Cost-Optimised Designs of ME-GI Fuel Gas Supply Systems
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The environmentally friendly GI concept is class approved and ME-GI engines are already powering numerous vessels at sea. With 200 engines ordered, the ME-GI engine sets the new industrial standard for two-stroke propulsion engines in liquefied natural gas (LNG) carriers, liquified petroleum gas (LPG) carriers and container vessels.

The ME-GI engine is exposed to varying gas qualities depending on the bunker supplier and the position of bunkering. On LNG carriers, the fuel gas quality will also fluctuate depending on the specific point in time of the ships voyage for example loaded or ballast. One of the benefits of the diesel-type combustion utilised in the ME-GI is the ability of the two-stroke engine to run on almost any fuel gas quality with no or limited decrease in efficiency. The ME-GI engine is thus not vulnerable to gas quality, low methane number and knocking does not pose a risk.

The high degree of fuel flexibility is provided by operating the ME-GI engine in three different modes: The dual fuel mode, which maximises the amount of fuel gas and minimises the pilot oil consumption, the specified fuel gas mode, where almost any mixture of fuel oil and gas can be specified, and finally the fuel oil only mode. The multi-fuelled ME-GI engine changes reliably and seamlessly between fuel gas and heavy fuel oil (HFO). Whenever the vessel enters either a harbour or an emission restricted zone, the owner can draw on the advantage of a high degree of fuel flexibility. Furthermore, service experience has confirmed the largest benefit of the ME-GI, namely that it maintains its high efficiency without any methane slip during load changes and during variations in ambient air conditions.

Many of the challenges and decisions required to make a fuel gas ready vessel are often related to the fuel gas supply system (FGSS) for fuel gas operation. MAN Diesel & Turbo is continuously involved in designing reliable and cost-optimised FGSS solutions for both LNG carriers and LNG-fuelled ships.

The main purpose of the FGSS is to match the FGSS discharge pressure with the demand of the ME-GI engine. If the ME-GI is combined with dual-fuelled (DF) MAN Holeby GenSets to cover the electrical consumption on board, the FGSS matches the fuel gas demand of main and auxiliary engines, and at the same time, handles the fuel gas supply variables, tank pressure, boil-off gas (BOG) rate under different conditions, gas composition, suction and discharge temperature. The ME-GI requires high-pressure (HP) fuel gas, i.e. 300 bar at 45°C, and the DF gensets require low-pressure (LP) fuel gas, i.e. approx. 6 bar at 0-60°C.

Since the LNG carriers already have LNG on board, the prevailing challenge is to design an efficient FGSS capable of handling and supplying BOG to the ME-GI and for example DF gensets and/or auxiliary boilers. For container ships, the primary challenge is to design LNG tanks and FGSS space efficiently in order not to take up valuable container space. However simple it may sound, when it comes to the various design demands placed by ship-owners with respect to space limitations, power consumption, redundancy, voyage pattern and cost management, it becomes a complex optimisation puzzle to deal with the different requirements. New layouts of fuel gas supply systems are continuously developed to accommodate new demands together with improvements of the individual components. The choices to be made related to type of technology or components are numerous, some of the most important being:

1. Tank type and gas holding time
2. Charter, including for example the time spent in emission restricted areas
3. BOG amount – the available equipment utilising BOG, for example auxiliary boiler or genset running on BOG
4. Reliquefaction plant
5. Redundancy in FGSS
6. Electricity demand and consumption
7. Electricity production, power take out (PTO), gensets or DF gensets
8. Steam production and consumption

Several companies worldwide such as Burckhardt Compression, Kobelco, TGE Marine Gas Engineering, Hyundai Heavy Industries, Daewoo Shipbuilding & Marine Engineering, Mitsubishi Heavy Industries, Mitsui Engineering & Shipbuilding (MES), Hamworthy, Samsung Heavy Industries Machinery & Electric System and MAN Cryo have designed fuel gas supply systems. Different applications call for different FGSS solutions, therefore MAN Diesel & Turbo is cooperating closely with industry partners to ensure cost-effective solutions for ME-GI fuel gas supply systems.

The newly developed MAN Diesel & Turbo pump vaporiser unit (PVU) matches the requirements for supply of high-pressure LNG to the ME-GI engine. The PVU has redefined previous fuel gas supply systems with its low installation costs, less space requirement and full redundancy.
For comparison, various physical-chemical characteristics of LNG and ethane are listed in Table 1. Highlighting some of the properties of LNG reveals characteristic differences defining the possible ways of storing and handling the LNG on its way to the engine. On ships, natural gas (NG) is often stored in the liquefied state close to atmospheric pressure, thereby reducing the volume to 1/600th of the original volume.

The figures in Table 1 may also be obtained from the computerised engine application system (CEAS) available on the website http://marine.man.eu/two-stroke/ceas. Based on input containing the overall desired engine layout, CEAS provides important engine and performance characteristics gathered in the CEAS engine data report.

One of the important characteristics of LNG is that the chemical composition and methane number varies depending on the composition of NG and the liquefaction process at the refinery. NG, which has a high percentage of methane, consists of a mixture of various hydrocarbon gases: methane (CH\(_4\)), ethane (C\(_2\)H\(_6\)), propane (C\(_3\)H\(_8\)), butane (C\(_4\)H\(_10\)) and pentane (C\(_5\)H\(_12\)), as well as carbon dioxide (CO\(_2\)), nitrogen (N\(_2\)) and hydrogen sulphide (H\(_2\)S). At the refinery, gas impurities, sulphur (S\(_2\)) and CO\(_2\), are removed and the gas is cooled to its boiling point (-162°C) at atmospheric pressure.

Fig. 1 shows the variation in methane number versus LNG production capacity in metric tonnes per annum (mtpa). The largest production is seen at lower methane numbers. The yellow square in Fig. 1 shows that an engine requiring LNG with a methane number of minimum 70 (AVL) can use 90% of the global LNG supply. The green square shows that an engine requiring a methane number of minimum 80 (AVL) can use only 38% of the global supply. The ME-GI engine can be operated on all LNG qualities.

On LNG carriers and LNG-fuelled vessels, LNG is stored in tanks at -162°C. The continuous heat influx from the surroundings results in the development of BOG and an increase in tank pressure over time. Furthermore, when LNG is handled, during for example bunkering, excessive BOG is generated in the tank. Means of controlling the tank pressure must be installed regardless of the ship type. When the FGSS is designed for ethane, which has a higher boiling temperature than methane, the amount of BOG will be reduced.

The LNG composition will also change over time, termed ageing, when stored on board the ship. The lighter hydrocarbons of LNG (methane) will vaporise before the heavier components, accordingly, BOG supplied from the top of the storage tank has a high content of methane. The energy content of LNG is dependent on LNG chemical composition and temperature.

LNG also contains nitrogen. For most LNG, the nitrogen content is limited to approximately one percent. Nitrogen boils at -190°C, so it boils off rather quickly compared to methane. In BOG, we see as much as 20% nitrogen, and this large amount of nitrogen dilutes the energy content and needs to be taken into consideration when sizing compressors to feed the engine.

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### LNG Characteristics

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### Table 1: Fuel gas properties and requirements to fuel gas supply pressure and temperature for the ME-GI engine

<table>
<thead>
<tr>
<th>Fuel gas</th>
<th>LNG</th>
<th>Ethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower heating value (MJ/kg)</td>
<td>49.2</td>
<td>47.5</td>
</tr>
<tr>
<td>Boiling temperature (°C at 1 bar)</td>
<td>-162</td>
<td>-89</td>
</tr>
<tr>
<td>Supply pressure at ME (bar)</td>
<td>300 bar at 45°C ± 10°C</td>
<td>380 bar at 45°C ± 10°C</td>
</tr>
<tr>
<td>Supply pressure at Genset (bar)</td>
<td>6 bar at 0-60°C</td>
<td></td>
</tr>
</tbody>
</table>
The typical layout of FGSS designs has often been based on a conventional high-pressure cryogenic pump and vaporiser solution. However, the well-proven technologies of these FGSS systems have a cost. MAN Diesel & Turbo is therefore continuously involved in cost-optimising reliable FGSS solutions.

**LNG carriers**

When designing an FGSS for LNG carriers, in particular the amount of BOG has a large impact. A boil-off rate in the range of 0.08 to 0.1% per day must be handled continuously in loaded condition.

**Combined solution with pump and vaporiser unit, fuel gas compressor and partial reliquefaction**

An FGSS design for an LNG carrier may be based on:

1. Compressor supplying the ME-GI engine with HP fuel gas and the DF gensets with LP fuel gas
2. MAN Diesel & Turbo pump and vaporiser unit supplying the ME-GI engine with HP fuel gas. The PVU is described in Section *MAN Diesel & Turbo Pump Vaporiser Unit*
3. Partial reliquefaction system or combinations of these systems depending on the vessel type, voyage pattern and technical layout of the ship. The FGSS shown in Fig. 2 provides a high degree of fuel flexibility and full redundancy in gas operation.

The centrifugal pump submerged into the cargo tank has several functions, it feeds supply lines for both ME-GI and DF gensets and, in addition, it provides the option to feed the DF generators directly from the cargo tank through an LNG heater. Tank type C is the preferred tank type for smaller LNG carriers and gas-fuelled ships. For some tank types the size of the submerged
pump may be reduced if the tank pressure is controlled using this option.

One of the options for supplying HP fuel gas to the ME-GI engine is the LNG HP piston pump and LNG vaporiser.

The compressor is designed to feed BOG to the ME-GI engine with a pressure between 200–300 bar depending on the engine load, while simultaneously feeding DF gensets with 6 bar fuel gas pressure. The compressor operates in parallel with the PVU. Another design parameter is the load-dependent, controlled and instantaneous changes of the required fuel gas supply pressure for the ME-GI engine.

In this specific layout, the compressor is supplied with gas from a cold box. The cold box is in principle a heat exchanger, where warm excess fuel gas at 300 bar is cooled and expanded via two Joule-Thomson valves to one bar gas pressure. In the flash drum, some of the excess fuel gas is mixed with cold gas from a cargo tank and approximately 70% of the flow is returned to the cargo tank as LNG. The gas combustion unit (GCU) provides a method to burn off excessive gas in an emergency situation with a critically rising tank pressure.

The suction drum is not needed if the FGSS configuration is based on the MAN Diesel & Turbo PVU, since the effect of the suction drum is obtained by recirculating LNG through the HP pump.

However, the suction drum has to be incorporated in the design if the FGSS is built the conventional way with a separate LNG HP pump and vaporiser. The purpose of the suction drum is to ensure that there is a large LNG volume on the suction side of the LNG HP pump securing cold suction temperatures and avoiding cavitation.

The FGSS in Fig. 2 is designed with partial reliquefaction, but optionally the compressors can also feed a full reliquefaction system as shown in Fig. 3. However, it is not a requirement from the ME-GI. The main components in the reliquefaction process are: A nitrogen three-stage compressor (the last stage is coupled to an expander), a cold box and a BOG compressor. The cold box has three passages, one is for cooling of BOG, another is precooling of HP nitrogen and the third passage is low-pressure nitrogen providing the cooling for the cold box.

**Compressor characteristics**

As mentioned, several parameters must be considered when designing an efficient FGSS. One of these is the
The total amount of BOG, which is highly dependent on the ship operation cycle (loaded or ballast voyage) and the tank pressure level. The varying parameters may result in extreme operating conditions for the fuel gas compressor ranging for example from ultra-cold to warm start-ups.

The five-stage Laby®-GI fuel gas compressor is designed with a single and gas-tight compressor casing. All five stages are combined in a vertical crank gear and form the six-crank compressor. The balanced crank gear is an efficient way of minimising compressor vibrations in order to ease the installation on the deck of an LNG carrier, see Fig. 4.

The fuel gas compressor is designed for low suction temperatures. The thermal design and material selection means that it is not necessary to precool the compressor or to heat the fuel gas prior to start-up. With a pressure range covering up to 300 bar, the three oil-free labyrinth-sealed, low-pressure stages (stages 1 to 3) are complemented with two stages of piston ring sealing systems (stages 4 and 5). By combining the labyrinth sealing technology and piston ring sealing, a long lifetime of the sealing elements is obtained.

Each compressor stage is followed by an intercooler to fully control the inlet temperature to the following stage, as the temperature typically increases 150-200ºC between the stages. Bypass valves are provided over stage one, stages two and three, and stages four and five. These valves regulate the flow in the compressor according to the supply pressure required by the engine. Fuel gas is supplied at 6 bar to the DF gensets after the second stage.
Five-stage twin-compressor system

For owners and charterers requiring full redundancy of BOG delivery, a simplified and cost-optimised system based on two fuel gas compressors has been proposed, leaving out the conventional cryogenic pump and vaporiser. The operating conditions for an LNG carrier are surplus BOG in loaded condition and approximately 50% BOG (of the cargo tank content) in ballast condition, if a 10% heel is maintained. This allows the vessel to operate on boil-off gas 75% of the time. The short period (approx. 25%) of operation on LNG does not allow a reasonable payback time covering the CAPEX of the LNG cryogenic pump.

The layout of the FGSS for an LNG carrier can be designed as shown in Fig. 5 with a submerged LNG supply pump and two compressor strings delivering simultaneously high-pressure fuel gas to the ME-GI and low-pressure fuel gas to DF gensets.

Two Laby®-GI fuel gas compressors are each capable of handling 100% of the BOG, thereby, the ME-GI engines will consume 50% each of the compressed fuel gas. The power consumption of the compressor is six times that of the cryogenic pump, when delivering the same flow to the main engine. The main compressor will be operating continuously to ensure full redundancy, and the second unit can be started manually in case of a malfunction. Studies show that two compressors handling 75% of the BOG each might be sufficient in most cases. Furthermore, it is important to look at the inlet temperature of BOG to the gas compressor. If the temperature can be lowered, a smaller compressor size can be chosen. Insulation of BOG pipes on deck has often been discussed as a way to lower the temperature.

Compressor

The Laby®-GI pressure range of 150-300 bar covers the required fuel gas delivery pressure in the load range of ME-GI dual fuel engines from MAN Diesel & Turbo. However, reliable piston compressors applicable in this FGSS design are produced by several makers, for example MES, General Electric, and Kobelco. The GE compressor requires pre-heating of the fuel gas.

Atlas Copco has developed a new compressor solution to suit the ME-GI engines. The new solution takes advantage of the serial combination of a centrifugal compressor for the initial compression and a piston compressor for the last stage.
Standard high-pressure multi-compressor system

Since shipowners increasingly demand cost-optimised solutions, MAN Diesel & Turbo and Burckhardt Compression have developed a simple FGSS for both ME-GI powered LNG carriers as well as other ME-GI powered vessels. As an example, Fig. 6 shows the FGSS for a 174 kcum LNG carrier based on multiple small and compact compressor units. The system supplies fuel gas to the ME-GI engine and DF gensets.

For this purpose, Burckhardt Compression developed a CT-D compressor design solution based on the well-proven trunk piston technology. Depending on the specific setup, and as an alternative to the Laby®-GI, the CT-D design can contribute to a tangible CAPEX reduction for the complete propulsion system.

The standard high-pressure range compressors from Burckhardt Compression with a discharge pressure up to 310 bar are divided into four compressor types with flow capacities from 24 kg/h, up to 500 kg/h for the CT compressor shown in Figs. 7 and 8, and 675 kg/h for the CX compressor. More than 700 compressors are already installed worldwide, a part of these in CNG filling stations. The first orders for marine applications have also been achieved.

The FGSS solution shown in Fig. 6 is based on four CT-D compressor units, where each unit with two CT-compressors driven by a common electric motor delivers 1000 kg/h. The application of multiple compressors opens interesting partial redundancy options. Full redundancy is obtained if five CT-D compressors are installed. The system provides efficient part-load operation, where one compressor unit can be taken out of operation, when the load drops.

**Fig. 6: Fuel gas supply system solution with four CT-D compressors for a 174 kcum LNG carrier**

**Fig. 7: Cross section of the CT compressor**

**Cost-Optimised Designs of ME-GI Fuel Gas Supply Systems**

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![Diagram of Fuel Gas Supply System](image-url)
Further benefits are the simplified installation of the small unit, see Fig. 8, and the slightly reduced or comparable power consumption compared to the Laby®-GI.

As with the Laby®-GI solution, a partial reliquefaction system based on a common cold box and suction drum can be built in without requiring an additional compressor.

**Compressor characteristics**

The CT-D compressor is built with an inter-cooler between the five stages to fully control the inlet temperature to the next stage. Since the FGSS is based on multiple smaller compressors, the smaller rating of the electric motor enables the use of less expensive and less complicated variable frequency drives than for the larger motors. The electric motor and the variable frequency drive must be ATEX approved.

The use of a variable frequency drive gives an optimum turn-down power curve, see Fig. 9. The figure shows a comparison of relative shaft power (shaft power/shaft power\textsubscript{max}) as a function of relative flow (flow/flow\textsubscript{max}) for the CT compressor operated with variable frequency drive (ideal curve) and conventional bypass (blue curve).

Normal in-between maintenance work on the CT-compressors can be performed by the engineers on board. The maintenance cycle of the CT compressor is higher than on the Laby®-GI, though still manageable, which makes this design an attractive alternative.

**Standard high-pressure twin-compressor system**

For smaller LNG carriers even less than four CT-D compressors are required. As an example, the FGSS in Fig. 10 for a 30 kcum LNG carrier only needs two CT-D compressors.
LNG-fuelled vessels
Pump and vaporiser unit based system

The design of an FGSS for an LNG-fuelled vessel may be based on:

1. MAN Diesel & Turbo pump and vaporiser unit supplying HP fuel gas to the ME-GI engine

2. BOG compressor or an LNG supply pump and vaporiser supplying LP fuel gas to DF gensets

or combinations of these systems depending on the vessel type, voyage pattern and technical layout of the ship. In the FGSS design, shown in Fig. 11, the power demand is covered by four DF gensets. This well-proven system provides a high degree of fuel flexibility and full redundancy.

LNG tank types for LNG-fuelled vessels

Since container ships do not carry LNG, the LNG tanks and FGSS must be designed so a minimum of valuable container space is taken up. Generally, storing and supplying LNG requires approximately 3-4 times the volume compared to HFO if tank type C is chosen.

The IMO classified LNG tanks are divided into integrated tanks or membrane tanks and independent tank types. The independent tank types are subdivided into IMO A, B and C, where tank types A and B are low-pressure tanks (p<700 mbar) and tank type C may be pressurised with up to 2 bar. A more in-depth

Fig. 11: Fuel gas supply system for LNG-fuelled vessels based on the pump and vaporiser unit
explanation of the different tank types can for example be found on the webpage of IMO or World Ports Climate Initiative (WPCI).

When choosing the tank type, the essential parameters are the tank design pressure, the amount of BOG, and for how long excess BOG must be retained in the tank. This places demands on how the variations in temperature and pressure are handled during bunkering operations, ballast and loaded voyages and also on the investment in equipment utilising the excessive BOG. Another design parameter to consider is if the FGSS is designed with a BOG compressor, the design pressure of the LNG tank may be reduced.

Today, the preferred tank type is type C, where the relatively high design pressure allows up to weeks to pass before the BOG must be handled in an economically and environmentally safe way. However, when the LNG tank is specified together with an ME-GI engine, there are no restrictions in the choice of tank type, and any tank type can be applied.

Several manufacturers (TGE, Cryomec, Cryostar and others) have specialised in designing and developing different tank configurations.

LNG is stored in tanks at -165ºC as liquid gas, and the heat influx from the surroundings will result in an increasing gas pressure over time. In ballast, the amount of BOG decreases and the temperature of the tank increases. It is common practice to leave approximately 10% of the tank volume for the last part of the ballast voyage. By installing a spraying system in the top of the tank, the tank may be cooled and the pressure controlled by distributing the leftover cold LNG with the spraying system. The advantages of the system is that the cooling period necessary to cool the tank before bunkering can be shortened and a more flexible planning of overhaul is allowed for example on compressors.

LNG supply pump
The centrifugal pump submerged in the tank has several functions. The pump is part of the spraying system and delivers cold LNG at 6 bar to the suction side of the PVU HP pump. The size of the submerged pump may be reduced for some tank types if the DF gensets are consuming from the tank and, thus, controlling the BOG pressure.

Vaporiser
The heat required to vaporise the LNG can be delivered by the main engine high temperature cooling water system. The jacket water heats up a glycol-water solution, which transfers the heat to the cold LNG in the vaporiser. The temperature of the LNG is raised from -162ºC to 45ºC.

Ongoing research is focused on developing alternative configurations of the system, other solutions to drawing the heat from the jacket water and on utilising a medium with a higher thermal efficiency than the glycol solution.

Combined solution with pump, vaporiser unit and BOG compressor
In the cost-optimised FGSS shown in Fig. 12 for LNG-fuelled vessels, the ME-GI engine is supplied with fuel gas from the PVU and a small capacity high-pressure compressor. The small capacity compressor allows up to 20 days in harbour before the BOG pressure constitutes a problem.

The power-supply in this setup is the ME-GI driven PTO and a DF genset for harbour operation. For this solution, the BOG compressor can be equipped with a BOG side stream to feed the gensets. One big benefit of this solution is that the methane slip is completely avoided because the ME-GI does not produce any methane slip and the genset operation on gas is very limited.
Fig. 12: Fuel gas supply system for LNG-fuelled vessels
The turnkey pump and vaporiser unit (PVU) developed by MAN Diesel & Turbo combines the cryogenic pump and vaporiser in a compact unit, which offers a simplification of the entire FGSS. Fig. 13 shows the in-house developed PVU, which needs only 8 m² of space.

The PVU consists of three cryogenic booster pumps, a compact vaporiser, LNG, glycol and 10 μm NG filters.

The cost optimisation has been achieved by optimising the overall layout of the system and by reducing the number of valves, safety valves and blow-off lines. The control of the PVU is done using the MAN Diesel & Turbo developed multi-purpose controllers (MPCs). This simplifies the interface with the ME-GI engine, which uses the same controllers.
MAN Diesel & Turbo has developed the hydraulically driven high-pressure pump (warm end) based on the well-proven principle from the fuel booster injection valve used on the ME-GI, see Fig. 14.

A benefit is the replacement of the suction drum by continued circulation of LNG through a cold-return line and the cold-end pump. To obtain full redundancy, the PVU is designed with three high-pressure pumps in parallel, but only two pumps are required to supply LNG to the ME-GI engine. The HP hydraulic supply system for the HP pump has been removed from the ATEX zone. The size of the vaporiser has been reduced significantly by introducing a bounded-type vaporiser.

The PVU continuously delivers a stable fuel gas pressure also during load variations without overshooting. Fig. 15 shows the pump-pressure during shutdown of gas operation at maximum continuous rating MCR engine load. The PVU pressure control eliminates the need for pulsation dampers.

The PVU sizes currently available in the product range are shown in Fig. 16.

![Gas pressure response in the PVU during shut down of gas operation](image)

<table>
<thead>
<tr>
<th>PVU-1000-1.1</th>
<th>PVU-3000-1.1</th>
<th>PVU-5000-1.1</th>
<th>PVU-7000-1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG (kg/h)</td>
<td>1,600</td>
<td>1,601-3,000</td>
<td>3,001-4,900</td>
</tr>
<tr>
<td>Engine power (MW)</td>
<td>-8.9</td>
<td>9.0-16.6</td>
<td>16.7-27.1</td>
</tr>
<tr>
<td>L x W x H (mm)</td>
<td>2,800×2,000×2,000</td>
<td>2,800×2,000×2,000</td>
<td>3,700×2,240×2,200</td>
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</table>

![The PVU product range](image)
Fig. 17 shows the scope of supply, where the red boxes are systems or components delivered by a supplier approved by MAN Diesel & Turbo. The FGSS supplier is responsible for the part of the system shown in grey. Note that MAN Cryo can deliver a full fuel gas supply system including the PVU.
The combination of the ME-GI engine with the different FGSS configurations outlined above offers efficient and price competitive alternatives for the marine industry, also targeting the small market segment for CNG vessels.

Previous FGSS designs were often based on the relatively expensive cryogenic pump and vaporiser solution. This design and the price have been challenged by the introduction of various cost-optimised, reliable and compact compressor configurations and the cost-optimised PVU.

The cost-optimised FGSS solutions for LNG carriers based on two fuel gas compressors or multiple smaller compressor units can contribute to a considerable CAPEX reduction. The low part-load power requirement also seems to be an advantage with this solution.

The FGSS solutions are optimised in detail with the different requirements arising from the different ship types in mind but also with the intention to fully utilise the capabilities of the individual components without compromising redundancy or part-load operation, which may be integrated into the system in more ways than previously.

The newly developed pump and vaporiser unit is a turnkey FGSS system from MAN Diesel & Turbo, which has been cost-optimised by improving the overall layout and by reducing the overall number of components.
### Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATEX</td>
<td>atmosphere explosive</td>
<td></td>
</tr>
<tr>
<td>AVL</td>
<td>Anstalt für Verbrennungskraftmaschinen List</td>
<td></td>
</tr>
<tr>
<td>BGU</td>
<td>boil-off gas unit</td>
<td></td>
</tr>
<tr>
<td>BOG</td>
<td>boil-off gas</td>
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<tr>
<td>CAPEX</td>
<td>capital expenditure</td>
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<tr>
<td>CEAS</td>
<td>computerised engine application system</td>
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<td>DF</td>
<td>dual fuel</td>
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<td>FGSS</td>
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<tr>
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<tr>
<td>HFO</td>
<td>heavy fuel oil</td>
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<tr>
<td>HP</td>
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<tr>
<td>HPS</td>
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<tr>
<td>IMO</td>
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<tr>
<td>LNG</td>
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<td>LP</td>
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<tr>
<td>LPG</td>
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<td>maximum continuous rating</td>
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<tr>
<td>PVU</td>
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