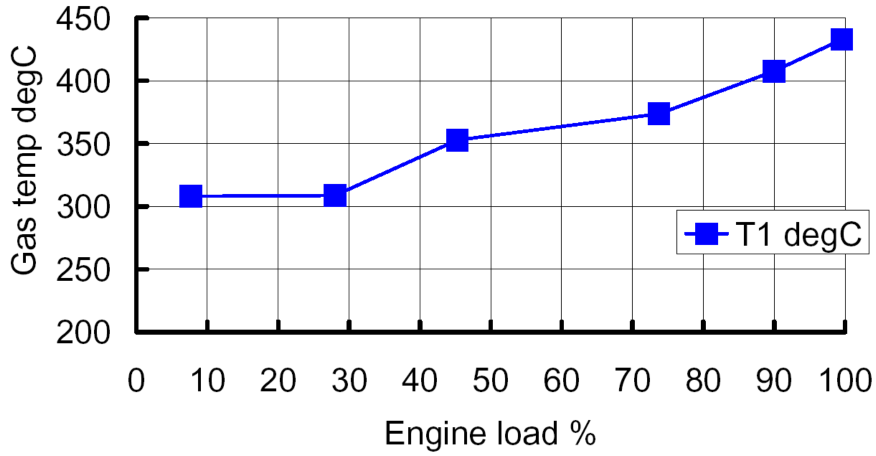


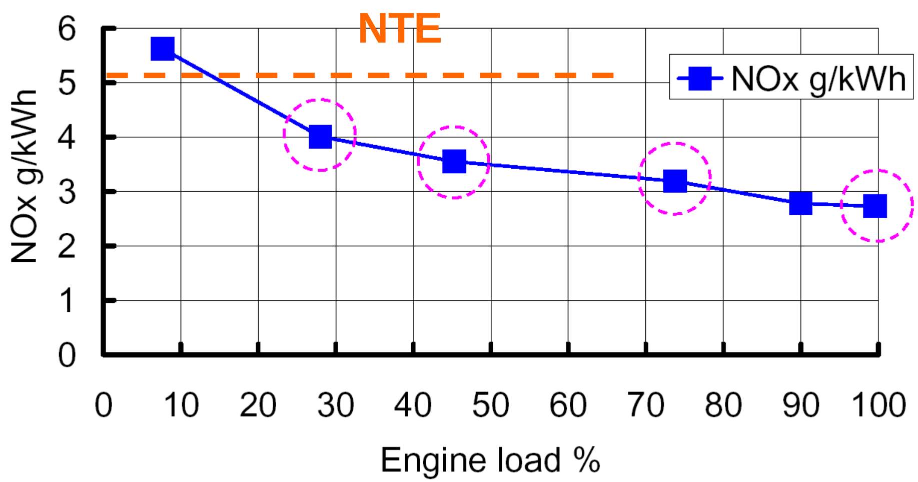


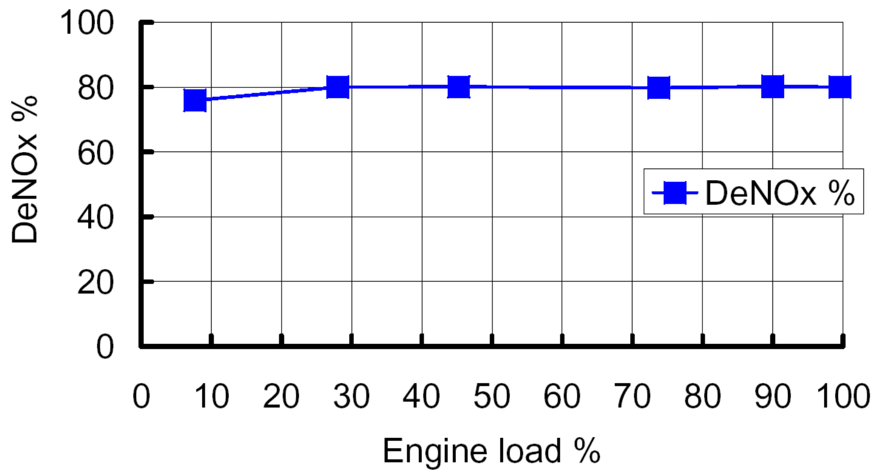
SCR performance – sea trial

- DeNOx control setting = 80%

- DeNOx result = 80% at every E3
- E3-cycle value = 3.1 g/kWh
- Less than NTE at every E3 point







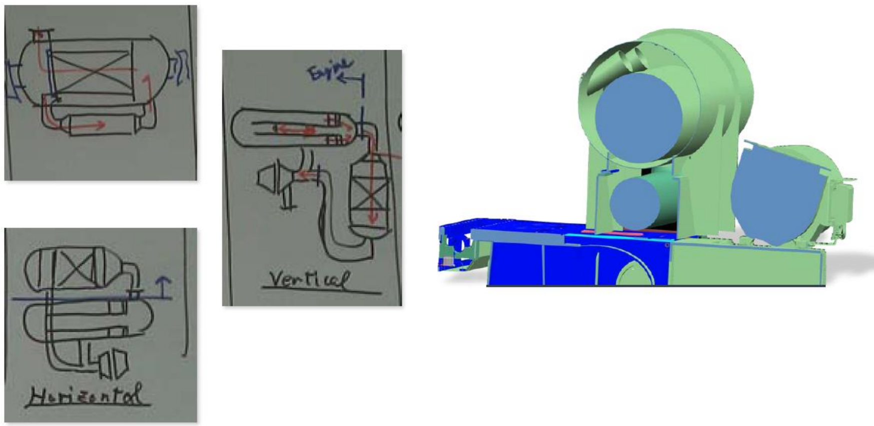
Tier III operation cost of high pressure SCR

What does it cost:

SFOC penalty:	Negligible (1% only at low load, Nil at other loads) without any fuel-saving measure
After-burner expense:	Nil
Urea consumption:	16 l/MWh (40% solution, deNOx 14.4 --> 3.4 g/kWh)

SCR in future

- **Compacting and integrating**



Compacting and integration "brainstorming"

- **Fuel-optimized engine + SCR**
  = "Minimum CO_2 & Minimum NO_x"

Summary

Summary

- **NOx reduction**
  - EGR can meet Tier 3
  - SCR can meet Tier 3

- **Cost**
  - CAPEX: SCR < EGR
  - OPEX: EGR < SCR
  - Total: depending on time for sailing in ECA

- **Size**
  - EGR: EGR2 integrated on engine (except auxiliary systems)
  - SCR: Compact SCR investigation ongoing

FAQ: "Which is available in 2016?"

Ans.: "Both are available"

New Question: "Which way to go after Tier III?"

Consider:

- More NOx reduction required in future?
- More CO2 reduction required in future?
- Gas?
- Who consumes HFO?
- Which way are auxiliary engines going?

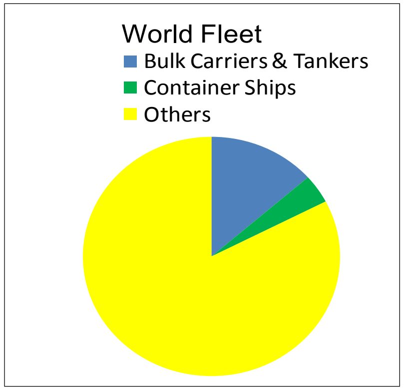
Quo Vadis?

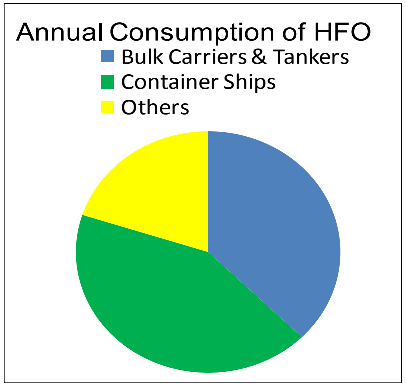
Thank you for your attention!

Consumption of HFO in the world

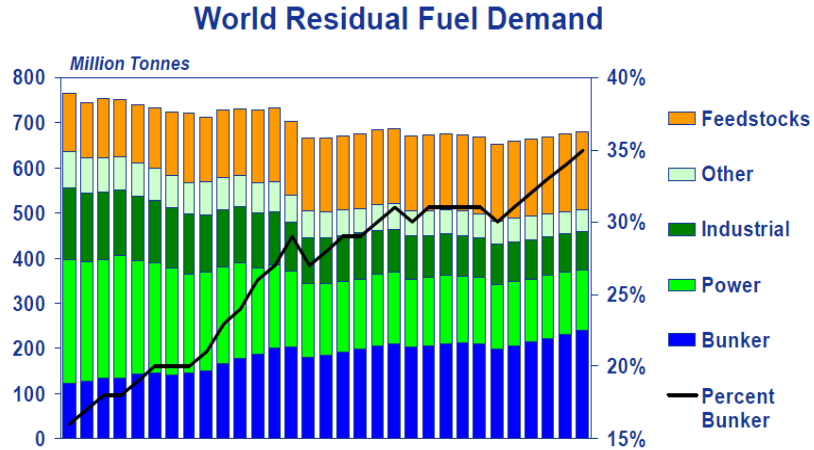
Impact of Global Sulfur Limit of 0.5% due to become mandatory since 2020

- The fleet of container ships carrying 1,100 TEU or more and bulk carriers & tankers of 10,000 DWt or larger is less than 20% of total world fleet.
- Around 80% of total HFO demand is consumed by this 20% fleet of large container ships, bulk carriers, oil tankers and chemical tankers.
- Annual consumption of HFO (heavy fuel oil) is more than 200 million tons.





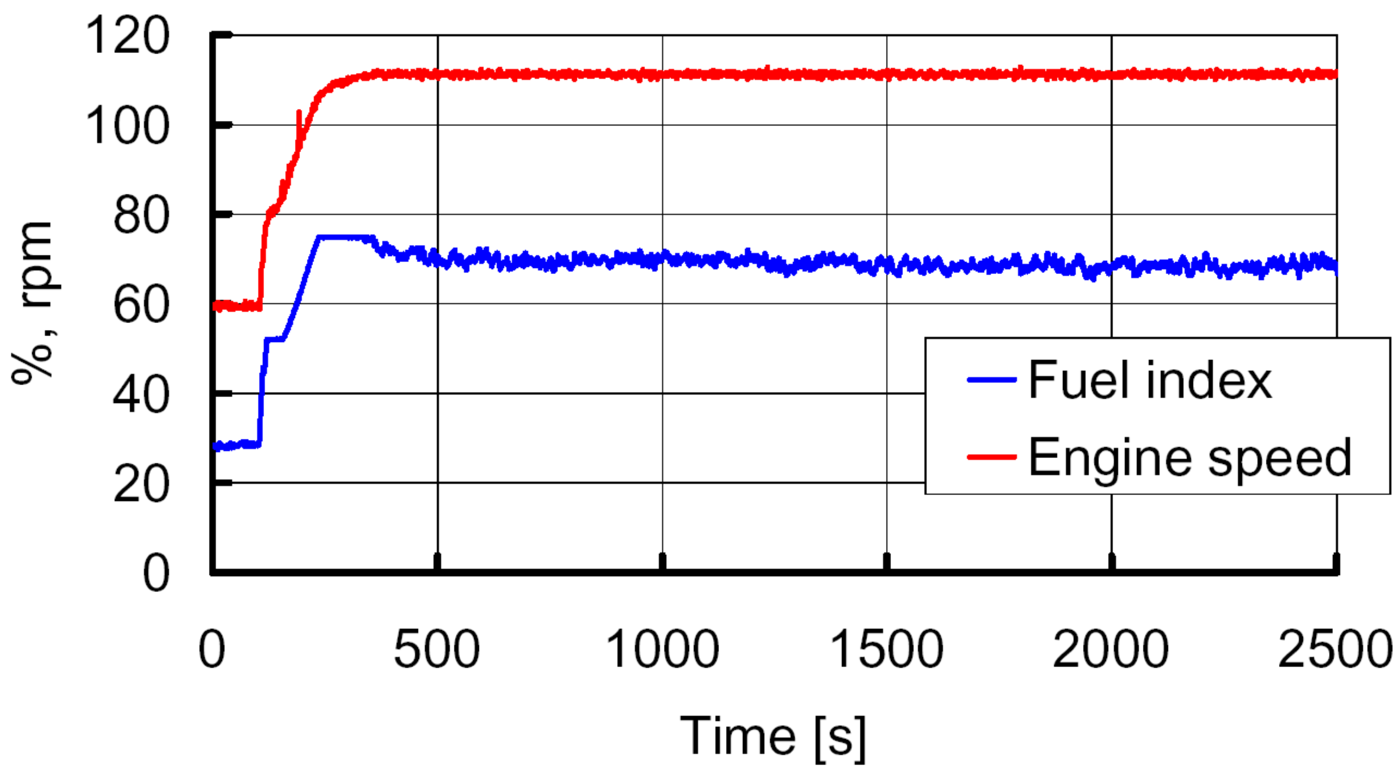
Fuel surcharge will be approx. **60 billion USD** per year, if price difference between LSHFO/MGO and high sulfur HFO is assumed 300 USD/ton when global sulfur limit of 0.5% is implemented.



Source: "Residual Fuel Outlook" prepared by Purvin & Gertz Inc. for EGCSA workshop at Hamburg 8/9 September 2010

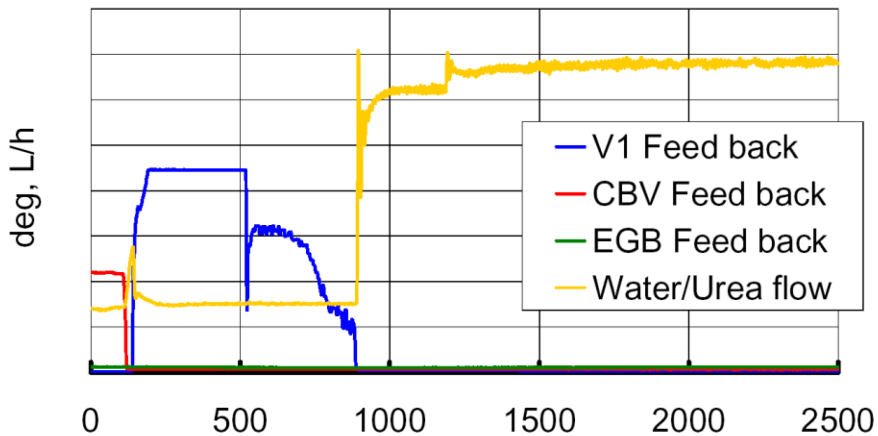
Transient response tests - sea trial
FAST loading

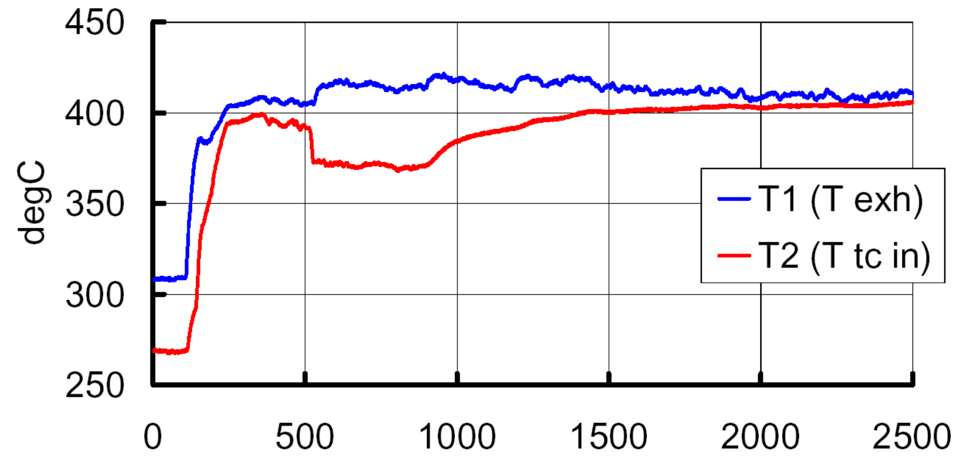
- Conditions: Loading quickly HALF --> 90% load in 3 min

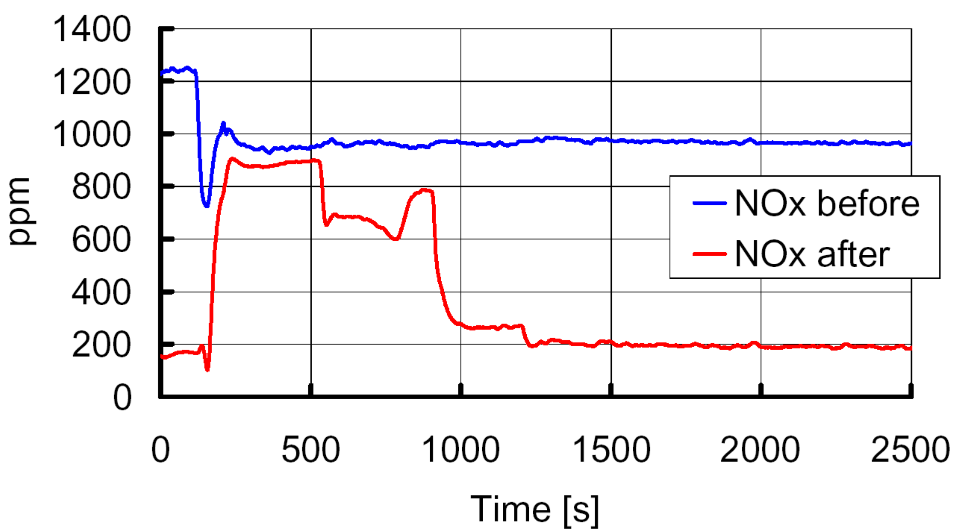


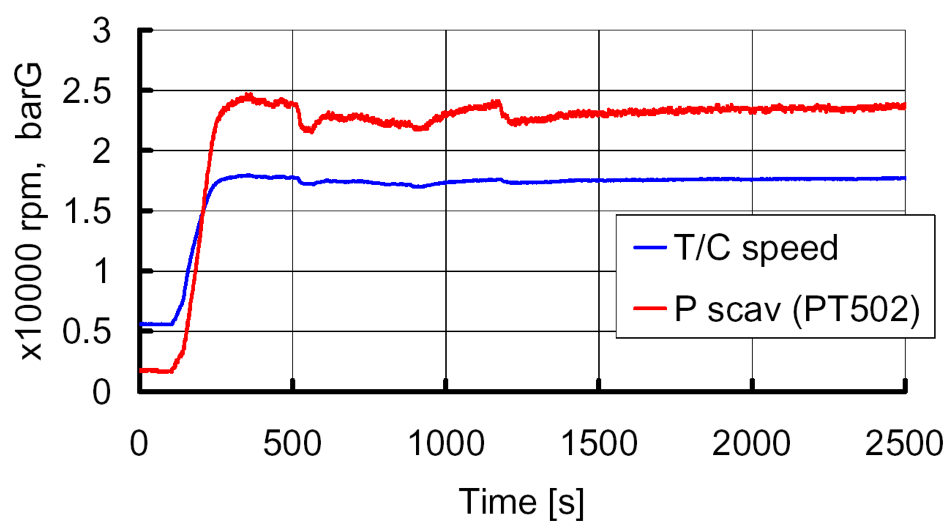
Transient response tests - sea trial
FAST loading

- **SCR-bypass opens**
- **Fast loading possible (A function prepared just for ‘emergency’)**



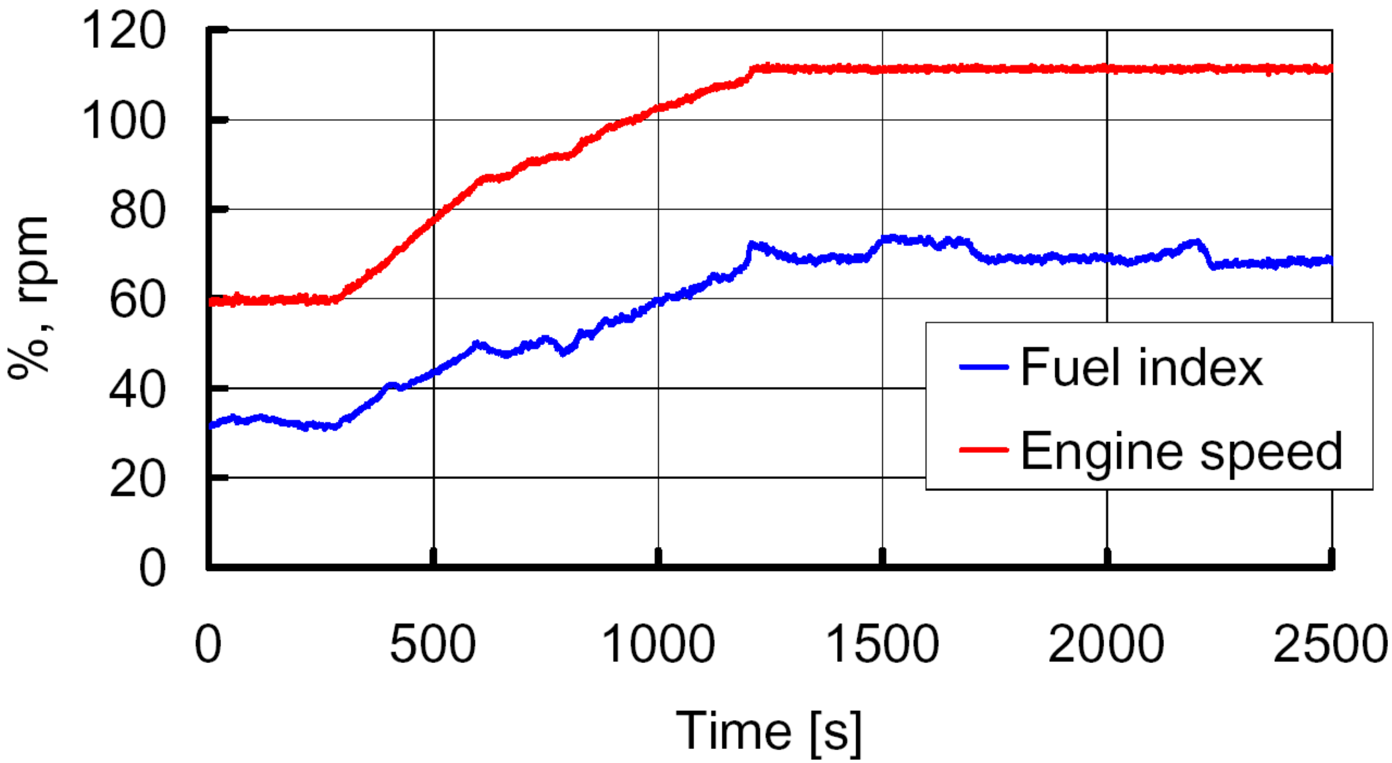






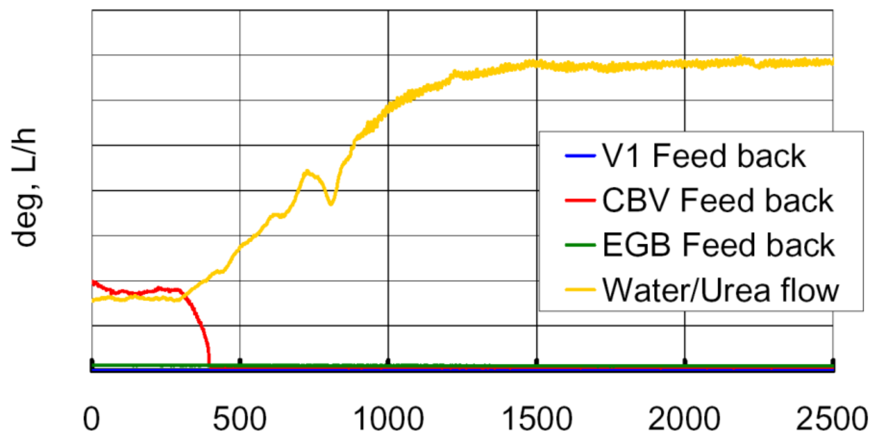
Transient response tests - sea trial
NORMAL loading

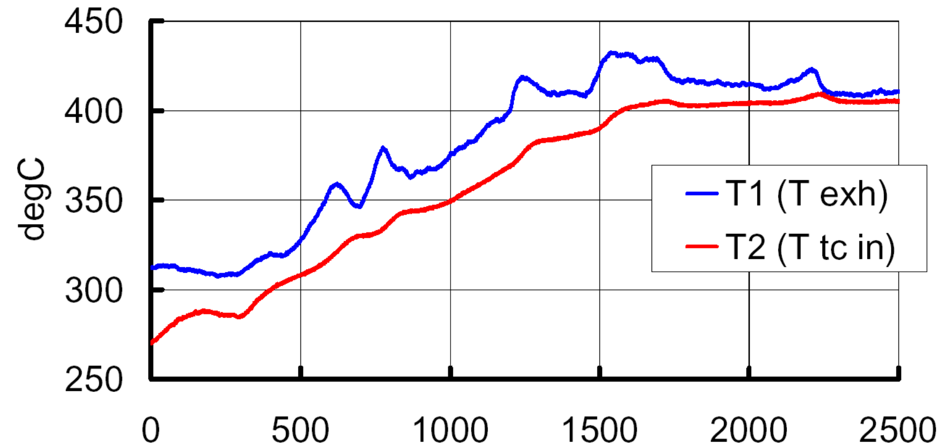
- Conditions: Loading HALF --> 90% load in 15 min

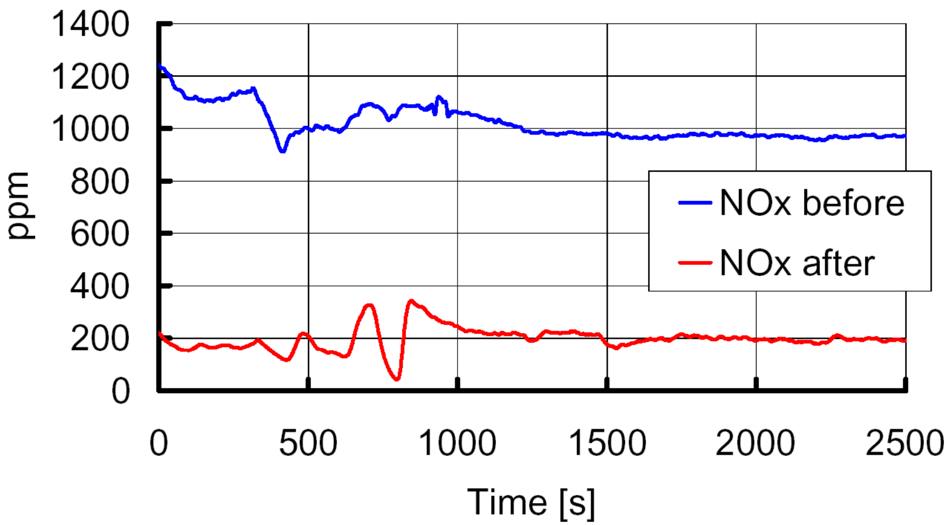


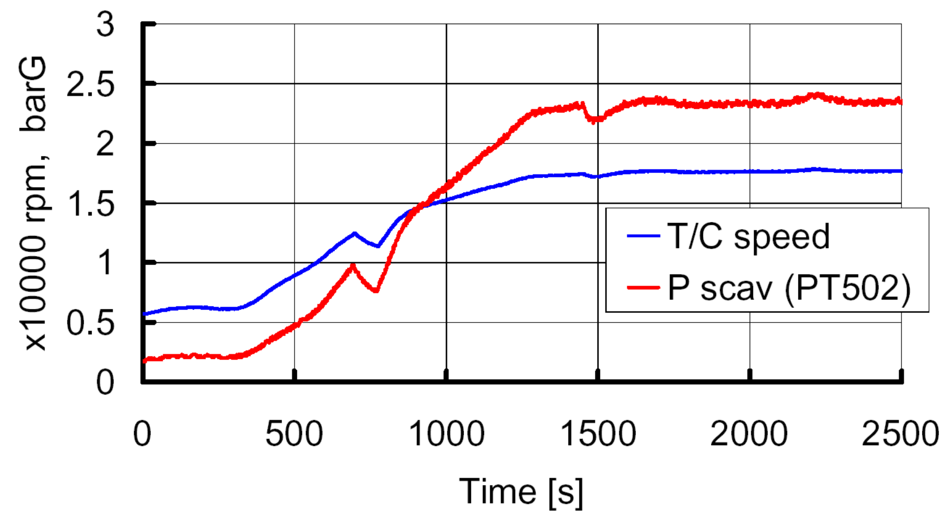
Transient response tests - sea trial NORMAL loading

- **SCR-bypass kept closed**
- **Continuous deNOx possible**



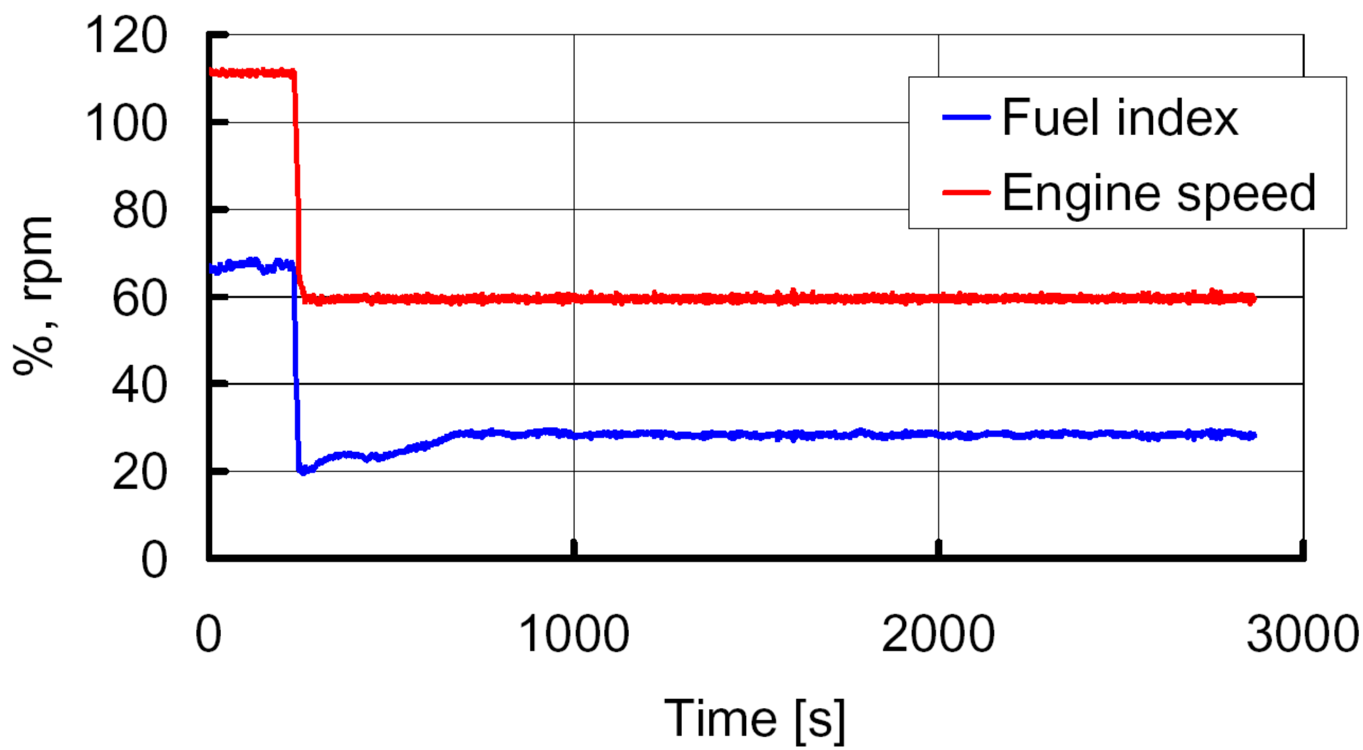






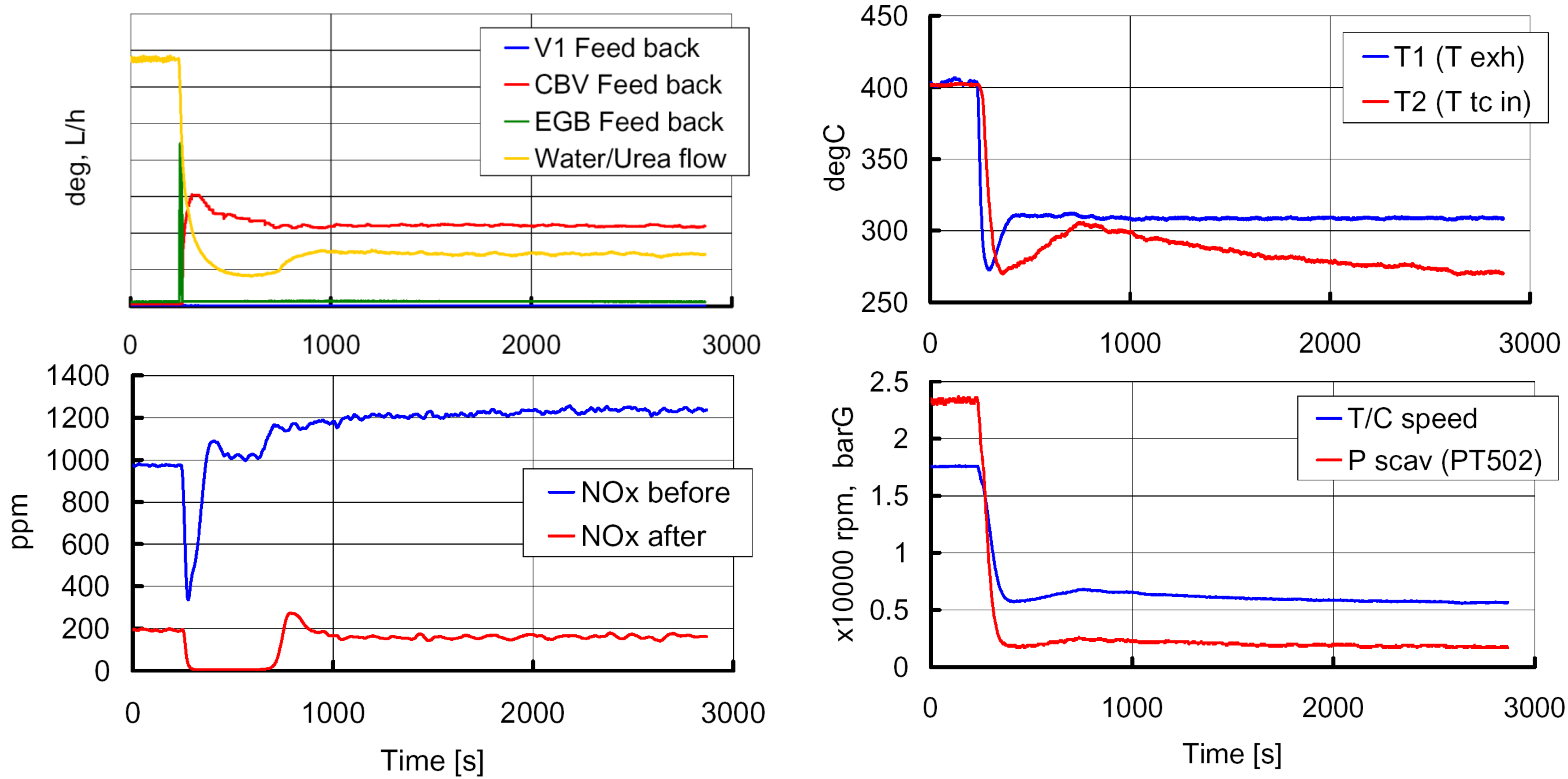
Transient response tests - sea trial
FAST UNLOADING

- Conditions: Unloading 90% load --> HALF in a few secs



Transient response tests - sea trial
FAST UNLOADING

- **EGB and CBV open**
- **Fast unloading possible**



Low temperature operation on HFO - testbed

- Low temp. 230C, high temp. 370C
- 1 SB per 30 min

<u>Loading and SB are effective.</u>