

# COGES



## Reliability, Redundancy, and Maintenance



### GE Marine

October 2015

**Imagination at work.**

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# Powering the world's airline fleets

Every **2 SECONDS**, an aircraft with GE engine technology is taking off somewhere in the world

At any given moment, **MORE THAN 2,200** of these aircraft are in-flight, carrying between 50 and 500 passengers

That's **MORE THAN 300,000** people... right now... who are depending on our engines



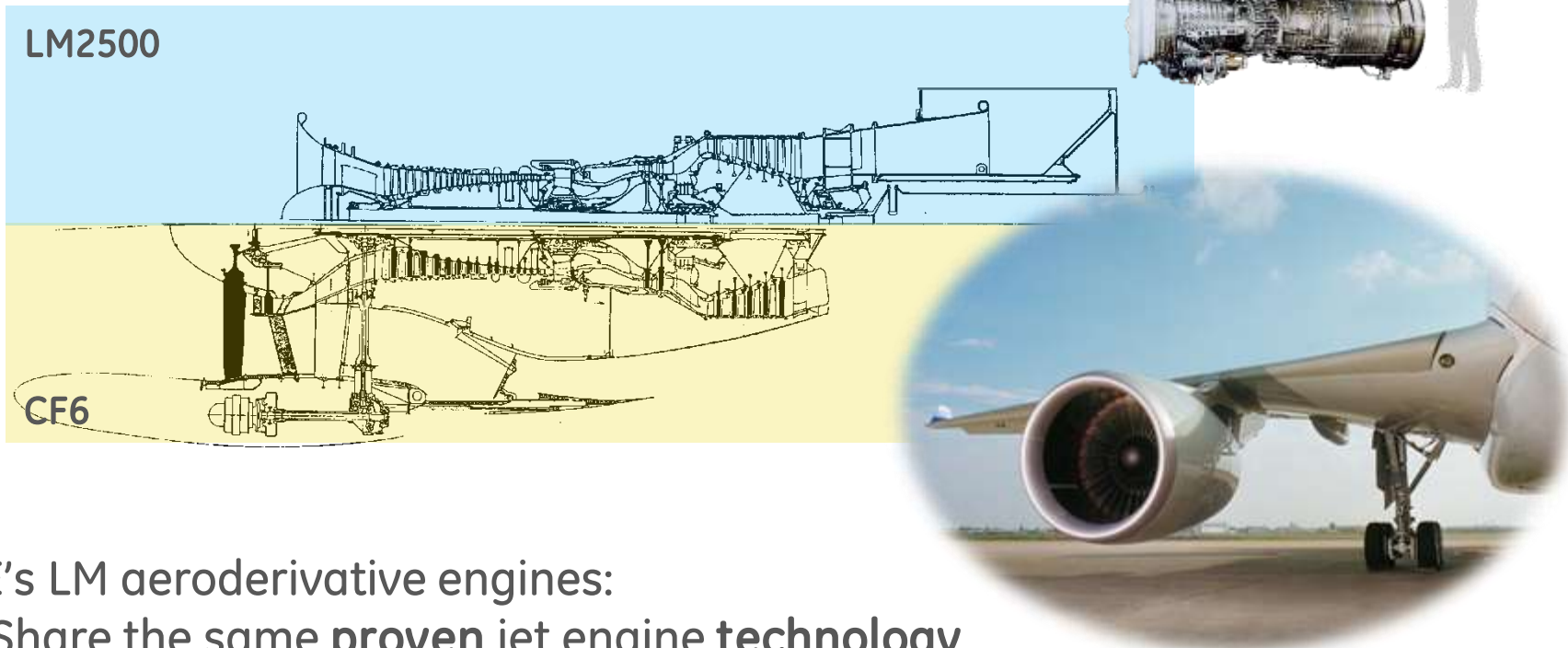
Engine fleet: **29,000**

\*CFM International is a 50/50 JV between GE and Safran  
EA is a 50/50 JV between GE and PW



This is GE Aviation

# LM2500 gas turbine is a GE CF6 aircraft engine at heart



GE's LM aeroderivative engines:

- Share the same **proven jet engine technology**
- Are built under the **same quality system**, in the same factory
- Can be serviced worldwide ... **like a jet engine**

High reliability = higher availability & minimal operational impact



# Flight experience leveraged to marine performance

## CF6...



**43**  
YEARS  
in service

- Best-selling widebody engine ever ... **7,800+** delivered
- **406** million hours flown
- **~760** shop visits in '14
- **1,700** a/c in operation

NEW ENGINE deliveries beyond **2020**



## LM2500 family ...

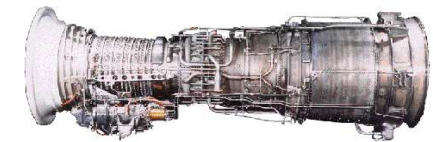
- Best-selling marine & industrial gas turbine ever ... **3,400+** delivered
- **88** million operating hours
- **Constant** technology injection from flight engines



LM2500+G4  
**35 MW**



LM2500+  
**30 MW**



LM2500  
**25 MW**

*All Ratings are at ISO No losses*

# Nearly 74 million operating hours of industrial experience ... *plus* 14 million more in marine

## LM2500 Industrial Fleet Operating Experience\*

LM2500 FLEET	ALL	SAC	DLE
Total Engines	2,109	1,531	578
Total Operating Hours	73,489,993	61,298,612	12,191,381
High Time Engine	253,292	253,292	144,648



LM2000 & LM2500	ALL	SAC	DLE
Total Engines	1,112	892	220
Total Operating Hours	62,541,948	56,485,382	6,056,566
High Time Engine	253,292	253,292	144,648

LM2500+	ALL	SAC	DLE
Total Engines	654	439	215
Total Operating Hours	10,134,026	4,487,353	5,646,673
High Time Engine	135,075	135,075	117,199

LM2500+G4	ALL	SAC	DLE
Total Engines	343	200	143
Total Operating Hours	814,019	325,877	488,142
High Time Engine	58,987	28,455	58,987

\* Estimated as of Dec 31, 2014



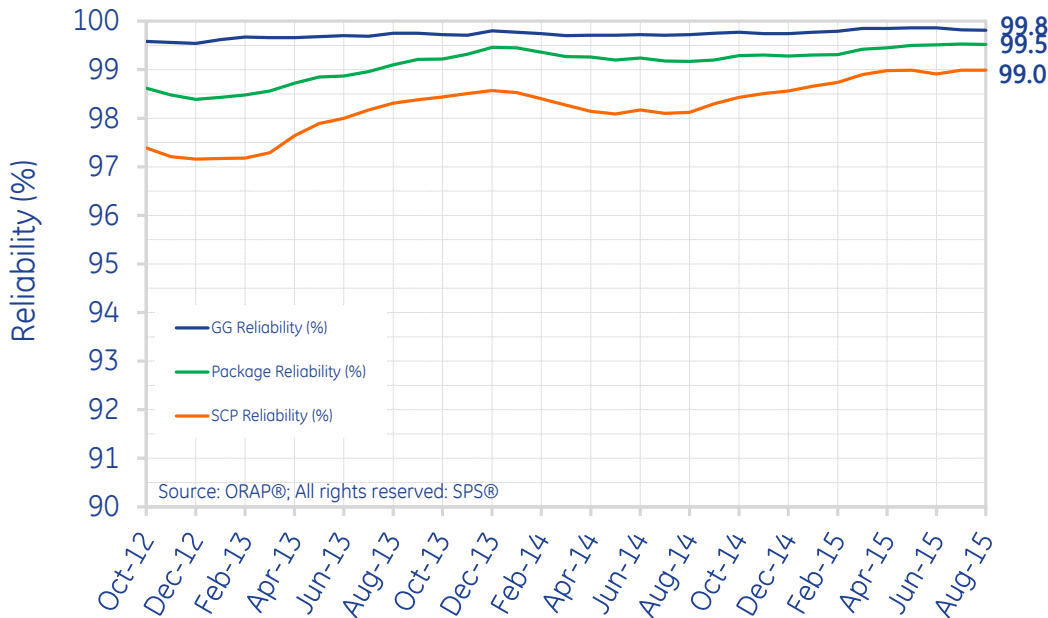
# LM2500 reliability ...

## *independent 3<sup>rd</sup> party report*

$$Reliability = \left( 1 - \frac{Forced\_Outage\_Hours}{Unit\_Period\_Hours} \right) * 100$$

12 month rolling ending August 2015

Fleet Mean



Reliability only accounts for *unscheduled* maintenance events

97% of events are external to gas turbine.

- Repairable underway
- Components stocked on-board
- Similar to diesel engine accessory change-outs

Package Level - (Gas Generator) + (Package Only\*)

Simple Cycle Plant (SCP) - (Gas Generator) + (Package Only\*) + (BOP)

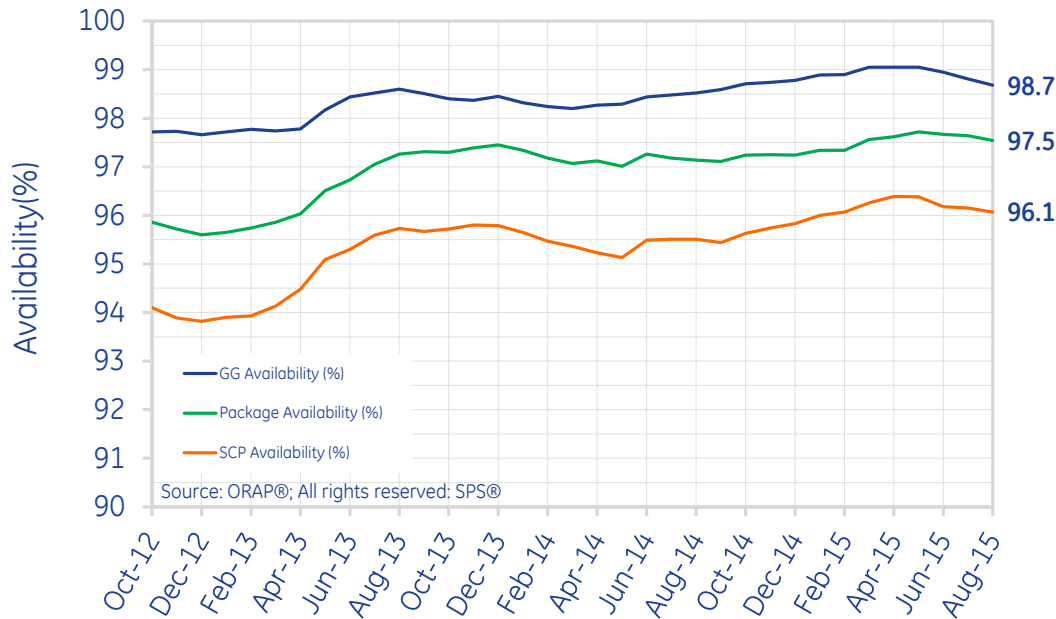
Package Only\* (C&A, Electrical Generator, Power Turbine)



# LM2500 availability ... independent 3<sup>rd</sup> party report

12 month rolling ending August 2015

Fleet Mean



Availability =

$$\left(1 - \frac{\text{Forced\_Outage\_Hours} + \text{Scheduled\_Outage\_Hours}}{\text{Unit\_Period\_Hours}}\right) * 100$$

Availability accounts for both **scheduled** and **unscheduled** maintenance events

**Scheduled events are typically planned around ship operations**

Package Level - (Gas Generator) + (Package Only\*)

Simple Cycle Plant (SCP) - (Gas Generator) + (Package Only\*) + (BOP)

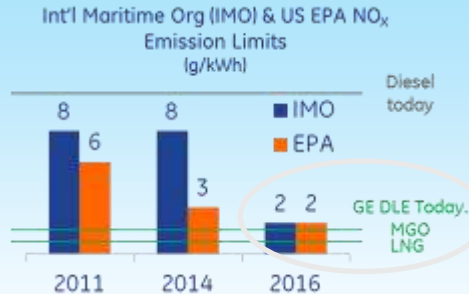
Package Only\* (C&A, Electrical Generator, Power Turbine)



# COGES value ...

## Through system solutions & technology

### Emissions



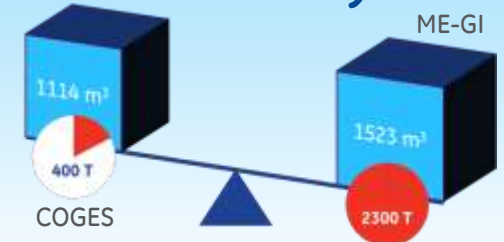
Tier III IMO compliance today  
... without exhaust after-treatment

### Engine Availability



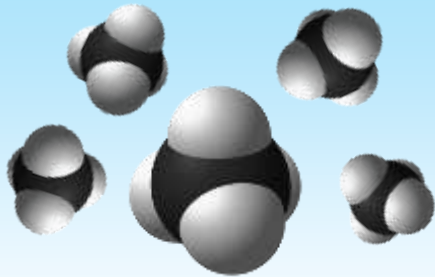
High standards inherited from  
Aviation flight engines  
>99% engine reliability

### Power Density = Flexibility



Weight & volume advantages  
... 80% lighter & 30% smaller  
vs. slow speed diesel\*

### Fuel Flexibility



Dual fuel engine, able to  
handle wide gas variation  
with no methane slip

### Support Network



World-wide service network  
Gas Turbine "Swap out" in  
24-48 hours

### Life Cycle Cost



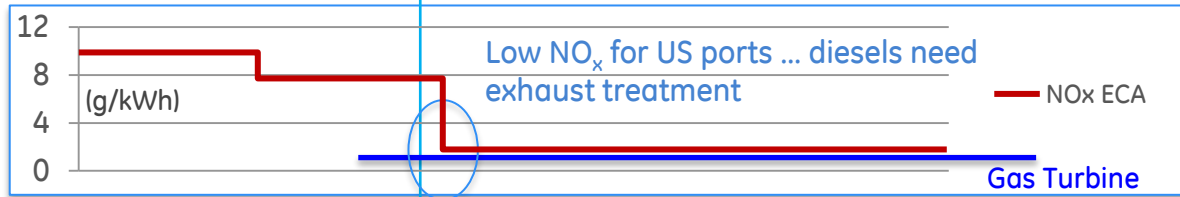
Savings in lube oil, pilot fuel,  
maintenance & crew versus  
diesel technology



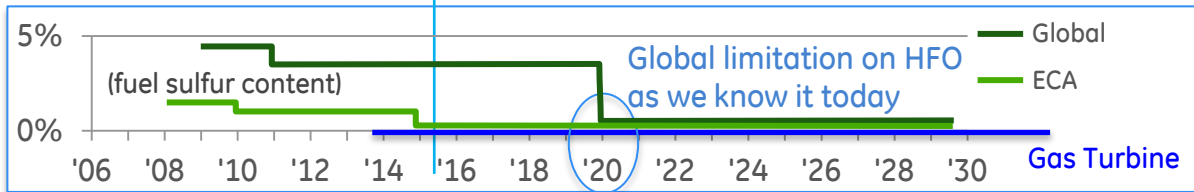


# Emissions regulations are tightening globally

## NO<sub>x</sub> limits



## SO<sub>x</sub> limits



Emissions Control Areas (ECAs)

## Growing Emissions Control Areas ... ECAs are being established

- North America active from 2016
- Baltic & North Sea ... active for SO<sub>x</sub>, NO<sub>x</sub> proposed
- Mediterranean Sea and Norwegian, Mexican and Japanese coastlines all possible future ECAs

Gas turbines can meet all foreseeable emissions regulations today without post combustion treatment ... and no methane slip ... *EVER!*



# COGES: Operating modes



October 2015

Imagination at work

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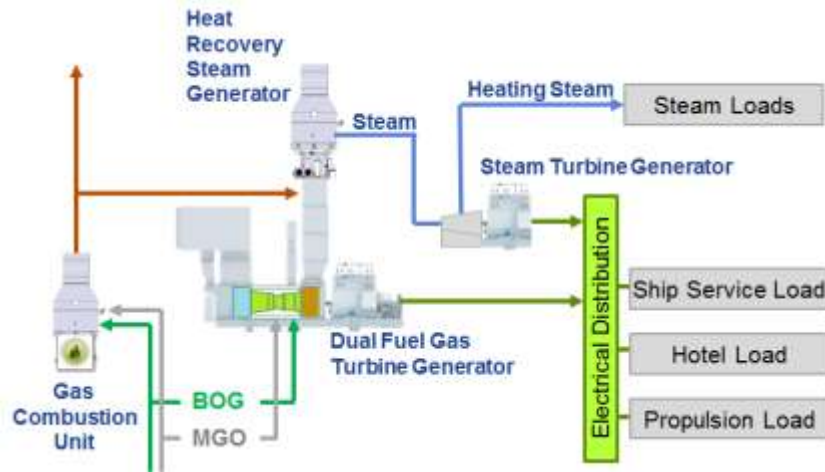
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# COmbined Gas turbine, Electric and Steam (COGES) system for propulsion & power

## LNG Carrier

1 x COGES

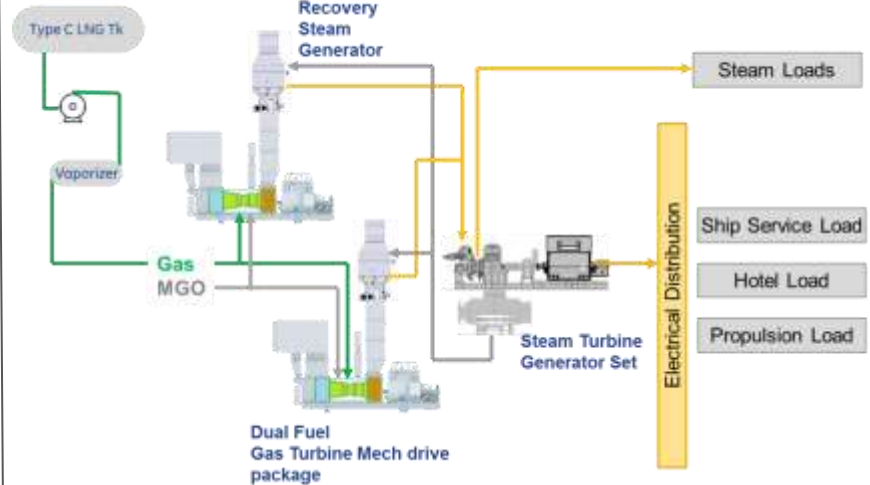
BOG = boil-off gas  
MGO = marine gas oil



- Dual fuel capable ... LNG & MGO
- Single gas turbine application

## Container Ship

2 x COGES

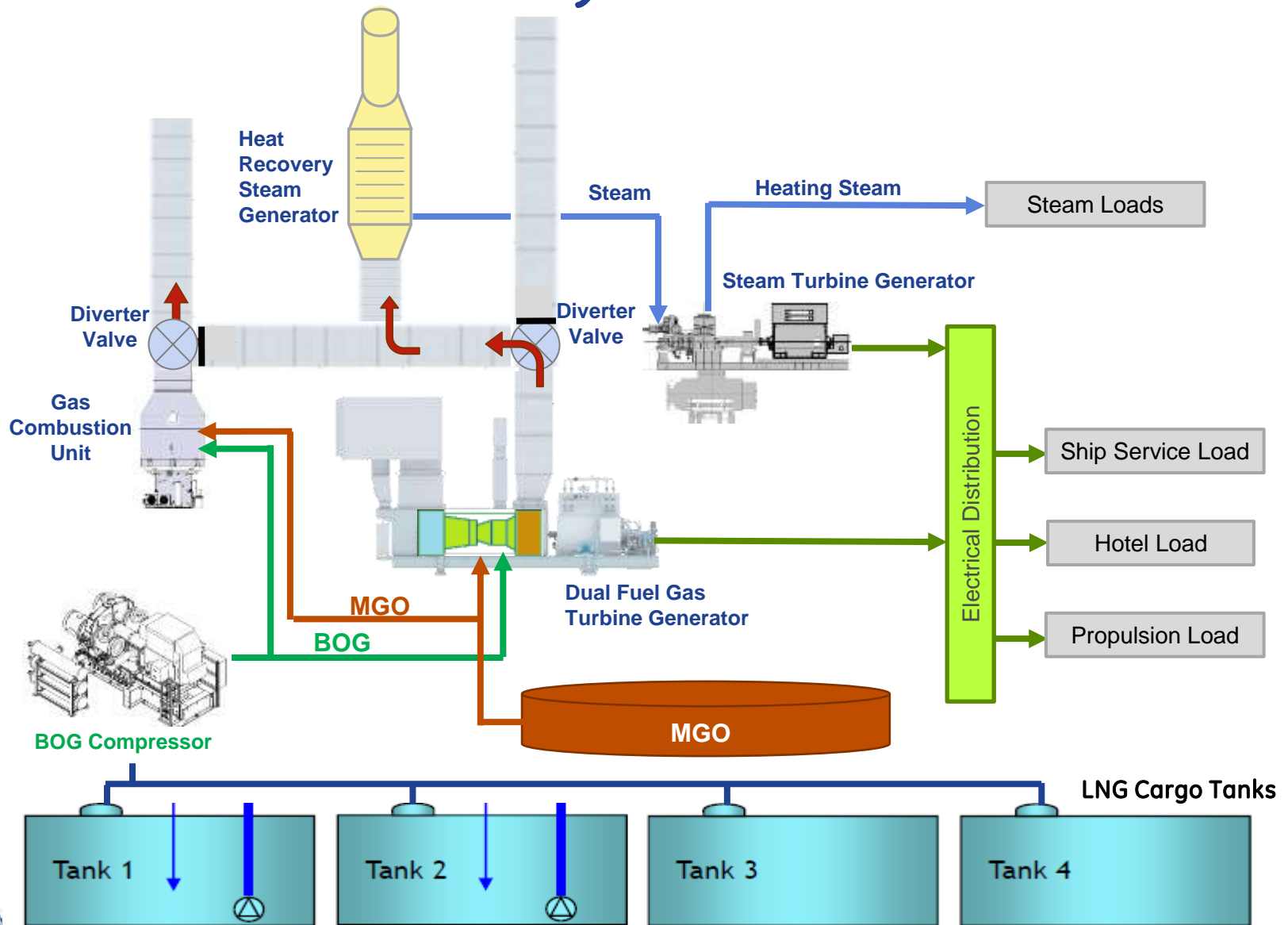


- Dual fuel capable ... LNG & MGO
- 2 x COGES to meet higher power requirements

Bringing aircraft engine quality, reliability & power density to marine

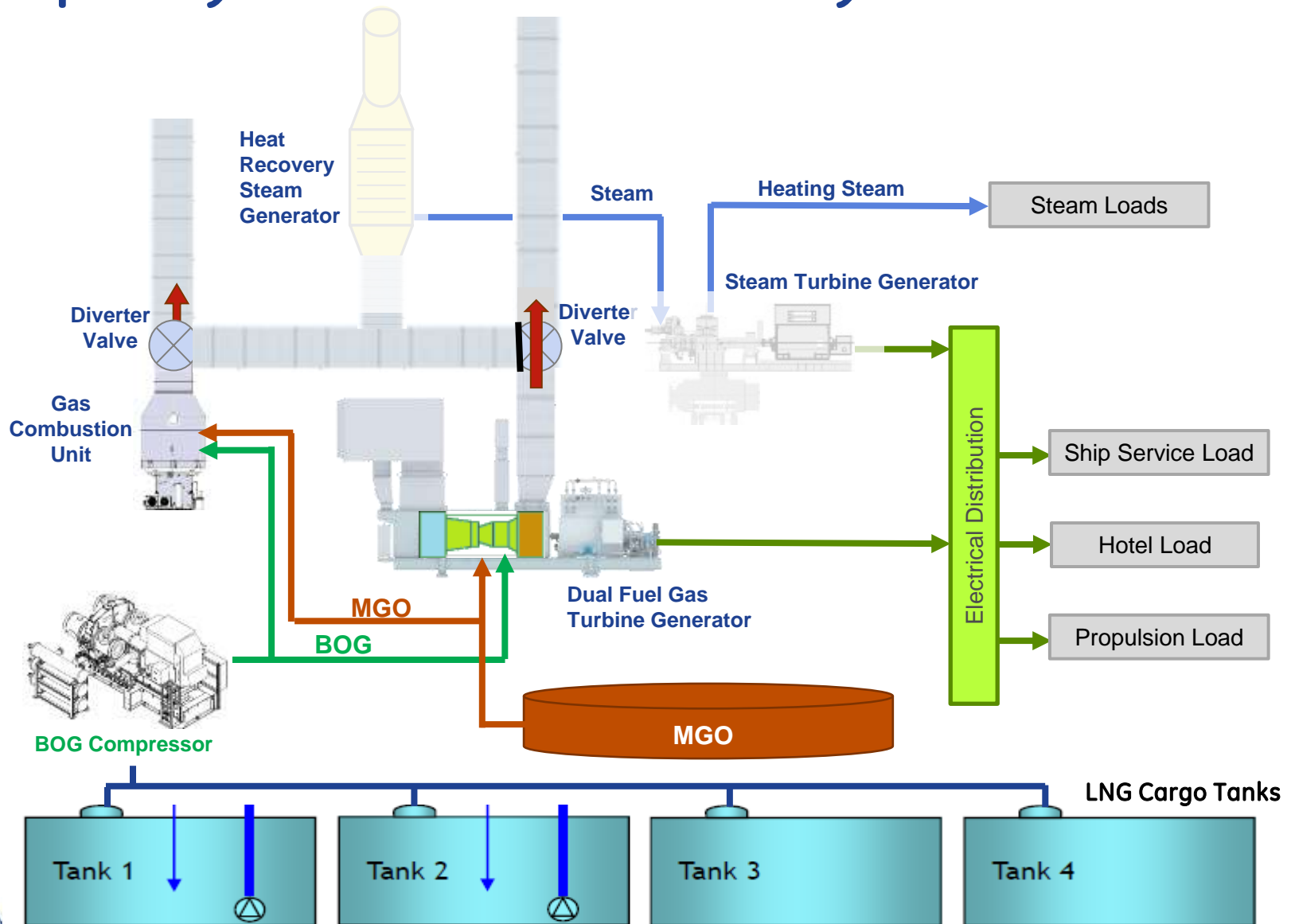


# Normal combined cycle mode (GTG+STG)



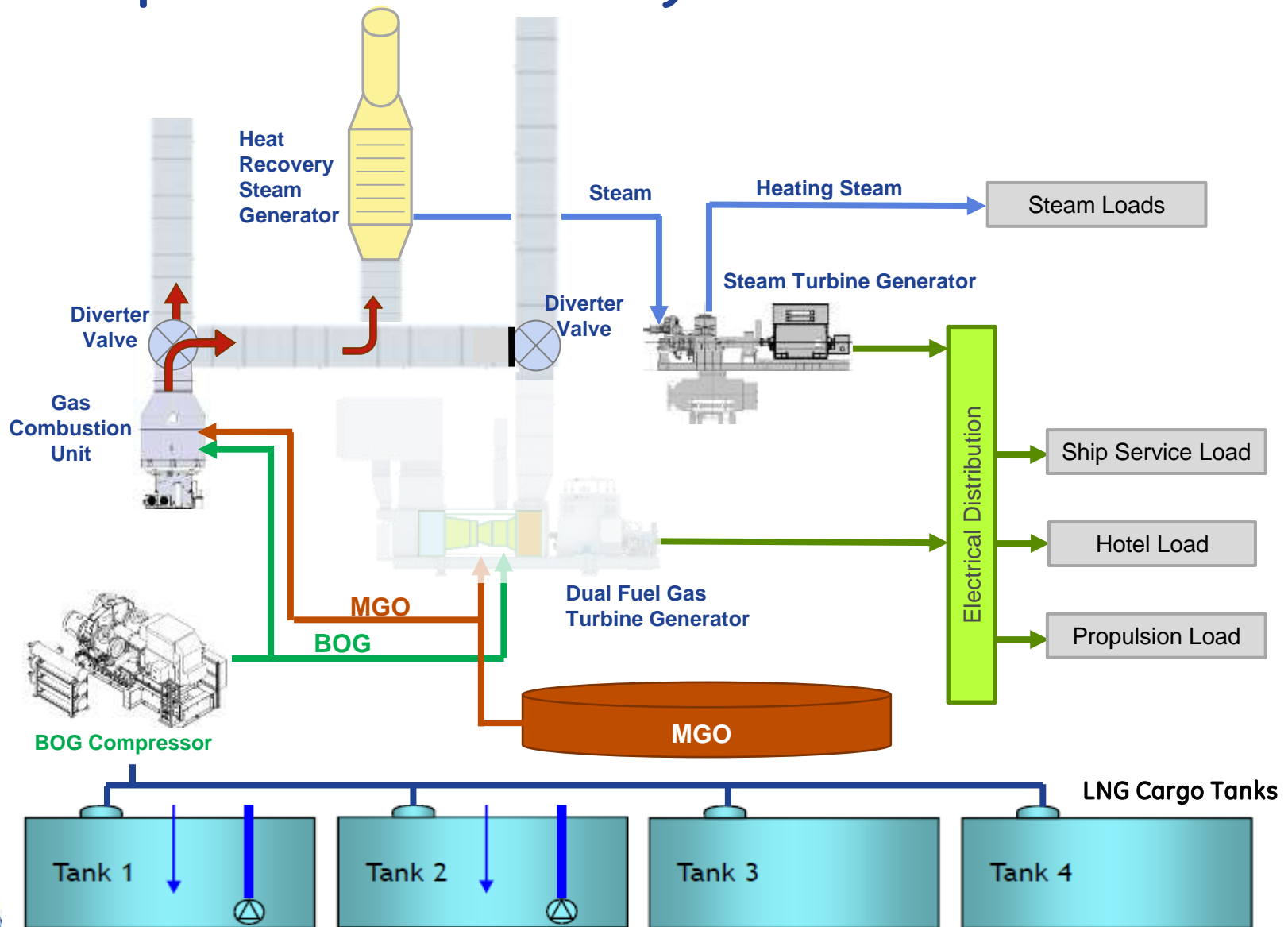
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# Simple cycle mode (GTG only)

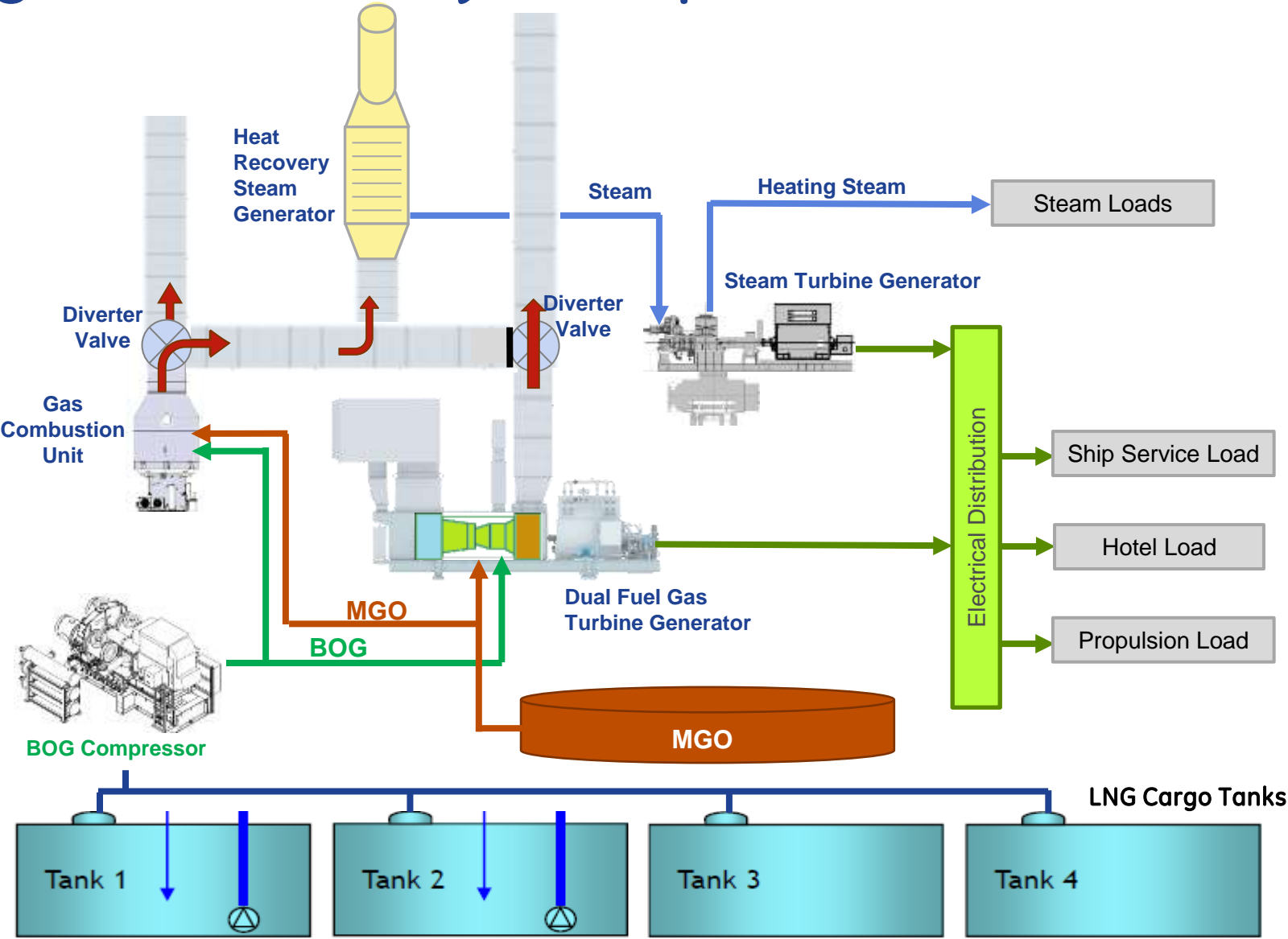


IMAGINATION AT WORK

# Backup mode (STG only)



# High redundancy (independent GTG & STG)



# Notional operational speed

Equipment out of service	Power available	Notional speed	Comments
Normal ops	30 MW	19.5 kt	GTG + STG
No start diesel	30 MW	19.5 kt	Not used in normal ops
No STG	24 MW	19 kt	GTG + start diesel
No GTG	11.5 MW	14.5 kt	STG + start diesel 1% unscheduled + 3% scheduled downtime

Assume 2.5 MW for non-propulsion loads

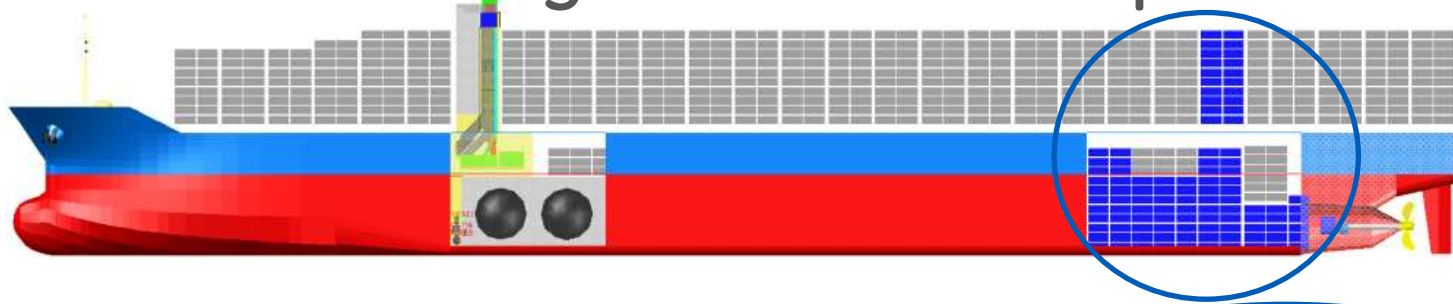
STG = Steam turbine generator set

GTG = Gas turbine generator set

Redundancy of 2 independent prime movers (plus start diesel)



# COGES for ultra large container ships



## Power Density

- Smaller engine room
- More room for cargo

## Emissions

- Meets IMO Tier 3/US EPA Tier 4 NO<sub>x</sub>
- Meets 2020 SO<sub>x</sub>

## Design efforts underway:



Lloyd's Register

Working closely with class society



Full ship design at Kormarine (Oct '15 in Busan)



Full ship design at Marintec (Dec '15 in Shanghai)

### Example:

7% cargo increase on 18k TEU ship

Avg. freight rate/TEU = \$1,315\*

Extra TEU's carried = 1,260

Extra revenue per voyage = \$1.7M

10 voyages/year =

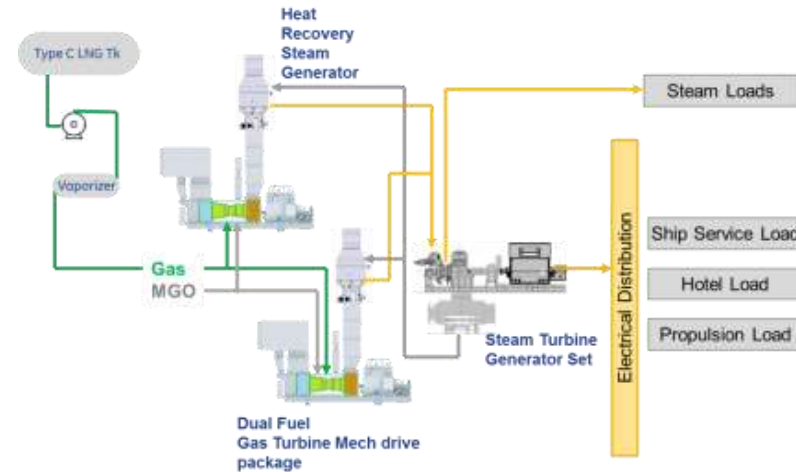
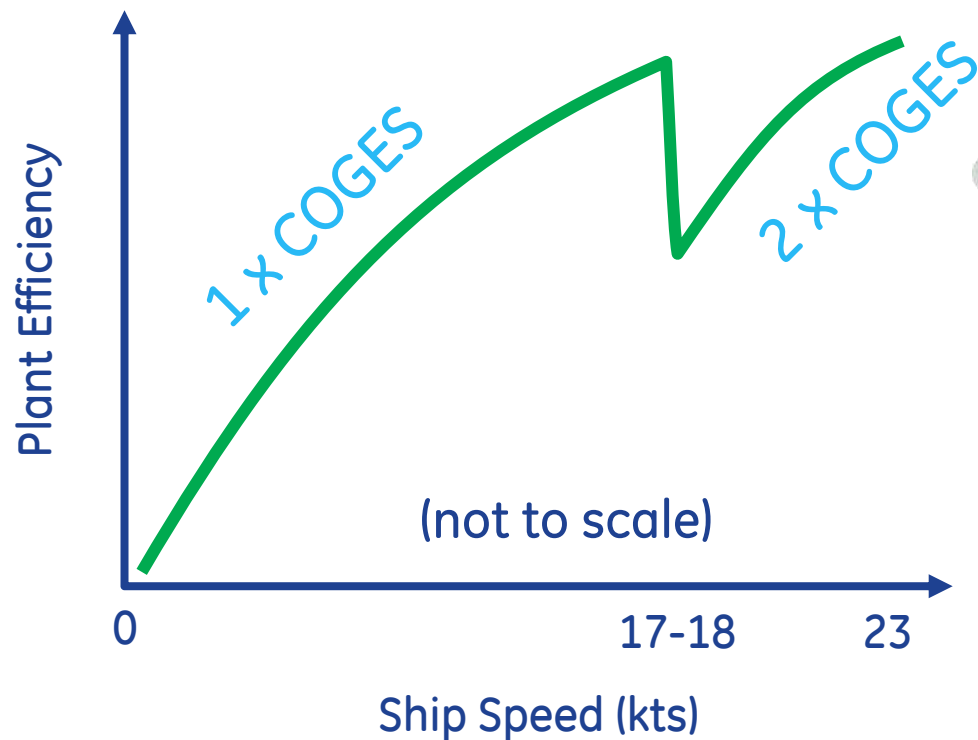
**\$17M** Extra revenue per year

**Design available within 2015**



\* Source: "Maersk Line raises the bar with record fourth quarter as full-year profit soars", Lloyd's List, 2/25/15

# ULCS ... 2 x COGES gives you two optimal operating points



# COGES



## Maintenance: Customized Service Agreements



GE Marine  
October 2015

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# COGES maintenance program

## Condition based...

Maintenance actions *when warranted by gas turbine condition*

## Three levels...

1. **Routine preventive & corrective** – performed by ship's crew ... includes condition assessment and inspections plus minor repairs
2. **Onboard maintenance** – performed by a GE technician and/or trained ship's crew (e.g., gas turbine borescope)
3. **Depot** – Hot section refurbishments and full overhauls

### Annual maintenance

- Preventive & corrective
- Lease pool yearly fee
- Unscheduled Engine Removal reserve

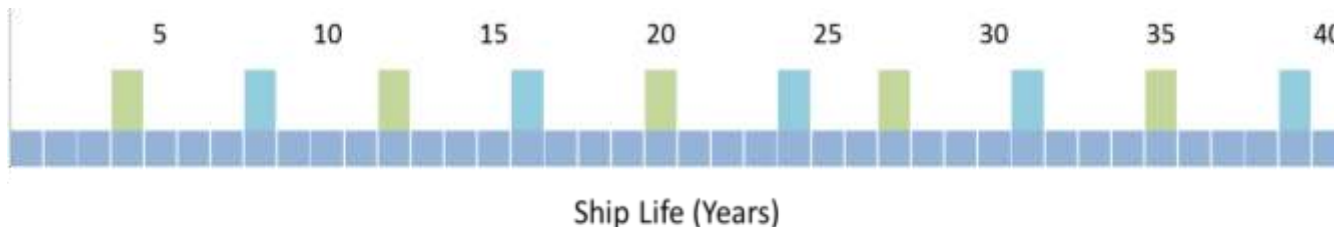
### Partial overhaul

- Every 25k-30k hrs
- Combustor
- HP turbine
- Lease pool use fee

### Full overhaul

- Every 50k-60k hrs
- Partial overhaul, *plus*
- Compressor
- Bearings & frames

Maintenance Cost Profile



# Gas turbine crew maintenance tasks

<b>Visual Inspections</b>	
GT Exterior and Enclosure Inspection and Cleaning	Quarterly
Compressor Inlet Inspection	Semi-annual
Borescope Inspection (GE training available for crew to replace GE Technician)	Semi-annual (GE Technician)
First stage compressor blade Inspection	Annual
Exhaust Inspection	Semi-annual
Variable Stator System Inspection	Semi-annual
<b>Cleaning</b>	
Lube and Scavenge Pump Inlet Screen and Electronic Chip Detector Inspection/Cleaning	Semi-annual
On-line Water Wash	As required
<b>Testing</b>	
Lube Oil Test	Monthly*

**<300 man hours  
per year!**

\*Sample sent to GE for testing

**Reduces crew cost for (2) unlicensed engineers**



# Gas generator can be swapped in 24 hours



View of engine room on the *Celebrity Summit* cruise ship

Package doors open to engine room ... GG removed with built-in lift gear



# Customer service agreements (CSA) provide a predictable maintenance forecast for your GT...

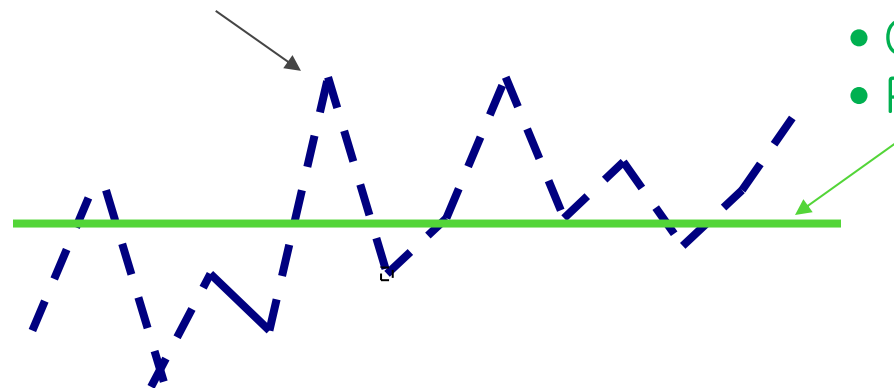
Fixed price through engine life

Predictable costs

Simplified invoicing



Transaction-based maintenance costs ...  
variable, not guaranteed



**CSA-based fixed price**

- Guaranteed by GE
- Predictable



# Customer responsibility in a CSA



- Preventative maintenance... less than 300 hours per year
- Procurement ... shipboard & dockside parts & tooling
- Logistics ... cranes, lifting equipment, work areas

View of gas turbine on the Celebrity *Summit* cruise ship





# GE responsibility in a CSA



Maintenance Action	Frequency	Standard	Recommended
<b>Availability</b>			
<b>Reliability</b>			
<b>Quality</b>			
<b>Routine Preventative Maintenance (Scheduled)</b>			
Borescope Inspection	Semi annual	X	
Crew Assisted On-Site Maintenance	Condition Based	X	
Remote monitoring and diagnostics	Condition Based	X	
Depot Maintenance	Condition Based	X	
<b>Corrective Maintenance (Unscheduled)</b>			
Crew Assisted On-Site Maintenance	Condition Based		X
Depot Maintenance	Condition Based		X
<b>Materials Management</b>			
Spare Part Replenishment	Condition Based		X
Component Repair	Condition Based		X
<b>Leasing</b>			
Lease Gas Generator Pool	Annual		X
Gas Generator Usage Fee	As required for depot events		X
<b>Training</b>			
	By Request		X



# Lease gas generator or spare engine?

## Lease gas generator

- ✓ Annual cost plus weekly usage fee
- ✓ Better fit for customers with small fleets

## Considerations

- ✓ Shared asset with other customers
- ✓ GE guarantees quality & availability

## Spare engine

- ✓ One-time purchase price
- ✓ Better fit for customers with large fleets

## Considerations

- ✓ Asset location at customer's discretion
- ✓ Customer manages asset

