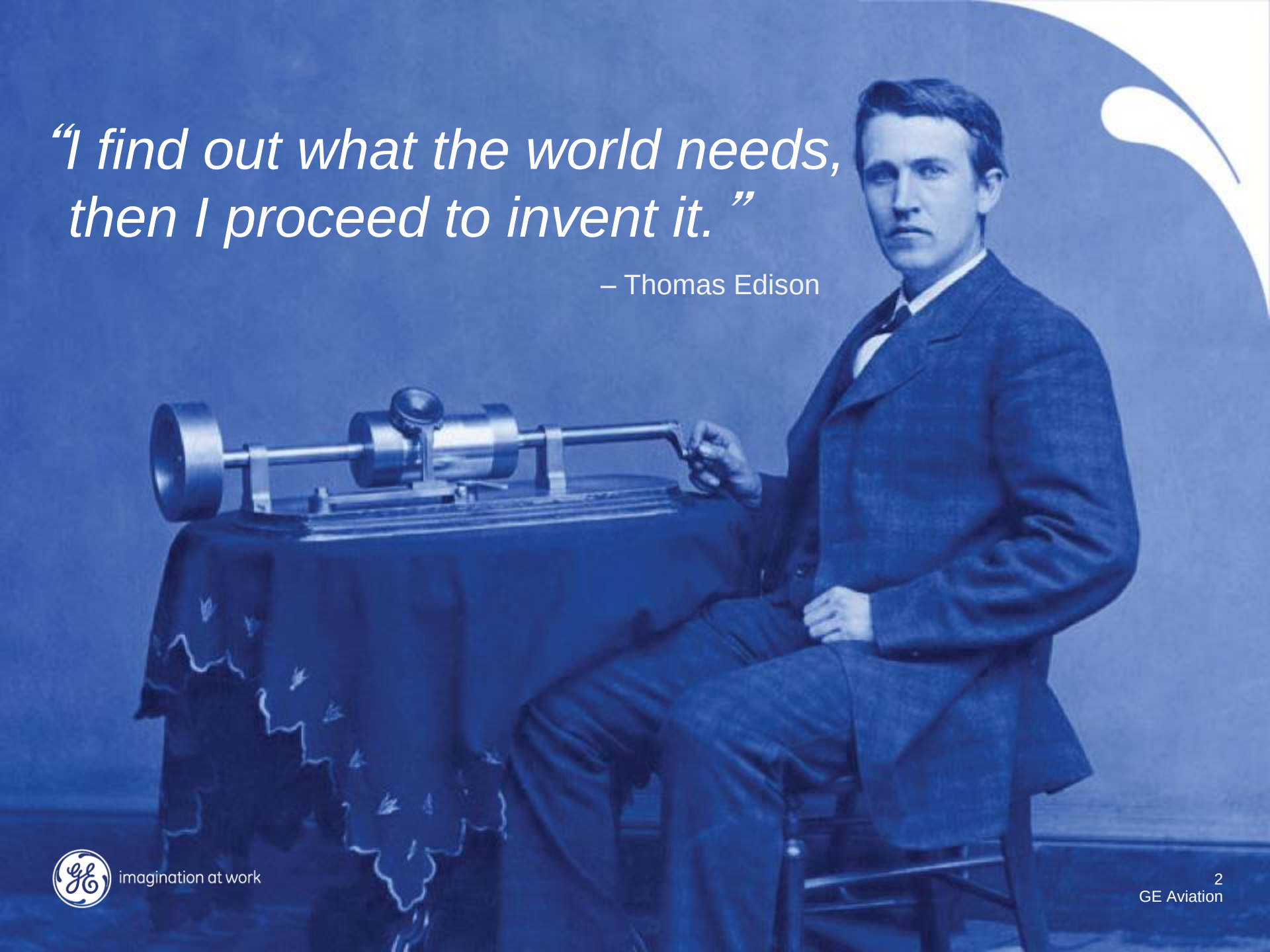
GE Marine

Gas Turbine-Based Power & Propulsion systems for LNG Carriers

LNG 17

Brien R. Bolsinger
Vice President Marine Operations
April 2013

imagination at work



imagination at work

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

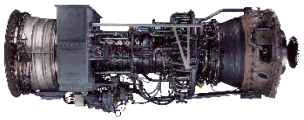
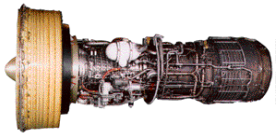
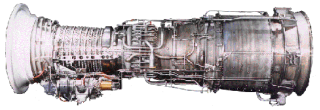
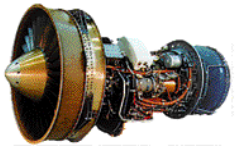
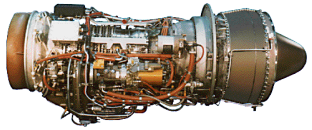
Large portfolio spanning the industry

imagination at work

Where we now play

GE imagination at work

GE Marine GT genealogy

		Applications		Power Output SHP/KW Thermal Efficiency
CF6-80C2		MD-11 B747, 767 A300/310/330	LM6000	 59,900 / 44,700 42.7%
			LM2500+G4	 47,370 / 35,320 40%
CF6		DC-10	LM2500+	 40,500 / 30,200 39%
			LM2500	 33,600 / 25,060 38%
CF34		Bombardier Embraer	LM500	 6,000 / 4,470 32%

All Ratings are at ISO No losses

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

Technology infusion continually made from aircraft engine developments

imagination at work

Gas turbine value in referenced fleet

1992

2013

Fast Ferries

Cruise Ships

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

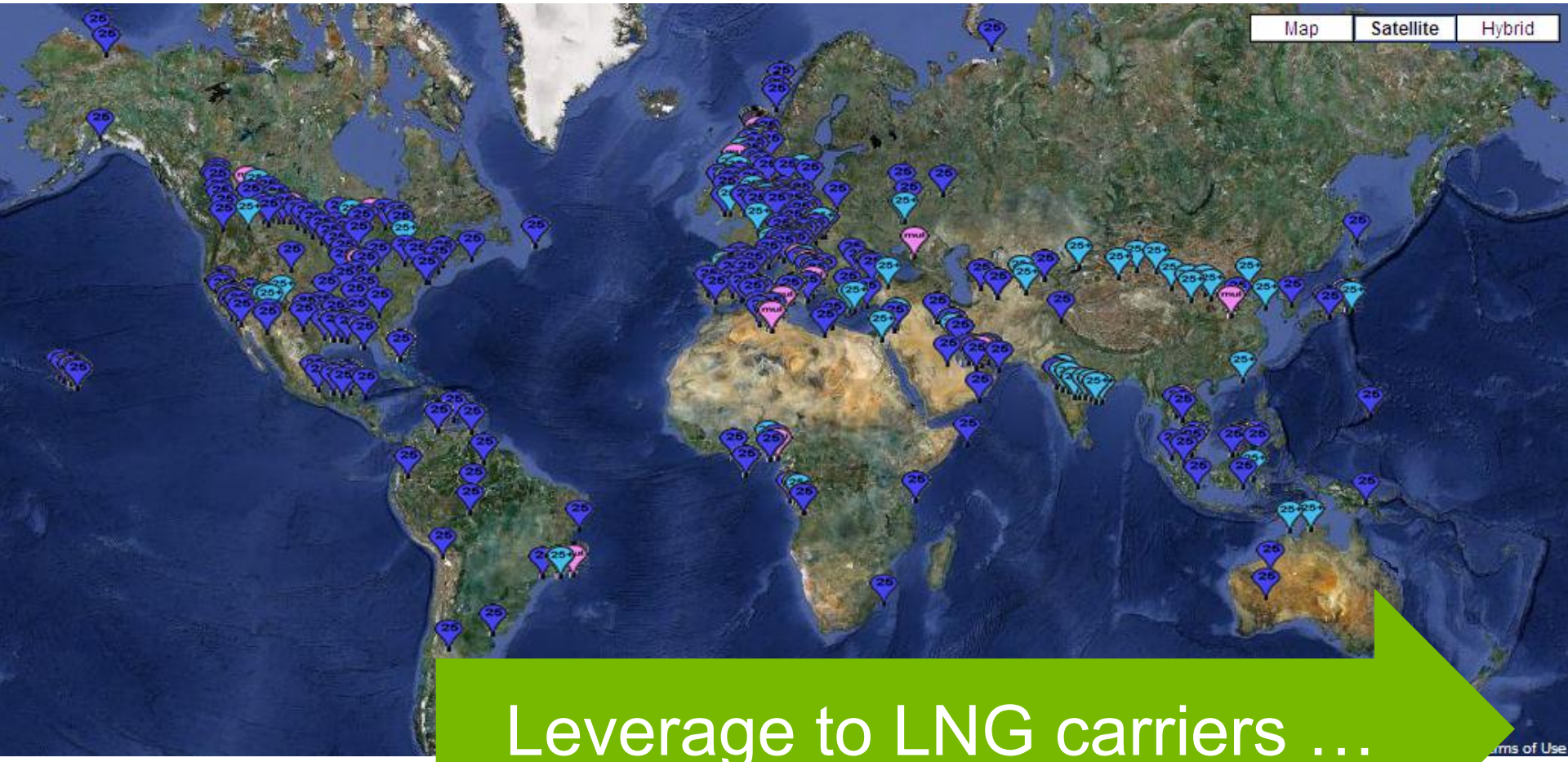
- Small volume ➔ more revenue generating space
- Small volume & low weight ➔ arrangement flexibility … Queen Mary 2 & Princess installed GT in base of funnel

First LM2500 LNG-powered fast ferry on sea

Additional revenue space enhances payback

imagination at work

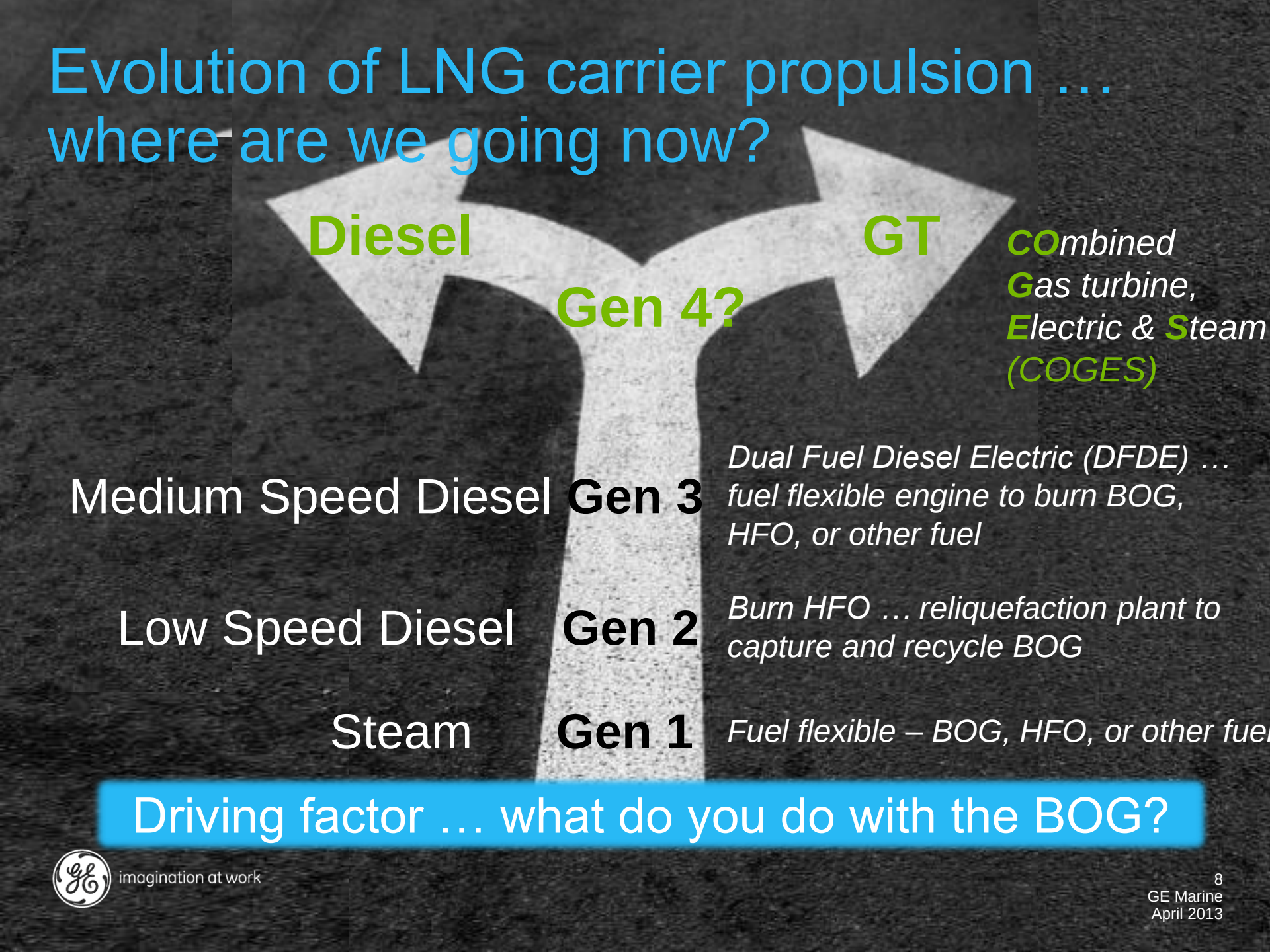
1,200+ LM2500s delivered for marine … plus 1900+ delivered for industrial



Leverage to LNG carriers …

imagination at work

Evolution of LNG carrier propulsion … where are we going now?



Diesel

GT

Gen 4?

***CO**mbined **G**as turbine, **E**lectric & **S**team (COGES)*

Medium Speed Diesel **Gen 3** *Dual Fuel Diesel Electric (DFDE) … fuel flexible engine to burn BOG, HFO, or other fuel*

Low Speed Diesel **Gen 2** *Burn HFO … reliquefaction plant to capture and recycle BOG*

Steam **Gen 1** *Fuel flexible – BOG, HFO, or other fuel*

Driving factor … what do you do with the BOG?

imagination at work

Gas turbines vs. diesels

Can the GT beat the Diesel

Characteristic Critical to Quality	GT	Diesel
Fuel Cost	🟢	🟢
Emissions	🟢	🔴
Cap Ex	🟡	🟢
Volume	🟢	🟡
Weight	🟢	🟡
Maintenance Cost	🟢	🟡
Availability	🟢	🟢
References	🟡	🟢
Efficiency	🟢	🟢

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

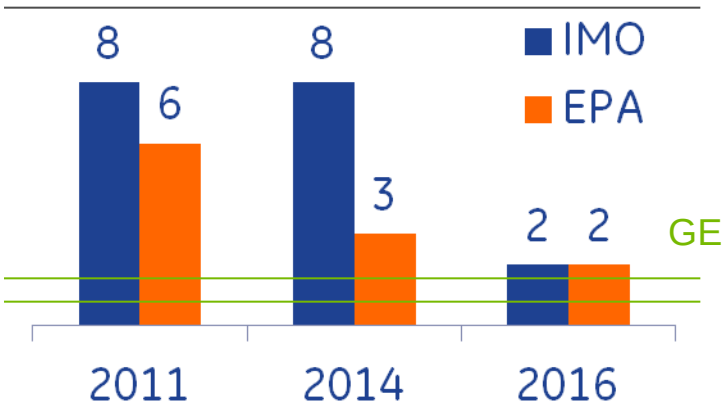
GT on condition maintenance & 24 hour change out mean high engine availability

GT combined cycle more efficient than diesel

imagination at work

Tougher environmental regs favor GT

Int'l Maritime Org (IMO) & US EPA
NO_X Emission Limits
(g/kWh)



Diesel today

GE DLE Today.
MGO
LNG

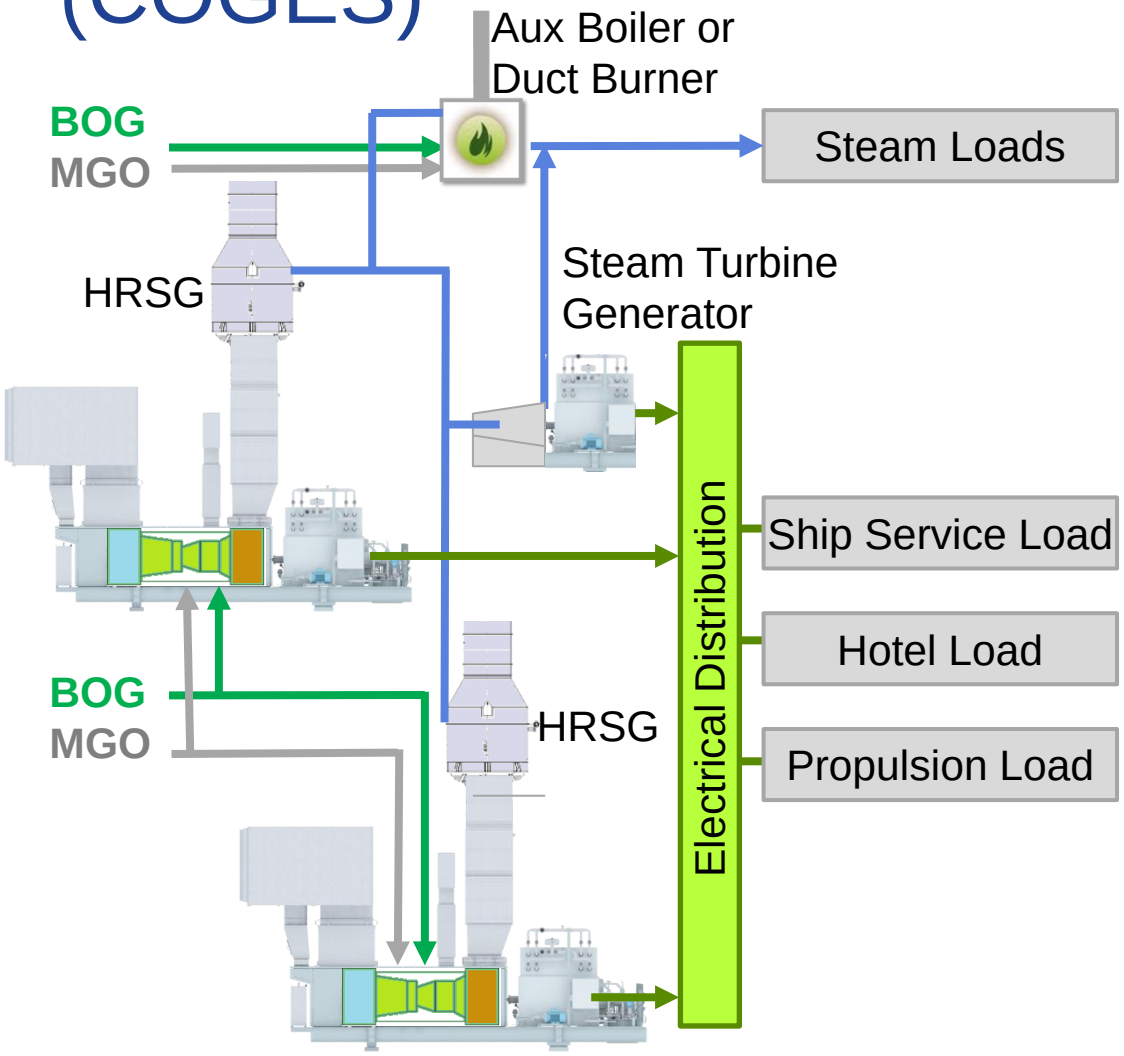
Emission Control Areas (ECA)
Possible Future ECA

Emission Control Areas established … stringent NO_X & SO_X emission levels

Move toward LNG as clean alternative

- No sulfur ➔ **No SO_X**
- GE **Dry Low Emissions** (DLE) system **meets 2016** limits today … **without SCR**
- Initial trend is dual fuel … DLE is **dual fuel** capable

COmbined Gas turbine Electric & Steam (COGES)



Gas Turbine Generator (2 ea.)
LM2500, LM2500+, LM2500+G4

Design Flexibility:

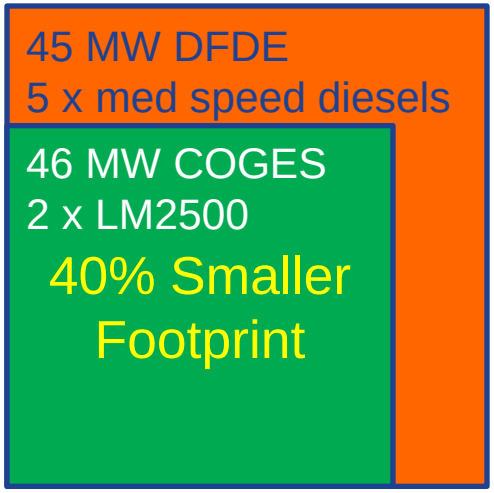
- Multiple sources of electrical power and steam
- Dual fuel Boil Off Gas (BOG) & Marine Gas Oil (MGO) capable
- For power in excess of available BOG, can use Forced Boil Off Gas (FBOG) to supplement BOG or switch to MGO
- Aux diesel provides black start capability
- Use excess BOG … duct fired boiler

2 x GT Plant Reliability

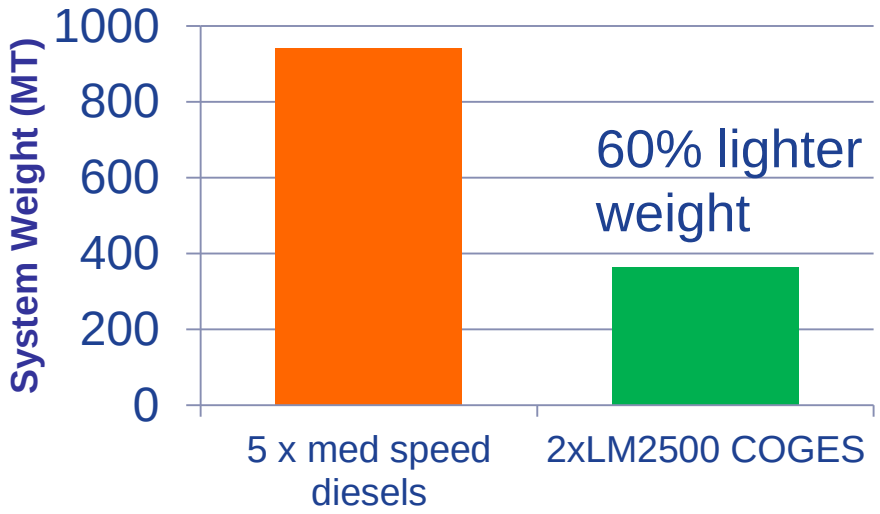
- Normal operations: 1 x GT + HRSG & Steam Turbine Generator
- 1 GT unavailable → no effect on normal operation

Clear size and weight advantage

Footprint*



Weight**



* Includes GT, Diesel, generators & heat recovery only

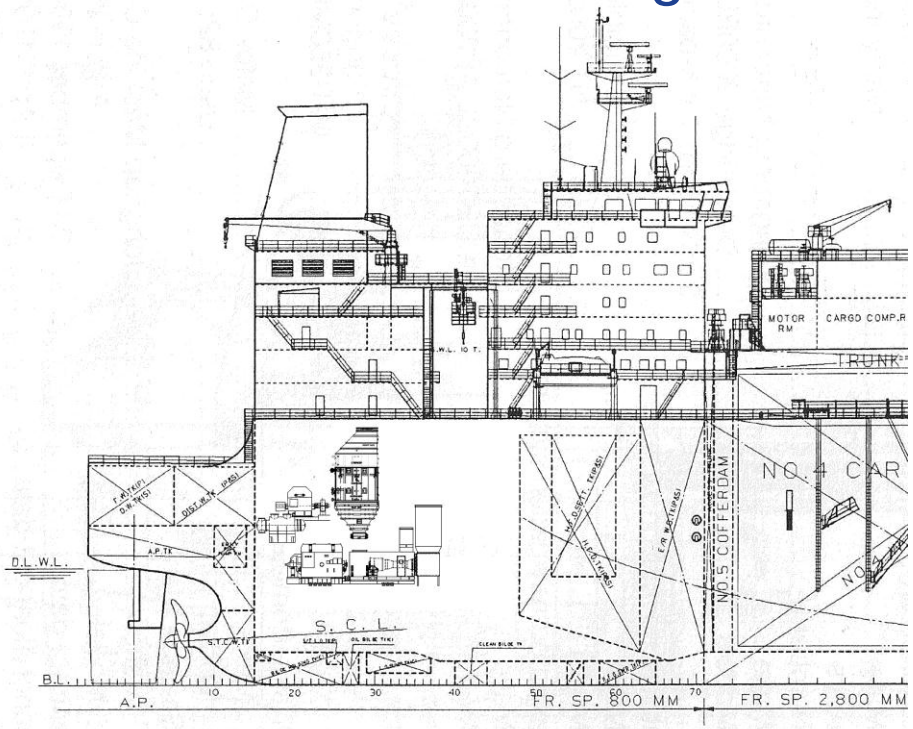
** Includes GT, Steam turbine, Diesel, generators & heat recovery & GT auxiliaries

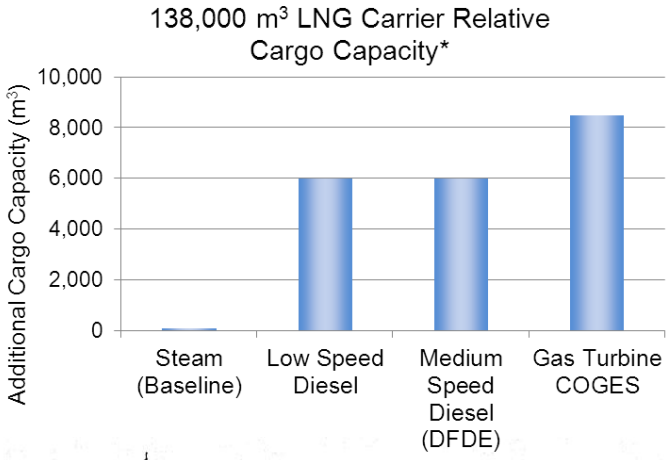
Small COGES footprint and low weight mean arrangement flexibility and increased cargo capacity

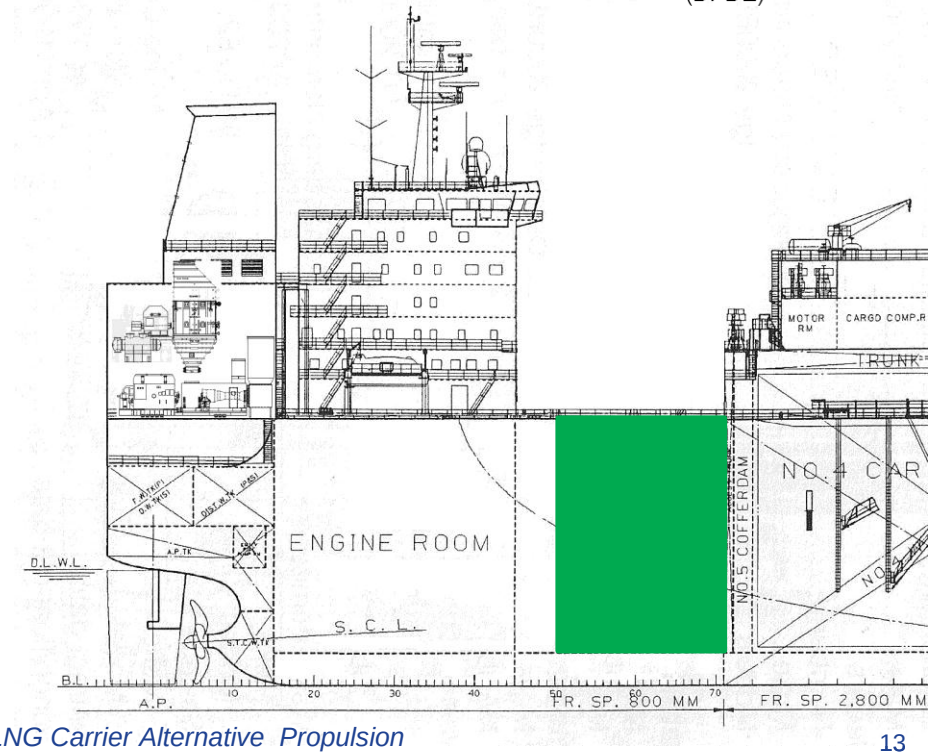
imagination at work

More room for cargo …

Conventional Arrangement







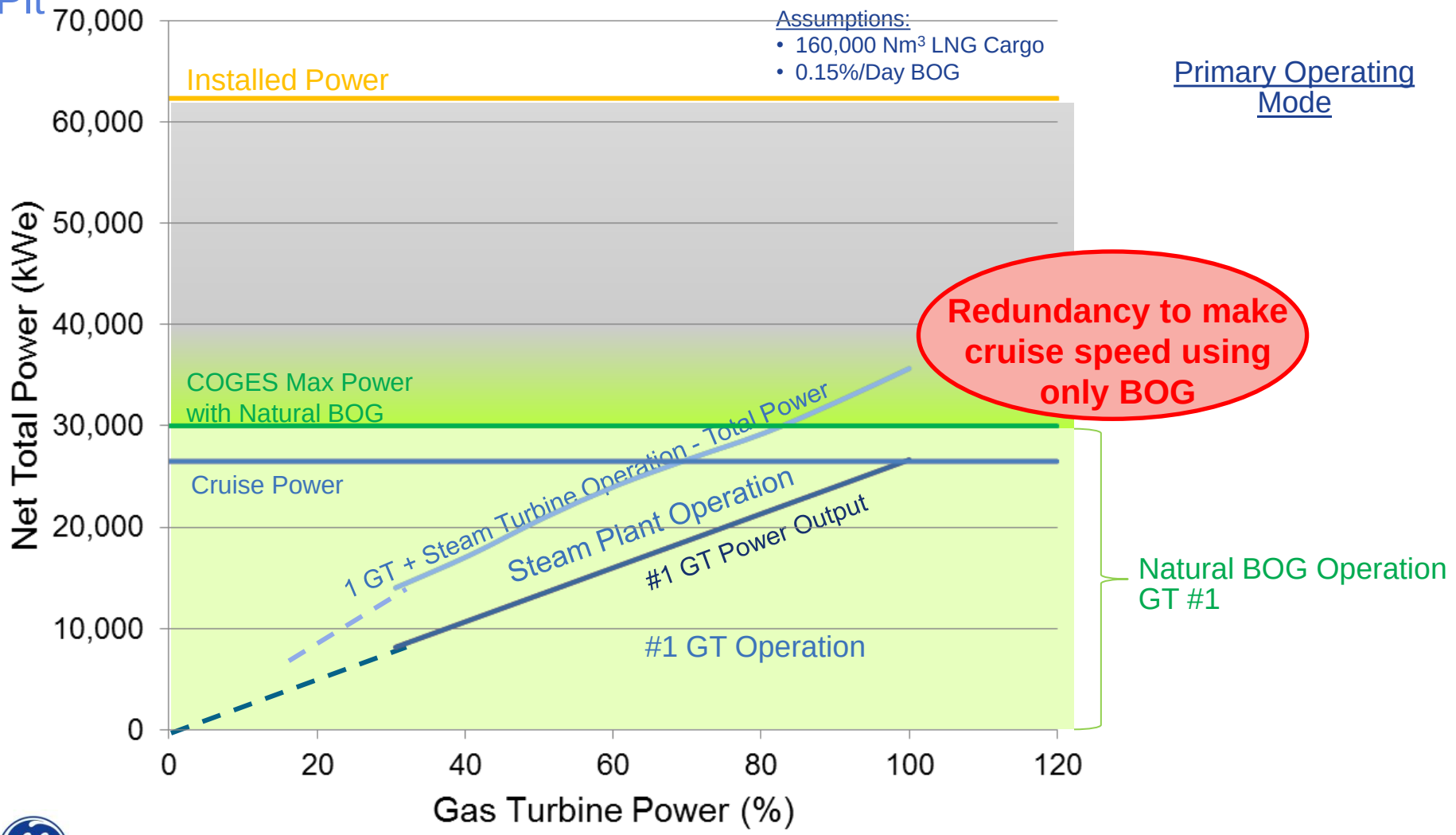
Gas turbine volume and power density can yield up to 10 % more cargo volume, >30% more than low speed diesel & dual fuel diesel electric

imagination at work

* Gilmore R et al, "*LNG Carrier Alternative Propulsion Systems*", SNAME Greek Section , 2005

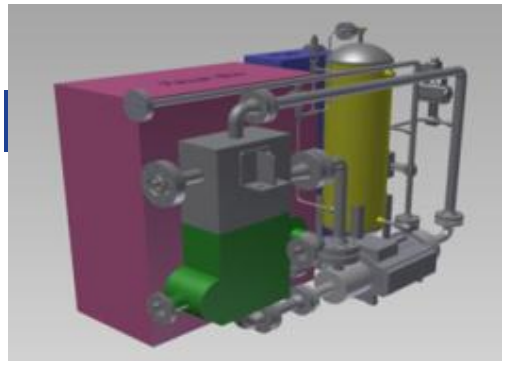
COGES Normal Operating Envelope

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



imagination at work

Exhaust energy recovery option … Supercritical CO_2 (sCO_2) power cycl



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

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

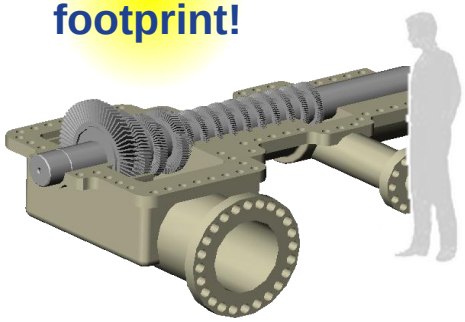
Flexible cycle … integrates with diesel or gas turbine

Compact, closed loop system … minimal O&M

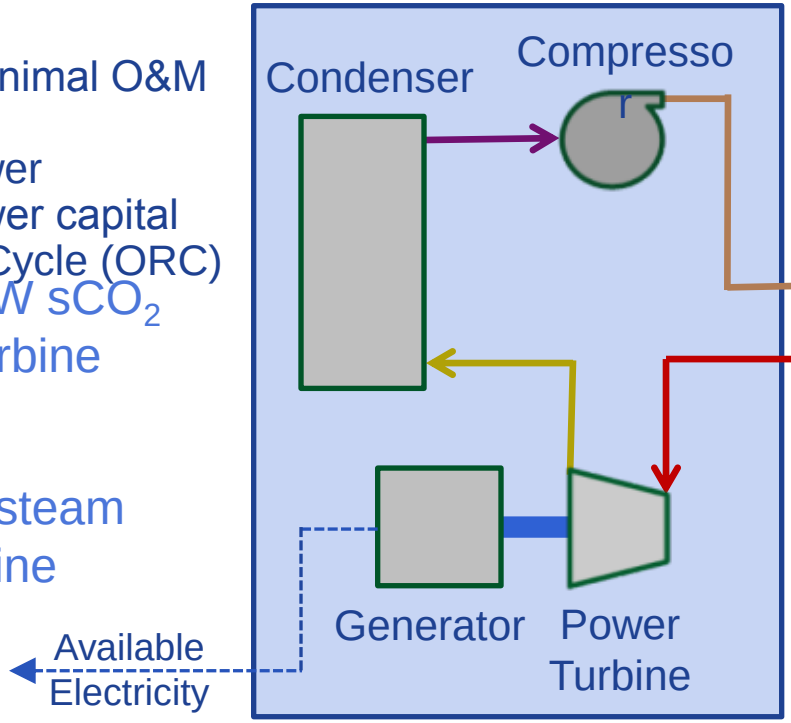
Competitive thermal-to-electric power conversion efficiency … typically lower capital cost vs. steam or Organic Rankine Cycle (ORC) technologies

Small footprint!

10MW sCO_2 turbine



10MW steam turbine

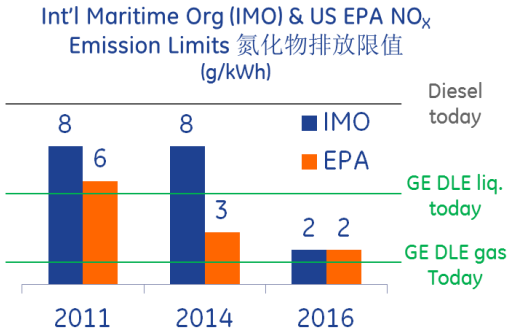


imagination at work

Key COGES advantages

Emissions

Tier III IMO compliance today … without exhaust after-treatment



Emission Control Areas (ECA)
Possible Future ECA

Maintenance

24 hour swap-out … high availability

World-wide GE Service Network

Small Footprint

Ship design flexibility … extra room for cargo

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

imagination at work

imagination at work