

An aerial photograph of a large container ship sailing on the ocean. The ship's deck is densely packed with multi-colored shipping containers in shades of red, blue, green, and white. The ship's wake is visible in the dark water.

MAN B&W ME-GI installation in very large or ultra large container vessels

MAN Energy Solutions

Future in the making

MAN B&W dual-fuel, two-stroke engines

Future in the making



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As a result of MAN Energy Solutions' innovation, more possibilities for burning greener fuels now exist. Today, customers can choose between different engine platforms that have been developed to ensure efficient and green fuel-combustion by MAN B&W dual-fuel, two-stroke engines. The ME-GI dual-fuel engines described in this paper have been based on an optimised engine design platform, which has resulted in a lighter and a more powerful engine.

Introduction

MAN Energy Solutions keeps optimising and evaluating cost prices of the engine and related systems, for example the fuel gas supply system. The guidelines presented in this paper are intended for the shipowners installing MAN B&W ME-GI engines in very large container vessels (VLCV) or ultra large container vessels (ULCV).

The important common denominator behind our dual-fuel engines is the principle of non-premixed combustion, or diesel combustion. The engines are based on the proven principles from two-stroke engines operated on heavy fuel oil (HFO), marine diesel and gas oil (MDO and MGO). The fuel is injected and burned directly resulting in high efficiency, combustion stability and that the engine can react on fast load changes in heavy weather and under high ambient temperatures.

The diesel principle makes the ME-GI engine a future-proof solution with a robust combustion that can burn gas independent of methane number and without methane slip and therefore without formaldehyde formation.

The ME-GI engine will comply with a potential future legislation concerning methane slip and formaldehyde

formation. The engine burns gas at a high temperature, i.e. at 1300°C or higher, this limits or hinders generation of N₂O in the exhaust gas. N₂O is a strong greenhouse gas (GHG) and it is expected that emission of N₂O and methane (methane slip) will be regulated in the future.

Furthermore, the engine platforms designed according to the diesel principle allow the crew to switch seamlessly between different fuel modes. On a container vessel with an ME-GI engine, it is possible to change between two different fuel modes: Dual-fuel and fuel oil mode. The two fuel modes provide a high degree of fuel flexibility and the ability to comply with emission restrictions. However, with the ME-GI engine installed, the ship will still be competitive when the demand for fuel oil operation occurs.

One of the advantages with gas-fuelled vessels is the ability to adjust operation when the fuel prices rise and modern exhaust-emission limits tighten. Indeed, service experience shows that the ME-GI engine delivers significant reductions in CO₂, NO_x and SO_x emissions.

The diesel cycle ensures that operation on gas can be maintained during heavy weather and high ambient air

temperature independent on the type of combusted gas. Operation under the mentioned conditions is maintained without any increase of methane slip, which affects the environment and the operational efficiency.

The ME-GI is an engine already accepted within the maritime community, which has led to above 200 engines in total on order and in service. June 2018, the engines in service have accumulated more than 160,000 operating hours on gas and the number will rapidly increase over the coming years as new engines enter into service.

Novel ME-GI technology

The following sections provide a brief description of the novel technologies behind the ME-GI engine and the fuel gas supply system (FGSS) supplying gas to these engines in VLCVs or ULCVs.

If you need further information about our engine types, our engine programme can be found by following the link given in [1]. Besides, our Computerised Engine Application System (CEAS) gives access to performance data and different lists of capacities, see [2].

The 90ME-GI and 95ME-GI engine design

The optimised engine design platform has resulted in a lighter engine as the length, width and height of the engine have been reduced. The optimised and lighter engine frame size is the result of an optimisation of:

- The connecting rod - introduction of the Flexrod
- The exhaust valve and fuel injection
- Integration of the top-controlled exhaust valve (TCEV) and fuel

booster injection valve (FBIV) on the cylinder cover

- Increased flexibility of the main bearing support
- Improved piston crown design

Part of the weight optimisation is achieved by integrating the exhaust valve actuator, the high-pressure pipe and the hydraulic cylinder unit into the TCEV, see Fig. 1.

The control and actuation of the exhaust valve are integrated into the TCEV. A distributor block placed on the exhaust valve provides high-pressure hydraulic oil via two control valves to the exhaust actuator on top of the exhaust valve and to the booster function in the FBIV. Since the fuel oil injection pressure is generated by the booster function in the FBIV, the high-pressure fuel-oil pipe has been removed as well. Besides a weight optimisation, the dynamic behaviour of the fuel oil injection system has been improved.

The engine control system fully controls the combustion process by electronic control of fuel injection and exhaust valve opening according to the measured instantaneous crankshaft position.

Dual fuel operation requires injection valves for both pilot fuel oil and gas. The FBIVs operate as main injection valves when the engine operates in fuel oil mode and as pilot oil injectors when the engine operates in dual fuel mode. This means that the engine does not require additional or special pilot oil valves.

The top cover of the 90 and 95ME-GI has three FBIVs and three gas injection

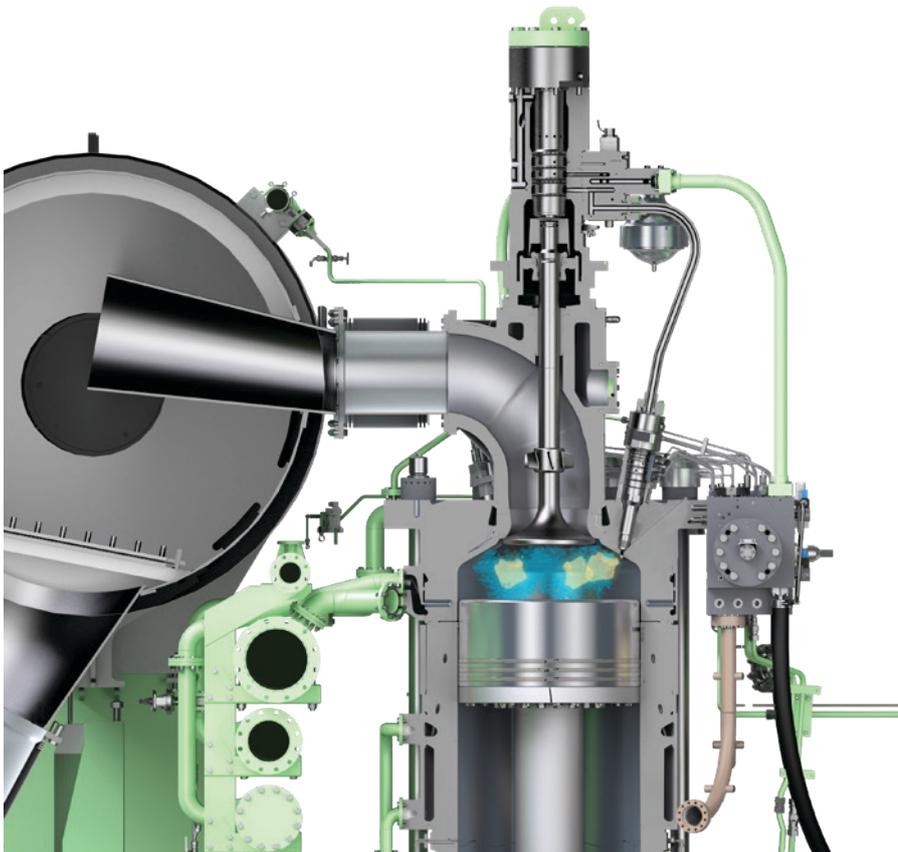


Fig. 1: The ME-GI engine top

valves. The gas supply system on the GI engine is of the common rail type, where the pressure in the fuel gas supply system is constantly equal to the gas injection pressure.

The high-pressure gas is distributed via a chain of double-walled pipes to each cylinder, where the gas enters the gas distribution block and finally the gas valves via the gas distribution channel in the cylinder cover.

To increase simplicity and reduce installation costs the supply and return of gas have been combined in one double-walled chain pipe, see Fig. 2. The gas distribution block effectuates the engine control system signal into a safe and correctly timed administration of fuel to the engine. When the gas injection valves are opened with hydraulic oil, a gas jet is injected into the combustion chamber.

One of the benefits of the robust diesel-type combustion is the ability to maintain safe gas operation and reliably to perform changeover between fuel oil and gas even in rough weather conditions.

Previously, gas operation had to be stopped if an unexpected fault occurred on a single cylinder. Another recent benefit added to the design is that one cylinder can be withdrawn from gas operation, while the engine continues in gas operation on the remaining cylinders. The cylinder not operating on gas may continue on fuel oil with unchanged load and performance depending on the nature of the fault.

The ME-GI control and safety system is designed to fail to safe condition. Incidents occurring during fuel gas running result in a fuel gas stop and an

automatic immediate changeover to fuel oil operation. Following the changeover, gas in the high-pressure fuel gas pipes and the fuel gas auxiliary system returns to the service or cargo tank. The changeover to fuel oil mode is always done without any power loss of the engine.

As part of an extensive safety system, the high-pressure gas is supplied and returned through the double-walled and ventilated chain pipe. The double-walled pipe is ventilated by continuously exchanging and monitoring the air in the space between the inner and outer pipe to test for hydrocarbon leaks. The outer pipe acts as a shield to the engine room and protects the crew in the event of leaks. This piping design makes it possible to designate the engine room as an ordinary, and not hazardous, working area.

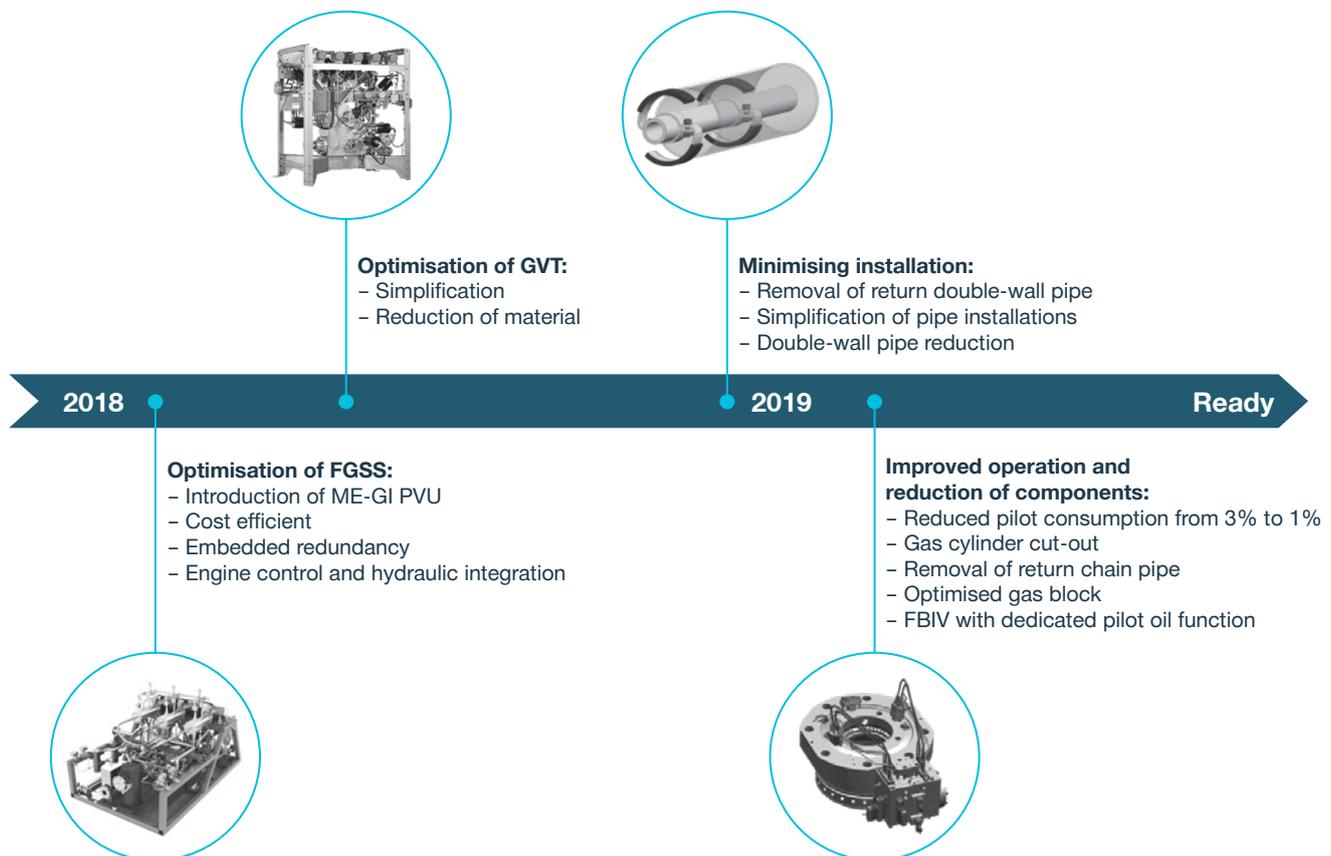


Fig. 2: Brief description of the latest ME-GI and FGSS developments (tekst skal rettes I pp)

Fuel gas supply system design

The FGSS designed and optimised to supply the ME-GI engines in VLCVs and ULCVs, is shown in Fig. 3.

If the ME-GI engine is combined with dual-fuelled (DF) MAN Holeby gensets to cover the electrical consumption, the FGSS matches the fuel gas demands of main and auxiliary engines.

The FGSS must be able to supply fuel to all engines taking into consideration all gas supply variables.

The main components of the fuel gas supply system are:

- booster pump in the LNG fuel tank
- LP pump and vaporiser unit (PVU)
- standalone low-pressure vaporiser
- gas valve train (GVT) in front of the ME-GI and gensets

The requirements to gas supply-pressure and temperature are:

- for the ME-GI engine: high-pressure gas at 300 bar, 45°C and
- for the dual-fuel gensets: low-pressure gas at 6 bar, 0-60°C

The amount of gas available in dual fuel mode depends on the amount available from the FGSS, i.e. on the voyage type

and tank conditions. The engine control system (ME-ECS) receives information from the FGSS control system about the available amount of fuel gas and it calculates the required amount of fuel oil. Today, the ME-GI engine operates on 3% fuel oil and 97% gas fuel, the short-term target is a further reduction of the pilot oil consumption to 1%. This improvement is expected to be available for all ME-GI engines for delivery in 2020 and onwards.

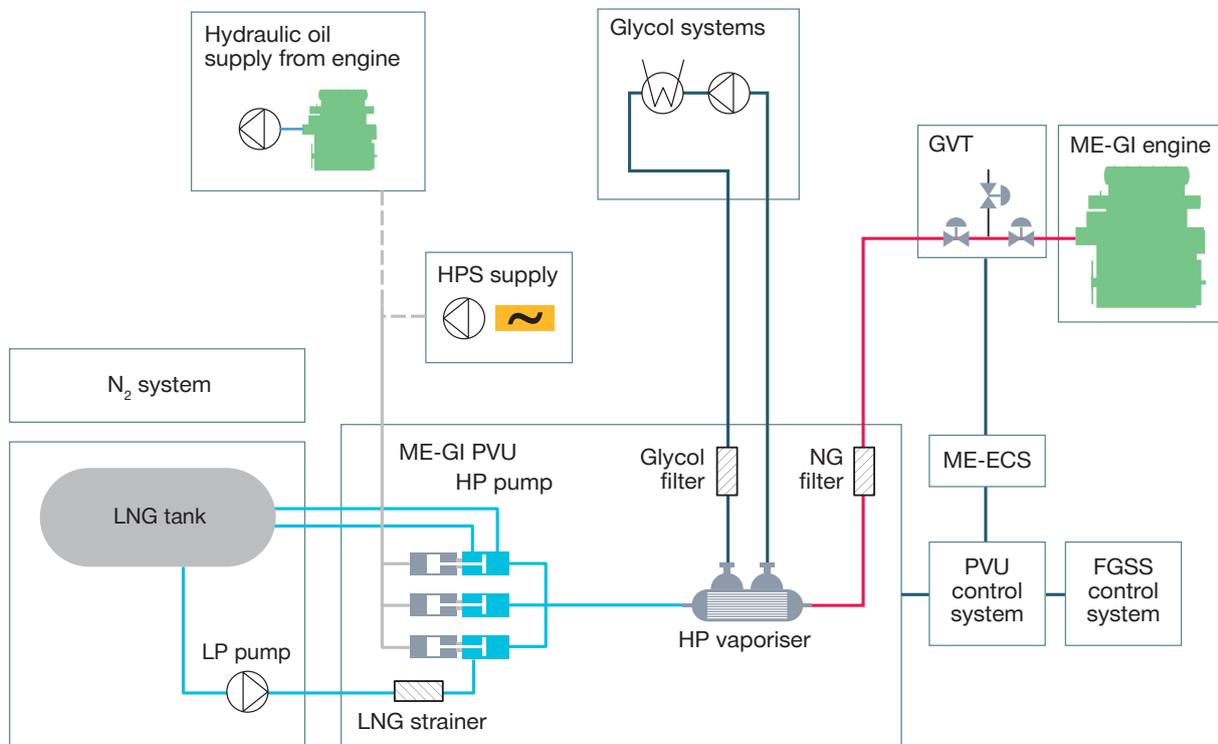


Fig. 3: Schematic representation of the fuel gas supply system for G90ME-GI, G/S95ME-GI and DF gensets

Pump vaporiser unit

The ME-GI pump vaporiser unit (PVU) developed by MAN Energy Solutions is a standardised and compact high-quality pump unit for supply of LNG to the two-stroke ME-GI engine and DF gensets, see Fig. 4.

The pump unit is designed with three hydraulically activated cryogenic pumps, a vaporiser, filters and a control system with safety functions. The low-pressure or booster pump in the LNG fuel tank supplies the PVU with LNG at approximately -163°C . The cryogenic pump is a high-pressure reciprocating pump with three cylinders actuated by linear hydraulic pistons. Pressurised LNG flows through a compact, printed-circuit heat exchanger, where it is heated by warm glycol water to 45°C .

A high-pressure natural gas (NG) filter catches fine particles present in the

gas before the gas is directed towards the gas valve trains (GVTs) and the engines. The gas pressure is controlled by controlling the hydraulic flow to the cryogenic pump in the PVU unit. Separate control of the three pump heads provides 100% redundancy. The PVU control system has been integrated into the ME-GI ECS.

It is also a possibility to integrate the hydraulic oil supply that activates the cryogenic pumps into the engine systems, the main engine will then generate all hydraulic power and the gensets will not be needed when operating the PVU.

Gas valve train

The GVT, see Fig. 5, controls the safe admission of gas to the ME-GI engine. It is installed between the fuel gas supply system and the ME-GI engine to provide a double block and bleed

function, when the engine is not running on gas or when requested by the ME-GI ECS.

The GVT is controlled by the ECS and it separates the FGSS from the ME-GI during shutdown. As the GVT represents the ME-GI interface to external systems, it can only be delivered by approved suppliers.

In previous versions of the GVT, the N_2 purge connection was a part of the GVT, whereas in the present generation, the N_2 purge connection is installed on the ME-GI engine. Today, the GVT is equipped with slow-opening valves that applies the high-pressure gas slowly in order to avoid pressure shocks on the seals.

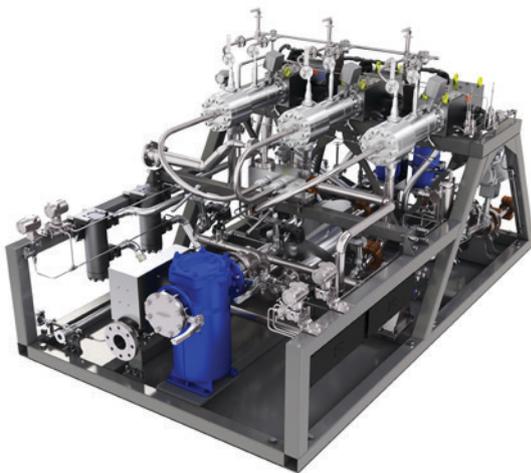


Fig. 4: The pump vaporiser unit. Fig. 5: The gas valve train

Evaluation of high-pressure gas piping location

The ME-GI engine and the diesel principle has proven to provide the shipowner and ship operator with superior performance and efficiency compared to market's competition.

Since the ME-GI engine requires high-pressure gas it has been of the utmost importance to find a safe distribution of gas to the ME-GI engine as well as to the DF gensets. MAN Energy Solutions has previously initiated a fire and explosion study of

the present engine room design with high-pressure piping [3]. To investigate also the routing of pipes on large containerhips a known vessel designer's view and official technical solution has been requested [4]. The study has the purpose to shed more light on regulations, production issues and to discuss potential recommendations. It is our intention to minimise a potential hesitation the customer may have towards installing high-pressure gas piping.

The four different piping locations are listed below and shown in Fig. 6.

- A. In the pipe tunnel in the double bottom
- B. In the longitudinal recess in the side of the cargo holds
- C. In the passageway below open deck
- D. On open deck alongside the hatch coaming

The vessel designer has performed an evaluation of four different options for the location of high-pressure gas transfer pipes transferring LNG from the FGSS to the engine room, where the fuel is supplied to the ME-GI and to the gensets. The LNG supply for such a vessel is 7500 kg/h including supply to two auxiliary engines.

The evaluation has been performed for a 14,000-teu container vessel arranged with accommodation and engine room separately. The LNG storage tanks and PVU are placed below the accommodation avoiding a reduction of the number of containers.

The location of the high-pressure gas transfer piping has to comply with rules and regulations for LNG fuelled machinery [5, 6]. The pressure loss in the high-pressure pipe system is estimated to 4-5 bar for all four locations. Besides, expansion devices have to be installed to accommodate temperature fluctuations and hogging/sagging deflections for all four locations as well.

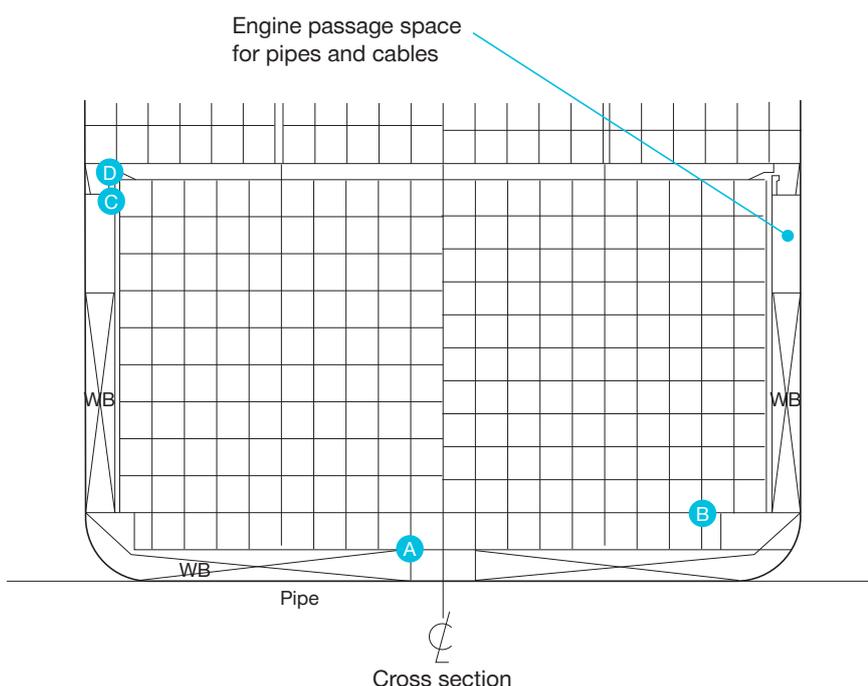


Fig. 6: Four potential piping locations [4]

Summary

In the study the vessel designer concludes that based on regulations and potential production issues, all four locations seem to be feasible. However, the risk perceived by the customers with respect to location of the high-pressure-gas piping needs to be addressed. The customer concerns are summarised below [4]:

- Are the gas pipes located on open deck?
- Are the gas pipes arranged accessible?
- Is the proper safety distance kept?
- Is the ventilation increased in enclosed spaces?
- Are compartments divided to minimise the spread of any gas release?

The different locations (A-D) have been evaluated and ranked in Table 1 taking into account the customer concerns listed above. The locations have been assigned values from 1 to 5, where 5 is the optimal solution and 1 is the least optimal solution with respect to the parameters:

1. Regulation
2. Production/complexity

3. Accessibility
4. Perception of risk

The values 2, 3, and 4 denotes a graduation of the four key words between the two extreme ends [4].

The value 5 in Table 1 is described as [4]:

1. Regulations: the solution complies fully with regulations
2. Production/complexity: the best solution with focus on production/complexity
3. Accessibility: the best accessibility
4. Perception of risk: the lowest perception of risk

and the value 1 is described as [4]:

1. Regulations: the solution complies with regulations but additional requirements are foreseen
2. Production/complexity: not the optimal solution, it requires additional focus on production
3. Accessibility: the lowest accessibility
4. Perception of risk: the largest perception of risk

If the perception of risk is not considered, the most feasible location is the passageway. However, if the

perception of risk is addressed, the location on open deck is as feasible as the passageway.

The study results in measures to minimise or eliminate the perception of risk for each location.

A. Location in cargo hold recess:

- a. Move the gas pipe further away from the shipside
- b. Arrange the closed duct with inspection openings

C. Location in passageway:

- a. Increase the rate of ventilation
- b. Divide the passageway into gastight sections
- c. Relocate equipment (electric equipment, air vents, ventilation ducts) to the opposite side of the passageway

D. Location on open deck:

- a. Use double-walled pipes
- b. Relocate air inlets to the opposite side of the gangway

On LNG carriers, the gas piping is placed on open deck and the pipe length and the amount of supplied gas is comparable to the needed amount for ME-GI engines installed in container vessels. ME-GI engines have already been ordered for 65 LNG carriers, 130 engines in total.

Table 1: Evaluation scheme for high-pressure pipe locations

Location	1. Regulations	2. Production/complexity	3. Accessibility	4. Perception of risk
A. Pipe trunk	3	2	1	1
B. Cargo hold recess	4	4	3	2
C. Passageway	5	5	5	3
D. Open deck	4	3	5	5

Cost comparison of typical large bore dual-fuel engines

The specific engine types (11G90ME-C10.5-GI and 12G95ME-C9.6-GI) have been selected according to vessel speed and SMCR, see Figs. 7 and 8.

The following section is devoted to an economic and partly technical comparison of 11G90ME-C10.5-GI with 11X92DF for a 14,000-teu container vessel and of 12G95ME-C9.6-GI with 12X92DF for a 21,000-teu container vessel. The comparison includes the auxiliary equipment required for the engine to run, see Figs. 3 and 10.

The technical and economic conditions on which the study is based are as follows:

- The ME-GI and X-DF engines installed in the 14,000-teu vessel have the same vessel speed at SMCR, i.e. 46,422 kW and 75.7 rpm.
- The ME-GI and X-DF installed in the 21,000-teu vessel also have the same vessel speed at SMCR, i.e. 63,840 kW and 80 rpm. However, the four layout areas are different, see Fig. 9.
- OPEX calculations are based on the SMCR point from Fig. 9 and the load profile in Table 2.
- The FGSS has been included in the calculations of OPEX and CAPEX, see Figs. 3 and 10.

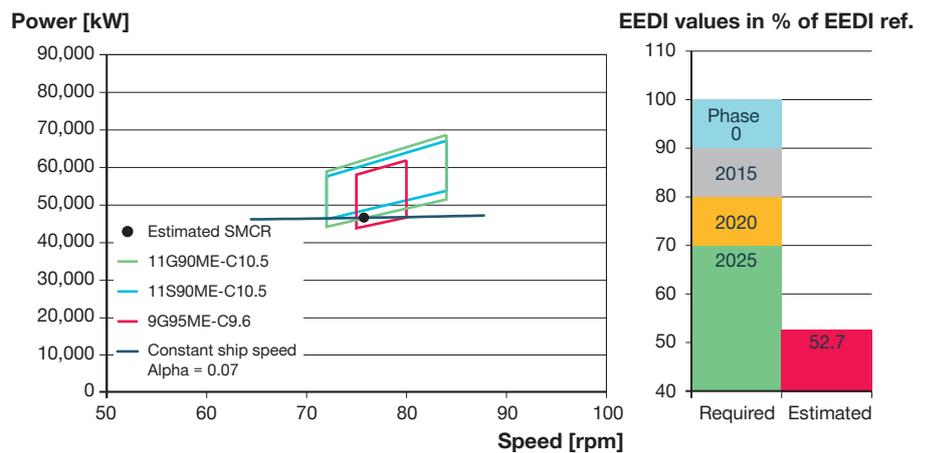


Fig. 7: Layout diagrams and EEDI values for ME-GI engine proposals for a 14,000-teu container vessel

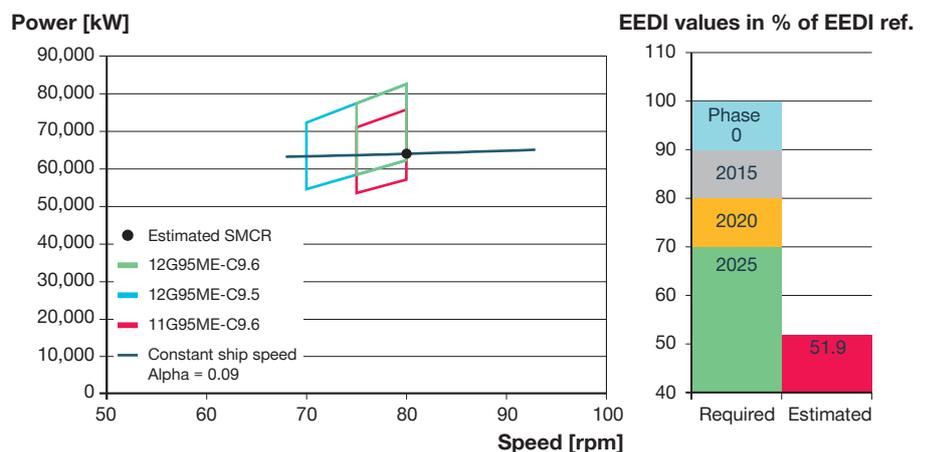


Fig. 8: Layout diagrams and EEDI values for ME-GI engine proposals for a 21,000-teu container vessel

The load profiles listed in Table 2 provide the basis for calculation of OPEX for the ME-GI and X-DF engines. Table 2 shows one year of operation, equivalent to 6000 operational hours, divided into number of anticipated hours of Tier II and III operation.

Besides, Tier II and Tier III operation consists of two modes each: fuel oil and gas mode. The number of operational hours in each mode is shown in Table 3.

The main technical differences between the FGSS for the ME-GI engines, see

Fig. 3, and the FGSS for the X-DF shown in Fig. 10 lie in the PVU (the high-pressure pump) for the ME-GI engine and the low-pressure vaporiser for the X-DF engine.

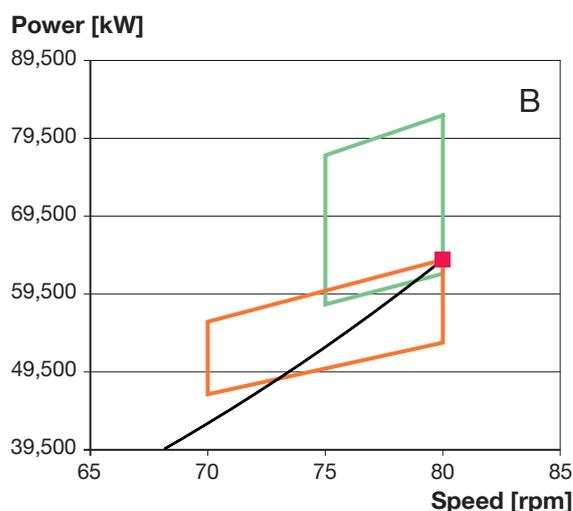
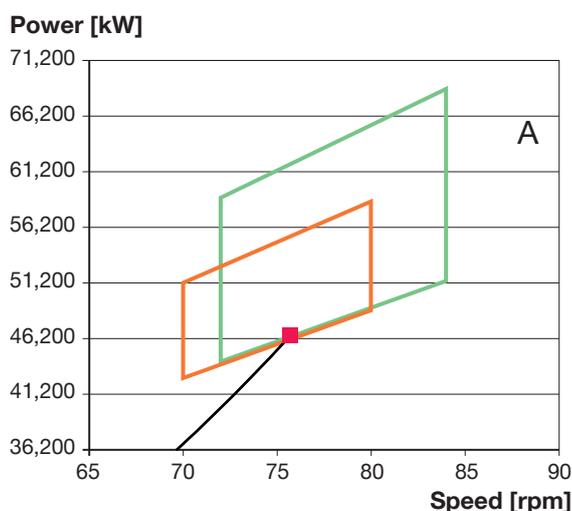


Fig. 9: a) Layout area for 11G90ME-C10.5-GI-TIII (green) and 11X92DF (orange) for a 14,000 teu vessel, b) 12G95ME-C9.6-GI-TIII (green) and 12X92DF (orange) for a 21,000-teu vessel

Table 2: Load profiles: 6,000 operational hours (one year) divided into Tier II and III operation

Load profiles			
Tier II mode operation		Tier III mode operation	
Engine load [%]	Operational hours [%]	Engine load [% power]	Operation time [% hours]
100	5	65	25
85	30	50	25
65	45	35	25
50	5	25	25
35	5		
25	10		

Table 3: The number of operational hours in Tier II and Tier III operating modes

Tier II and III fuel modes	ME-GI/X-DF operational hours	
	21,000-teu vessel	14,000-teu vessel
Tier II fuel oil mode	0	570
Tier II dual fuel mode	5700	5130
Tier III fuel oil mode	0	0
Tier III dual fuel mode	300	300

The two ME-GI engines receive fuel gas from identical FGSSs and the two X-DF engines are supplied from identical FGSSs. Fig. 11 shows the cost

distribution for the two types of FGSS for the ME-GI and X-DF engine, respectively.

CAPEX for the fuel gas supply system for ME-GI engines amounts to 5.5 million USD and for X-DF engines to 4.9 million USD.

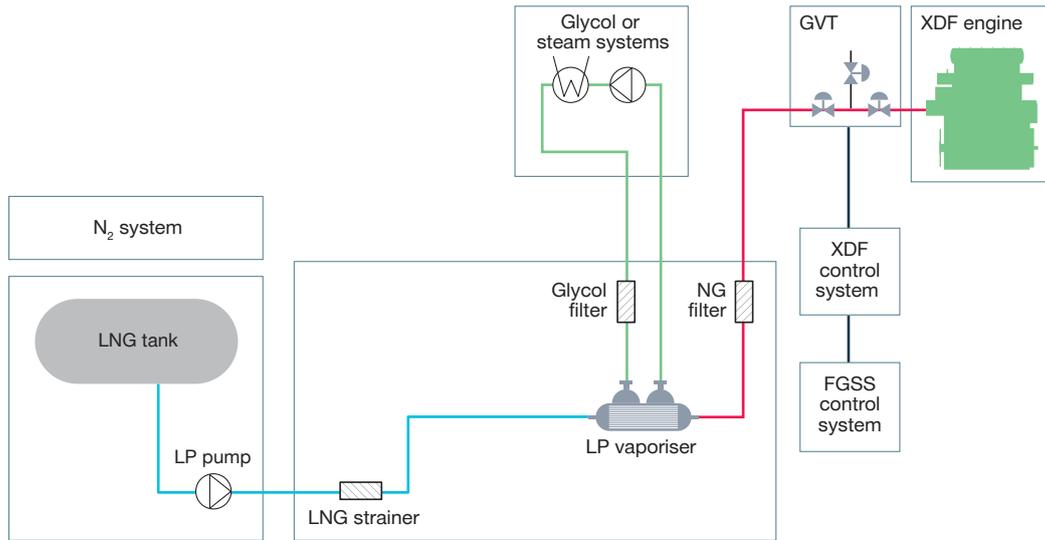


Fig. 10: Schematic representation of the fuel gas supply system for 11X92DF/12X92DF and DF gensets

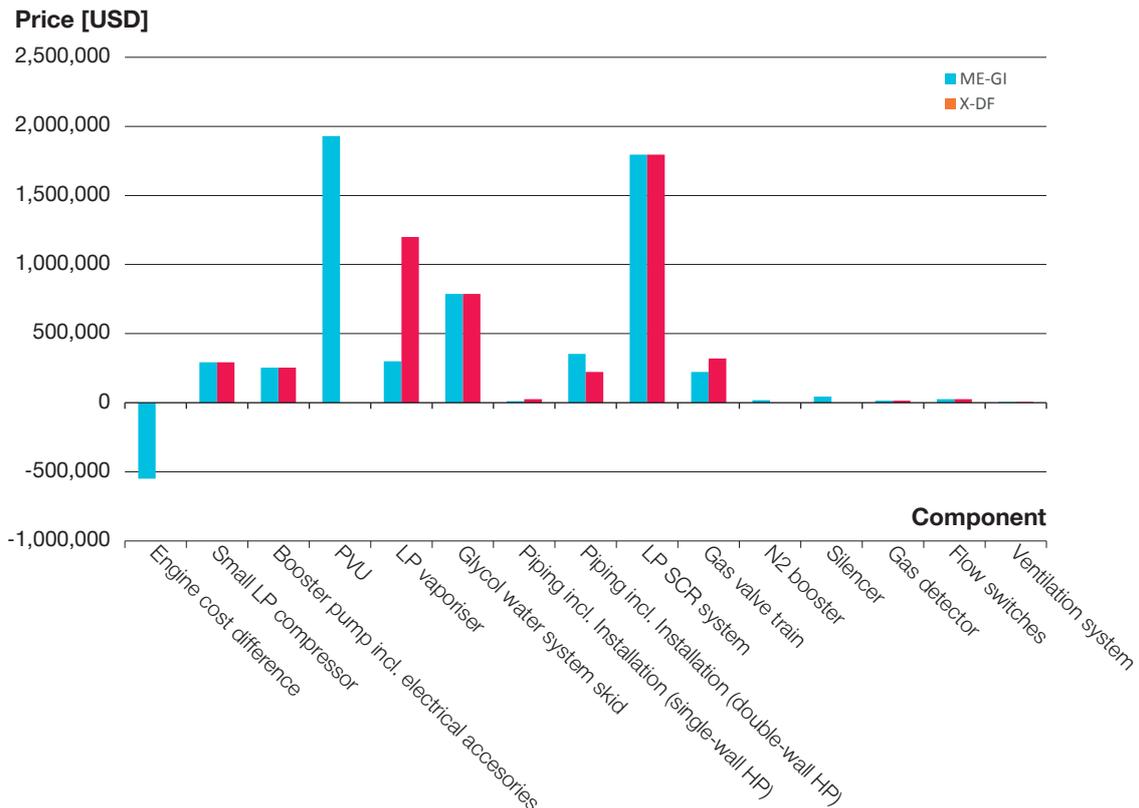


Fig. 11: Fuel gas supply system CAPEX for ME-GI (red) and X-DF (blue)

The net present values in Fig. 12 have been calculated for the ME-GI and X-DF engines based on a 15-year cost calculation period, the layout points in Fig. 9, the load profiles in Table 2 and 3 and current oil, HFO and LNG prices, etc.

Table 4: OPEX and CAPEX 14,000 and 21,000-teu vessels

14,000-teu vessel		21,000-teu vessel	
NPV ME-GI 14,000 teu	3,247,934 USD	NPV ME-GI 21,000 teu	7,096,336 USD
CAPEX ME-GI relative to X-DF	-600,000 USD	CAPEX ME-GI	-600,000 USD

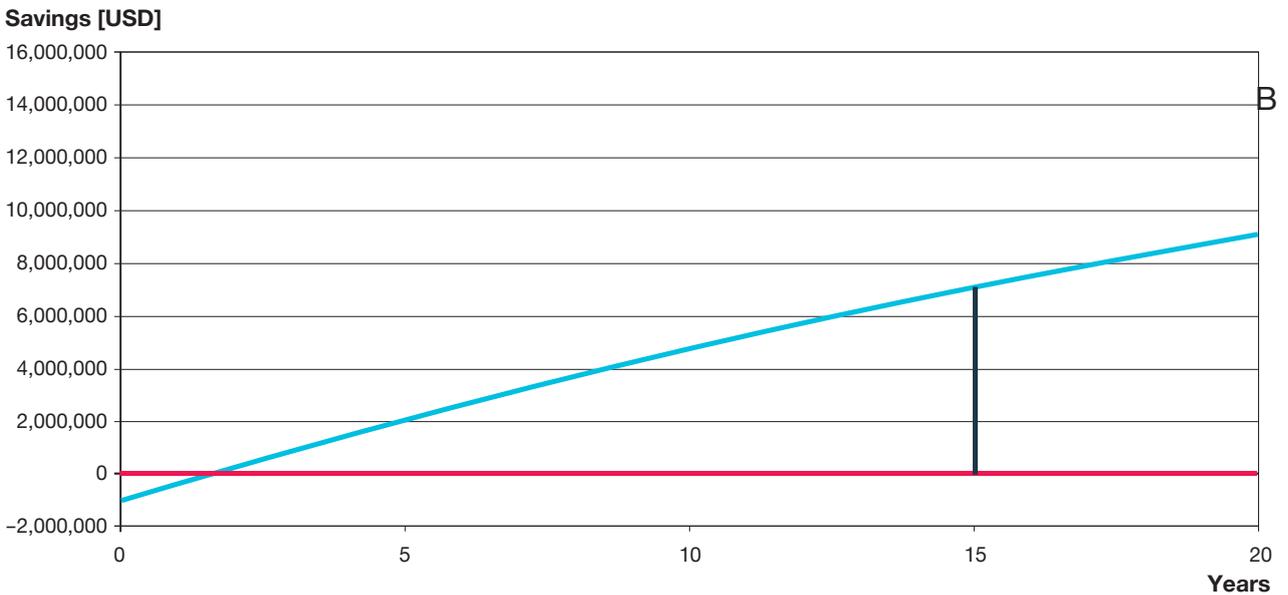
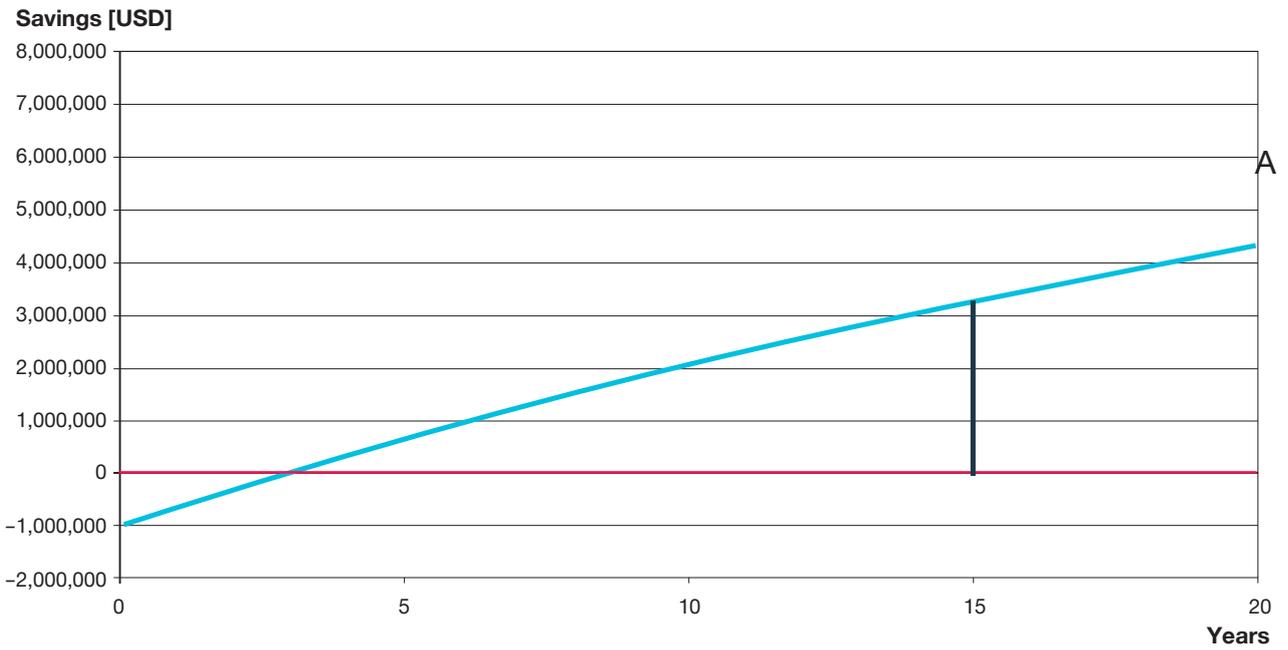


Fig. 12: NPV a) 14,000 teu (X-DF: red, ME-GI: blue) and b) 21,000 teu-vessel (X-DF: red, ME-GI: blue)

Summary

A number of environmental protection measures will be enforced in the future. At MAN Energy Solutions, we always aim at designing and building engines and systems that can comply with present and future legislation and compete with the always-changing marine market.

The adaptation of MARPOL Annex VI concerning emission of sulphur oxide and particulate matter will change the shipping world. After 1 January 2020, all vessels will have to comply with the use of fuels with max. 0.5% sulphur globally. With the ME-GI engine platform, MAN Energy Solutions has introduced a true green solution with the freedom to choose almost any gas fuel, gas quality available, and still have an efficient combustion. In the latest design of the ME-GI engine, we introduce a reduction of the pilot oil consumption from 3 to 1%.

Another concern arises when combusting hydrocarbons, even the simplest of them all, methane, burns

with a number of stable and unstable intermediates.

Formaldehyde is a stable intermediate that forms in cold regions of the combustion at temperatures from 200–600°C. Temperatures in this range are also present in the exhaust gas system, so the methane slip is converted into formaldehydes. It is estimated that approx. 10% of the methane turns into formaldehydes. The emission of formaldehyde, being carcinogenic, is regulated in some countries. In the ME-GI engine based on the diesel principle, combustion takes place at 1300°C and higher, and neither methane slip, N₂O nor formaldehyde of any significance will occur in the exhaust gas.

The minimum reduction in carbon intensity per transport work must reach 40% by 2030 compared with 2008, with the aim of reaching 70% by 2050. A reduction in greenhouse gas emissions from ocean shipping must be at least 50% by 2050 compared with 2008.

This is achieved by focusing on reducing the emission of methane and volatile organic compounds. Methane has an 86 times stronger climate effect than CO₂. As of first of July 2018, methane slip from gas engines is restricted on inland waterways in China. The 1.5-2 g/kWh limit recently enforced shows a trend towards reducing the methane slip from two-stroke engines instead of NO_x emissions. A requirement the Otto-cycle engine may have difficulties fulfilling.

The next step towards protecting the environment could very well be to expand this regulation to cover Chinese waters in general.

The environmental benefits of installing an ME-GI engine are numerous, together with a comparable CAPEX and lower OPEX compared to our competitor, the ME-GI engine constitutes an attractive and green two-stroke solution for vessel propulsion.

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Appendix

The pros and cons for the four high-pressure pipe locations are summarised below [4]:

- A. In the pipe tunnel in the double bottom
- B. In the longitudinal recess in the side of the cargo holds
- C. In the passageway below open deck
- D. On open deck alongside the hatch coaming

A. High-pressure pipes located in the double bottom

Pros

Space saving. Ballast, bilge and liquid fuel pipes will be located within the double-bottom trunk.

No need for mechanical damage protection.

Easy route to the engine room via the duct which ends at the engine room bulkhead.

Cons

For production, the installation of the pipes shall take place at an early stage where the sections are welded together and this might give some adjustment challenges for the double-wall piping.

Accessibility.

Gas detection will be needed.

In service inspection is difficult.

B. High-pressure pipes located in the cargo hold pipe recesses

Pros

Space saving.

Always easy accessibility.

Easy to provide mechanical protection.

Easy route from tank room to the engine room.

Production friendly as the installation can take place after ship is welded together.

Cons

Double-wall pipes will be needed.

Arrangement for expansion is limited.

Gas detection will be needed.

C. High-pressure pipes located in the passage ways below open deck

Pros

No need for additional mechanical protection.

Easy inspection.

Sufficient height, will be located at the top of the passage way.

Easy route from tank room to the engine room as the passage way passes the engine room.

Cons

Limitation to the shipside.

Electrical equipment installed will need to be relocated.

Gas detection will be needed.

Regulation 5.7.2.

D. High-pressure pipes located on open deck/hatch coamings

Pros

Avoid the secondary enclosure.

Easy inspection.

No need for gas detection.

Cons

Limitation to the shipside.

Mechanical protection against heavy seas and ice protection.

Route from tanks to consumers will need to penetrate upper deck twice.

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