ME-GI – Dual Fuel Done Right.
MAN Diesel – K98ME – Largest Diesel
87,220kW at 97rpm (117,000HP)
Two-stroke MAN Low Speed Engines
All available as ME-GI, Dual Fuel Engines
# Reference List M and G-series

## MAN B&W Two-stroke Engines

<table>
<thead>
<tr>
<th>Type</th>
<th>On order/ Delivered</th>
</tr>
</thead>
<tbody>
<tr>
<td>K98</td>
<td>756</td>
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<tr>
<td>K90</td>
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<td>K80</td>
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<td>L90</td>
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<td>L80</td>
<td>201</td>
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<tr>
<td>L70</td>
<td>353</td>
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<tr>
<td>L70 ME-GI</td>
<td>2</td>
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<tr>
<td>L60</td>
<td>671</td>
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<tr>
<td>L50</td>
<td>345</td>
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<tr>
<td>L42</td>
<td>170</td>
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<tr>
<td>L35</td>
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<table>
<thead>
<tr>
<th>Type</th>
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<td>S90</td>
<td>271</td>
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<tr>
<td>S80</td>
<td>605</td>
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<tr>
<td>S70</td>
<td>2,282</td>
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<td>S65</td>
<td>55</td>
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<td>S60</td>
<td>3,956</td>
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<td>S50</td>
<td>5,579</td>
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<td>S46</td>
<td>794</td>
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<td>S42</td>
<td>1066</td>
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<td>S40</td>
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<td>S35</td>
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<table>
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<th>Type</th>
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<td>G80</td>
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<td>G70</td>
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<tr>
<td>G70 ME-GI</td>
<td>10</td>
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<td>G60</td>
<td>51</td>
</tr>
<tr>
<td>G50</td>
<td>71</td>
</tr>
</tbody>
</table>

As of 2013.05.17

Totals: 286 GW

20,765 Engines
MAN Diesel
“S90” to “G95” series
Licensees’ share of total MW since 1982

Sum of SMCR kW

Totals: 278,500,507 KW 20,050 Engines

Korea 53.99 %
Japan 25.45 %
China 10.72 %
Europe+ others 9.84 %
LEP: 10EU + 13nonEU
LEP Shipyard support: 1EU + 2nonEU
LEO: 7EU + 7nonEU
LEO Performance Specialist: 1EU
LEP/LEO Manager: 1EU
LEP/LEO total: 42
Reference List
MAN B&W Two-stroke Engines

Delivered / Orderbook as at Nov. 2012

% GW
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

2012  2013  2014  2015

Totals: 276,973,626 KW  20,008 Engines

As of 2013.01.02

LSP/RASA
What is the ME-GI Engine?

The ME-GI is derived from the industry’s standard MC and ME engine.

- Proven design, >20,000 engines in service.
- **Diesel cycle** high fuel efficiency ~50% versus 30%’s for other engine types.
- High fuel flexibility – burn all gas grades **without derating. Burns all fuel types.**
- High **reliability** – same as fuel engines.
- **No derating** because of **knocking** danger.
- **Negligible methane slip.**
- **ONLY demonstrated and procured 2 stroke dual fuel engine.**
First ME-GI Order
Two x 3,100 TEU LNG-Powered Containerships

- **Totem OceanTrailer Express (TOTE Inc), USA, built by NASSCO, San Diego**

**Vessel Technical Specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Overall:</td>
<td>764 ft.</td>
</tr>
<tr>
<td>Breadth:</td>
<td>106 ft. (Panamax)</td>
</tr>
<tr>
<td>Depth:</td>
<td>60 ft.</td>
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<tr>
<td>Draft:</td>
<td>34 ft.</td>
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<tr>
<td>Speed:</td>
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</table>

**Propulsion Plant**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Engine Type:</td>
<td>Dual Fuel Slow Speed</td>
</tr>
<tr>
<td>Main Engine Model:</td>
<td>MAN B&amp;W 8L70ME-C8.2-GI</td>
</tr>
<tr>
<td>Main Engine MCR:</td>
<td>25,191 kW x 104.0 rpm</td>
</tr>
<tr>
<td>Main Engine NCR:</td>
<td>21,412 kW x 98.5 rpm</td>
</tr>
<tr>
<td>Aux Engine Type:</td>
<td>MAN 3 x 9L28/32 GenSets</td>
</tr>
</tbody>
</table>

Scheduled delivery for the first ship: Q4 2015 / Scheduled delivery for the second ship: Q1 2016
Second ME-GI Order: Teekay Fuel-Efficient LNGC

Teekay Initial Order for 2 + 3, 173cum LNGC

Additional Order – July 2013, 3 additional vessels ordered with ME-GI, total order now 5 + 5 LNGC’s.

Each Vessel has 2 x 5G70ME-GI Engines, with delivery starting 2016.

"At 19,5 knots, the ME-Gi engine can give more than 30-tonnes-per-day savings of heavy fuel oil (HFO) over a dual-fuel diesel-electric (DFDE) engine while still maintaining very efficient fuel consumption at speeds down to 15 knots."

"At today’s fuel prices this could stack up to $20,000 per day, plus a 10% saving of operating costs. This is the next evolution”

Tony Bingham, Teekay’s technical manager of LNG,
Tradewinds 21-12-2012
Third ME-GI Order – Matson 3,600 teu
World’s Largest Dual Fuel Engine

- 7S90ME-GI
- 42,700kW – (57,000HP)
- 2 + 3 Order at Aker Philadelphia
- World’s Largest Dual Fuel Engines
▪ NASSCO – 4 Product Tankers for American Petroleum Tankers (G Engines)
▪ NASSCO – 2 Product Tankers for Seacor (G Engines)
▪ Aker Philly – 4 + 4 Product Tankers for Crowley (S Engines)
▪ Other ship types- Imminent

▪ ALL Jones Act ocean-going ships on order have ME engines
▪ ALL are “READY FOR” ME-GI.

▪ How can they be “ready for”?

▪ ME-GI is Diesel cycle and doesn’t require derating because of knocking danger, so installed engine volume is the same for fuel or gas operation – Otto cycle engines need additional volume for same power output.
The North American Market for ME-GI and retrofits

- The North American market has been the first to embrace ME-GI technology due to ECA.

- For over 2 decades, MAN MC and ME engines have been the EXCLUSIVE choice of 2 stroke engines for Jones Act ocean going vessels.

- Ability to retrofit to ME-GI is an important possibility for our customers. Because the ME-GI uses Diesel cycle, retrofit of existing engines is an option without affecting size, deadweight, fuel consumption, etc.

- ANY MC (mechanical) or ME (electronic) engine can be retrofit to ME-GI. Primary obstacle to retrofit is cost of FGSS, particularly LNG tanks.
LNG Fuel Price Scenario

Fuel price scenario

- HFO 2.7% S
- LSHF 0.5% S
- MGO 0.1% S
- LNG

Source: GL-MAN container vessel advanced propulsion roadmap
### Similarities to ME:
- Proven power density
- Good part load SFOC
- Good transient engine response
- No issue with fuel quality (Methane Number irrelevant)
- Safety:
  - No risk of misfiring/knocking
  - No risk of explosion in scavenge receiver

### Differences to ME:
- NOx emission levels lower (approx. 25%)
- SFOC tuning IMO tier II levels
  - 1 – 3% improvement
- Near zero PM levels
- Greenhouse Gas Impact
  - 20% lower due to C/H ratio of methane
The ME-GI retains the high efficiency of the Diesel process by using high pressure gas injection.

High pressure gas injection injects gas at high pressure (300 bar) into the combustion chamber after the pilot fuel has begun burning. The high pressure injection overcomes the pressure in the combustion chamber.

Since fuel cost is the major component of Life Cycle Cost, 2 stroke, high pressure injection efficiency advantage will continue to grow as fuel prices increase.

The ME makes it possible for “ready for” dual fuel retrofits that are not reasonably possible with low pressure engines without a large CAPEX investment and a lifetime OPEX cost.
**ME-GI - Mr Diesel vs Mr Otto: Diesel to Dual Fuel Combustion**

**Mr. Diesel’s Process**  
(High Pressure Injection)

- Fuel in cylinder before gas
- Diesel process is maintained
- Power density remains the same
- Load response is unchanged
- No pre-ignition / no knocking
- Insensitive to gas mixture
- Negligible methane slip
- NO\textsubscript{x} reduction to Tier III level by EGR and / or SCR

MC or ME can be retrofit to ME-GI.

**Mr. Otto’s Process**  
(Low pressure Injection)

- Gas in cylinder before fuel
- Otto process gas-air pre-mix
- **Power reduction** required due to **Pre-ignition / knocking** risk
- **Load ramp** needed
- **Gas mixture** important
- **Significant Methane Slip**
- Lower NO\textsubscript{x} due to **low efficiency**.
- Can **only** be **retrofit** if **excess capacity** is installed initially (20% larger engine, 20% greater fuel tanks, etc)

"ME-GI is a Two-stroke Diesel Engine"
ME-GI Experience: Based on demonstrated performance

Chiba Power Plant Japan (1994) - 12K80MC-GI-S
Operating 20,000 hrs on high pressure gas

ME-GI customer demonstrations, May 2011 and April 2012

Customer Demonstration
Hyundai - November 2012

Customer Demonstration
Mitsui, Japan, April 2013
Retrofit: From MC to ME

- **Hydraulic system:**
  - Pump station
  - Automatic filter unit
  - Piping
  - Power cabling

- **Engine mounted:**
  - Hydraulic cylinder unit (HCU)
  - Fuel booster
  - High pressure fuel pipes
  - Alpha lubricator system (if not already installed)

- **ME-B control system:**
  - ME-B control cabinet incl. control units
  - Operation panels (MOP / LOP)
  - Crank shaft positioning system (angle encoder system)
  - Junction boxes at engine side
  - PMI system (if not already installed)
  - Cabling
Retrofit: ME to ME-GI Modifications

New components
- Double wall gas pipes
- Gas injection valves
- Large volume accumulators
- ELGI valves
- Control and safety system

Modified components
- Cylinder cover

- Well-proven ME technology
- Simple modification from \textit{MC} or \textit{ME} to ME-GI
ME-GI Development

1. From actual footage (colorized)
   - Yellow = pilot oil
   - Blue = gas fuel

2. Conventional slide fuel valve
3. Gas fuel valve
4. High pressure safety valve
5. Gas distribution channel (yellow)
6. Gas distributor block
7. Gas chain link double-walled pipes
ME-GI Development
ME-GI concept: Combustion Principles

Diesel process:
Interlocked Gas Injection Sequence

- Gas Injector
- Gas Channel
- Window Valve
- Gas Control Block
ME-GI Design - Gas Block

- More compact design
- Pipes removed
Gas injection system details:

- Hydraulic activation of blow-off and purge valves
- Reduction of number of pipes on gas block
- Pipes assembled on common flange for easy maintenance/overhaul of gas valve
- Connection block included for easy maintenance
ME-GI Design updates
Easy maintenance

All connections through adapter block

- Gas inlet
- Gas outlet
- Hydraulic oil
- Sealing oil
- Hydraulic oil drain
- Oil drain window/gas-valve
- Low pressure oil

- Connector block with pipes, remains on the engine during cylinder cover dismantling
Laby-GI Gas compressor & HP pump: Full redundancy & fuel optimized
**ME-GI Development**

**Results: SFOC/NO\textsubscript{x} Tuning**

**Improving efficiency in gas mode:**

**SFOC/NO\textsubscript{x} tuning**
- NO\textsubscript{x} margin in gas mode
- SFOC reduction potential
- Design limits maintained

**Results**
- SFOC reduced 1-3%
- NO\textsubscript{x} margin is still available

**Released in engine program and CEAS**
Heat Release at 75% Load

Heat Release & Overall Performance: SFOC equal or better
Emissions

**NOx**: 24% lower

**CO2**: 23% lower
The Fuel Gas Supply System (FGSS) of the high pressure system takes only a fraction of the power absorbed by a diesel electric system, and is far less complicated.
DFDE Solution

- Power requirement at propeller = 12,500kW – but **MUCH** more has to be installed due to Otto Cycle and electrical losses.

Engine *de-rate* due to low pressure injection ~20% + DE losses = 34,000kW installed for a 25,000 output. **9,000kW bought and installed that isn’t available.**
What High vs Low-Pressure Gas Means

- Low-pressure injection leads to Otto cycle problems like methane slip, large derating, fuel gas quality and ambient temperature losses, load ramps, etc.

![Diagram showing the effect of charge air temperature and methane number on knocking and derating.](image)

**LP load ramp to avoid knocking**

**LP knocking causing derating**
Liquid Fuel – 6 cylinder, 4 stroke – 50 bore = 1,200kW/cyl

Dual Fuel – 6 cylinder, 4 stroke – 50 bore = 950kW/cyl
(Note: 80 methane number gas – this is important)

1200 – 950 = −250kW/cyl or 79% of fuel engines.

Fuel Engine = 24.9 bar MEP, DF = 20.0 bar

Conditions: 80 methane number, low ambient temperature —

if lower methane number or higher ambient temp, then the numbers are even lower.
ME-GI Propulsion Mode - Best Efficiency

FPP 25,280kW

7G70ME-GI 25,480 kW

DF or CR GenSets
Comparison of Engine Efficiencies (from manufacturer Programmes)

SFOC DF/GI gas/diesel engines

- G60ME-C-GI in Gas Operation
- G60ME-C-GI in HFO operation
- Competing DF eng. in Gas operation
- Competing DF eng. in HFO operation
- Competing 4-stroke Diesel engine

- 42700 kJ/kg as reference for all SFOC figures
ME-GI Concept – Using Fuel types as available / as desired

**Fuel oil only mode:**
- Operation profile as conventional standard engine

**Dual fuel operation modes:**

**Gas mode “Minimum fuel”**
- Full operation profile available
- Full load acceptance available
- Full power range available
- Load variation is governed by gas injection
- Pilot fuel can be MDO, MGO or HFO
- Minimum pilot fuel used at load > 25% (3 => 1 %)
- Increased pilot fuel at loads < 25% load
- Dynamic mix. of gas and fuel at loads < 25% load

**Mixed mode “Specified gas”**
- Full operation profile available
- Amount of gas fuel is specified on Gas MOP
- Load variation is governed by fuel oil injection
63% of available gas is not for Otto-cycle use

- 63% of available gas has a methane number lower than 80 – where low-pressure, Otto-cycle engines are rated.
- Lower gas quality causes lower output in low-pressure, Otto-cycle engines!
- ME-GI can burn ALL gas grades with no efficiency or power loss.

### MN range (AVL) | Global LNG production (mtpa) | % of total LNG produced
---|---|---
0 - 70 | 26 | 10 %
70 - 75 | 118.3 | 43 %
75 - 80 | 26.1 | 10 %
80 - 100 | 102.8 | 38 %
0 - 100 | 273.15 | 100 %

Source: Shell International
The gas companies recommend an actual derating point of 70 MN, and they are normally not able to guarantee the methane number.

This corresponds to a power derating of at least 20% to be able to maintain a sufficient power margin during heavy weather operation.
>60% of available gas is below 80 methane number.

Effect of methane number on low-pressure gas engine:
High Ambient Temperature

- Ambient temperature also derates the low-pressure engine.
- Gas quality and temperature derates are cumulative!

- ME-GI is NOT affected by ambient temperature.

Derating: 2% / Δ1°C
Methane Number and Ambient Air Temp are cumulative – check your application carefully

Effect of Methane number:
- Power (%)
- Methane number
- Derating: 1% / Methane number

Effect of charge air temperature:
- Power (%)
- Charge air temperature (after charge air cooler)
- Derating: 2% / Δ1°C
Low-pressure gas requires that the engines use a “load ramp” to avoid knocking, requiring slow, prescribed levels of acceleration to reach a desired power level.

So while there is talk about being able to run on gas throughout the full engine operating range, with these load ramps, how would a ship be able to manoeuvre within these constraints?

In a diesel-electric application, load ramps are not such an issue, but with a direct coupled main propulsion engine, having such issues makes for compromised manoeuvring.
The ME-GI uses aftertreatment to fulfill Tier III.
Why does ME-GI require aftertreatment?

- NOx is produced from the reaction of nitrogen and oxygen gases during combustion, particularly at high temperatures. The ME-GI retains the high temperature required for high efficiency (reflected in fuel consumption numbers), so it generates more NOx.

- Higher Temperature = HIGHER EFFICIENCY = Higher Nox = aftertreatment
- Lower Temperature = LOWER EFFICIENCY = Lower Nox = no aftertreatment

- Not having aftertreatment means compromised combustion process, lower efficiency, higher SFOC / SGC AND high METHANE SLIP.
EGR Unit Integrated on Engine

- Distribution chamber
- Dual cooler
- EGR scrubber
- EGR blower
- EGR inlet pipe & pre-scrubber
- Cylinder bypass
IMO NOx Tier III
Exhaust Gas Recirculation (EGR)
EGR Principle

- O₂ in the scavenge air is replaced with CO₂.

- CO₂ has a higher heat capacity thus reducing the peak temperatures.

- Reduced O₂ content in the scavenge air reduces combustion speed thus reducing the peak temperatures.

- Decreased peak temperatures reduces the formation of NOₓ
EGR is also of benefit when outside ECA in Tier II areas.

Pay me (a little) more now, or a LOT later (forever) due to low efficiency / high fuel consumption.
Otto Cycle engines require aftertreatment when operating on fuel.

Will Class, EPA, USCG allow a dual fuel ship to be constrained to ONLY gas operation or be in violation of the ECA?

From Class society - “if there is a disruption of gas supply, in diesel mode for the US ECA, the USCG would need to grant an exemption and there is no provision so far on this case”.

Rules for on-road – If aftertreatment isn’t available, “vehicle must exit and stop at soonest opportunity until problem is rectified”. Can a ship afford to be compromised like this?

**What use is a dual fuel ship that isn’t dual fuel?**
Practical Effects of Diesel vs OTTO Cycle to a Vessel

LNG tanks would be (at least) 10% larger for same range (or 10% less range for same size tanks) due to decreased efficiency so they’d take up cargo space.

Engine size (and cost) would be 15-20% larger due to derating.

Larger equipment volume affects deadweight, cargo capacity, range, cost, and ability to retrofit.
So what is methane slip?

Methane slip is the fuel (LNG) going through the engine and up the stack without performing a useful purpose. Wasted. Completely.

Why is methane slip a problem? For four reasons:

1. First, it is 23 times worse as a greenhouse gas than CO$_2$. Some say “well, it’s not regulated”. So does that mean we should be ignoring a huge pollutant?

2. Second, methane slip is wasted fuel, so you have to **add** methane slip to the gas consumption numbers to get a realistic idea of **real** gas consumption. Make sure that the SGC includes the methane slip!

3. Thirdly, it is said that there is natural methane in the atmosphere anyway, so a little more slip does not harm? Of course it does, because it disturbs a natural balance.

4. In the Otto combustion process, methane gas is burned at low temperature. In the combustion boundaries, some of the methane gas turns into formaldehydes. Roughly 10% of the methane slip changes to become formaldehydes in the exhaust gas. Formaldehydes are a **cancer causing** agent, also know from glue, and we expect that future legislation will take this into account, and call for retrofit solutions.
Global Warming Potential, 20 years
ME-GI vs RT-flex

GWP (Global Warming Potential in CO₂ equivalents), values from the latest two IPCC reports and for the two most commonly used time frames:

<table>
<thead>
<tr>
<th></th>
<th>IPC: Inter-governmental Panel on Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific emission (g/kWh)</td>
<td>2007 IPPC</td>
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<tr>
<td>ME-GI Diesel mode</td>
<td>526.4</td>
</tr>
<tr>
<td>ME-GI NOₓ mode</td>
<td>452.4</td>
</tr>
<tr>
<td>RT-flex on gas</td>
<td>485.7</td>
</tr>
</tbody>
</table>

Derating

- The low-pressure gas solution has a very large derating because there is a very large risk of the engine destroying itself due to knocking or detonation, so the power density has to be severely curtailed:

- In order to minimize the self-destruction risk, the engine is derated so it only operates in a very small window.
Low-Pressure Injection

- **CAPEX**
  - Due to the necessary derating to counter the knocking risk, up to 20% larger engine must be installed to achieve the same power.
  - The ship design will now have to accept 20% more engine and ancillaries for the same power. 20% more volume, and that is assuming that it is good grade gas and low ambient or else the volume gets even larger.

- **Piping**
  - Because gas consumption for a low-pressure engine is so much higher, much physically larger pipes have to be installed compared with ME-GI.

- **Gas tanks**
  - Because of the lower gas economy, larger tanks have to be installed for the same range, or the same size tanks with a compromise in range. As tanks are the highest cost item in the fuel gas supply system, this in itself indicates that the low-pressure system will be more expensive.
This derating caused by low pressure knocking risk means that in order to get the same power, you need to install about 15% more engine volume.

So now there is 15% more engine (including 15% more weight and equipment) taking up what used to be cargo space, deadweight, tanks, etc., because the Otto-cycle low-pressure engine is always at risk of knocking, so it has to be derated.
Low-pressure injection requires rupture discs in the exhaust for all of the unburned methane (wasted fuel!) that goes up the stack unburned.

The ME-GI does not require rupture discs, as all fuel is used in the combustion process, not an exhaust risk.
High-pressure piping
Gas is led to the engine in a double-walled pipe. The inner pipe is certified to 1.5 times the operation pressure, and the thickness of the outer pipe is sized to take 1.5 times the rupture pressure of the inner pipe.

The pipes are located so heavy objects cannot be dropped on the piping and cause damage.

In case of a leak in the inner pipe, on-line hydrocarbon detectors cause the system to immediately revert to fuel operation, and the system lines purged of gas by nitrogen.

If the system shuts the gas down, the switch-over to fuel is immediate with no loss of power.
Questions to ask

- What is SGC including methane slip? What is SFOC?
  - Are the numbers published? (LP injection = No, ME-GI = Yes)

- Does gas with a methane number below 80 lower power output?
  - (LP injection = YES, ME-GI = NO)

- Does higher ambient temperature lower power output?
  - (LP injection = YES, ME-GI = NO)

- Is there a large power derating compared to the liquid fuelled engine?
  - (LP injection = YES, ME-GI = NO)

- Is there an additional derating for fuel economy?
  - (Yes for both LP and ME-GI)
Questions to ask

- Is aftertreatment required for normal operation on gas/fuel for Tier III?
  - \( LP = \text{No / Yes}, \ ME-GI = \text{Yes/yes} \)

- How to manoeuvre with a load ramp?
  - \( LP = \text{?}, \ ME-GI = \text{no load ramp} \)

- What % is methane slip during operation and manoeuvring?
  - \( LP = \text{5-10%}, \ ME-GI = \text{0} \)

- Is there a risk of crankcase and exhaust explosions?
  - \( LP = \text{Yes, ME-GI = No} \)

- Can fuel engines be retrofitted to dual fuel?
  - \( LP = \text{maybe, but with 20%++ loss of power, ME-GI = Yes!} \)
## ME-GI Development

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Diesel cycle</th>
<th>Otto cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas Injection (ME-GI)</td>
<td>Spark Ignition</td>
</tr>
<tr>
<td>Combustion processes</td>
<td>Turbulent non-premixed</td>
<td>Premixed</td>
</tr>
</tbody>
</table>

### Combustion processes
- Diesel cycle: Turbulent non-premixed
- Otto cycle: Premixed

### Pilot fuel oil
- Diesel cycle: 3-5%*
- Otto cycle: Approx. 1%

### Combustion pressure variations
- Diesel cycle: Unchanged
- Otto cycle: Increased

### Knocking during load change
- Diesel cycle: None
- Otto cycle: Possible

### Misfiring
- Diesel cycle: None
- Otto cycle: Possible

### High ambient temperature
- Diesel cycle: Insensitive
- Otto cycle: Sensitive

### Scavenge air receiver explosion risk
- Diesel cycle: No
- Otto cycle: Yes

### Crankcase explosion risk
- Diesel cycle: No
- Otto cycle: Yes

### Exhaust receiver explosion risk
- Diesel cycle: No
- Otto cycle: Yes

* Amounts smaller than 3-5% can be realised, if a max. engine load lower than 100% during diesel operation can be accepted.
## ME-GI Development

<table>
<thead>
<tr>
<th></th>
<th>Diesel cycle</th>
<th>Otto cycle</th>
</tr>
</thead>
<tbody>
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<td><strong>Engine type</strong></td>
<td>Gas Injection (ME-GI)</td>
<td>Spark Ignition</td>
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<td>Dual fuel capability</td>
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<td>No</td>
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<td>Power density</td>
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<td><strong>Gas mode efficiency</strong></td>
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<td>Diesel mode efficiency</td>
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<tr>
<td>Load response</td>
<td>Unchanged</td>
<td>Load ramp required</td>
</tr>
<tr>
<td>Port-to-port gas operation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Transient response</td>
<td>Unchanged</td>
<td>Limited</td>
</tr>
</tbody>
</table>
# ME-GI Development

## Engine Type

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Diesel cycle (Gas Injection (ME-GI))</th>
<th>Otto cycle (Spark Ignition)</th>
<th>Dual Fuel (Dual Fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas running load range</td>
<td>0 to 100% load</td>
<td>0 to &lt; 100% load</td>
<td>0 to &lt; 100% load</td>
</tr>
<tr>
<td>Gas injection pressure</td>
<td>300bar</td>
<td>5-7bar</td>
<td>5-7bar</td>
</tr>
<tr>
<td>Gas quality/requirements (LCV)</td>
<td>In-sensitive</td>
<td>Sensitive</td>
<td>Sensitive</td>
</tr>
<tr>
<td>Methane number dependant</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Below Tier II/III*</td>
<td>Below Tier III</td>
<td>Below Tier III</td>
</tr>
<tr>
<td>NOₓ reduction according to Tier III</td>
<td>All fuels</td>
<td>Only gas</td>
<td>Only gas</td>
</tr>
<tr>
<td>Methane slip</td>
<td>0.1% of SFOC</td>
<td>2-4% of SFOC</td>
<td>2-4% of SFOC</td>
</tr>
<tr>
<td>GWP</td>
<td>Reduced by 20%</td>
<td>Increased</td>
<td>Increased</td>
</tr>
</tbody>
</table>

* Tier III limits can be achieved by either installing SCR or EGR
MAN B&W ME-GI

Teekay 163cum LNGC – World’s first fuel efficient LNGC (2 x 5G70ME-GI)

Tote Containership – World’s first dual fuel containership (8L70ME-GI)

Brodosplit – World’s first int. DF containership (8S50ME-GI)

Matson Containership – World’s largest dual fuel engine (7S90ME-GI)
Why Diesel Cycle, High Pressure ME-GI?

- All MC or ME engine can be retrofit to ME-GI
- Diesel Cycle efficiency maintained
- Aftertreatment allows operation on Gas OR fuel in ECA
- at high Diesel Cycle efficiency
- Negligible methane slip
- No knocking
- No load ramps
- No gas quality derating
- No ambient temperature derating
- ONLY dual fuel 2 stroke with DEMONSTRATED performance
Press Release
MAN Diesel & Turbo

Contract Makes First
Commercial ME-LGI Engine Reality

Electronic LGI (Liquid Gas Injection), methanol-powered engine
fills niche segment and delivers green emissions

Vancouver-based Waterfront Shipping has confirmed its Methanol Carrier
Project for a series of 16,000-dwt methanol carriers, each powered by an
MAN B&W ME-LGI main engine running on methanol. The confirmation stems
from a Letter of Intent MAN Diesel & Turbo and Waterfront signed in July of
this year. MAN Diesel & Turbo officially designate the ME-LGI engine as ME-
EB 34.4 LI.

In collaboration with leading shipping lines, Waterfront reports that it is behind
2+1 x 6G50ME-LGI engines ordered by both Westfalen Lassen and Mitsu-
O.S.K. Line (MOL), as well as 1+1 x 6G50ME-LGI with Marinvest.

Hyundai Mipo Dockyard Co., Ltd. (HMD) will build the Westfalen Lassen
and Marinvest vessels, while HHI-AEMD, Hyundai Heavy Industries' engine
and machinery division, will construct the engines. For the MOL contract, which
followed close after, Miramis Napon Shipbuilding will construct the
newbuildings, while Mitsui Engineering & Shipbuilding (MES) will build the
engines.

Jim Greene, Senior Vice President – Low Speed Promotion & Sales – MAN
Diesel & Turbo, said: “This order represents a real market breakthrough for
our Liquid Gas Injection engine and is the first such, commercial project that
is not reliant on external funding. Simply put, the ME-LGI engine was chosen for
these carriers because it is the engine best suited to the application. The LGI
engine is designed to handle low-flash point, low-sulphur fuels like LPG and
Methanol, etc. Consequently, its green credentials are striking with emissions
of sulphur being almost completely eliminated.”

ME-LGI development

MAN Diesel & Turbo announced the development of a new MAN B&W ME-
LGI dual fuel engine on 1 July, 2013. The engine expands the company’s
dual-fuel portfolio, enabling the use of more sustainable fuels such as
methanol, ethanol and Liquid Petroleum Gas (LPG).
ME-LGI schematic: Operation on LPG

LPG Booster-injection valve

LPG tank

Inert gas system

Open air

Engine room

Hydraulic oil

Sealing oil
Fuel Booster Injection Valve available for LPG

**Principle**

- **Control valve**
- **Hydraulic oil in**
- **Hydraulic oil out**
- **LPG 35 bar supply pressure**
- **LPG suction**
- **LPG boosting & injection**
- **Slide valve**
- **LPG fuel valve**
- **Ready**
- **LPG**
Schematic diagram for the ME-LGI engine operating on Methanol
Thank you for your attention

All data provided in this document is non-binding. This data serves informational purposes only and is especially not guaranteed in any way. Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.