GE Marine
Gas Turbine-Based Power & Propulsion systems for LNG Carriers

LNG 17

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April 2013
“I find out what the world needs, then I proceed to invent it.”

– Thomas Edison
GE marine vertical

Aviation
- Aeroderivative Gas Turbines
- Propulsion System Integration
- Mechanical Drive Packaging
- GT Generator Sets
- Waste Heat Recovery
- Hybrid Drive Solutions
- Integrated Diesel/GT Solutions

Oil & Gas
- Steam Turbines
- Exchangers
- Metering Systems
- Pumps & Valves
- Global Services

Energy Management
- Generators
- Switchboard
- Transformers
- Propulsion Drives
- Integrated Automation Systems
- Motors

Transportation
- Diesel Marine Engines
- AC Drilling Motors
- DC Drilling Motors
- Drilling Parts

Large portfolio spanning the industry
Where we now play

Global Services and Process Solutions

Pressure Control

Artificial lift

Offshore & Shipping

Subsea

Drilling

Gas Storage & Pipeline Compression and Inspection

Power Gen

Liquefaction of Natural Gas (LNG)

Refinery & Petrochemical

Global Services and Process Solutions
GE Marine GT genealogy

Designed for marine applications with over 13,000,000 operating hours

Technology infusion continually made from aircraft engine developments

Applications

CF6-80C2

MD-11
B747, 767
A300/310/330

LM6000

CF6

DC-10

LM2500+

LM2500

LM500

CF34

Bombardier
Embraer

LM2500+G4

Power Output
SHP/KW

Thermal Efficiency

59,900 / 44,700
42.7%

47,370 / 35,320
40%

40,500 / 30,200
39%

33,600 / 25,060
38%

6,000 / 4,470
32%

All Ratings are at ISO No losses
Gas turbine value in referenced fleet

Fast Ferries

1992

First LM2500 LNG-powered fast ferry on sea

Cruise Ships

2013

Emissions ...no visible smoke, Low NO_x

Power density ... advantage vs. diesel engines

High power ➔ high speed
Low weight ➔ reduced displacement, reduced draft, reduced drag
Compact ➔ fits catamaran hull form

Small volume ➔ more revenue generating space
Small volume & low weight ➔ arrangement flexibility ... Queen Mary 2 & Princess installed GT in base of funnel

Additional revenue space enhances payback
1,200+ LM2500s delivered for marine ... plus 1900+ delivered for industrial

Leverage to LNG carriers ...
Evolution of LNG carrier propulsion ... where are we going now?

Gen 4?

Medium Speed Diesel
Gen 3
Low Speed Diesel
Gen 2
Steam
Gen 1

Driving factor ... what do you do with the BOG?

Combined Gas turbine, Electric & Steam (COGES)

Dual Fuel Diesel Electric (DFDE) ...
fuel flexible engine to burn BOG, HFO, or other fuel

Burn HFO ... reliquefaction plant to capture and recycle BOG

Fuel flexible – BOG, HFO, or other fuel
## Gas turbines vs. diesels

**Can the GT beat the Diesel**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>GT</th>
<th>Diesel</th>
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<td>Fuel Cost</td>
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<tr>
<td>Efficiency</td>
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When using LNG, MGO, or low sulfur HFO, large price disparity eliminated.

DLE brings GT advantage … gas turbines do not require after treatment.

First-cost gap more than overcome by smaller footprint, volume, installation costs and cost of diesel after treatment for emissions.

GT on condition maintenance & 24 hour change out mean high engine availability.

GT combined cycle more efficient than diesel.
Tougher environmental regs favor GT

Int’l Maritime Org (IMO) & US EPA NO\textsubscript{X} Emission Limits (g/kWh)

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Diesel today

GE DLE Today. MGO LNG

Emission Control Areas established … stringent NO\textsubscript{X} & SO\textsubscript{X} emission levels

Move toward LNG as clean alternative

- No sulfur → No SO\textsubscript{X}
- GE Dry Low Emissions (DLE) system meets 2016 limits today … without SCR
- Initial trend is dual fuel … DLE is dual fuel capable
CObined Gas turbine Electric & Steam (COGES)

Design Flexibility:

- Multiple sources of electrical power and steam
- Dual fuel Boil Off Gas (BOG) & Marine Gas Oil (MGO) capable
- For power in excess of available BOG, can use Forced Boil Off Gas (FBOG) to supplement BOG or switch to MGO
- Aux diesel provides black start capability
- Use excess BOG … duct fired boiler

2 x GT Plant Reliability

- Normal operations: 1 x GT + HRSG & Steam Turbine Generator
- 1 GT unavailable → no effect on normal operation
Clear size and weight advantage

Footprint*

45 MW DFDE
5 x med speed diesels

46 MW COGES
2 x LM2500

40% Smaller Footprint

Weight**

Small COGES footprint and low weight mean arrangement flexibility and increased cargo capacity

* Includes GT, Diesel, generators & heat recovery only

** Includes GT, Steam turbine, Diesel, generators & heat recovery & GT auxiliaries
More room for cargo ...

Conventional Arrangement

Gas turbine volume and power density can yield up to 10% more cargo volume, >30% more than low speed diesel & dual fuel diesel electric.

* Gilmore R et al, “LNG Carrier Alternative Propulsion Systems”, SNAME Greek Section, 2005
COGES Normal Operating Envelope

2 x LM2500+G4 1 x Stm Turbine Generator - Single Pressure (55 Bar) Stm Plt

Assumptions:
- 160,000 Nm³ LNG Cargo
- 0.15%/Day BOG

Primary Operating Mode

Redundancy to make cruise speed using only BOG

COGES Max Power with Natural BOG

Cruise Power

1 GT + Steam Turbine Operation - Total Power

#1 GT Power Output

#1 GT Operation

Installed Power

Net Total Power (kWe) vs. Gas Turbine Power (%)

Natural BOG Operation GT #1
Exhaust energy recovery option …

Supercritical CO$_2$ (sCO$_2$) power cycle

**Safe**, non-flammable, non-toxic, non-corrosive, thermally stable working fluid

**Simple**, in-stack waste heat exchanger … no boiling!

**Flexible** cycle … integrates with diesel or gas turbine

**Compact**, closed loop system … minimal O&M

**Competitive** thermal-to-electric power conversion efficiency … typically lower capital cost vs. steam or Organic Rankine Cycle (ORC) technologies

**Small footprint!**

- 10MW sCO$_2$ turbine
- 10MW steam turbine

![Diagram showing the power cycle](image)
Key COGES advantages

Emissions
Tier III IMO compliance today … without exhaust after-treatment

Maintenance
24 hour swap-out … high availability

Small Footprint
Ship design flexibility … extra room for cargo

Aircraft Engine Quality

World-wide GE Service Network

US$4,000,000 additional margin per shipment in same hull size!

Emission Control Areas (ECA)
Possible Future ECA