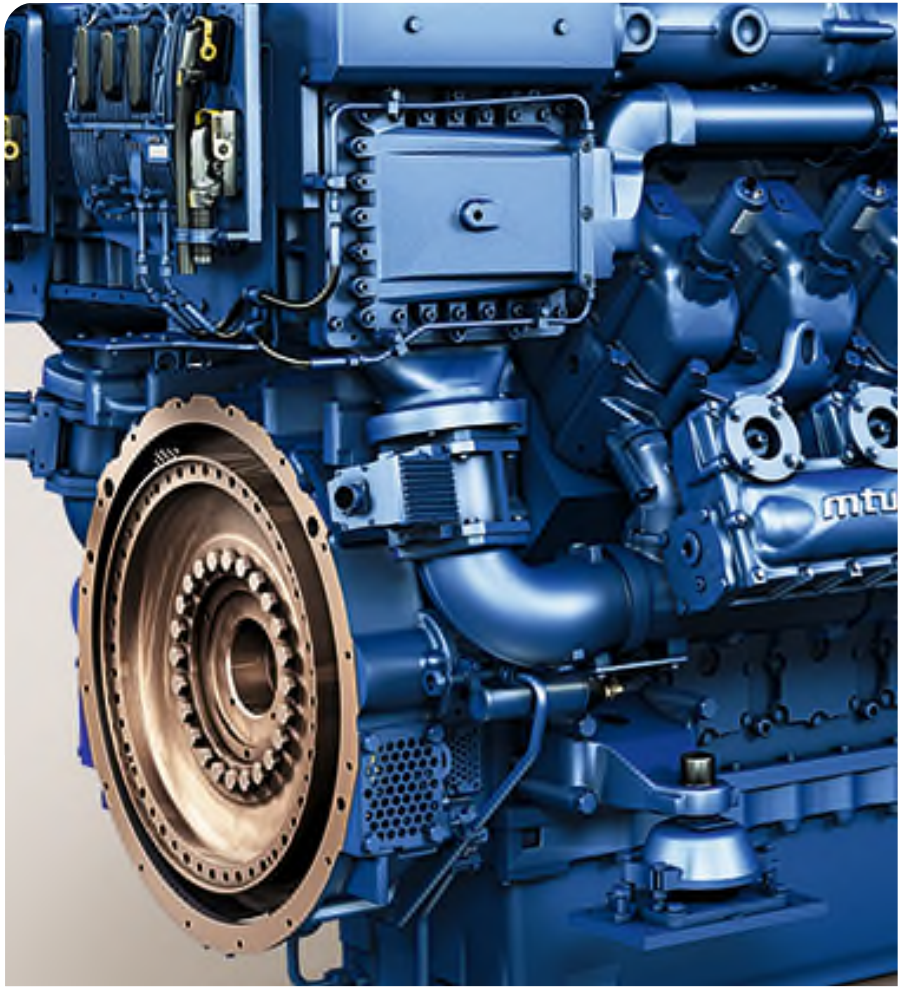


Gas Mobile Marine

S4000M05-N
Gas Mobile Marine

Interreg
Danube Transnational
Programme GRENDEL

Vienna, 7-8 March 2019, Arnd Lierhammer

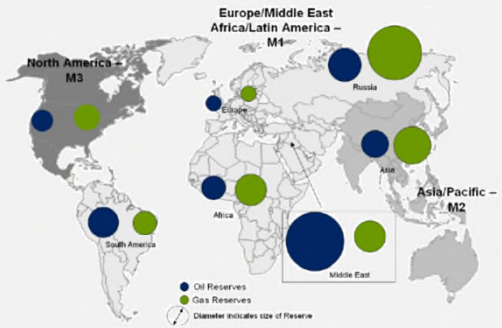
Power. Passion. Partnership.

Agenda

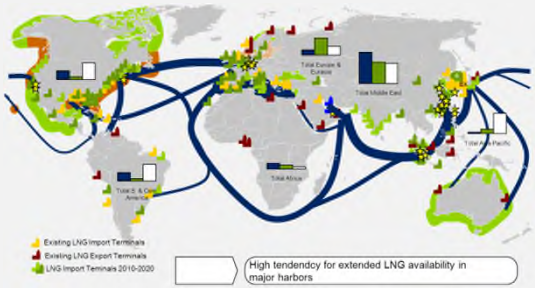
01 General Overview

General Overview
Main driving factors for Gas engines

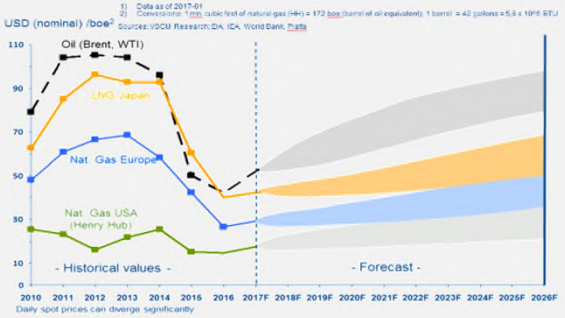
Large Reserves



Emission Regulations



Developing LNG*-Infrastructure



Low Gas Price

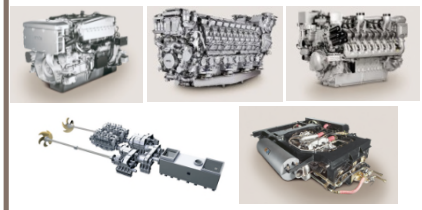
* LNG: Liquified Natural Gas
** ECA: Emission Controlled Area

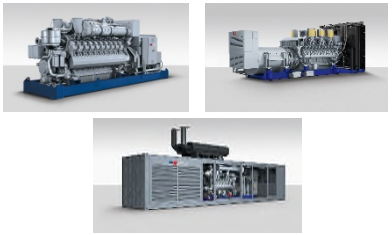
General Overview
In-house Gas Experience

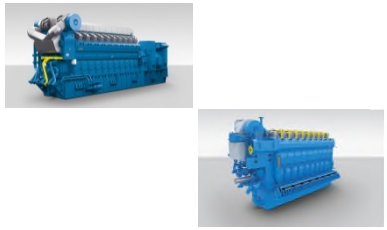
Rolls-Royce

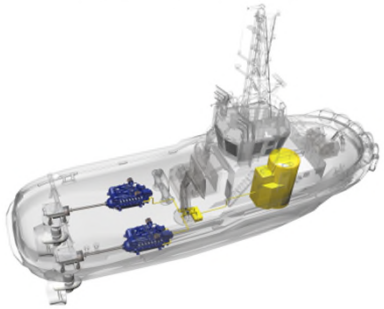
Rolls-Royce Power Systems AG

mtu	mtu onsite energy	Bergen Engines AS	Rolls Royce Marine
Mobile Applications High Speed Diesel Engines Propulsion systems	**Stationary Applications** High Speed Gas Engines High Speed Diesel Engines Gas and Diesel Generator sets Power supply systems	**Marine and Stationary Applications** Medium Speed Gas Engines Medium Speed Diesel Engines Medium Speed Gas and Diesel Generator sets	**Marine Design and Sytems** Ship design Shipside gas systems









General Overview
MTU Mobile Gas Portfolio Development

Marine

Rail

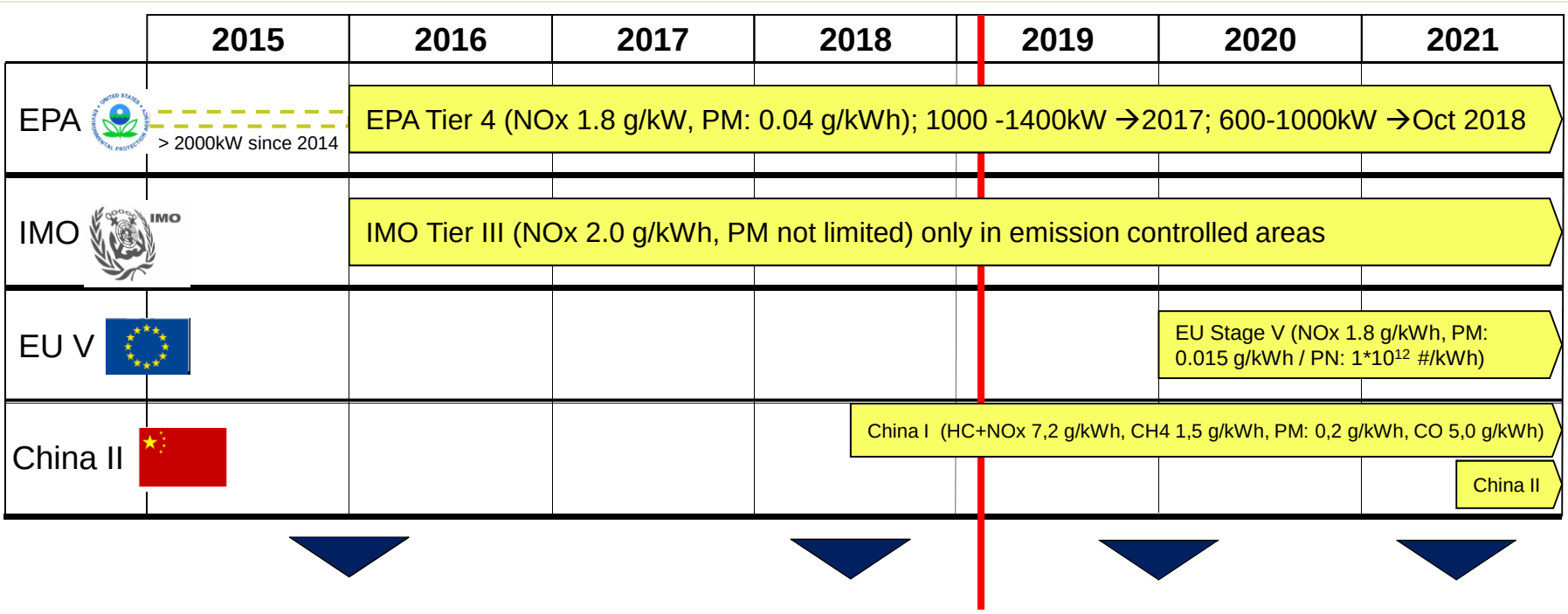
C&I / Mining

Marine application has been chosen as lead application

- Existing experience in gas fuelled ships – also in-house (Bergen)
- LNG infrastructure starts to develop from sea coast
- Technical rules and guidelines most developed (IGF-Code, DNV/GL, BV, LR)
- Highest technical requirements allows downgrade to land based applications
- Time to market

02 Emission Legislation

Emission Legislation Overview



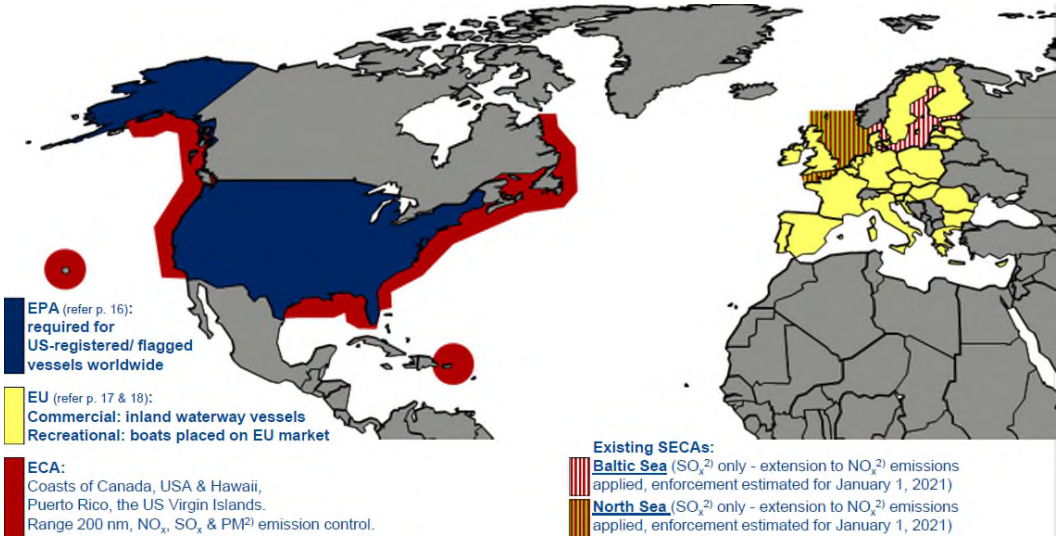
IMO Tier III
(in Emission Controlled Areas – ECA)
EPA Tier 4

China I

EU V

China II

Emission Legislation Overview



Existing ECAs
Coast of Canada, USA & Hawaii, Puerto Rico, US Virgin Islands

Applied ECAs (January 1, 2021)
North Sea and Baltic Sea

IMO Tier III
Vessels constructed on/after 1st January 2016 need to be **IMO Tier III** certified, if operation area is an Emission Controlled Area
Exemption: Recreational purpose yachts <24m length WL and/or <500GT, Naval vessels

EPA Tier 4
Vessels registered in the US need to be **EPA Tier 4 certified**, if engines manufactured on/after 1st January 2016
Exemptions: recreational provision, testing,…

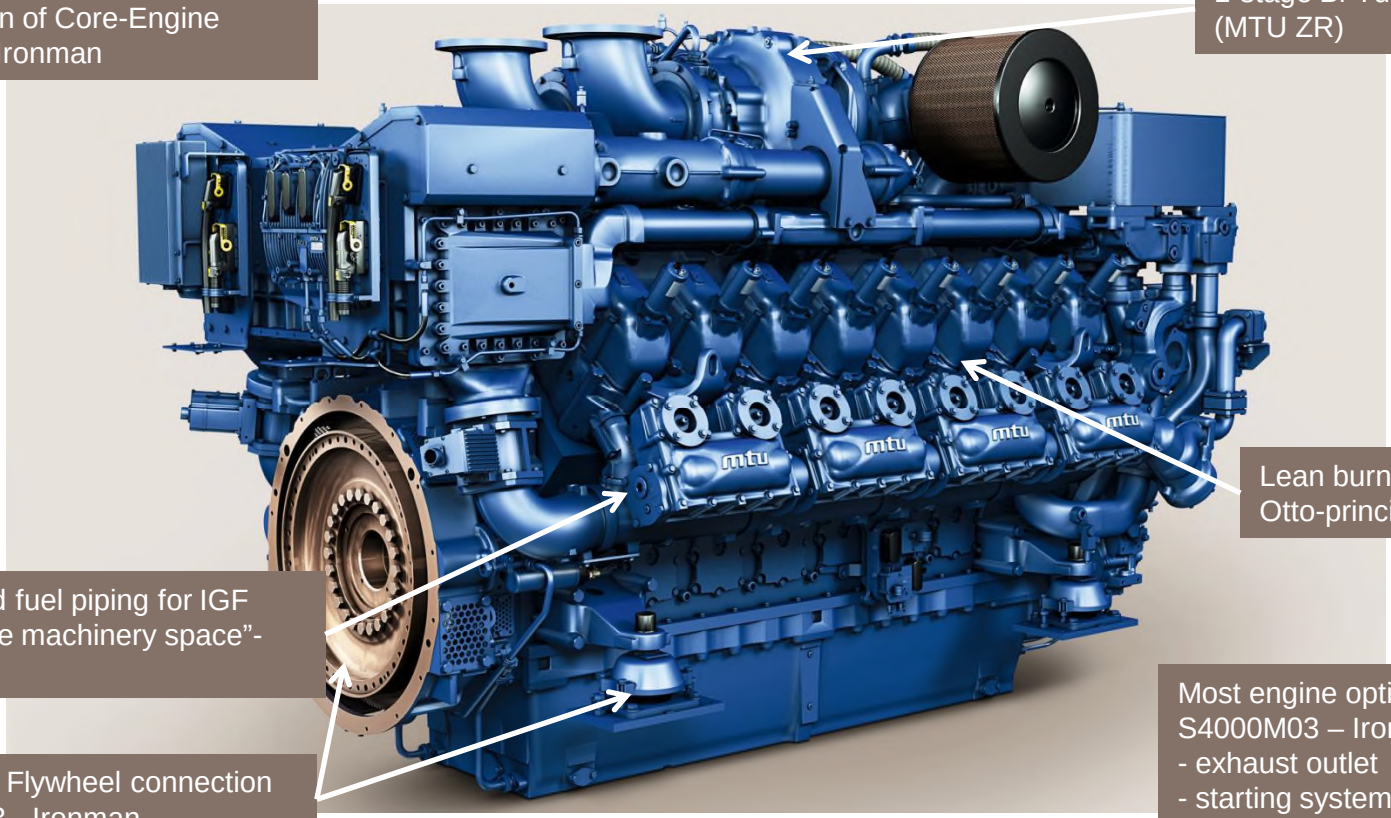
EU V
Engines (>300kW) for Inland waterway vessels used in EU need **EU V** certification from **1st January 2020** on

03 Engine Concept & Technical Data

S4000 M05-N
Engine Concept & Technical Concept

Proven design of Core-Engine S4000M03 - Ironman

1-stage Bi-Turbo (MTU ZR)



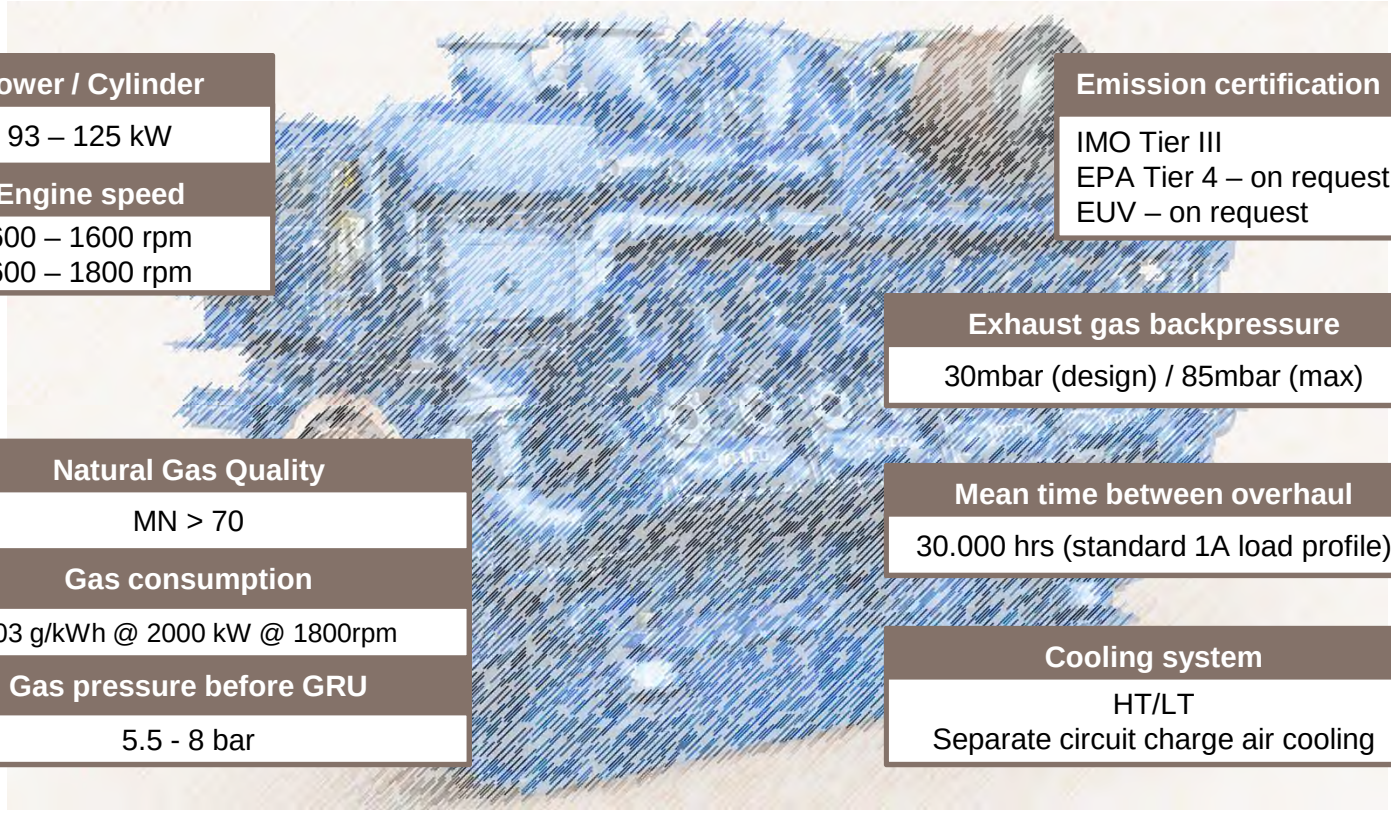
Lean burn gas engine Otto-principle

Double-walled fuel piping for IGF code “gas safe machinery space”-concept

Most engine options as S4000M03 – Ironman e.g.:
- exhaust outlet
- starting system
- PTO´s

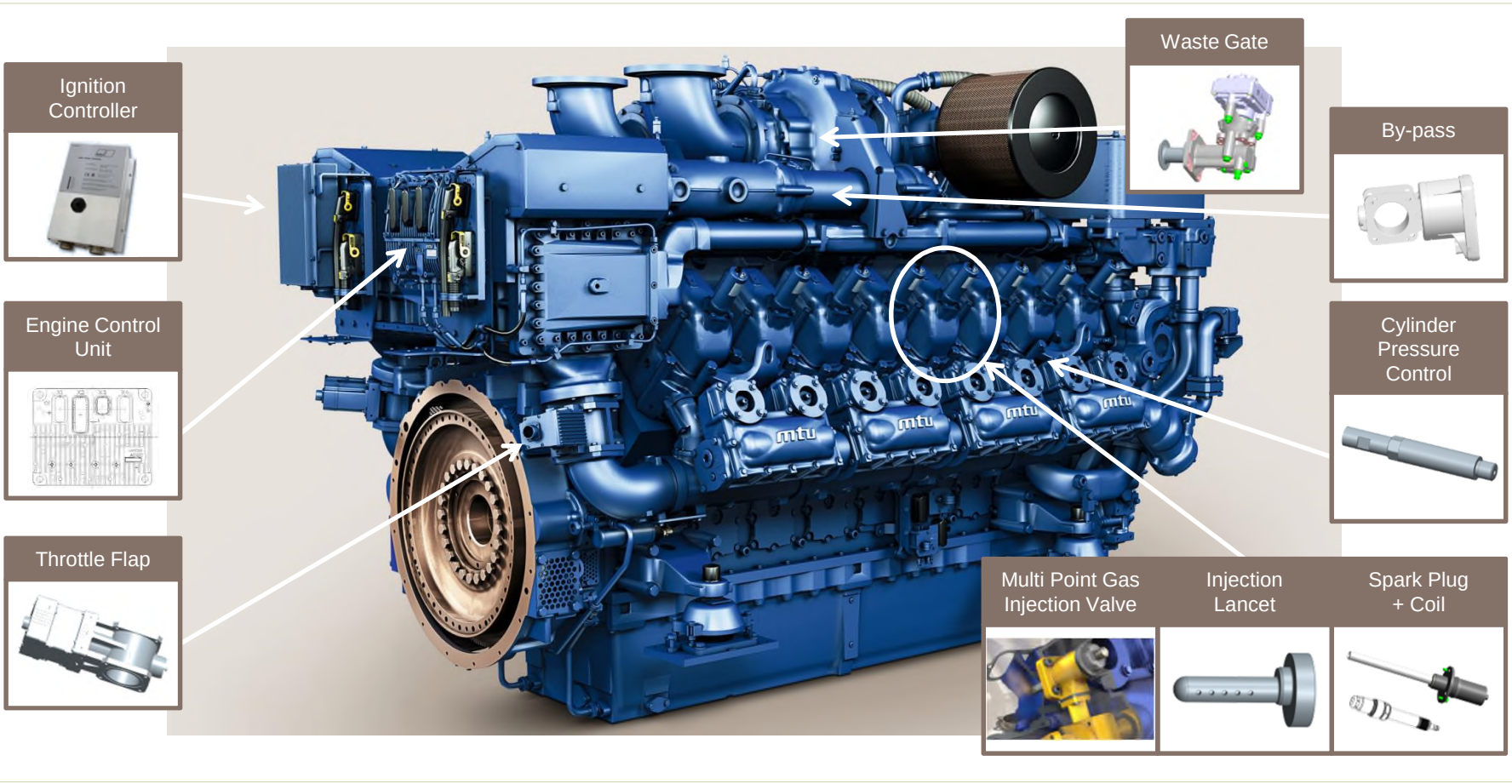
Footprint and Flywheel connection as S4000M03 - Ironman

S4000 M05-N
Engine Concept & Technical Concept



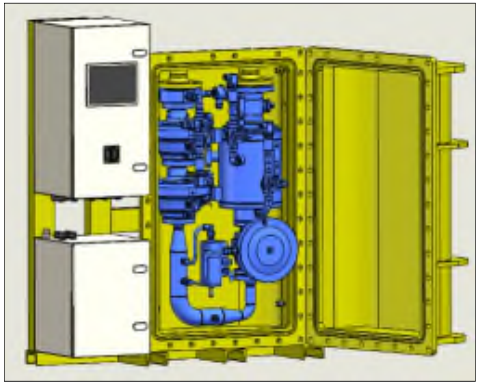
Power / Cylinder	93 – 125 kW
Engine speed	600 – 1600 rpm 600 – 1800 rpm
Emission certification	IMO Tier III EPA Tier 4 – on request EUV – on request
Exhaust gas backpressure	30mbar (design) / 85mbar (max)
Natural Gas Quality	MN > 70
Gas consumption	203 g/kWh @ 2000 kW @ 1800rpm
Gas pressure before GRU	5.5 - 8 bar
Mean time between overhaul	30.000 hrs (standard 1A load profile)
Cooling system	HT/LT Separate circuit charge air cooling

S4000 M05-N
Engine Concept & Technical Concept



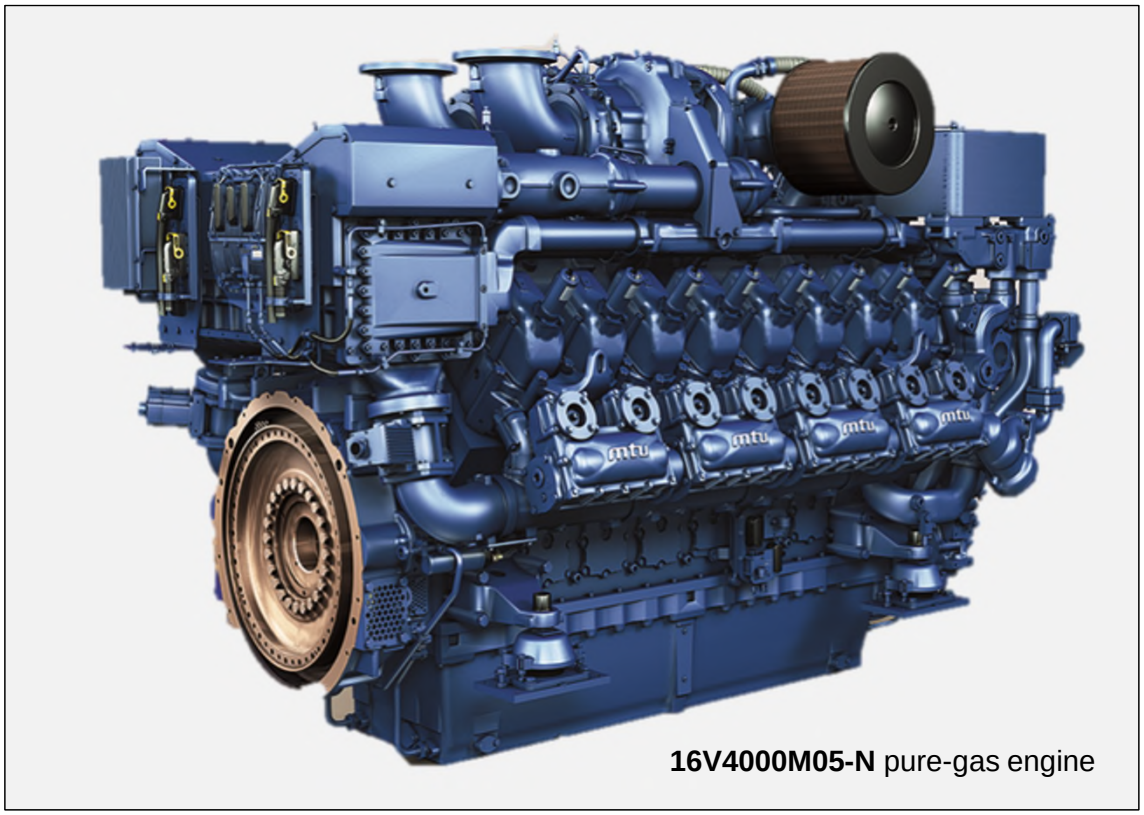
04 Standard scope of supply

16V 4000 M05-N
Standard Scope of Supply



Gas Regulation Unit (GRU)

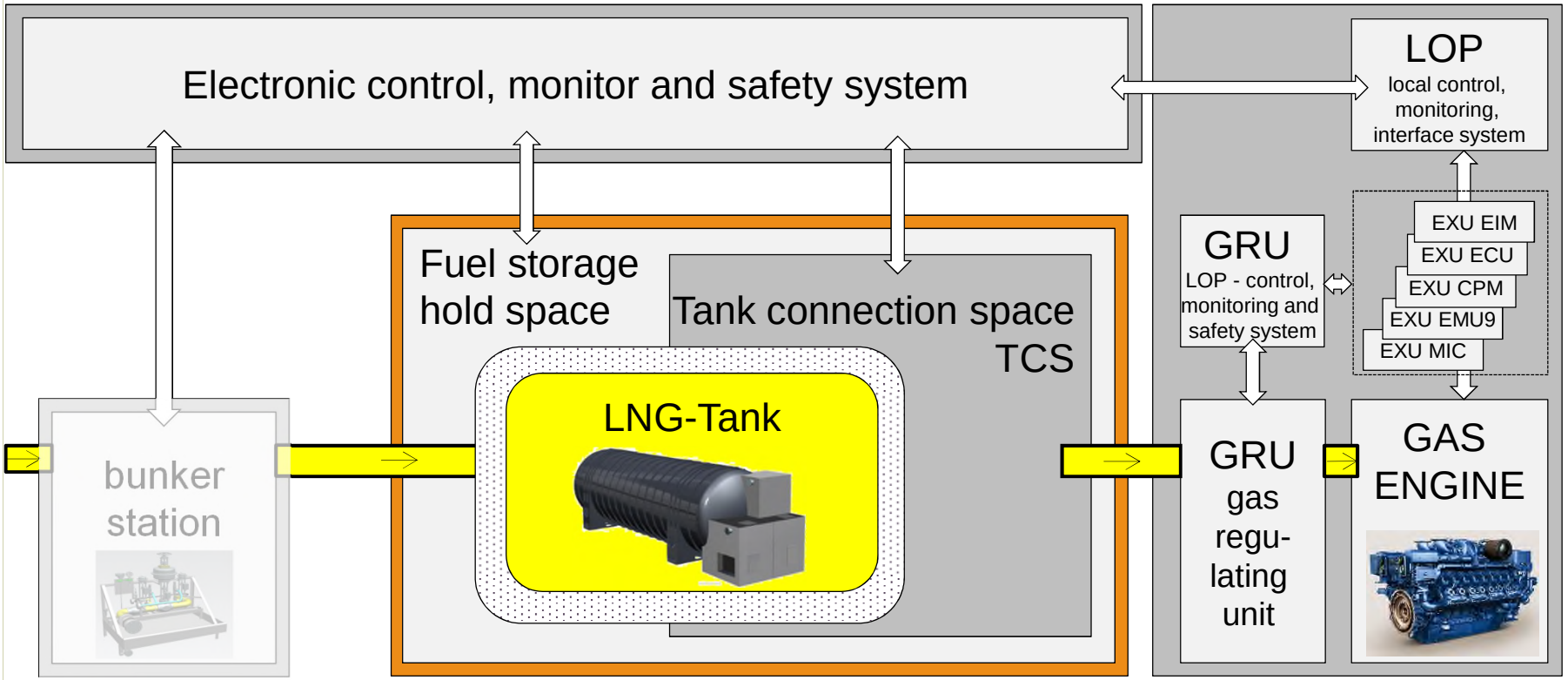
Local Operator Panel (LOP)



16V4000M05-N pure-gas engine

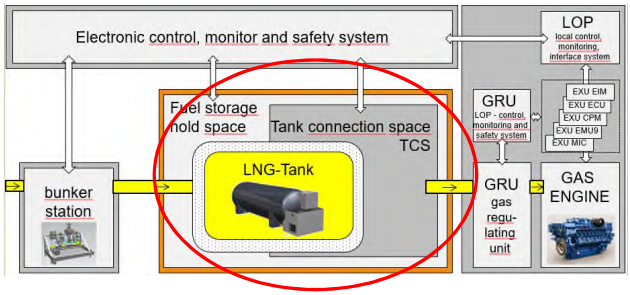
05 Shipside Gas System (optional)

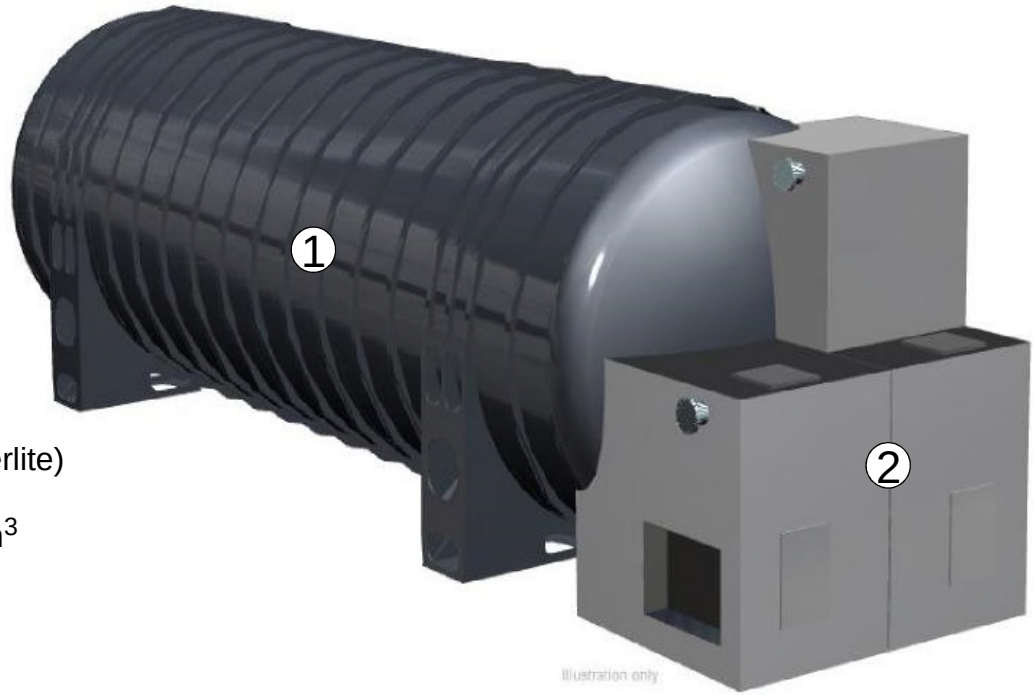
Shipside Gas System
Fuel gas system (LNG) – overview



Shipside Gas System
Fuel gas system (LNG) – tank and TCS

STORAGE TANK FOR LNG:

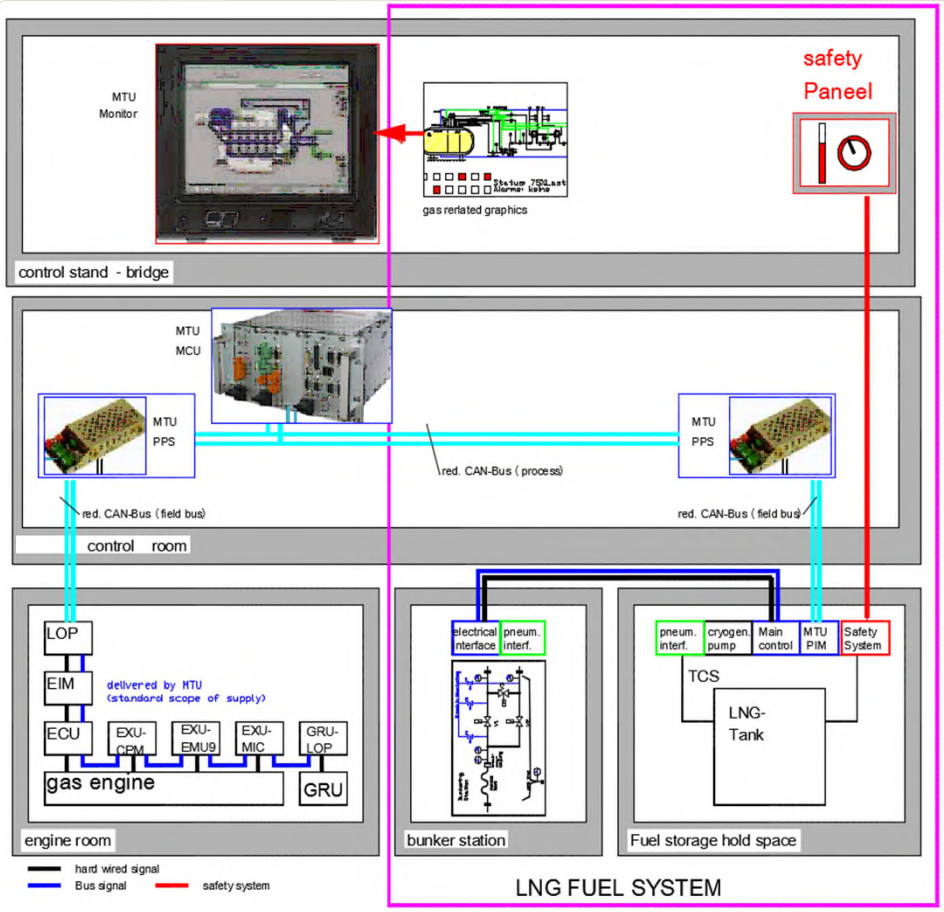




① **Storage tank for LNG:**
- -Double walled tank (vacuum isolated / filled with perlite)
- -The volume depends on the ship and load profile.
- -Typical tank size for MTU gas engines: 10 … 100m^3
- -Tank mounting position: horizontal or vertical

② **TCS (tank connection space):**
- -Regasification of LNG to NG with temperature and pressure, needed for MTU engines (within limits).
- -Monitoring and control of the tank pressure
- -Monitoring of the tank level (filling / consumption)
- -Boil-off gas (BOG) handling

Shipside Gas System
Fuel gas system (LNG) – Automation and control system



LNG Fuel System:

2 independent systems for:

- Control and monitoring system
- Safety system

Visualization:

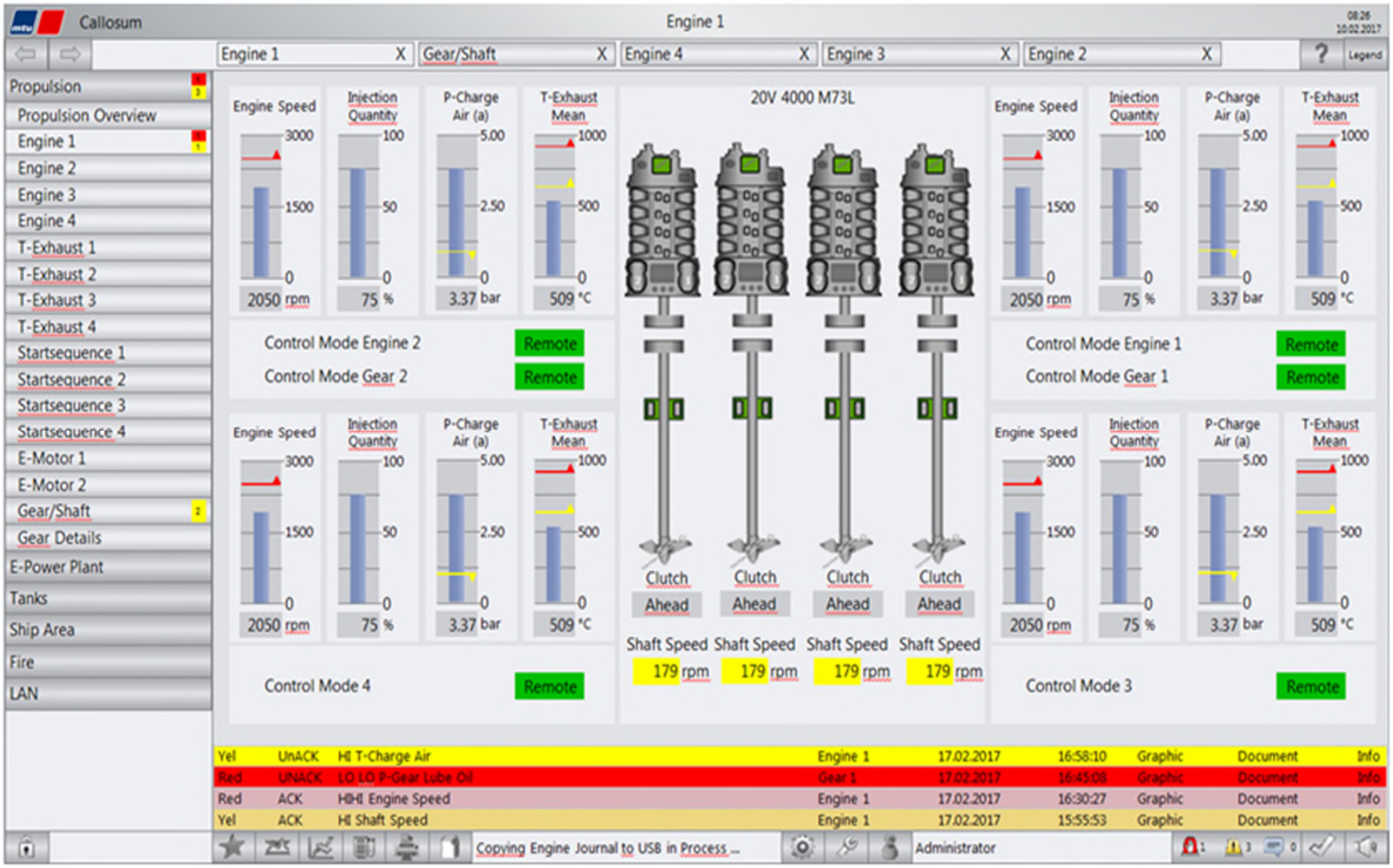
- engine control room
- control stand (bridge)

Shipside Gas System
Fuel gas system (LNG) – Automation and control system

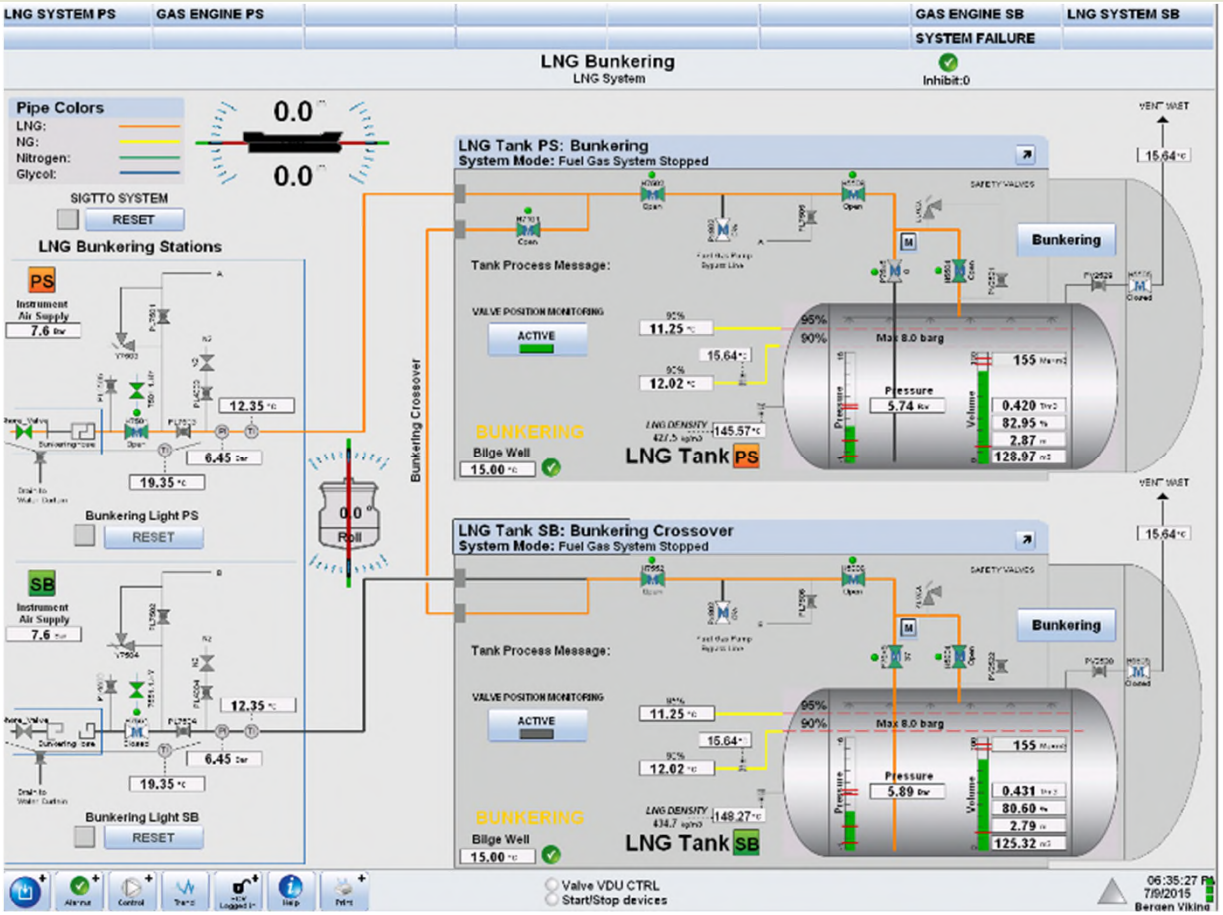
Main Process Functions:

- bunkering
- gas supply during normal operation (gas engines supply)
- Safety System (LNG-fuel-system) and monitoring to avoid critical situations
- Monitoring of all necessary information with regards to control of the regasification process in accordance to the acceleration behavior
- Alarm processing & Alarm monitoring
- Interface to the ship automation system
- Control and monitoring of the pneumatic panels

Shipside Gas System
Engine monitoring – typical monitoring layout



Shipside Gas System
Fuel gas system (LNG) – typical monitoring layout



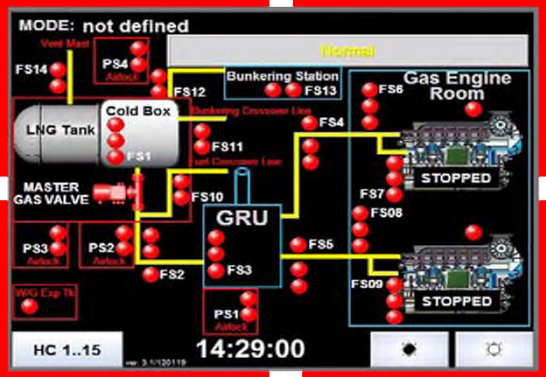
Shipside Gas System
Fuel gas system (LNG) – safety system

- monitor safety critical elements for the LNG fuel system.
- will perform a series of predetermined actions to reduce the safety hazard and if the situation calls for it make sure the LNG Fuel system will be shut down and returned to a safe state.

main task

gas detection

- will monitor the level of dangerous gases at strategic places in the ship and along the LNG fuel system.
- Typical mounting places are double walled piping of gas supply to the engine and in the TCS.
- Gas detection are built on a system of dual sensing, where two gas sensors operate in pair.



control

- In the case of a safety critical event the Safety System (LNG-fuel-system) will execute appropriate action to reduce or eliminate safety risks.
- Is built up with several levels of control depending of the safety critical event.

monitoring

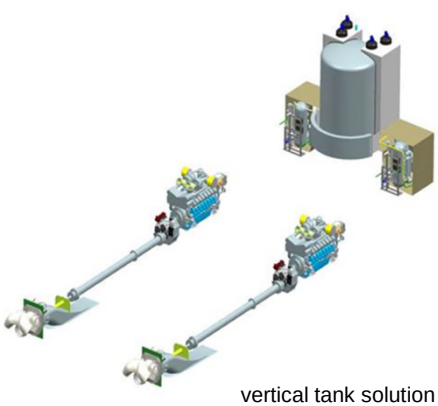
- Is designed to monitor safety critical signals from the LNG fuel system as well as other signals that are important to the safety of operating the LNG fuel system.

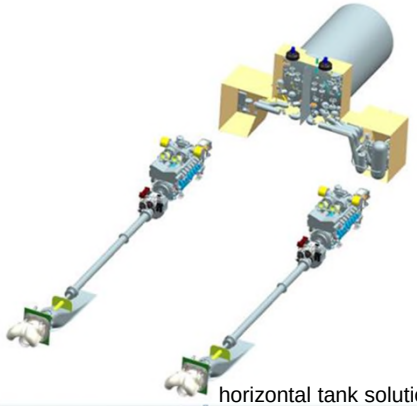
Shipside Gas System
Fuel gas system (LNG) – actual design studies

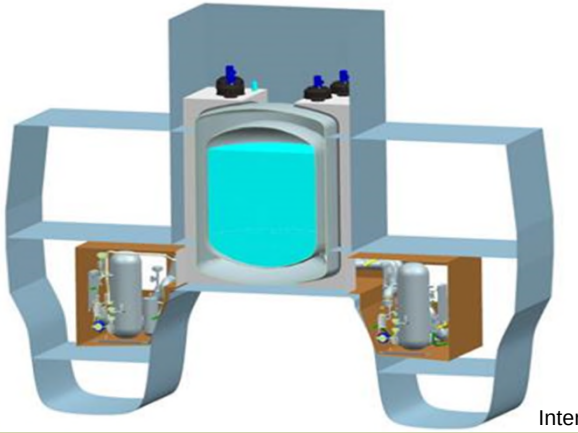
Brødrene Aa

a specialist for high speed catamarans (HSLC) made in carbon composite.

exemplary representation


vertical tank solution


horizontal tank solution


Intersection of hulls

06 Ratings, Portfolio & Market introduction

Portfolio, Ratings & Market introduction
Planned Marine Portfolio




Marine prop. IMO III / EPA 4* / EU V*	**8V 746 kW / 1000 kW 1600 rpm / 1800 rpm**	12V max 1500 kW	**16V 1492 kW / 1840 kW / 2000 kW 1600 rpm / 1800 rpm /1800 rpm**	20V max 2500 kW
Marine gens. IMO III / EPA 4* / EU V*	8V max 1000 kW	12V max 1500 kW	16V max 2000 kW	20V max 2500 kW

16V4000M05-N for main propulsion	SOD Q12/2018 with Lloyds Register - ABS, BV, DNV / GL subsequently
8V4000M05-N for main propulsion	SOD Q02/2020
12V4000 and **20V**4000	development subject to market demand
Constant speed engine	development subject to market demand
* **EPA 4** (with oxi-cat) and **EU V**	8V and 16V certification subject to market demand

07 References

References

High Speed Ferries:
2x 16V4000 gas engines @1.492kW
for *Reederij Doeksen*
2 vessels

Ro-Ro Ferry:
2x 8V4000 gas engines @ 746W
for *Stadtwerke Konstanz*
1 vessel

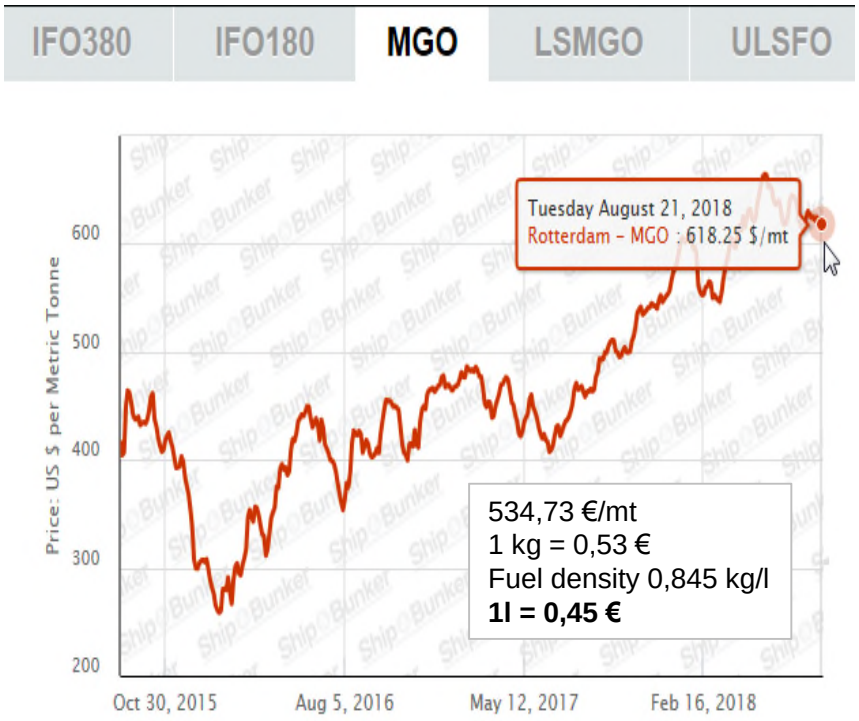
08 Customer Benefits

LCC Comparison IMO III - Gas vs. Diesel

Fuel price scenario - Oil / Natural gas

Current price of MGO (Marine Gasoil)

618,25 USD/mt → **0,45€/l**



→ **Scenarios**

Assumptions up to 2025	Low Case	Base Case	High Case
Emission requirements	**Europe:** IMO III in ECAs, IMO II remains standard **US:** EPA 3 / IMO II remains standard **China:** IMO II remains standard, no requirements for Inland Waterways	**Europe:** IMO III in ECAs and introduction of EU V + PN (2021) **US:** IMO III in ECAs (2019) **China:** Introduction of EPA 3 & ECAs in 2020 + PM (2023)	**Europe:** ECA for Mediterranean Sea **US:** IMO III + PN for the whole region including Canada & Latin America **China:** Introduction of other ECAs beside China & Singapore
Infrastructure	Low oil price leads to immediate cancellation of all planed infrastructure projects. Only the **15** existing bunkering stations will be operated.	In addition to the **15 already active** LNG bunkering stations, all of the **~60 planned** and proposed bunkering stations will be build and active in 2020.	Infrastructure will be build in regions like **Africa, Latin America and Asia** within short time and the LNG will be available with **worldwide coverage**
Natural Gas vs. Oil Prices	Price Ratio between Oil and Natural Gas (Barrel Oil Equivalent) of **1,5:1**	Price Ratio between Oil and Natural Gas (Barrel Oil Equivalent) of **2,5:1**	Price Ratio between Oil and Natural Gas (Barrel Oil Equivalent) of **5:1**
	Diesel 0,45 €/l	Diesel 0,45 €/l	Diesel 0,45 €/l
	LNG 0,30 €/l	LNG 0,18 €/l	LNG 0,09 €/l

Source: https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#MGO / 22/08/2018

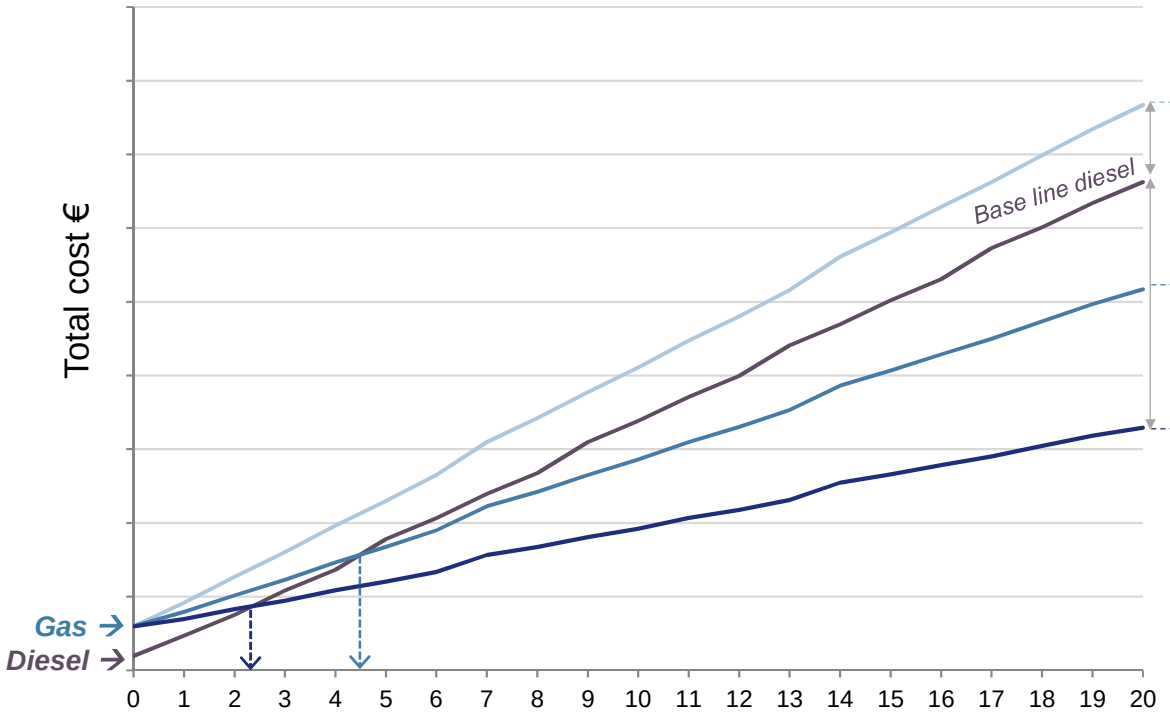
1 liter LNG equal to 0,6 m³ LNG gaseous

LCC Comparison IMO III - Gas vs. Diesel

Ferry ship scenario – 2x engines 16V4000M05 – 5,250h p.a.

Maintenance, *Invest & Consumption cost over 20 years

Costs are based on a generic Diesel / Gas engine 16V4000M05 (2.000 kW), operated in medium engine load. Calculation Aug. 2018



Low Case → Add'l cost gas engine + 16%

Base Case → Savings gas engine - 22 %

High Case → Savings gas engine - 50 %

Low Case: Price ratio Oil /Gas → **1.5 : 1**
Base Case: Price ratio Oil /Gas → **2.5 : 1**
High Case: Price ratio Oil /Gas → **5.0 : 1**

Assumed price for Marine Gasoil 0,45 €/l

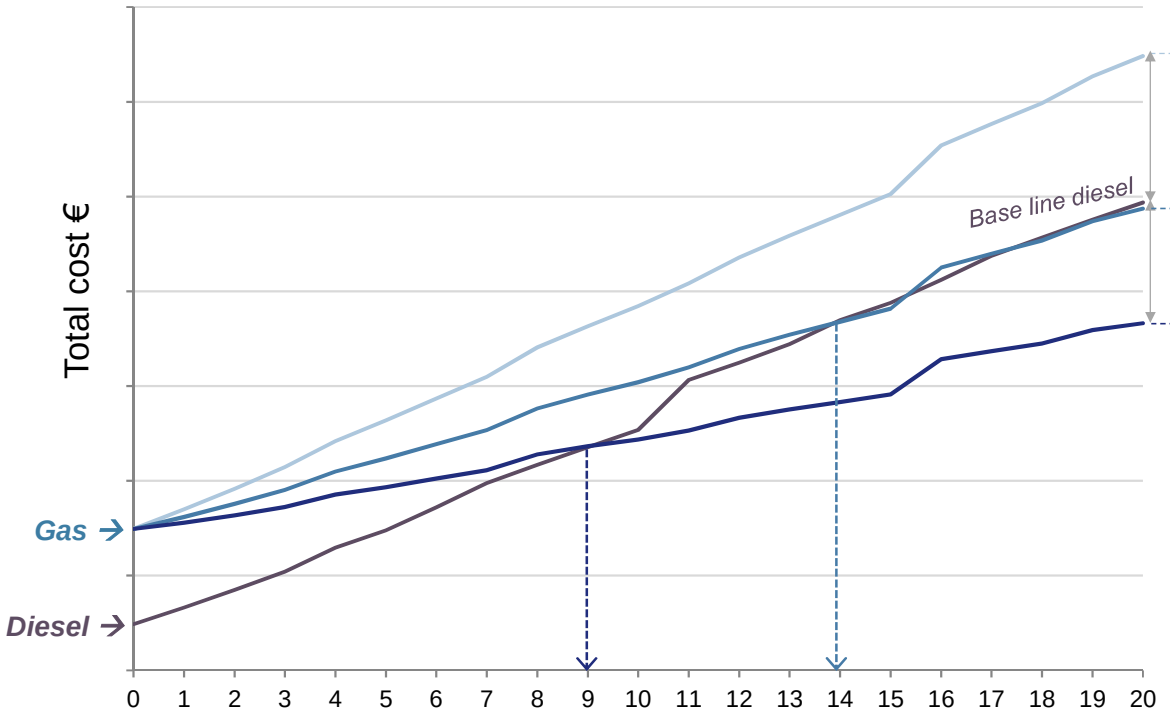
**Invest cost: 2 x engines + Tank system*

LCC Comparison IMO III - Gas vs. Diesel

Tug boat scenario – 2x engines 16V4000M05 – 2,400h p.a.

Maintenance, *Invest & Consumption cost over 20 years

Costs are based on a generic Diesel / Gas engine 16V4000M05 (2.000 kW), operated in medium engine load. Calculation Aug. 2018



Low Case → Add'l cost gas engine + 31%

Base Case → Savings gas engine - 1%

High Case → Savings gas engine - 26%

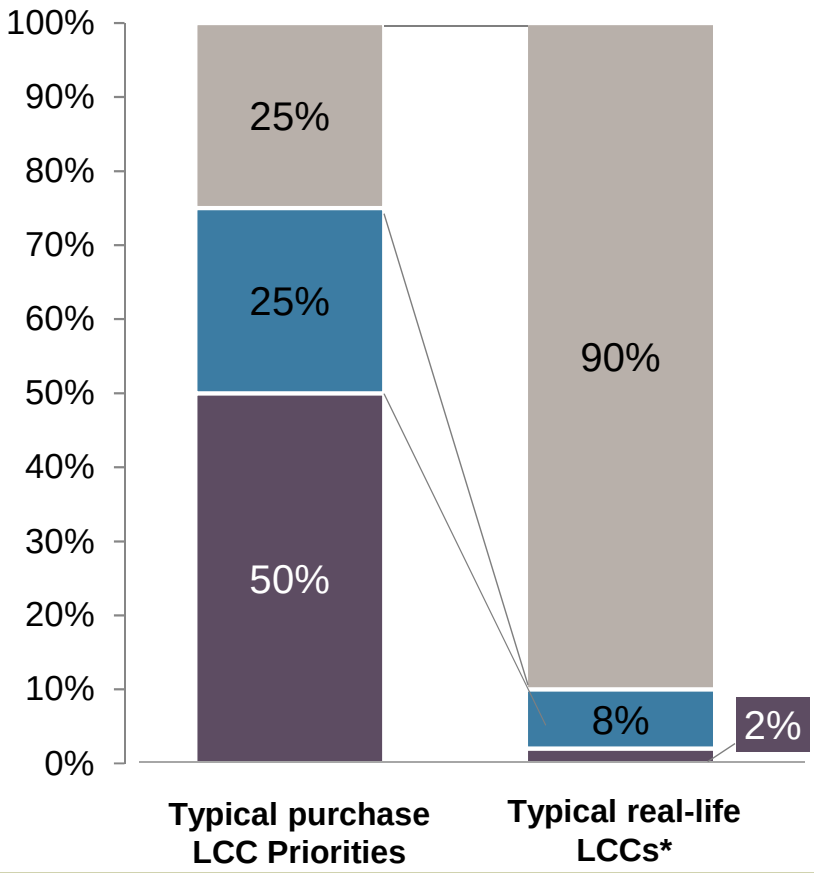
Low Case: Price ratio Oil /Gas → **1.5 : 1**
Base Case: Price ratio Oil /Gas → **2.5 : 1**
High Case: Price ratio Oil /Gas → **5.0 : 1**

Assumed price for Marine Gasoil 0,45 €/l

**Invest cost: 2 x engines + Tank system*

LCC Comparison IMO III - Gas vs. Diesel

Customer LCC priorities in the acquisition phase



Operational costs
Often seen as individual cost and not part of LCC. Operating cost are frequently asked separately. They are hard to predict due to uncertain fuel cost

Maintenance costs
Often seen as an individual cost and not part of typical LCC. They contain Preventive, corrective and condition based tasks.

Acquisition costs
Capital expenditure still the most important. Limited funds are frequently prioritised over break-even point and ROI.

* Costs are based on a generic Series 4000 diesel engine with 2xTBO operating life and one overhaul and continuous operation

Why lifecycle costs matter
https://www.youtube.com/watch?v=tcP8NDQ_Nws

09 Key Facts & Highlights

S 4000 Gas engine for Marine application Key Facts & Highlights

S4000 Gas engine for Marine application Key Facts / Highlights

Dynamic Acceleration Behavior

- ➢ Comparable performance characteristics to that of our series 4000 diesel engine for workboat application, no visible smoke, even at acceleration

Better environmental footprint compared with that of the diesel engine

- – 25% less Carbon Dioxide (CO_2)
- – Health-threatening substances in the exhaust gas - such as nitrogen oxides, sulfur oxides, fine particulate matter - of gas-powered engines are reduced by 80 up to 100% compared to IMO II diesel engine
- ➢ No Exhaust Gas After Treatment (SCR, Particulate Filter) required for IMO Tier III and EUV

Gas Safe Machinery

- – Engine built for “gas safe machinery space”
- ➢ No need for separate engine housing and ventilation within the engine room

First high speed pure gas engine in high power range

- – Currently available gas engines are primarily medium speed engines
- ➢ Pure gas high speed engines offer significantly less weight than medium-speed gas engines for the same performance → improved power-to-weight-ratio

S 4000 Gas engine for Marine application Key Facts & Highlights

S4000 Gas engine for Marine application Key Facts / Highlights

Multi Point Injection

– Cylinder individual injection of gas
➢ Identical combustion period in each cylinder
➢ Stable engine operation, increased availability

Engine Map

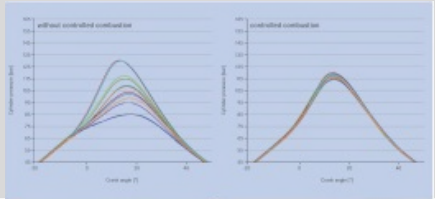
➢ All propulsion modes possible (fixed and variable pitch propeller)

Wide rpm range

➢ The rpm range is suitable for fixed pitch propellers to provide low-cost drive systems

Cylinder Pressure Based Combustion Control

– Minimization of the scatter band of the cylinder individual peak pressures
– Control of mean effective pressure, gain stability
➢ Reduction of fuel consumption and emissions



Thank you very much for your attention.

Power. Passion. Partnership.