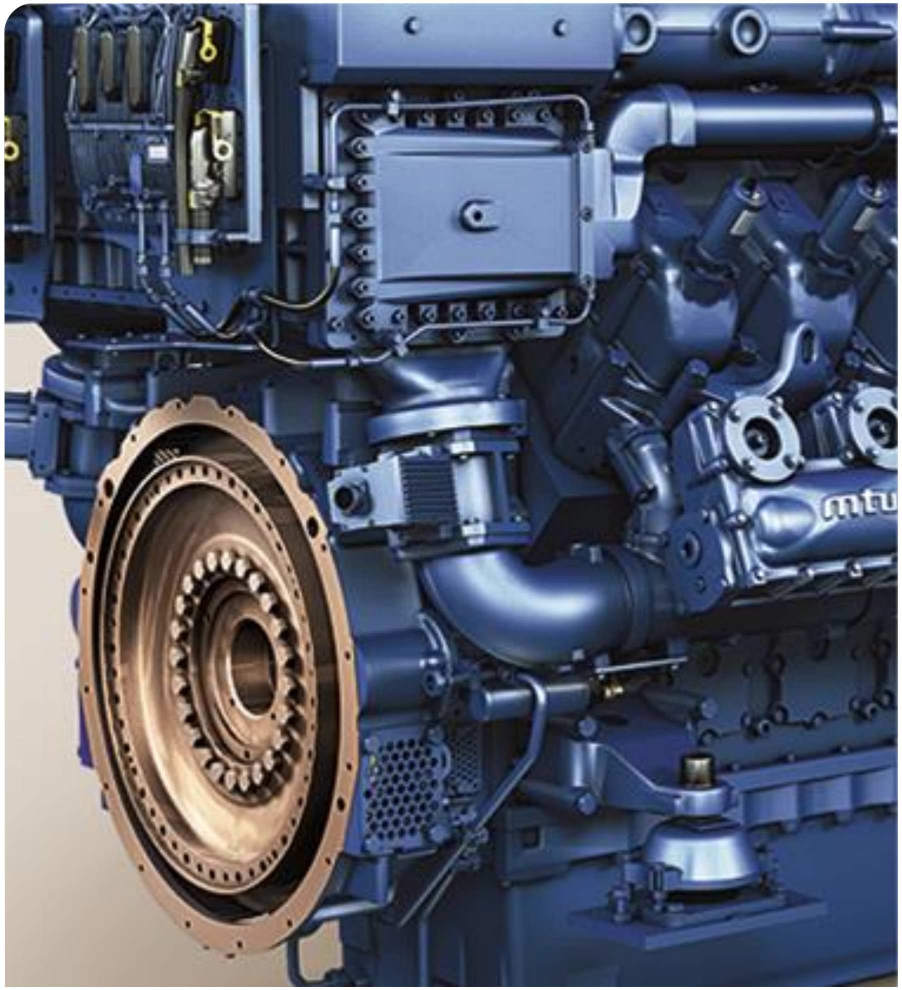


Gas Mobile Marine

S4000M05-N
Gas Mobile Marine

Workshop on Modernisation of Danube Vessels Fleet

FN, April 2018, Peter Rank

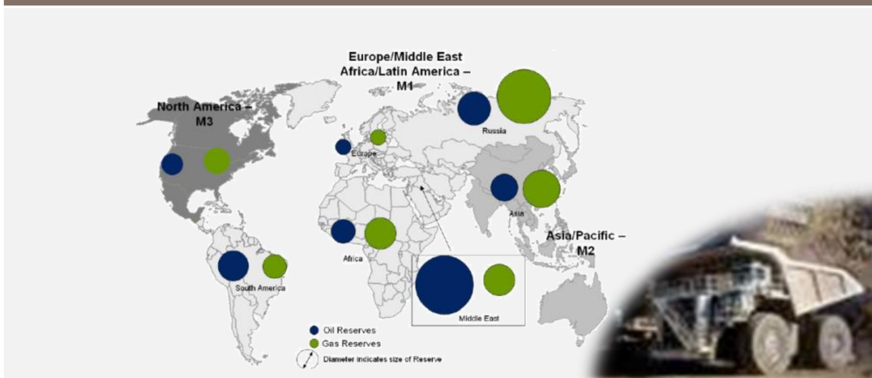
Power. Passion. Partnership.

Agenda

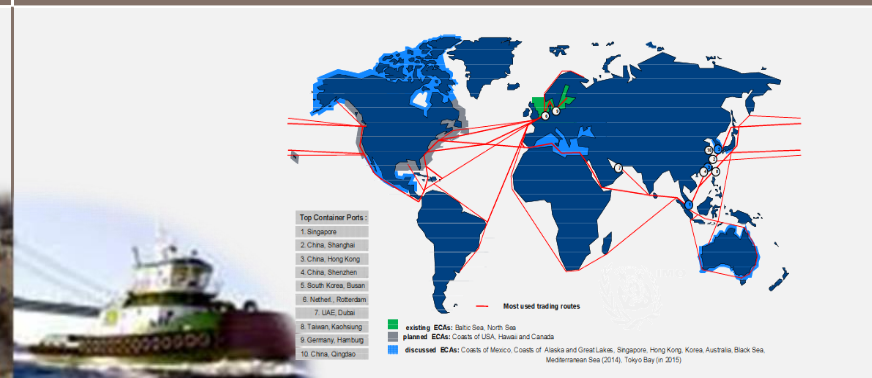
01 General Overview

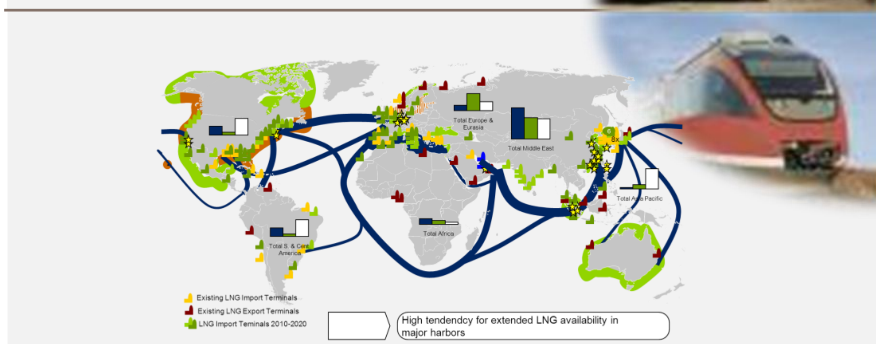
General Overview
Main driving factors for Gas engines

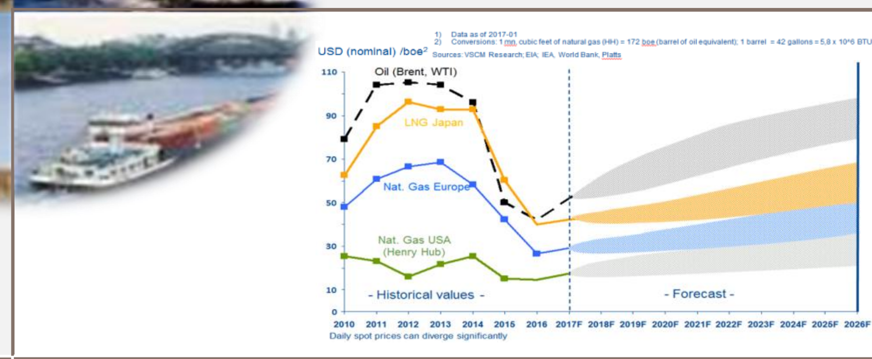
Large Reserves



Emission Regulations (ECA**)







Developing LNG*-Infrastructure

Low Gas Price

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

General Overview
In-house Gas Experience

Gas Mobile Marine

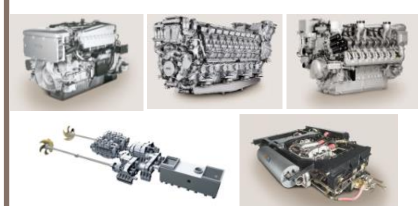
Rolls-Royce

Rolls-Royce Power Systems AG			Rolls Royce Marine
mtu	mtu onsite energy	Bergen Engines AS	

Mobile Applications

High Speed Diesel Engines

Propulsion systems



Know how transfer

Stationary Applications

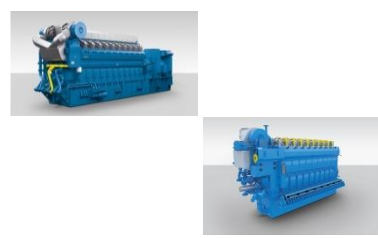
High Speed Gas Engines
High Speed Diesel Engines

Gas and Diesel Generator sets
Power supply systems

Marine and Stationary Applications

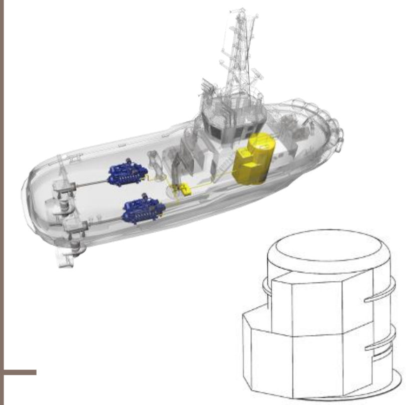
Medium Speed Gas Engines
Medium Speed Diesel Engines

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

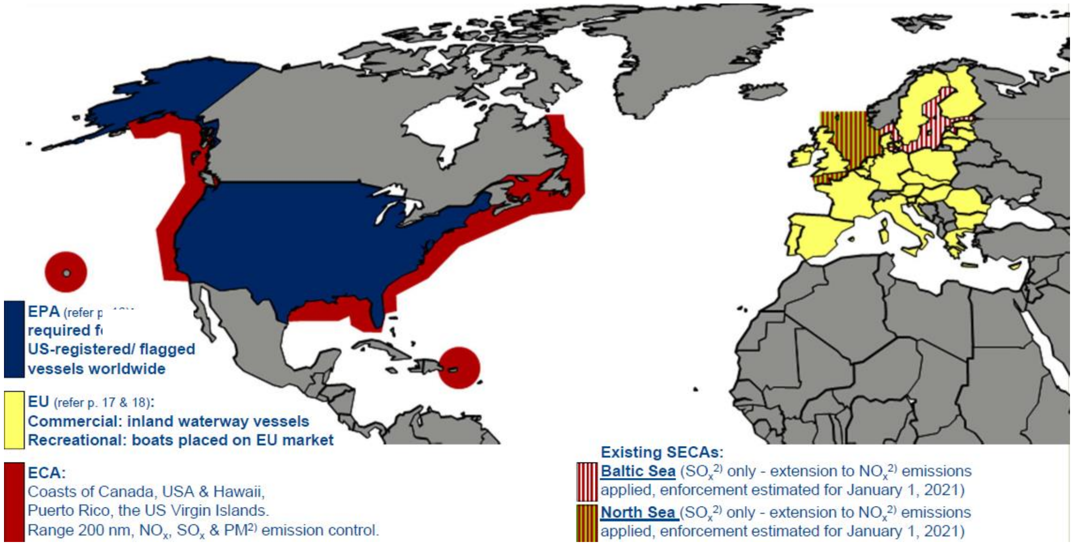
Emission Legislation Overview

	2015	2016	2017	2018	2019	2020	2021
EPA	> 2000kW since 2014	EPA Tier 4 (NOx 1.8 g/kW, PM: 0.04 g/kWh); 1000 -1400kW →2017; 600-1000kW →Oct 2018					
IMO		IMO Tier III (NOx 2.0 g/kWh, PM not limited) only in emission controlled areas					
EU V						EU Stage V (NOx 1.8 g/kWh, PM: 0.015 g/kWh / PN: $1*10^{12}$ #/kWh)	

IMO Tier III (in Emission controlled areas – ECA)
EPA Tier 4

EU V

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 consturcted 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,…

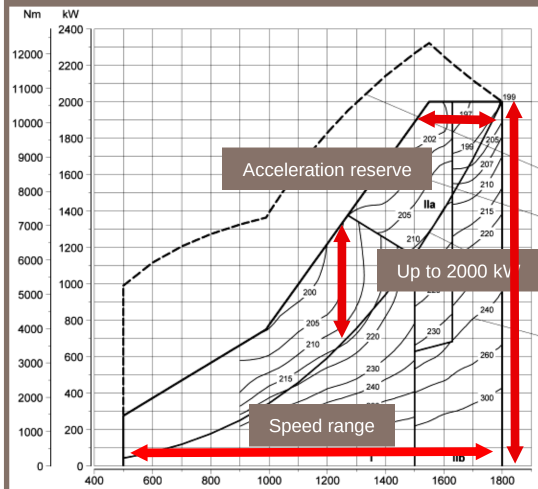
EU V
Engines (>300kW) for Inland waterway vessels used in EU need **EU V** certification from **1st January 2020** on

03 Engine Concept

S4000M05-N - Engine Concept Engineering Target

Gas Mobile Marine

Diesel like performance
Suitable for FPP applications



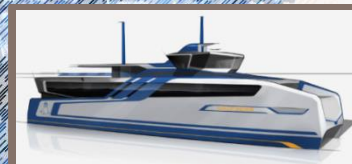
Use of proven S4000 base engine
Use of common S4000 parts

Comply to latest emission regulation limits

IMO Tier III

EPA Tier 4*

EU V*



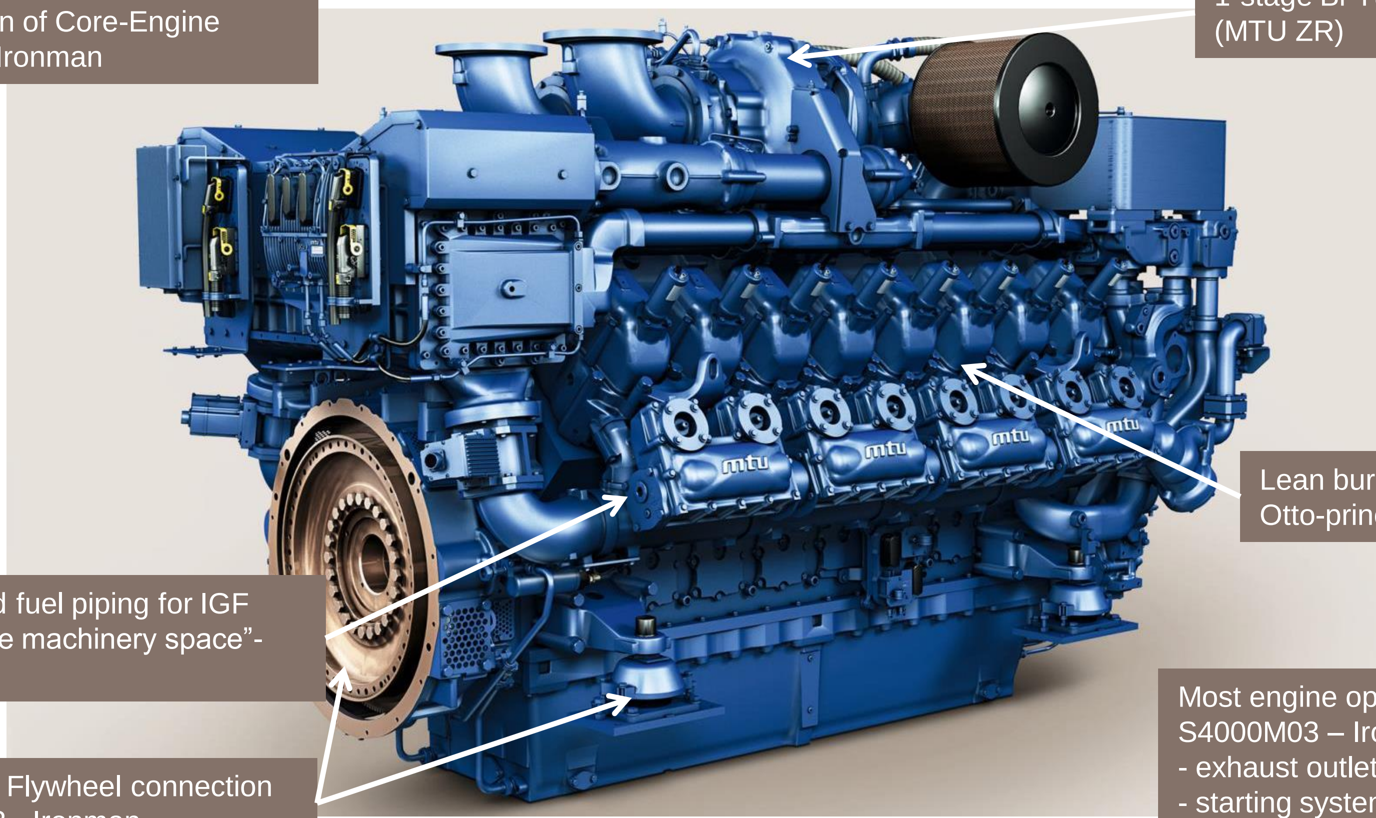
Heavy Duty Commercial Application (1A rating)

* on request

S4000M05-N - Engine Concept
Technical Concept

Proven design of Core-Engine S4000M03 - Ironman

1-stage Bi-Turbo (MTU ZR)



Lean burn gas engine Otto-principle

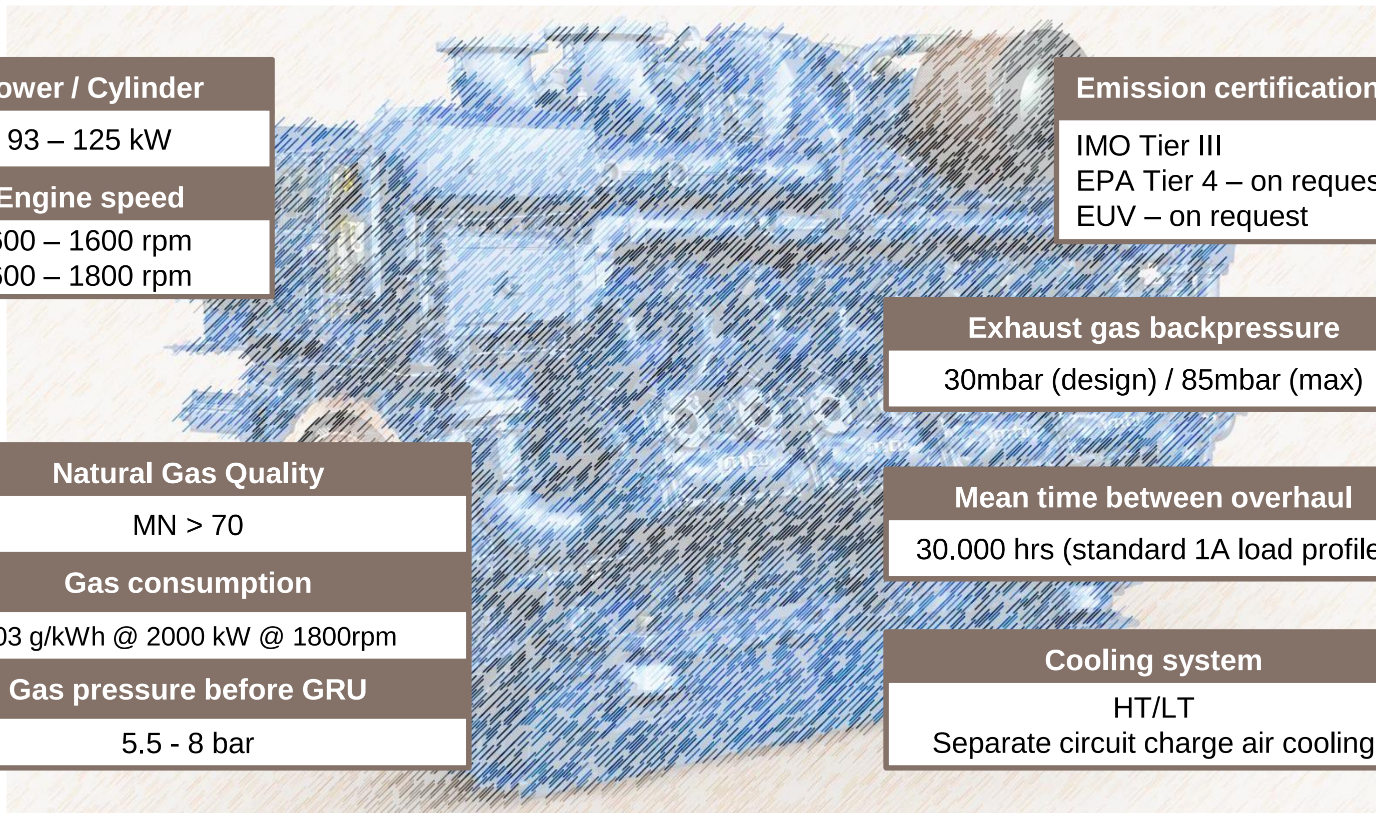
Double-walled fuel piping for IGF code “gas safe machinery space”-concept

Footprint and Flywheel connection as S4000M03 - Ironman

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

04 Technical Data / Features

S4000M05-N – Technical Data Engine



Power / Cylinder
93 – 125 kW

Engine speed
600 – 1600 rpm
600 – 1800 rpm

Natural Gas Quality
MN > 70

Gas consumption
203 g/kWh @ 2000 kW @ 1800rpm

Gas pressure before GRU
5.5 - 8 bar

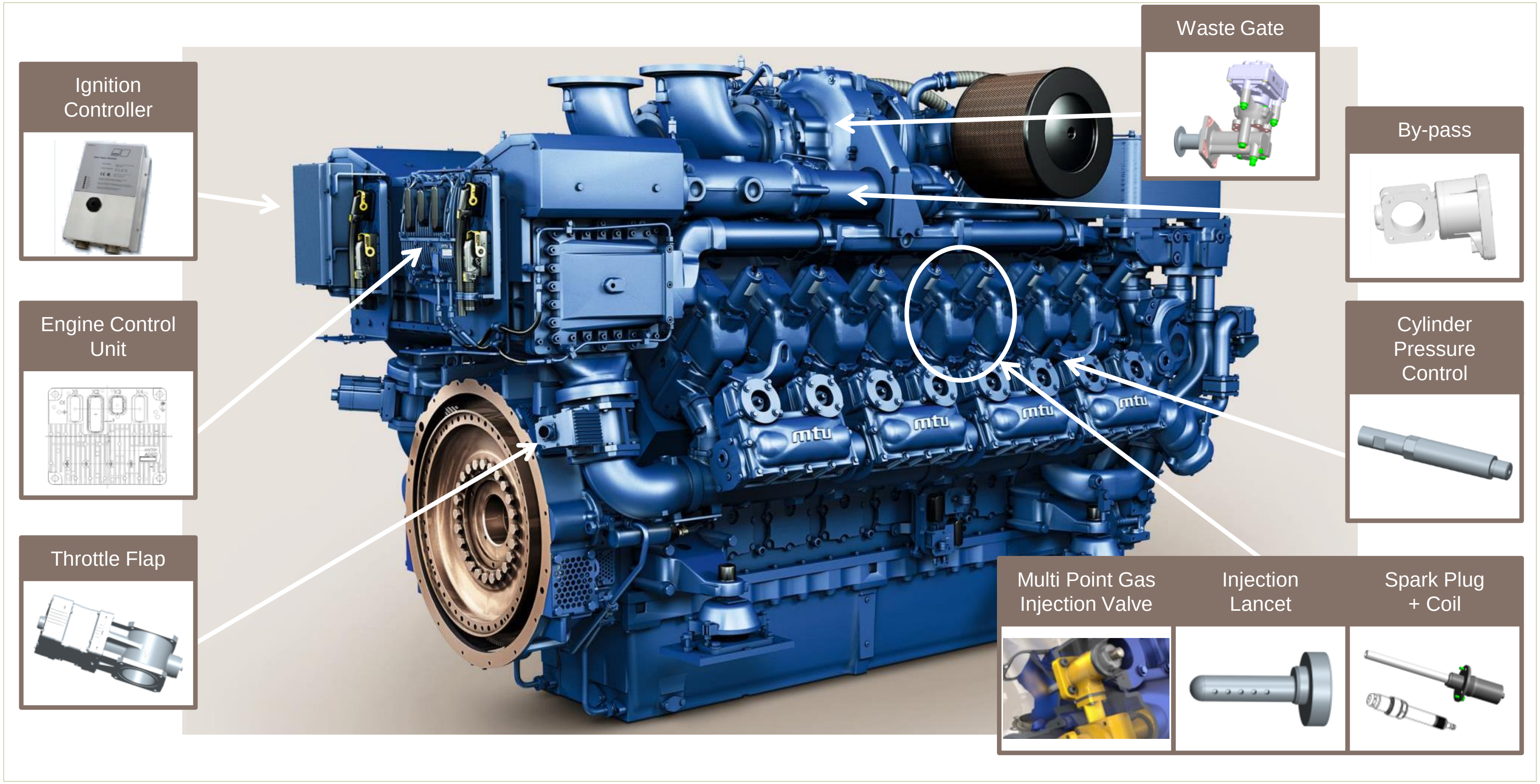
Emission certification
IMO Tier III
EPA Tier 4 – on request
EUV – on request

Exhaust gas backpressure
30mbar (design) / 85mbar (max)

Mean time between overhaul
30.000 hrs (standard 1A load profile)

Cooling system
HT/LT
Separate circuit charge air cooling

S4000M05-N – Technical Features
Gas Specific Engine Components



S4000M05-N – Technical Features
Cylinder Pressure Based Combustion Control

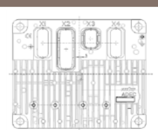
GAS MOBILE MARINE

Cylinder pressure based combustion control

Cylinder Pressure Sensor

Individual cylinder pressure measurement

Engine Control Unit



Combustion process control per cylinder

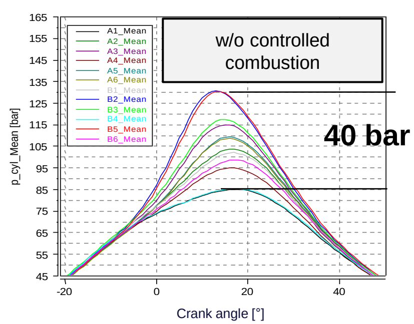
Observation of the in-cylinder individual burn rate

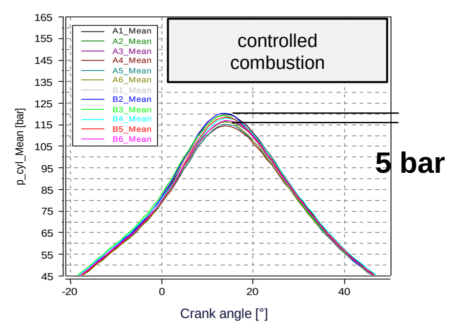
in time analysis of:

- Start of combustion
- Combustion progress
- Knock
- Max. peakpressure
- Misfiring
- BMEP to determine engine power

Benefits:

- Minimization of the scatter band of the cylinder individual peak pressures.
- Control of max. firing pressure, eliminate knocking when MN went down (rich gas)
- Control of mean effective pressure, gain stability (lean gas)

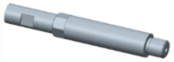




S4000M05-N – Technical Features
Interaction / function of key components

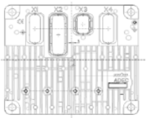
Cylinder pressure based combustion control

Cylinder pressure sensor



Individual cylinder pressure measurement

Engine Controller



Combustion process control per cylinder

Ignition

Ignition controller

Control of ignition energy and timing based on spark plug wear

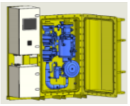
Spark plug + coil

Ignition of gas/air mixture

GAS

GRU

Gas flow and pressure control



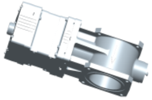
Multi point gas injection valve

- Air / Gas Mixture
- Injection duration

Charge air

Throttle flap

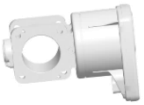
Air / Gas Mixture Injection duration



TC boost control

By-pass

TC boost control by charge air



Waste gate

TC boost control by exhaust gas

S4000M05-N – Technical Features
Diesel Like Performance

GAS MOBILE MARINE

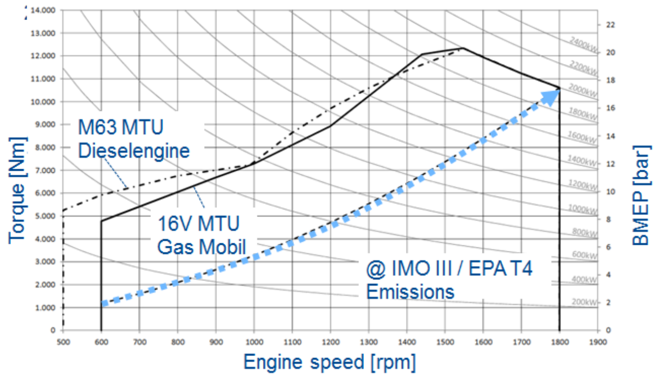
Achievements:

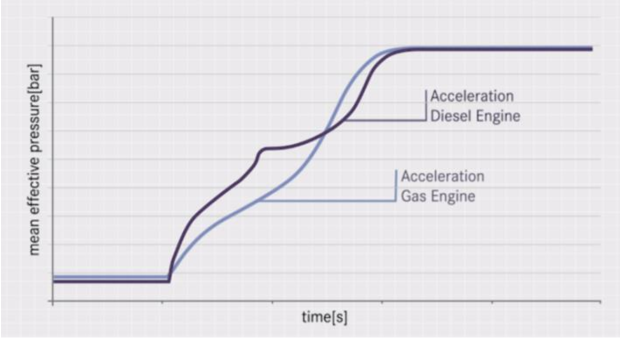
- Performance map/range like Diesel
- Suitable for Commercial Marine applications
- Compatible to fixed pitch propeller and thruster





✓ Dyno test confirmed dynamic acceleration

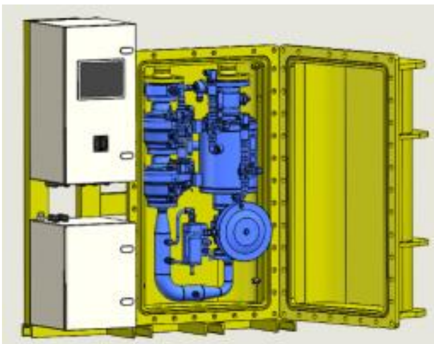




→ First pure Gas high-speed engine with Diesel like performance in the market.

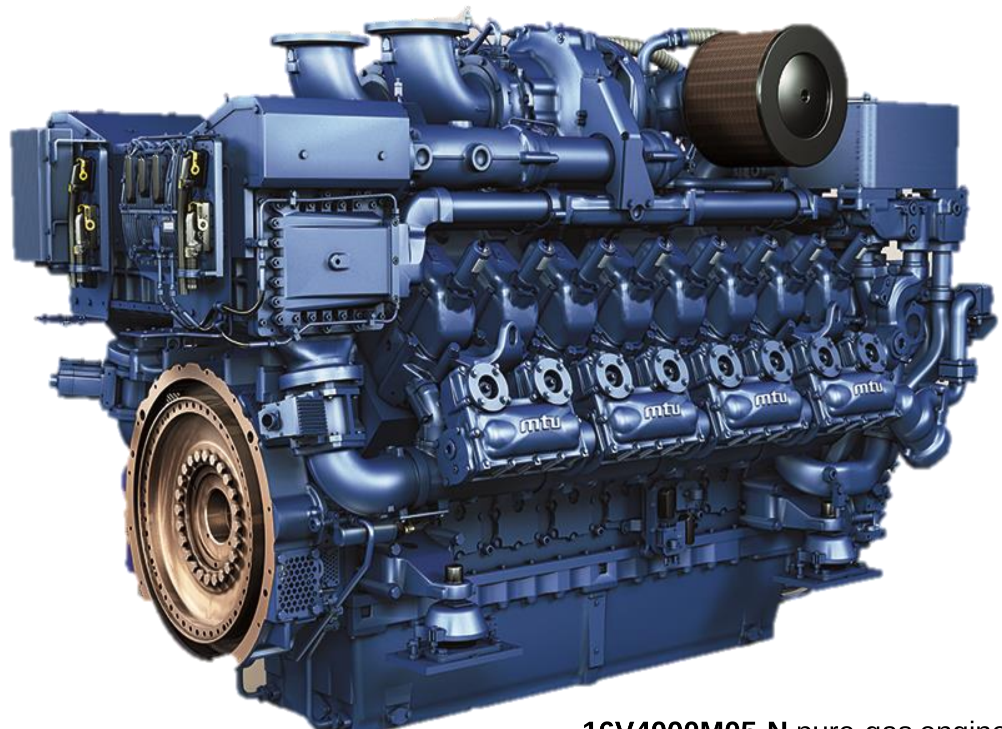
05 Standard scope of supply

16V4000M05-N - Scope of Supply
Standard Scope Overview



Gas **R**egulation **U**nit (GRU)

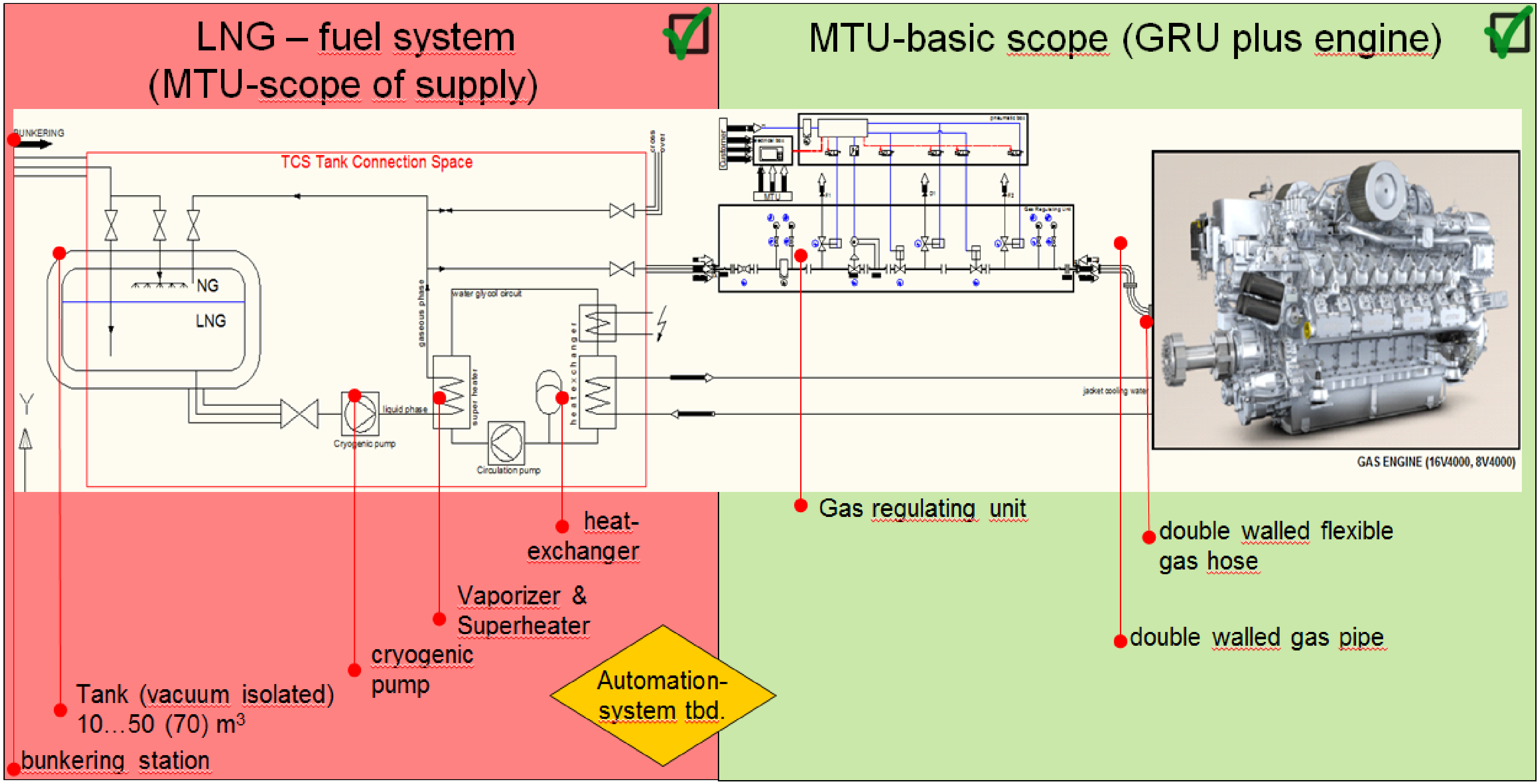
Local **O**perator **P**anel (LOP), customer interface



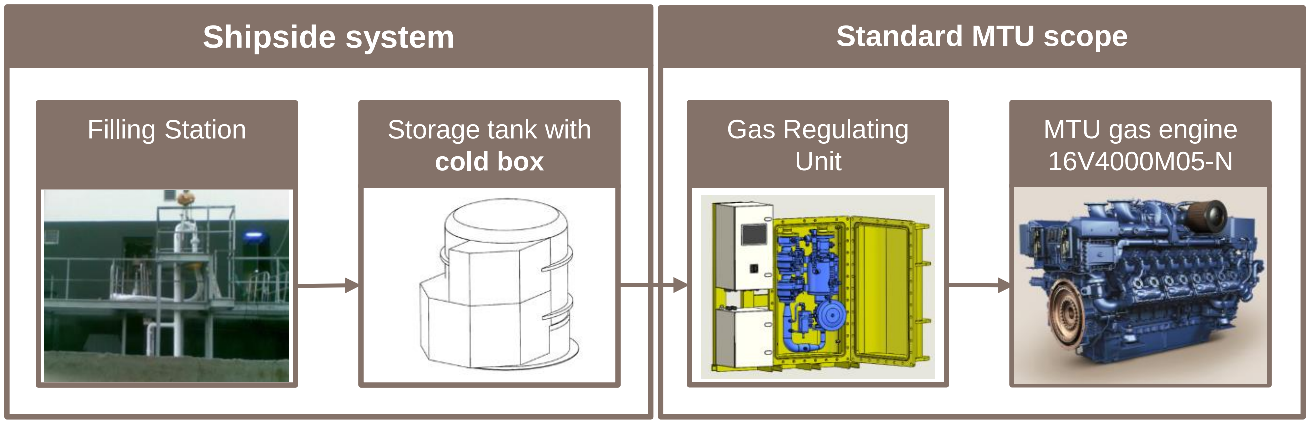
16V4000M05-N pure-gas engine

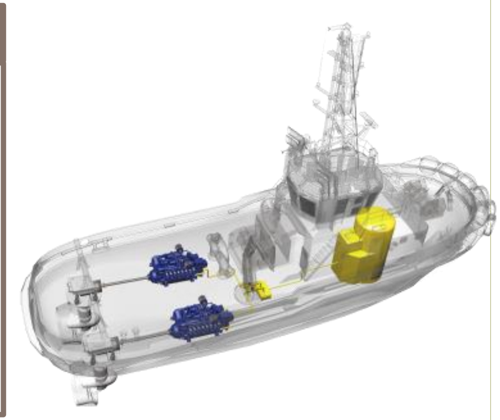
06 Shipside Gas System (option)

Overview – Product Scope
Marine Heavy Duty Gas System



Shipside Gas System
Fuel gas system (LNG) - MTU´s system approach

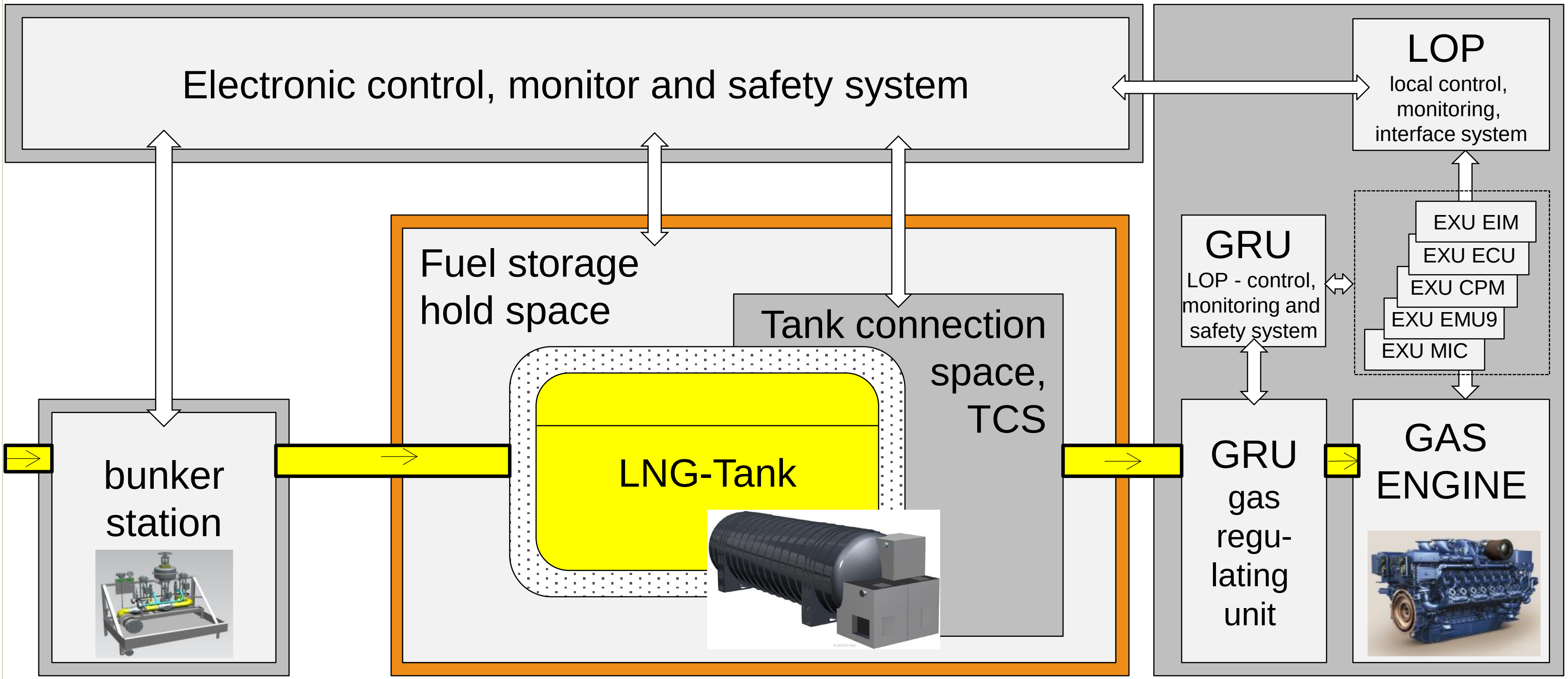




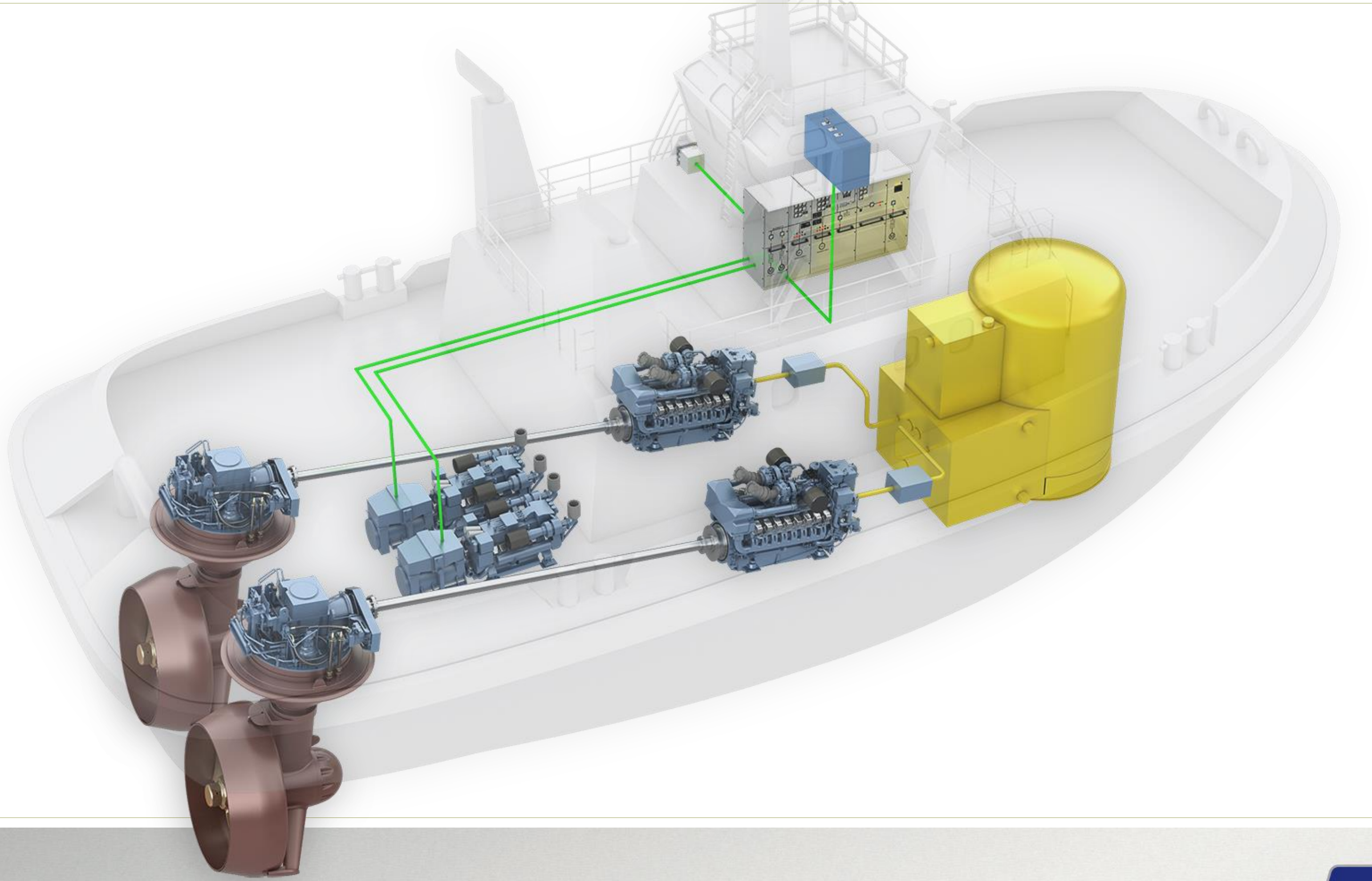
Today we see high investment cost for LNG storage and processing system due to non standardized solutions which have to meet strong safety requirements.

- ➔ MTU has launched a R&D project to develop a standardized system solution
- ➔ Typical MTU applications like ferries or Tugs and workboats shall be in the focus
- ➔ MTU will team up with Rolls-Royce Marine to benefit from their large experience in LNG propulsion and storage systems.

Shipside Gas System
Fuel gas system (LNG) – overview



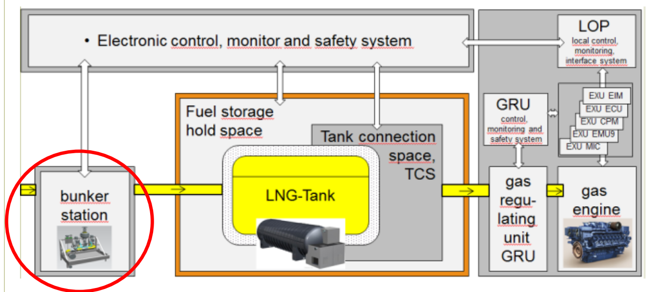
Shipside Gas System
Fuel gas system (LNG) – implementation, for example

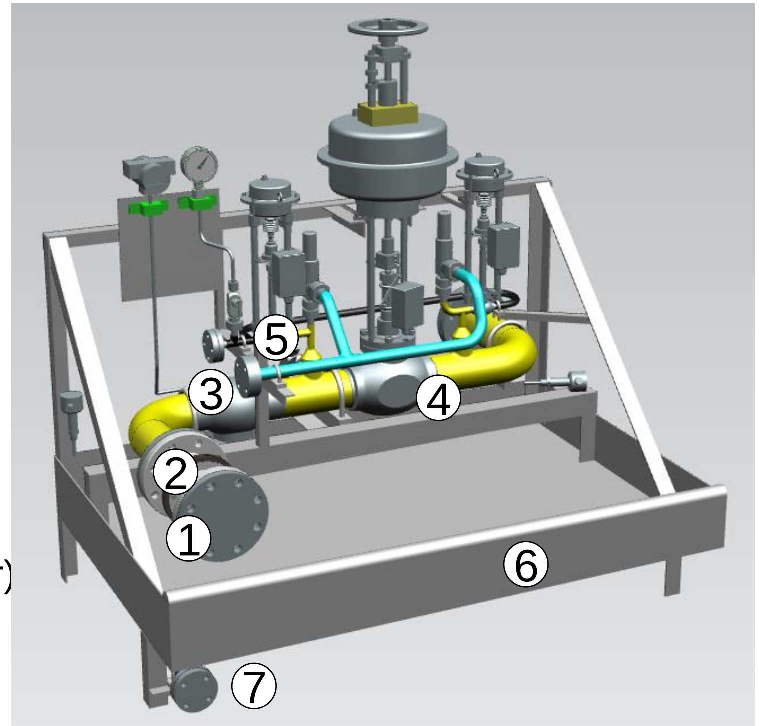


Shipside Gas System
Fuel gas system (LNG) – bunker station

GAS MOBILE MARINE

BUNKER STATION:





task:
connection point for the LNG supplier (ship/truck/…) to refill the tank and fulfill safety aspects.

components:

1 -flange for coupling system (in dependence of LNG supplier)
2 -break away coupling (safety)
3 -filter
4 -gas valve (pneumatic)
5 -N2 interface (bottles or onboard system)
 -pressure, flow and temperature sensors
 -pneumatic/electrical panel (not shown)

!! picture shows a single bunkering station!!

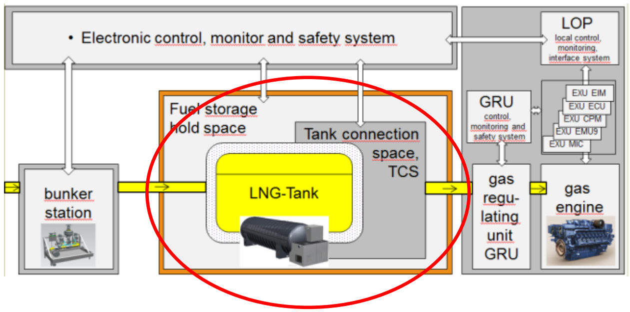
skid mounted bunker station:

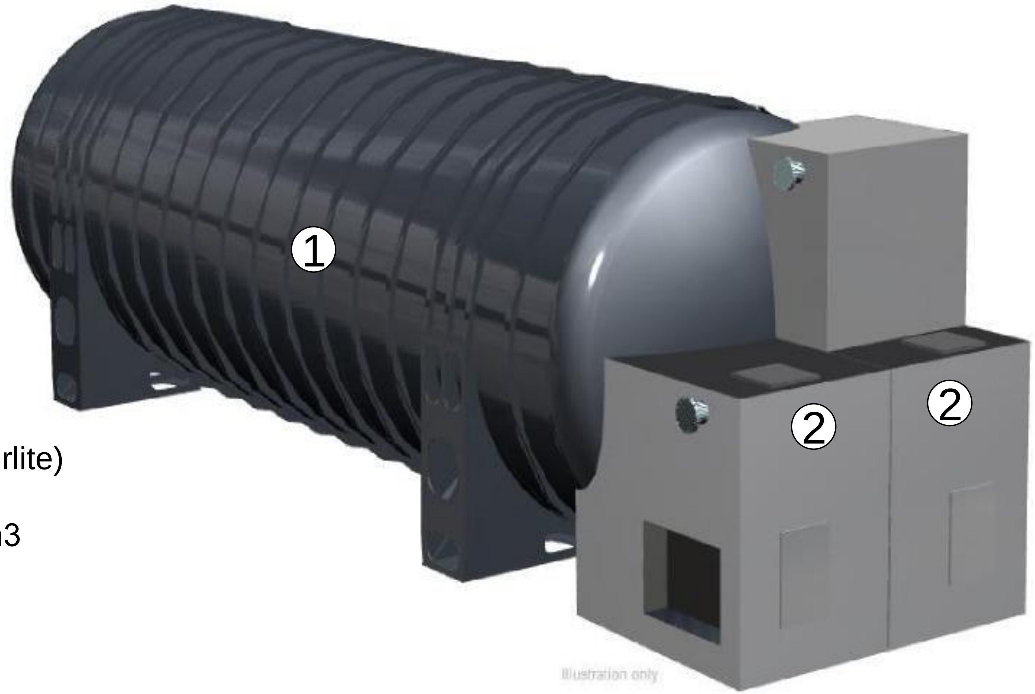
6 -drip tray with capacity of appr. 200 liter
7 -flange for removal of leaks, spilled fluids or other liquids

mtu

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

STORAGE TANK FOR LNG:





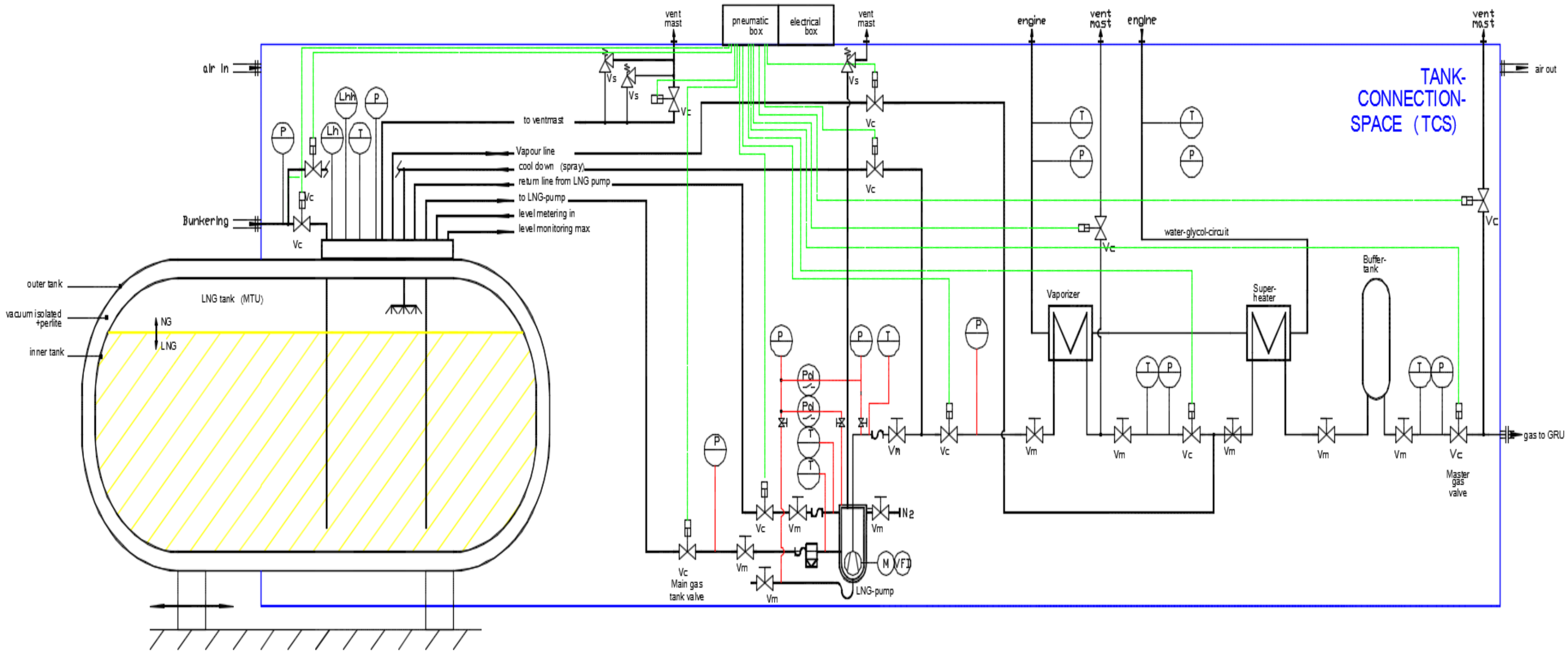
① **Storage tank for LNG:**

-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 … 100m3
-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) – P&ID



LNG tank
~10, 25, 50, 100 m³ horizontal
50 ..65 m³ vertical

cryogenic pump

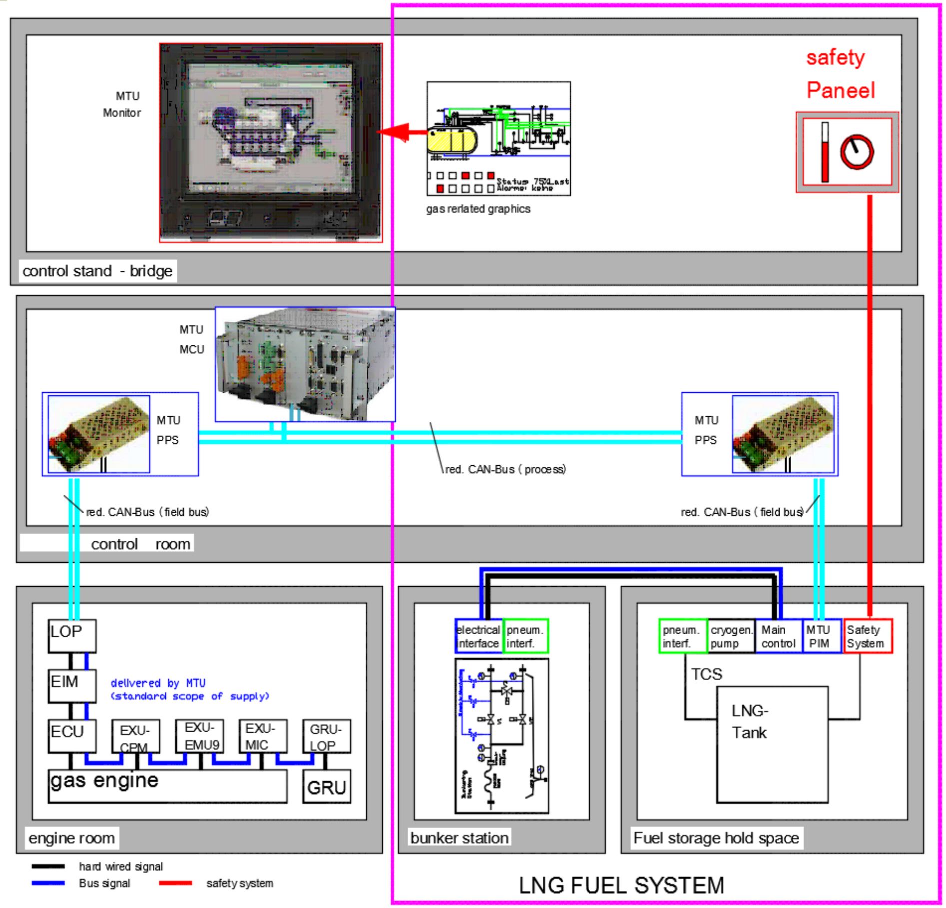
vaporizer

super-heater

buffer-tank (opt.)

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

GAS MOBILE MARINE



LNG Fuel system:

2 independent control and monitoring systems for:

-Control and monitoring system

-Safety system

visualization:

-engine control room

-control stand (bridge)

mtu

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

GAS MOBILE MARINE

The purpose of the control and safety system (LNG-fuel-system) is to perform control and monitoring of the LNG-fuel system and providing a safe operating environment for the vessel and crew.

Automation and control system:

With customized graphics the Automation and control system displays information from the alarm-, control- and Safety System (LNG-fuel-system). This system will be delivered as a standalone system. A interface to the ship automation system shall be provided (standard bus system).

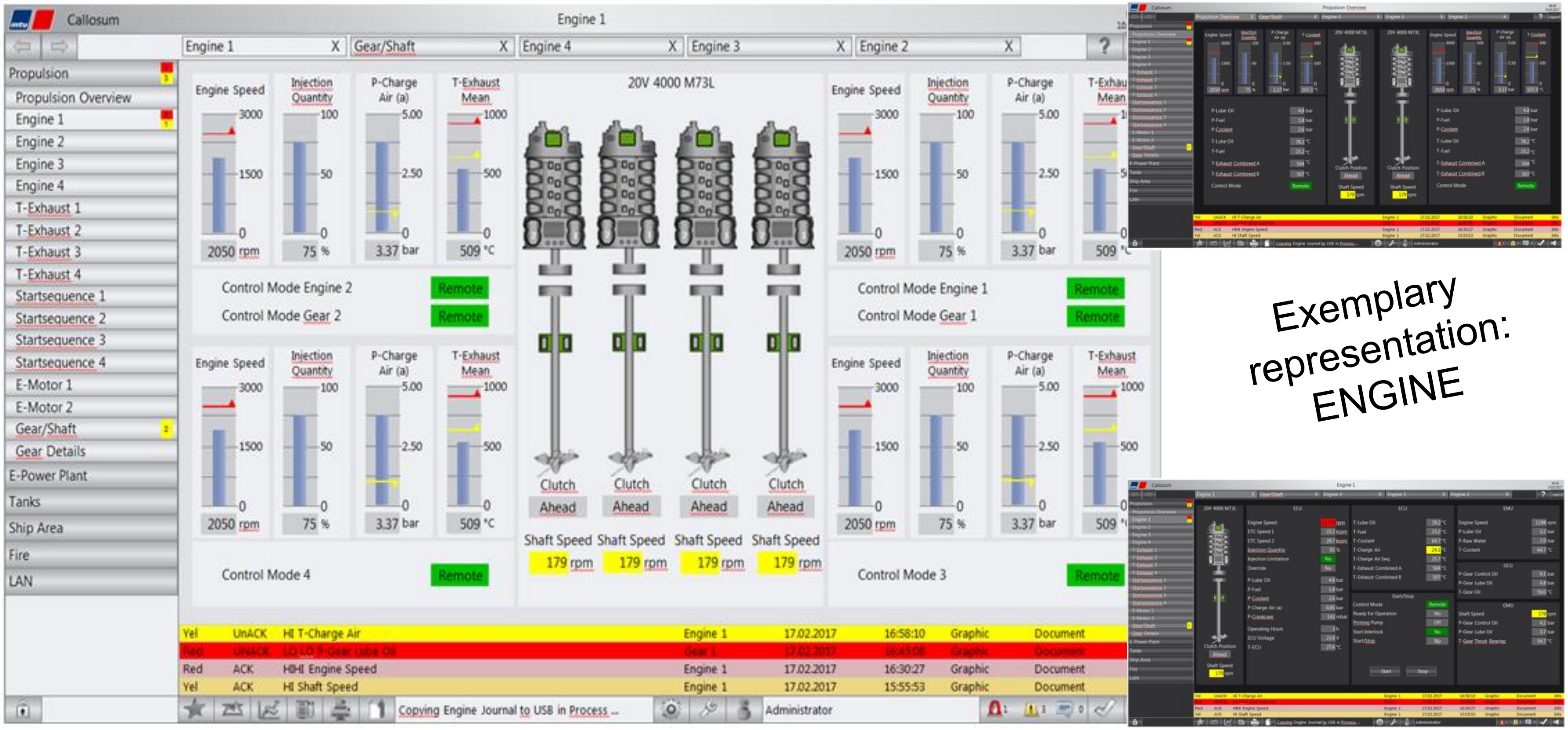
The primary function of the LNG control system is to maintain the required LNG-pressure conditions while supplying fuel gas at desired temperature and pressure to the gas engine. Connections to sensors located at critical points throughout the plant allows the control system the process.

Main process function:

- 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

mtu

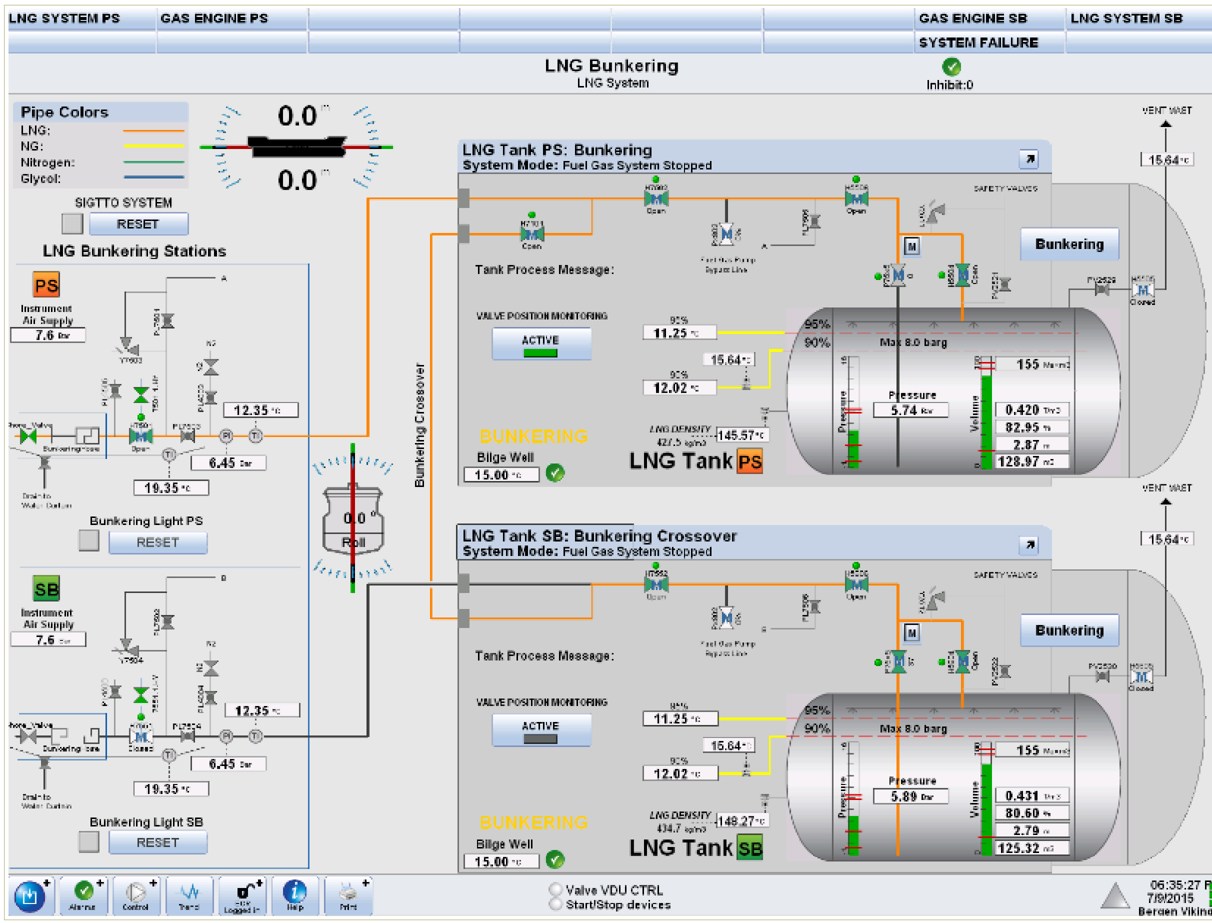
Shipside Gas System
Engine monitoring – typical monitoring layout

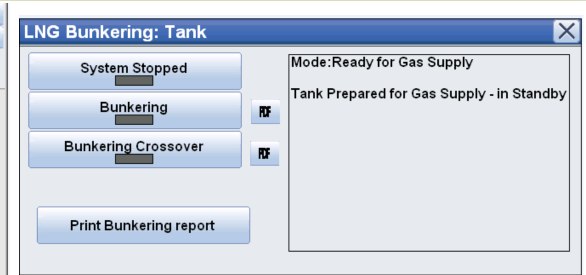


Exemplary representation: ENGINE

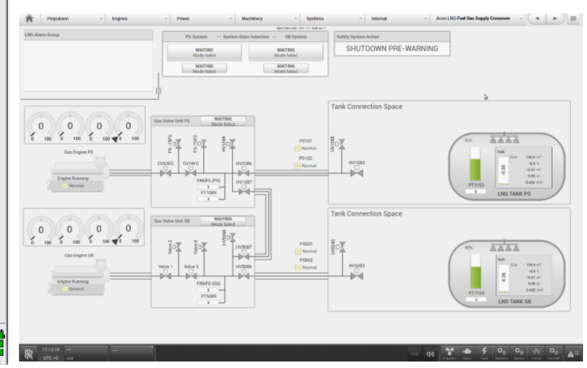
 S4000M05-N - Presentation for Sales | Project Gas Mobil Marine I Benjamin Jäger | March 2018

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





Exemplary representation: LNG-FUEL-System

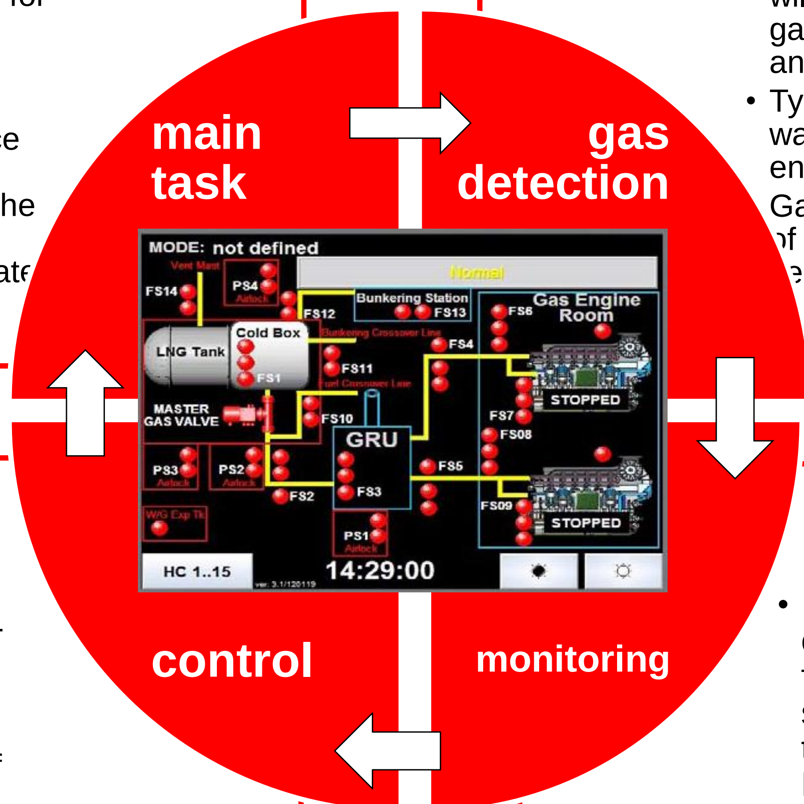


Shipside Gas System
Fuel gas system (LNG) – safety system

GAS MOBILE MARINE

- 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

- 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.



- 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.

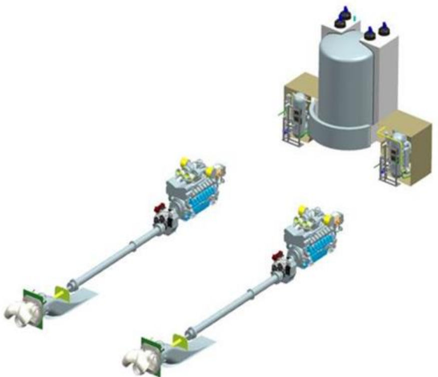
- Is designed to monitor safety critical signals from the LNG fuel system as well other signals that are important to the safety of operating the LNG fuel system.

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

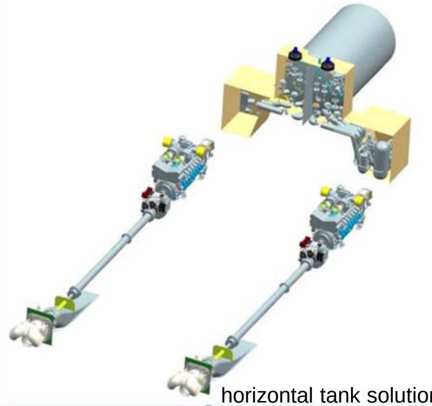
Brødrene Aa

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

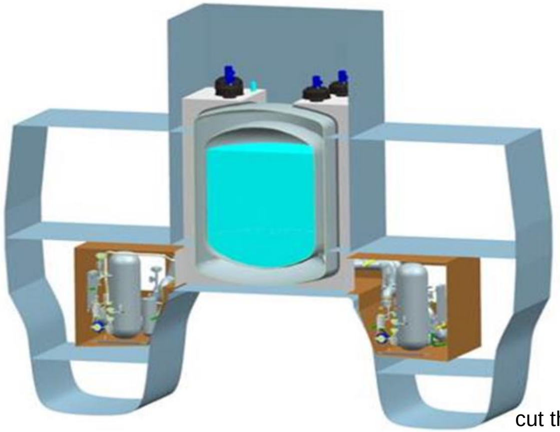
exemplary representation



vertical tank solution



horizontal tank solution



cut through the boat hull

07 Ratings, Portfolio & Market introduction

Portfolio, Ratings & Market introduction
Planned Marine Portfolio

Marine prop. IMO III / EPA 4* / EU V*	**8V max 1000 kW**	12V max 1500 kW	**16V max 2000 kW**	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 Q04/2018
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

Portfolio, Ratings & Market introduction
Planned Main Propulsion Ratings and Availability

	Power [kW]	Rated speed [rpm]	Availability (SOD)
8V 4000 M55RN	746	1600	Q02/2020
8V 4000 M65-N	1.000	1800	on request
16V 4000 M55RN	1.492	1600	Q01/2019
16V 4000 M55-N	1.840	1800	on request
16V 4000 M65-N	2.000	1800	12/2018

up to 1.000kW @1800rpm

up to 2.000kW @1800rpm

SOD –16V4000M65-N with Lloyds Register - ABS, BV, DNV/GL subsequently

08 References

References

High Speed Ferries:
2x 2x 16V4000 gas engines @1.492kW
for Reederij Doeksen
Engine delivery in 2017

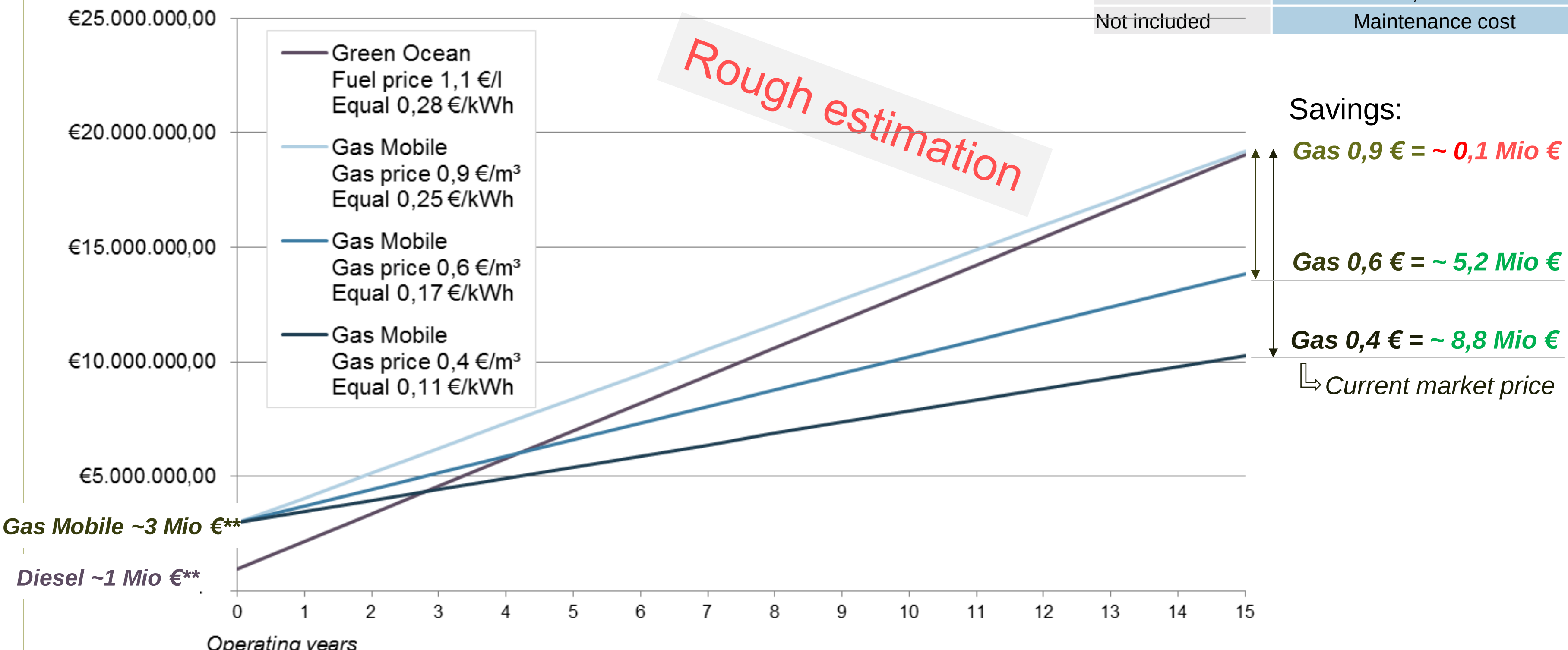
Ro-Ro Ferry (field test engines):
2x 8V4000 gas engines @ 746W
for Stadtwerke Konstanz
Engine delivery in 2020

09 Customer Benefits

Return On Invest
Comparison – Invest & Consumption Cost

Conditions	16V4000M65R	16V4000M65-N
	Green Ocean	**Gas Mobile**
Exhaust regulation	IMO III	IMO III
Engine rating [kW]	2.000	2.000
Speed [1/min]	1.600	1.800
TBO [h]	**21.000**	**30.000**
Load profile	Standard (LF 53 / LI 8)	
Operating time	60000 h @ 15 years	
Urea cost	0,35 €/l	-
Oil cost	4,50 €/l	
Coolant additive	4,10 €/l	
Not included	Maintenance cost	

Invest & Consumption* Cost over 15 years



Calculation March 2018

* **Includes:** Fuel, oil, coolant, urea (Green Ocean)

** **Invest cost:** Engine purchase + Tank system

S4000 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

S4000 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