Managing methane slip

MAN Energy Solutions
Future in the making

MAN Energy Solutions addresses methane slip to further increase LNG benefits

List of abbreviations

LNG	Liquefied natural gas
GHG	Greenhouse gas
SO_x	Oxides of sulphur
NO_x	Oxides of nitrogen
PM	Particulate matter
CO_2	Carbon dioxide
DF	Dual-fuel
CH_4	Methane
IMO	International Maritime Organisation
HFO	Heavy fuel oil
LPG	Liquefied petroleum gas
LFO	Light fuel oil
LCV	Lower calorific value
SCR	Selective catalytic reduction
EGR	Exhaust gas recirculation
GWP	Global warming potential
SNG	Synthetic natural gas
VLSFO	Very low sulphur fuel oil
NH_3	Ammonia
SI	Spark ignited

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Executive summary

MAN Energy Solutions sees the trend for large engines to change from oil to gaseous fuels as the starting point for a "Maritime Energy Transition". In this transition, fuelling with liquefied natural gas (LNG) is the first step in preparing engines for the broader use of a range of synthetic fuels, on the way to carbon-neutrality. With its high heating value combined with low carbon content, LNG enables a significant reduction in emissions of greenhouse gases (GHG), while an absence of sulphur content also enables reductions in emissions of particulate matter (PM) and oxides of sulphur (SO_x) – and all that comes at lower fuel costs.

Building on the initial reduction in GHG emissions, the Maritime Energy Transition calls for large marine engines to change from oil fuel to flexible dual-fuel capability, so that engines are able to run on a wide range of low-carbon or carbon-neutral fuels. Thus, the shift to LNG is a logical and important first step in preparing engines for the broader use of synthetic fuels.

Lately, the issue of methane slip has received a lot of attention and raised questions on the climate benefits of LNG as an engine fuel for marine applications. LNG is typically 85 % to 95 % methane (CH_4), a greenhouse gas considerably more potent than carbon dioxide (CO_2). In some contemporary reciprocating engines, its use can lead to emission of small but significant quantities of unburnt methane into the atmosphere.

MAN Energy Solutions is convinced that the issue of methane slip needs to be resolved. For its two-stroke engines, MAN is already offering technical solutions to minimise methane slip. For its four-stroke spark-ignited (SI) gas and dual-fuel (DF) engines, the company is energetically pursuing such solutions.

MAN's ME-GI two-stroke dual-fuel engines employ the Diesel combustion process. LNG is injected directly into the combustion chamber just after a liquid fuel pilot jet has initiated combustion. This minimises unburnt residues and allows MAN to quantify and guarantee methane slip levels in a range from 0.2 – 0.3 g/kWh over the ME-GI engines' load range.

In its range of four-stroke gas-burning engines employing the Otto combustion process, MAN has halved methane slip over the past ten years to a level where the combined GHG impact of CO_2 and CH_4 is today notably below the respective figure for liquid burning diesel engines. The company is now pursuing three separate routes to yet lower levels: Firstly, ongoing improvements to internal engine design and electronic controls will further increase fuel efficiency and minimise emission. Secondly, newly developed aftertreatment solutions, namely oxidation catalysts, have the potential to reduce methane slip by high double-digit percentages.

Thirdly, MAN is also evaluating options to bring the negligible methane slip of its ME-GI two-stroke dual-fuel engines to its medium speed dual-fuel engines by transferring the ME-GI Diesel combustion principle to its four-stroke dual-fuel engines.

With these countermeasures, MAN is confident that methane slip will not become a barrier to either the expansion of the market for gas-burning engines or the progression of the Maritime Energy Transition.

Increasing LNG benefits by decreasing methane slip

Forecasts call for the global energy economy to steadily shift from mineral oil to natural gas, as oil production peaks but production of lower priced natural gas continues to rise over several years. This is essentially positive news for users of large engines.

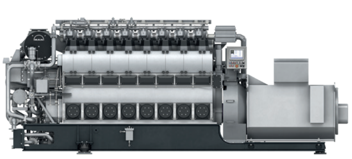
Large engines are a mainstay of the global economy, providing ship propulsion and electrical power generation, and fuelling them with LNG also has benefits for the environment.
LNG is predominantly methane (CH_4), which is the simplest possible combination of carbon and hydrogen. With only one carbon atom per molecule, methane's combustion in air produces the lowest emissions of the greenhouse gas (GHG) carbon dioxide (CO_2) of any hydrocarbon fuel. In addition, the combustion of LNG produces very low emissions of particulate matter (PM) and virtually no oxides of sulphur (SO_x) – commercially available LNG is sulphur-free.

At the same time, "lean burn" combustion technology is already widely used in large gas engines employing the Otto combustion process. It has the valuable benefits of enabling fuel-efficient combustion combined with low emissions of oxides of nitrogen (NO_x), in compliance with strict international limits without exhaust gas aftertreatment. Additionally, LNG used to power gas and dual-fuel engines has the potential to lower carbon dioxide (CO_2) emissions by up to 25 % compared to oil-fueled engines.

These properties of methane are already allowing gas-burning Otto engines to meet the most important international limits on polluting emissions in both marine and land-based applications.
In addition, fuelling engines with methane also offers immediate potential as a starting point for meeting ambitious targets for reductions in GHG emissions.

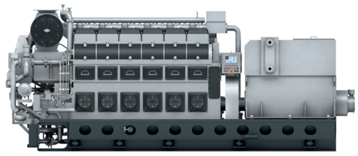
This overall scenario has kick-started growth in demand for the large two- and four-stroke dual-fuel engines designed and built by MAN Energy Solutions (Fig. 1 – MAN dual-fuel engine range). Significantly, in this shift to gas-burning engines, MAN and others also see the opportunity for global shipping to undergo a "Maritime Energy Transition". Following conversion from liquid fossil fuels to gaseous fuels, a road-map for marine engines envisages the mixing of LNG with increasing proportions of synthetic gaseous fuels on the way to 100 % synthetic fuels and, hence, carbon-neutrality.

The MAN dual-fuel engine range both two- and four-stroke



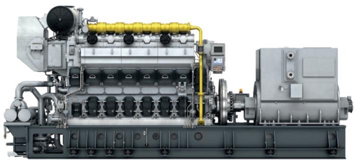
MAN 23/30DF
GenSet

625 – 1,200 kW



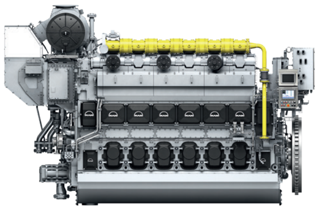
MAN 28/32DF
GenSet

1,000 – 1,800 kW



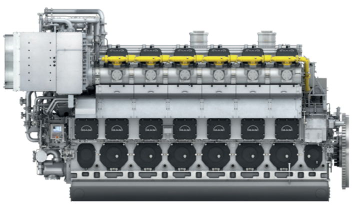
MAN 35/44DF
GenSet

3,060 – 5,300 kW



MAN 35/44DF
Propulsion

3,060 – 5,300 kW

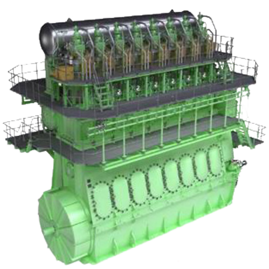


MAN 51/60DF
Propulsion

6,300 – 20,700 kW

MAN B&W ME-GA
Propulsion

14,150 – 16,980 kW



MAN B&W ME-GI
Propulsion

6,950 – 82,440 kW

Fig. 1: MAN dual-fuel engine range

Gas engine market development

Powering ships and providing on-board electrical power is a major application for MAN's engines and liquefied natural gas (LNG) is becoming more and more popular as their fuel. Highly compressed and readily transportable, LNG occupies only a fraction of the volume of the gaseous form of natural gas at pipeline transmission pressures.

Operators of both large marine and stationary engines are responding to the prospect of the long-term availability of a reasonably priced source of energy with increased demand for gas engines. Simultaneously, they are becoming aware of the potential of fuelling large engines with LNG as a route to compliance with emissions limits (e.g. SO_x).

This applies to both polluting and greenhouse gases, measured by units of work done in both g/kWh or "tonne miles" in the case of marine transport.

Moreover, as well as orders for new engines, MAN PrimeServ, the energy solution provider's after-sales organisation, is seeing growing demand for the conversion of existing oil-fueled engines to LNG fuelling on both land and sea. Accordingly, PrimeServ has developed the capability to retrofit MAN's major diesel engine series for gaseous fuels, with packages designed to ensure that the existing population of MAN two- and four-stroke engines remain viable assets during the Maritime Energy Transition.

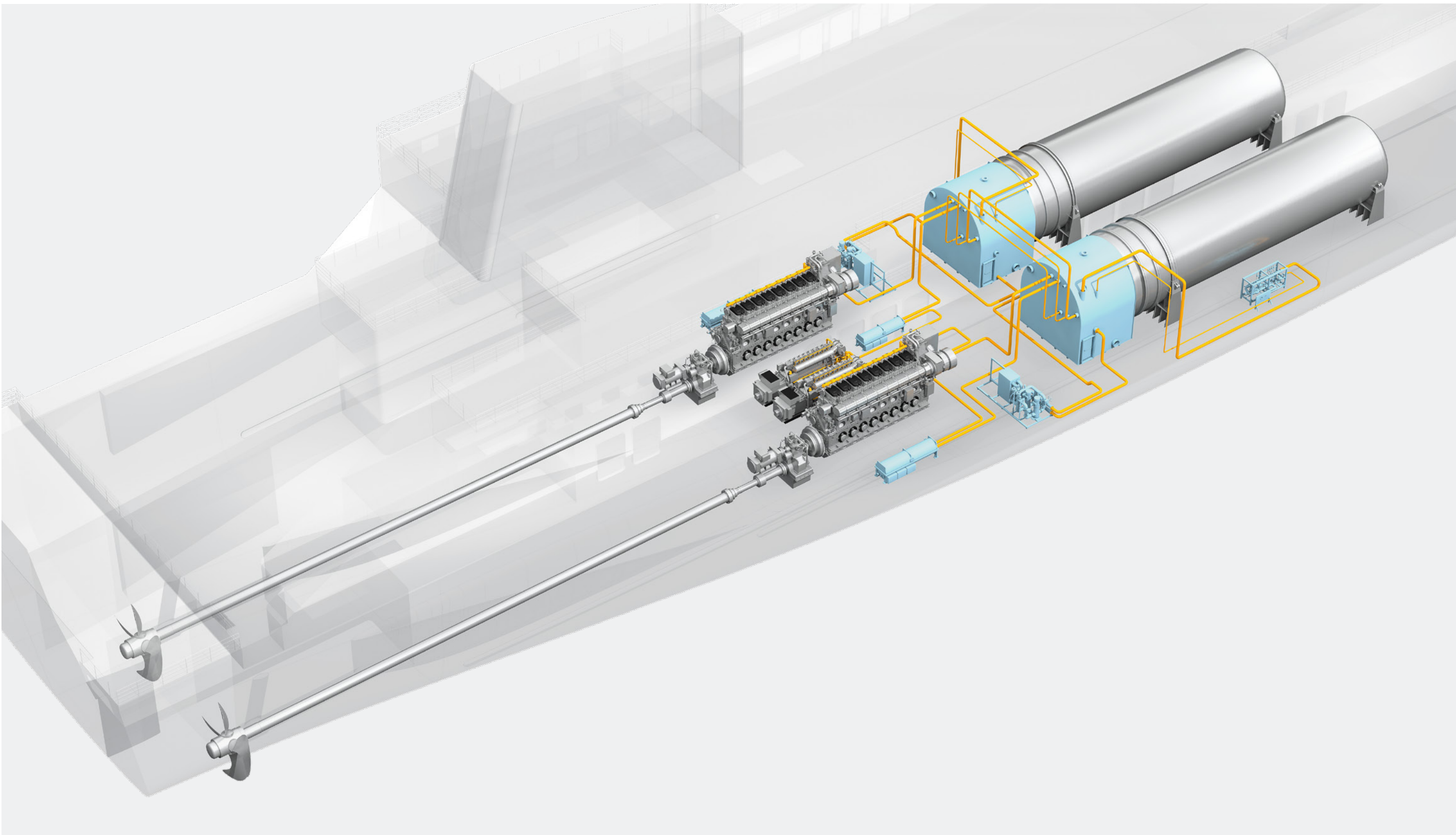


Fig. 2: LNG supply and bunker system

MAN Energy Solutions is offering complete LNG propulsion systems, including dual-fuel engines and the LNG fuel-gas supply system with LNG tanks, pumps and auxiliary equipment.

Emissions status

Large engines have been subject to progressively more demanding clean air legislation for over two decades. On land this includes the World Bank's Guidelines for New Plants producing electrical power and, at sea, three Tiers of limits on oxides of nitrogen (NO_x) issued by the International Maritime Organisation (IMO). From IMO Tier I to IMO Tier III, NO_x limits have been reduced by some 80 %, followed by IMO regulations on sulphur in marine engine fuels – the "Sulphur Cap 2020" which aims to reduce emissions of SO_x and PM.

Starting with CO_2, the IMO's focus has recently shifted to GHG in the form of enforceable targets for overall ship efficiency, prescribed by IMO's Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) [I]. More importantly, the IMO has also set the industry goal to reduce shipping's carbon emissions by 50 % until 2050.

To put these GHG targets into context – as well as emphasising the high-energy efficiency of engines used in international shipping, and the link between fuel efficiency and CO_2 – only 3 % of global CO_2 emissions is attributable to transport by sea. This makes shipping by far the lowest emitter of CO_2 in relation to the transport task performed, but this percentage will clearly rise if shipping decarbonisation does not keep pace with decarbonisation in other modes of transport.

The use of LNG offers significant reductions in polluting emissions and GHG. Furthermore, gas-burning Otto engines need minimised emissions reduction equipment versus oil-fueled engines – e.g. SCR or EGR for NO_x reduction – which reduces operating costs. In addition due to its chemical composition, LNG produces less CO_2 during combustion than liquid fuels (see Tab. 1).

Type of fuel	Carbon factor C_F (t CO_2)/(t fuel)	Approx. LCV* kJ/kg	Specific carbon intensity gram CO_2 / MJ
Diesel/Gas oil	3.206	42,700	75.1
Light fuel oil, LFO	3.151	41,200	76.5
Heavy fuel oil, HFO	3.114	40,200	77.5
Liquefied petroleum gas, LPG	3.015	46,000	64.4
Liquefied natural gas, LNG	2.750	48,000	57.3
Methanol	1.375	19,900	69.1
Ethanol	1.913	26,800	71.4

Tab. 1: Carbon factor and lower calorific values for different fuels, as defined by the IMO**

Note that LPG is a mixture of propane and butane, the values given here are for a 50/50 mixture. The primary content of LNG, pure methane, has an LCV* of 50,000 kJ/kg.

* LCV = lower calorific value
** 2014 Guidelines on the method of calculation of the attained energy efficiency design index (EEDI) for new ships, as amended by resolution MEPC.263(83) and MEPC.281(70)., IMO, 2017.

What is methane slip?

Without countermeasures, there are several routes by which methane can escape unburnt into the atmosphere from both two- and four-stroke gas-burning engines. This methane which evades combustion and is emitted via the engine exhaust as well as the crankcase ventilation is referred to as "methane slip". With the legislator's eyes now firmly on GHG, this aspect of gas engine operation has moved into focus, and if not properly addressed, could severely limit the expansion of LNG as fuels for large engines.

Typically, from 85 % to 95 % of natural gas and LNG is methane (CH_4), and methane is a GHG several times more potent than CO_2. A recent study has calculated the Global Warming Potential (GWP) of methane – i.e. its capability to trap heat in the atmosphere compared with the same mass of CO_2 (CO_2 equivalent or CO_{2e}) – at 84 – 86 over 20 years and 28 – 34 over 100 years.[1]

MAN is, thus, fully aware that the economic and polluting emissions benefits of LNG can only be leveraged completely if the issue of methane slip is solved. As well as a source of GHG leakage into the atmosphere, methane slip is also wasted fuel, not converted into energy.

In fact, engine designers are not alone in being confronted with the fuel wastage and GHG emissions related to LNG and, to maximise the environmental benefits of LNG, the complete natural gas supply chain must be escape-proof. The economic and ecological rewards are great and MAN is allocating considerable resources to its part in minimising the escape of methane to the atmosphere on a "well-to-wake" basis. This means from the moment natural gas emerges from the ground to the moment exhaust gases emerge from the gas-burning engine propelling a ship or providing its on-board electricity.

Methane emissions, gas mode

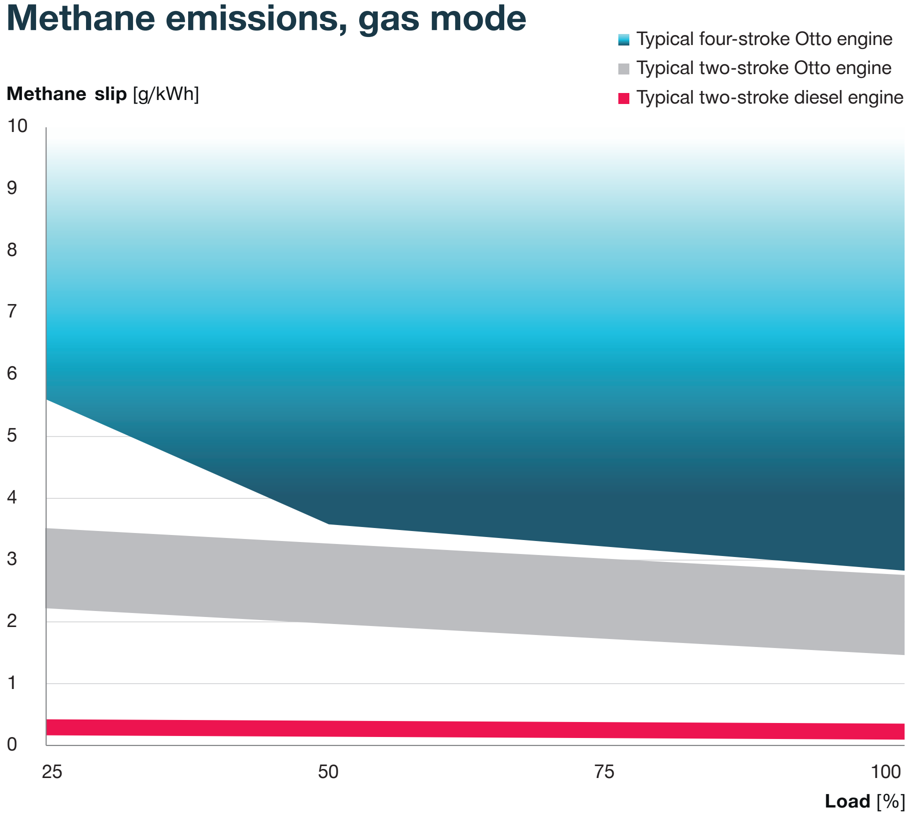


Fig. 3: Methane emissions in gas mode – comparison of different engine types

The phenomenon is most prevalent on gas-burning engines operating according to the Otto combustion process, where gas fuel and air are mixed homogenously prior to ignition and combustion. It affects engines in which the premixed fuel and air are ignited by a spark-plug – so called spark-ignited (SI) gas engines – as well as dual-fuel (DF) engines where a liquid fuel "pilot" initiates ignition of the air-gas mixture.

Marine GHG regulations

Understandably, methane slip is also now firmly in the IMO's sights and in 2019 the aim was declared to produce "concrete proposals to reduce methane slip and emissions of volatile organic compounds"[2]. This intention reinforces the IMO's "Initial Strategy" on decarbonisation, announced in 2018 and calling for a reduction in total annual GHG emissions from international shipping as a whole. The aim is that GHG should peak at the earliest date and then decrease by 2050 to only 50 % of 2008 levels, in pursuit of the 100 % decarbonisation of marine transport[3].

[1] IPCC, 2013: Climate Change 2013: The Physical Science Basis.
[2] https://www.marpol-annex-vi.com/eedi-seemp/
[3] http://www.imo.org/en/MediaCentre/PressBriefings/Pages/11-MEPC-74-GHG.aspx

Taking up the challenge

As designers and builders of both two- and four-stroke gas-burning engines, MAN's technical departments have been working for some time to minimise methane slip from engines using two different operating principles.

Two-stroke: Methane slip reduction

In its two-stroke engine programme, MAN Energy Solutions is already offering a very effective solution to minimise methane slip. ME-GI two-stroke dual-fuel (DF) engines are achieving extremely low levels of unburnt methane emission due to operation on the Diesel combustion principle (Fig. 3). This inherently low methane slip is explained by the fact that in the ME-GI two-stroke DF engines, the gaseous fuel is injected into the compressed charge air around top dead centre and only slightly after the liquid fuel pilot, when the pilot has already ignited. This ensures complete, very fuel-efficient combustion with maximised heat release. Since the gaseous fuel only enters the cylinder after the exhaust valve has closed and ignites immediately, there is no opportunity for methane to escape during cylinder scavenging. In addition, virtually no unburnt methane is trapped in crevice volumes, such as the "top land" between the piston and cylinder liner.

As shown in Fig. 4, levels of unburnt methane in the exhaust of MAN's ME-GI two-stroke DF engine are very low. Consequently, MAN can point to an effective solution to minimise methane slip in its two-stroke DF range and quantifies and guarantees methane slip levels in a range from 0.2 – 0.3 g/kWh over the ME-GI engines' load range.

The very high rate of combustion efficiency (the measure for completeness of combustion), as well as the higher compression ratio achieved by Diesel combustion with direct gas injection in MAN's ME-GI two-stroke DF engines, has further major benefits. They enable lower fuel consumption, and thus lower CO_2 emissions than DF engines with Otto combustion and pre-mixed gas admission. In addition, with direct gas injection ME-GI engines also achieve very stable operation on all commercially available grades of LNG. This contrasts with engines operating on the Otto combustion principle, which can be subject to knocking and require LNG with a minimum methane number of around 70 to maintain optimum performance.

On the pollutant emissions side, besides high combustion efficiency, the elevated combustion temperatures within the Diesel combustion process of ME-GI engines also cause nitrogen oxides (NO_x) emissions at almost the same level as oil fuel combustion, which need to be abated by either EGR or an SCR catalyst for compliance with IMO Tier III limits. However, such abatement technology is not limited to use in gas mode operation but can also be activated in liquid fuel mode in order to comply with IMO Tier III limits, thus providing full fuel flexibility under all boundary conditions. With regard to the possible use of exhaust aftertreatment to minimise the methane slip from two-stroke DF engines, oxidation catalysts are not found feasible given that the exhaust gas temperatures typical of two-stroke engines are too low to trigger a reaction with the unburnt methane. This fact currently makes MAN's ME-GI low-speed DF engines with direct gas injection the only viable option on the two-stroke engine market capable of coping effectively with methane slip.

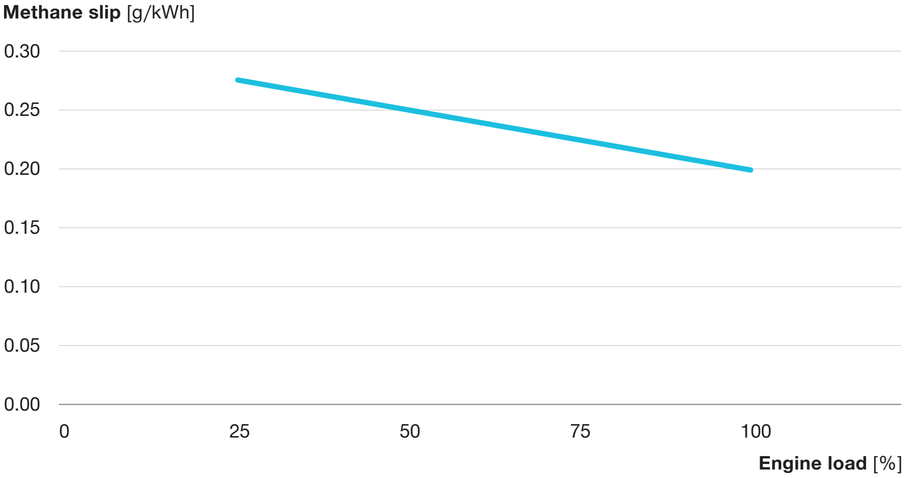


Fig. 4: Methane slip of MAN's ME-GI two-stroke DF engines at different engine loads (the figures are given with a tolerance of ± 0.1 g/kWh)

Fig. 5: Siem Confucius

The 'Siem Confucius' and sister ship, the 'Siem Aristotle', are the very first transAtlantic PCTCs (Pure Car Truck Carriers) to operate full-time on LNG. The vessels will transport cars for the VW Group between Europe and China and are both powered by MAN B&W S60ME-GI (-Gas Injection) dual-fuel, two-stroke main engines.

Solutions for retrofitting to alternative fuels

MAN Energy Solutions is able to deliver technical solutions and products that enable operation on all available marine fuels: Distillate, 0.50 %S VLSFO (very low sulphur fuel oil), high-sulphur HFO, biofuels, LNG, LPG, LEG (ethane) and methanol/ethanol. Tab. 2 below shows MAN's extensive portfolio of two-stroke engines.

The modular design of MAN's engines supports retrofitting to various engine configurations, and the electronically controlled ME-C engines can be readily converted to dual-fuel operation. The resulting dual-fuel engines can then, in turn, be retrofitted for operation on further fuels: for example, methanol engines (ME-LGIM) can be retrofitted to operation on LPG (ME-LGIP), etc.

Furthermore, MAN is working diligently towards offering engines and retrofit solutions for use with ammonia (NH3) as their fuel. The aim is to have an ammonia-burning engine ready by 2024.

All these products and developments will ensure the right solutions for future market demand for carbon-neutral propulsion. They reassure end users that their engines are future-proof and readily adaptable to operate on the fuels of today and tomorrow.

Fuel types	MC	ME-B	ME-C	ME-GI	ME-GA*	ME-GIE	ME-LGIM	ME-LGIP
0.0 – 0.5 % S VLSFO	Design	Design	Design	Design	Design	Design	Design	Design
High-S HSHFO	Design	Design	Design	Design	Design	Design	Design	Design
LNG	–	–	Retrofit***	Design	Design	Retrofit***	Retrofit***	Retrofit***
LEG (Ethane)	–	–	Retrofit***	Retrofit***	–	Design	Retrofit***	Retrofit***
Methanol / Ethanol	–	–	Retrofit**	Retrofit**	–	Retrofit**	Design	Retrofit**
LPG	–	–	Retrofit**	Retrofit**	–	Retrofit**	Retrofit**	Design
Biofuels	Design	Design	Design	Design	Design	Design	Design	Design
Ammonia****	–	–	(Retrofit**)	(Retrofit**)	–	(Retrofit**)	(Retrofit**)	(Retrofit**)

Tab. 2: Fuel flexibility – which MAN two-stroke engines can burn which fuels?

* Otto-cycle gas engine
** Only one second fuel per retrofit
*** Both LNG and LEG for same engine possible
**** Ammonia burning engine development started

Four-stroke: Methane slip reduction

On the four-stroke side, MAN has been addressing methane slip ever since it introduced DF engines in the mid-2000s and can already point to considerable success. For example, since the launch of the four-stroke MAN 51/60 DF engine, countermeasures have more than halved methane slip from that engine, giving this engine type a 5 % to 15 % advantage over liquid fuel engines in terms of GHG emissions, even when the methane slip is considered in that calculation.

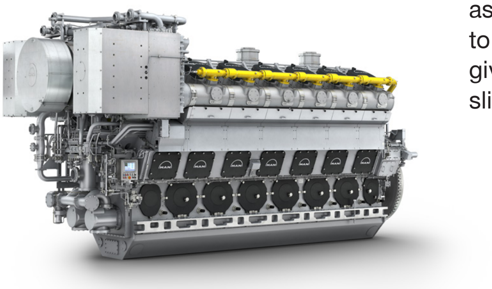


Fig. 6: MAN 51/60 DF

For the future, MAN's technical department already sees three promising routes to considerably lower methane slip. Firstly, ongoing improvements to internal engine design and electronic controls will further increase combustion efficiency and thus fuel efficiency. Secondly, newly developed aftertreatment solutions, namely oxidation catalysts, have the potential to reduce methane slip by 70 %. Thirdly, MAN engineers are evaluating ways to apply the technology of direct gas injection, as used on MAN's two-stroke DF engine to its four-stroke DF engines. This will give the potential to reduce methane slip by a value greater than 90 %.

50 %
reduction in methane slip
during last 10 years through improvements to internal engine design and electronic controls

70 %
reduction potential
through new aftertreatment solutions, like oxidation catalysts

90 %
reduction potential
through direct gas injection technology as used on ME-GI two-stroke engines

Internal engine design

The countermeasures devised and under investigation at MAN's technical department for four-stroke engines involve all the major aspects of internal engine design: control of engine operation; combustion processes and their control; basic engine architecture. As they mature, measures are being rigorously applied in both new four-stroke DF engines i.e. the 51/60 and 35/45 DF, and those diesel engines being retrofitted by the MAN PrimeServ after-sales department to run on LNG, such as 48/60 diesel to 51/60 DF conversions.

As outlined above, MAN's four-stroke SI gas and DF engines operate on the Otto combustion process, where gaseous fuel is pre-mixed with air before ignition. The air/fuel mixture is compressed and ignited by a spark-plug or liquid fuel pilot injection and is thus in the cylinder for all of the induction and compression strokes and part of the power stroke. In addition, because the four-stroke engines rely much more for gas exchange on inlet and exhaust valves, in the Otto process there are increased opportunities for the gaseous fuel to evade combustion.

An important line of attack centres the reduction in the overlap of inlet and exhaust valve openings and the timing of gas admission. Valve overlap creates an unavoidable period during the inlet stroke of a four-stroke engine when both inlet and exhaust valves are open in order to "scavenge" the cylinder (i.e. replace exhaust gases with charge air or air/fuel mixture). In Otto gas operation, minimising this overlap reduces the time in which air/gas mixture can reach the exhaust port, while close control of the timing and duration of gas admission from electrically-controlled valves in the inlet ports precisely limits the time that gas can enter the cylinder during exhaust valve opening.

In terms of engine architecture, a successful approach is the reduction of "crevice volumes" in the combustion chamber – i.e. areas where pockets of unburnt gas can be trapped that cannot be reached by the flame torches during combustion.

One example is the "top land" of the piston in spark ignited gas engines. This is the area above the top piston ring on the piston crown. By raising the position of the piston ring and so reducing the height of the top land, the associated crevice volume is reduced and the rate of combustion efficiency is increased.

Most recently, MAN has addressed the optimisation of methane conversion using enhanced combustion control and the inclusion of combustion pressure sensors in the cylinder to enable cylinder-pressure monitoring and cylinder-pressure-based combustion control. The benefits of cylinder cut-off in part load operation are also being utilised.

Simultaneously, the associated improvements in the combustion processes of MAN's four-stroke gas engines are also leading to considerable improvements in fuel efficiency.

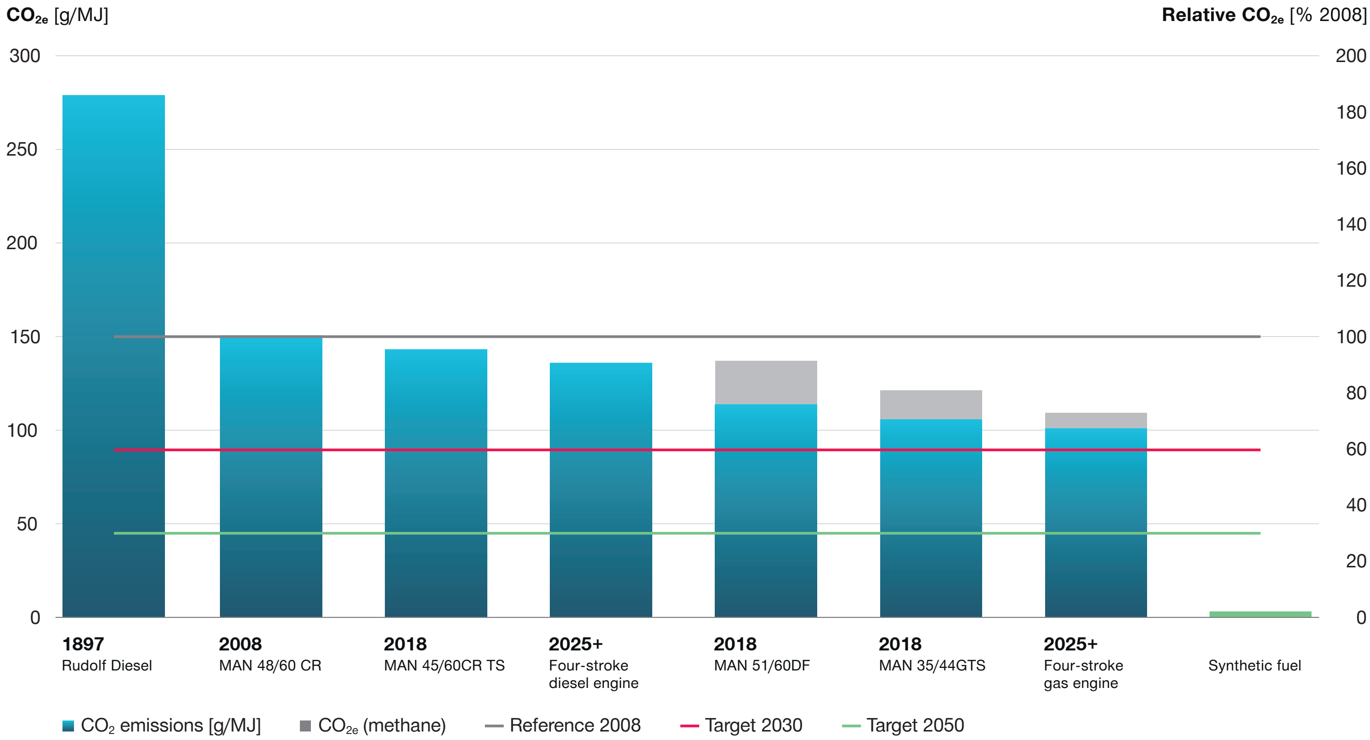


Fig. 7: Comparison over time of CO_2 emissions from different types of MAN four-stroke engines – how low can it go?

Aftertreatment

While an oxidation catalyst ("oxicat") is not an option for two-stroke engines because of unsuitably low exhaust gas temperatures, it is a well-established technology for removing unburnt hydrocarbons and carbon monoxide from four-stroke engine exhaust gases. The exhaust gas temperatures from MAN's four-stroke SI and DF engines are sufficient to support the oxidation of methane slip and MAN is participating in the "IMOKAT" project supported by the German Federal Ministry for Economic Affairs and Energy. The aim is to develop methane oxidation catalysts capable of a methane slip reduction of 70 % on both SI and DF gas engines. In laboratory tests with synthetic exhaust gas, the 70 % methane conversion rate has been achieved. The next step will be tests on a full-size engine.

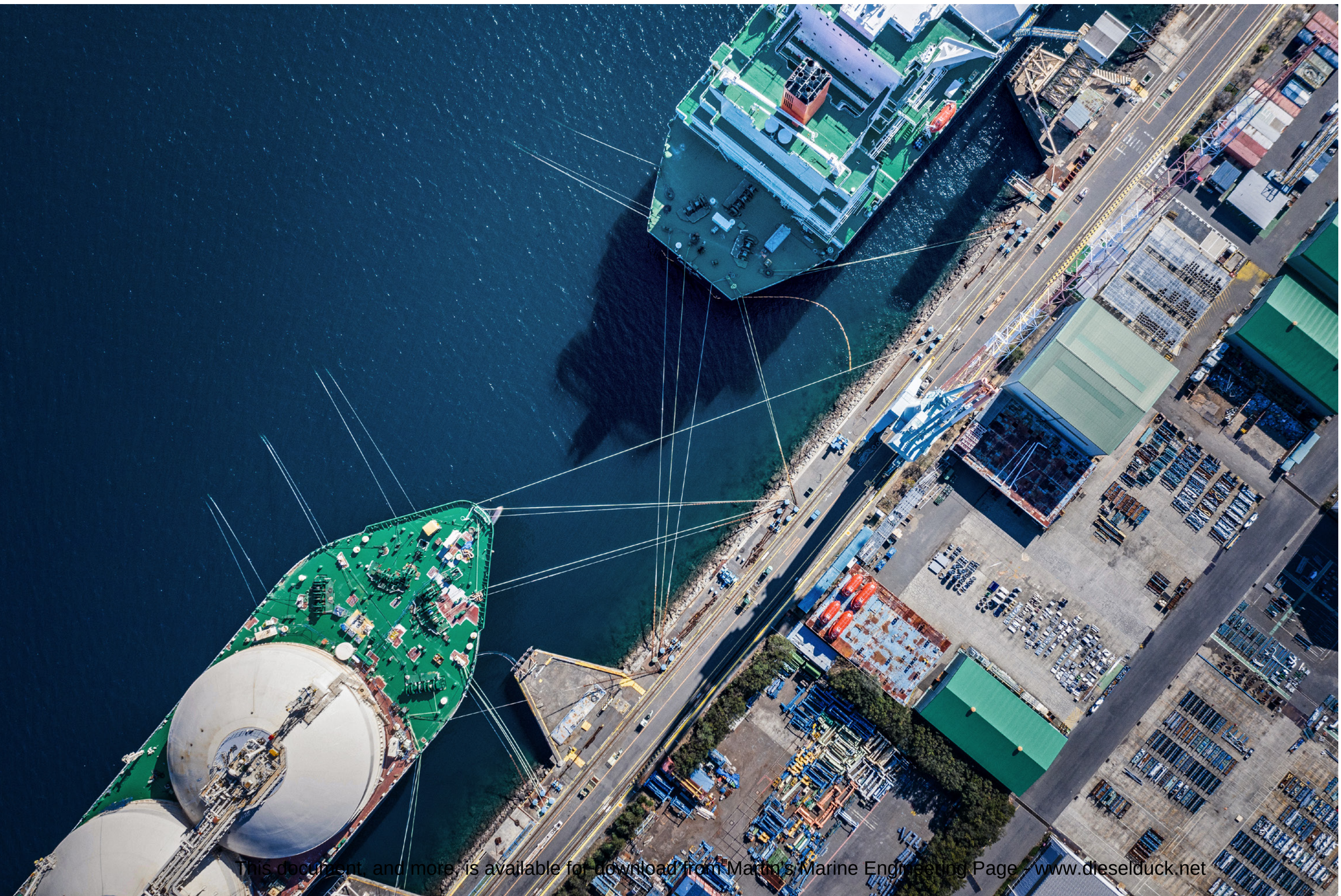
A special challenge with the oxicat is the need to integrate the catalyst on the engine before the turbocharger, where exhaust gases are hotter, since variations in exhaust gas temperature represent a particular challenge in terms of control engineering.

Direct gas injection

The technology of direct gas injection used on MAN's ME-GI two-stroke gas engines can also be applied on four-stroke DF engines, switching them to the Diesel combustion principle. It is estimated that this step would enable a further reduction in methane slip estimated at greater than 90 % compared to Otto gas engines with premixed cylinder charge.

As in the ME-GI, two-stroke DF engines, gaseous fuel would be injected with the diesel-fuel pilot into the compressed charge-air at around top dead centre. This will leave no scope for methane to escape during the four-stroke cylinder scavenging process. Accordingly, MAN's engineers are already assessing the feasibility of direct gas injection on four-stroke gas engines and will be able to apply the technology, when the market demands it.

As with MAN's ME-GI two-stroke DF engines, the direct injection of gas into the cylinder when compression is at its highest demands much higher gas inlet pressures. These present a considerable engineering effort and demand a more powerful compressor than for the low-pressure principle presently used on MAN's four-stroke Otto gas engines, where an air/gas mixture is admitted during the induction stroke. However, as stated above, in ME-GI two-stroke DF engines this additional first cost for the gas compressor is offset by the lower fuel consumption and hence lower CO_2 emissions attainable with Diesel DF combustion.



Retrofitting for future fuels

Advocating a Maritime Energy Transition, MAN Energy Solutions is convinced that synthetic, carbon-neutral fuels will open the way to a future of climate-neutral shipping. To meet the 2050 climate goals this also means that large parts of the existing global shipping fleet will need to be retrofitted from liquid fuel to dual-fuel liquid/gas operation. Incorporating the capability to take advantage of a range of low-carbon and carbon-neutral fuels will enable engines to run, for example, on carbon-neutral synthetic gas without further technical modifications. For four-stroke engines LNG is right now the only available fuel to meet today´s environmental standards on polluting emissions and to reduce CO_2 emissions by around up to 26 %, compared to four-stroke oil-fuelled engines – with the option to use SNG as soon as available, either as a drop-in fuel or up to 100 %. Conversion to dual-fuel operation is thus a future-proof investment.

The actual costs of the retrofit depend on the scope of technical solutions and conversions, ranging from very low in the case of LNG to synthetic natural gas, where no technical adaptations are needed, and up to 50 % to 75 % of a new engine for an initial liquid to gaseous fuel conversion.

However, the higher costs can be offset when the liquid fuel engine is due for a full overhaul. They are additionally justified when the retrofitted engine complies with emissions limits and avoids operating bans and penalties, including higher port fees.

Likewise assisting retrofit business cases are the potentials for significantly better engine performance from the upgrades to more modern technology included in the retrofits (e.g. addition of the latest electronic controls), access to more favourably priced fuel and possible clean air incentives and subsidies.

Ship name	Owner	Application	Conversion	Operation since	Savings (t/year)			
					NO_x	SO_x	PM	CO_2*
MV Wes Amelie	Wessels Reederei	Container ship 1000 TEU	MAN 8L48/60B to MAN 8L51/60DF	2017	207	10	6	1,088
MV Napoles	Baleària Eurolineas Maritimas	Ferry ship RoRo	2x MAN 9L48/60A to 2x MAN 9L51/60DF	2019	259	12	7	1,360

Tab. 3: Two examples showing emission savings after retrofit from liquid fuel to dual-fuel liquid/gas operation

*Methan conversion factor of 25 (for 100 years) used as CO_2 equivalent

Fig. 8: Wes Amelie

In 2017 'Wes Amelie', a 1,036-TEU feeder container ship owned by German Wessels Reederei, became the first container vessel globally to be converted to LNG.

A roadmap towards a Maritime Energy Transition

With its ME-GI two-stroke dual-fuel engines operating on the Diesel combustion principle, MAN Energy Solutions has already achieved extremely low levels of unburnt methane emissions and thus has an immediate, ready-made, very low methane slip solution for ship owners wishing to adopt LNG fuelling. Values of 23 % reduction in GHG emission have been measured on recent ME-GI engines.

On the four-stroke side MAN now expects a combination of engine-internal and aftertreatment measures to achieve methane slip levels that will enable continued expansion of the global four-stroke gas engine population. At the time of writing, MAN has already reduced methane slip from its four-stroke gas-burning engines by more than half in the last ten years, leading to a GHG benefit of approximately 5 % to 15 % compared to conventional diesel engines.

These developments are enabling and will enable engine operators on land and sea to continue to reap the economic and ecological benefits of SI and DF engines burning LNG. On the economic side, the advantages are lower fuel costs and fewer, less expensive emissions reduction devices than with liquid fuels. On the ecological side, gas engines operating on the Otto principle offer an immediate answer to current IMO Tier III limits on NO_x emissions and the Sulphur Cap without exhaust gas aftertreatment, and a valuable first step in reducing CO_2 emissions.

Following the projected first step of adopting LNG as the standard fuel for marine applications in place of liquid fossil fuels, MAN is a strong advocate of a Maritime Energy Transition. This shift from fossil-to-synthetic gaseous fuels would be achieved by the gradual mixing of progressively higher proportions of renewable, synthetic fuels with LNG.

To promote the Maritime Energy Transition, MAN foresees a fuel-flexible future that requires engines to be able to cope with a wide range of fuels from natural gas/LNG to synthetic fuels with decreasing levels of carbon content.

Since the maritime industry needs to include the Maritime Energy Transition concept and the idea of flexible, multi-fuel operation into their forward planning to meet IMO goals for GHG by 2050, MAN's technical departments have already started to develop and investigate the technologies to support this transition.

The new synthetic fuels envisaged will include, on the one hand, those produced from carbon-neutral "Power-to-X" sources, i.e. synthetic fuels or gases based on hydrogen derived from renewable energy sources such as wind, solar and hydroelectric power. On the other hand, ammonia (NH_3) based on hydrogen produced from renewable sources (green ammonia), or fossil-based with carbon capture (blue ammonia) is a promising option for two-stroke engines, with the potential to significantly decrease GHG emissions.

With the successes to date and the realistic prospect of further gains in its campaign to minimise methane slip, the proven dual-fuel-versatility of MAN's two- and four-stroke engines will mean that the Maritime Energy Transition will not be a technical issue but one of fuel availability, cost, market incentives and/or fuel supply infrastructure.

The retrofitting of existing liquid fuel engines to operation on gas will be an essential first step since, at a later stage, all such engines will also be able to operate on a range of carbon-neutral synthetic fuels, including synthetic natural gas (SNG) without further technical adaptation. Such retrofit conversions have been successfully implemented by MAN PrimeServ and are a central focus in MAN's strategy for the Marine Energy Transition. New equipment is being designed to be retrofittable to the existing engine population, so that engine users' earlier investments do not become "stranded assets".

Finally, realising this prospect of a new carbon-neutral age in shipping and large-engine-based power generation will require close cooperation between market stakeholders, regulators and politicians to promote and develop the necessary conditions and infrastructure for a fuel transition. For its part, MAN is already preparing for a fuel-flexible, low GHG future, is open to technological change and committed to developing the products needed, in-line with market developments.

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of the 120 tons of LNG will be replaced by SNG

56 tons

additional CO_2 savings per round trip through SNG blending

3264 tons

CO_2 savings already achieved by running on LNG in first three years after retrofit

MAN Energy Solutions and Wessels Marine GmbH have announced a technical showcase whereby the Wes Amelie, the first dual-fuel retrofit ever, will use climate-neutral SNG produced from renewable energy as drop-in fuel.

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