Environmentally Superior Vessels with LNG as Fuel; "Achievements and Prospects for the Near Future"

The 7th Asian shipbuilding Experts Forum (ASEF)
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MITSUBISHI HEAVY INDUSTRIES, LTD.
Our Technologies, Your Tomorrow

LNG as Fuel

① Environment Issues

② ECA, Operation with Fuel Oil

③ ECA, Operation with LNG

④ Topics of LNG as Fuel

⑤ LNG Fuel Ship in Europe

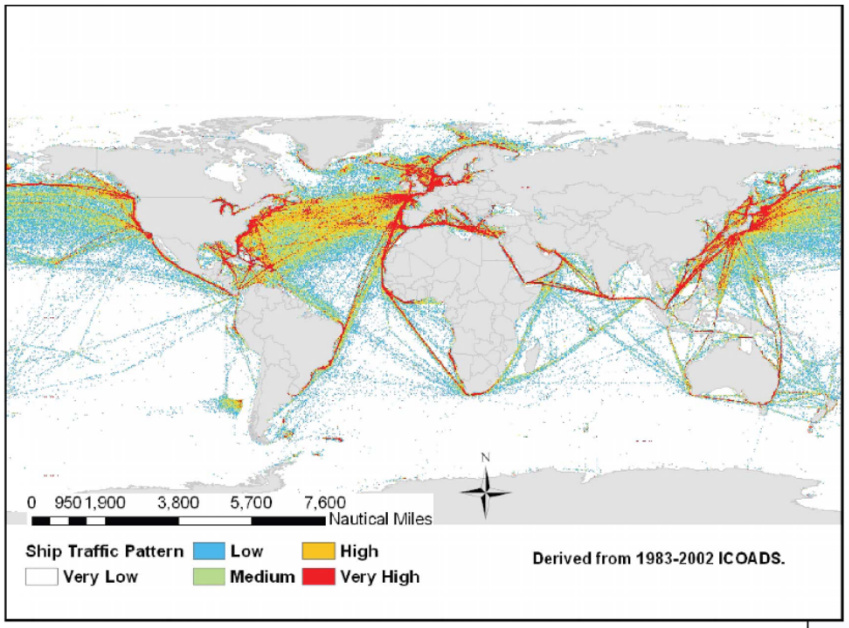
⑥ LNG Fuel Ship in Japan

⑦ MHI LNG Fuel ship

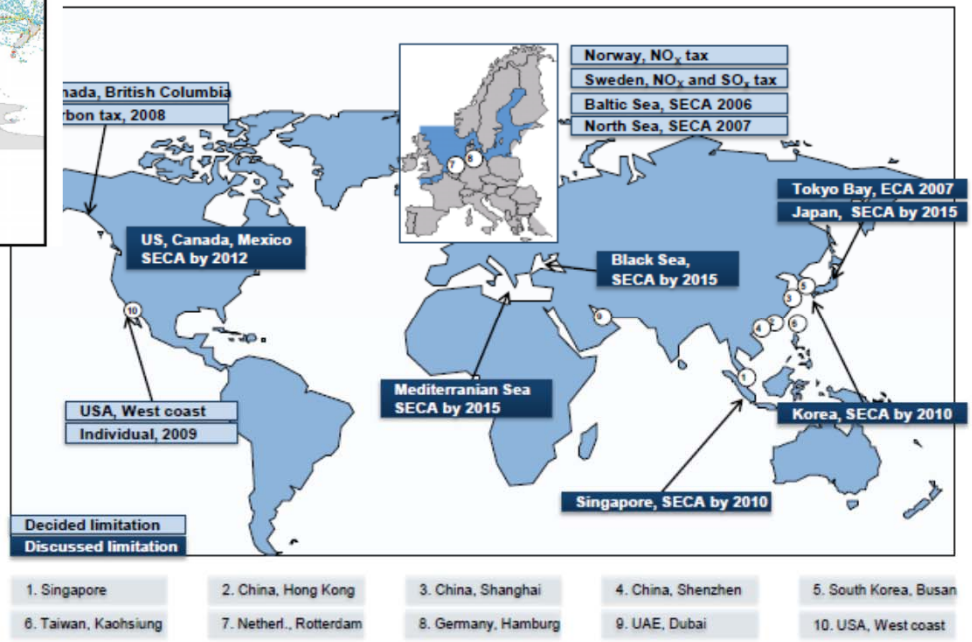
⑧ MHI Gas Ship Equipments

① Environments Issues

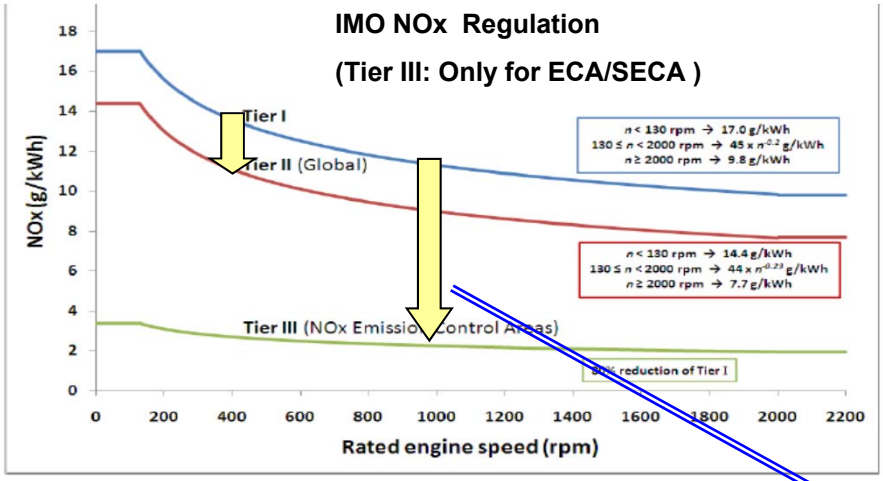
(World wide Ocean lane distribution)

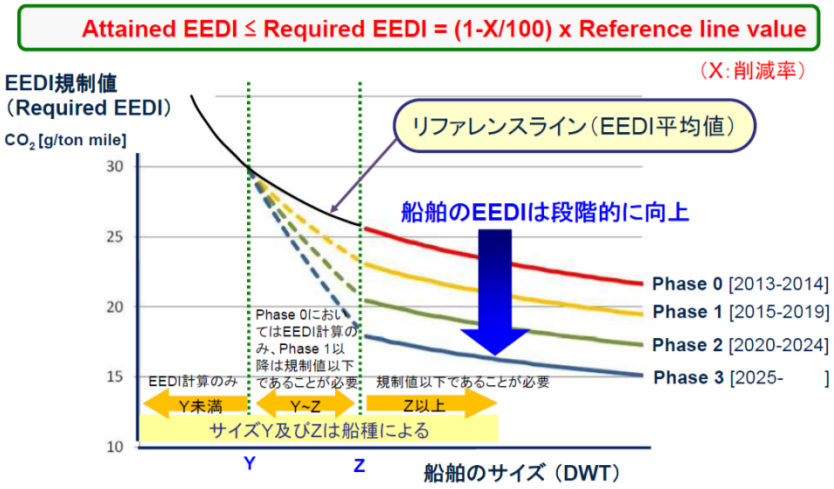


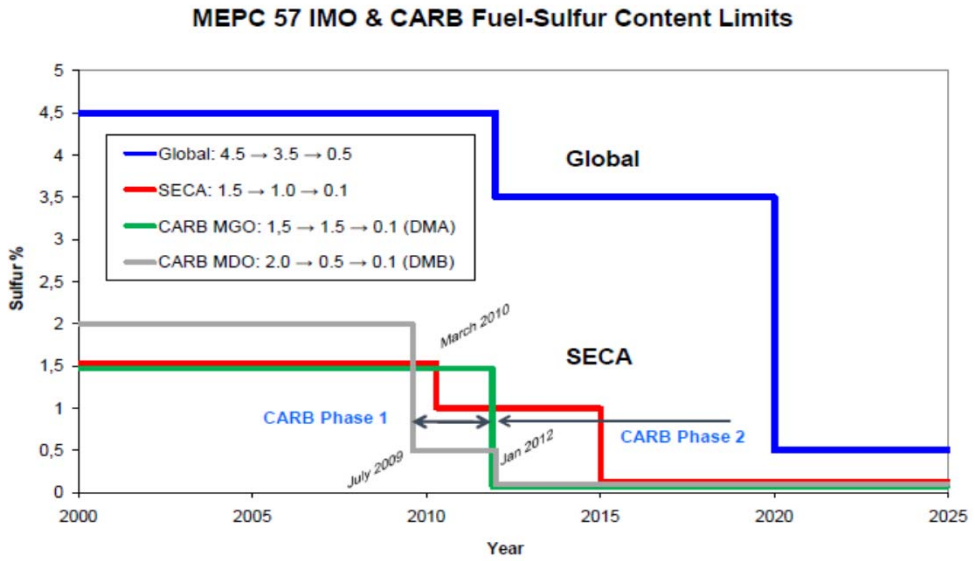
(ECA / SECA)



① Environments Issues （NOx, SOx, CO2）







Δ 80%: Some limit to Engine tuning technology

NOx regulation will conflict with EEDI

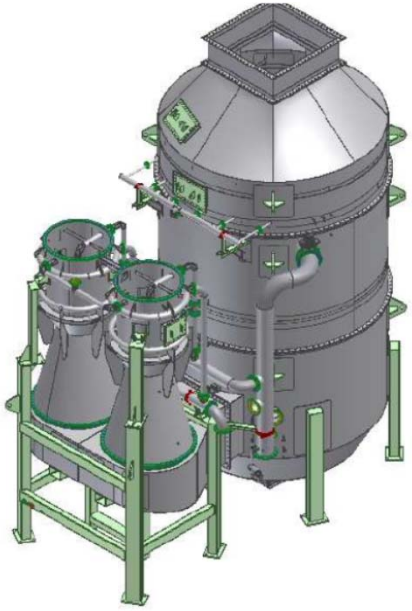
SOx regulation have some concern on Bunker price jumping

② ECA, Operation with Fuel Oil (Measures to SOx)

Measure - 1: Low Sulfur Fuel Oil

Measure - 2: Scrubber (Exhaust gas cleaning)

Exhaust gas Scrubber

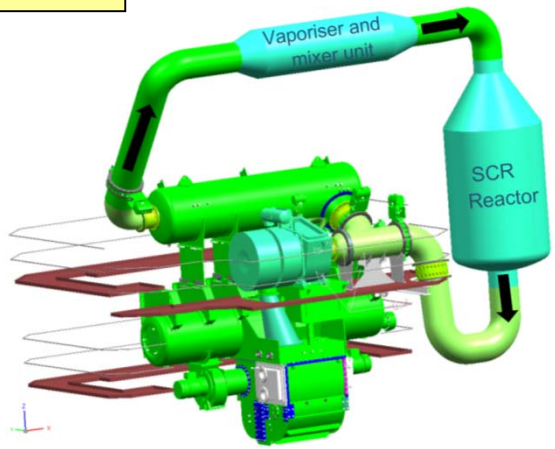


MAN D & T 's test with Scrubber

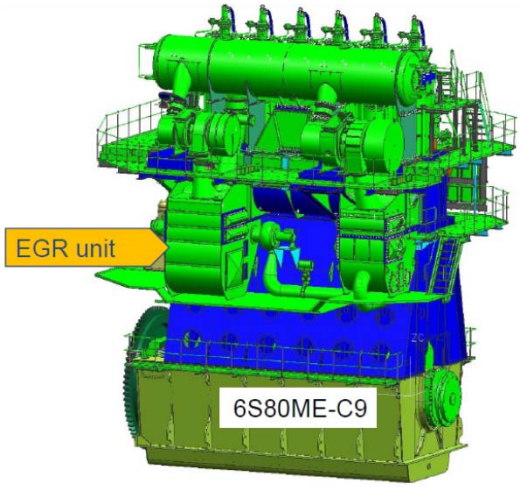
MHI: Under development, collaborated with MKK

② ECA, Operation with Fuel Oil (Measures to NOx)

SCR

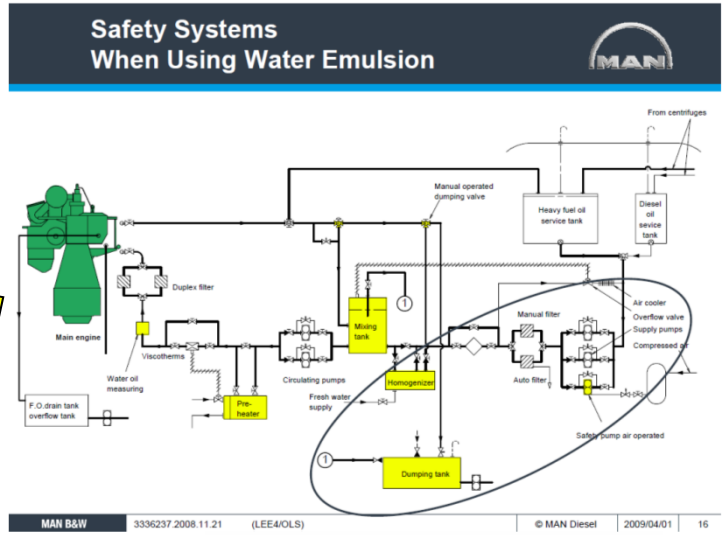


EGR

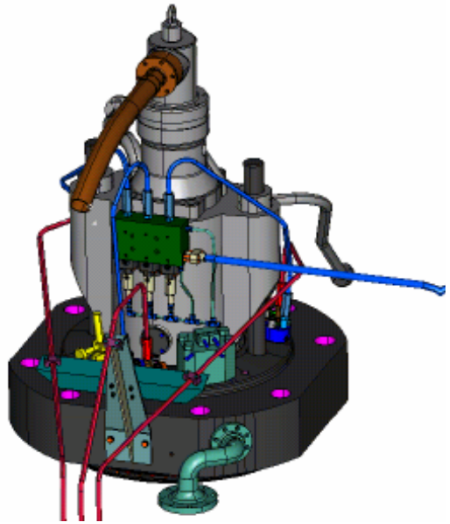


Single or combination

Water Emulsion



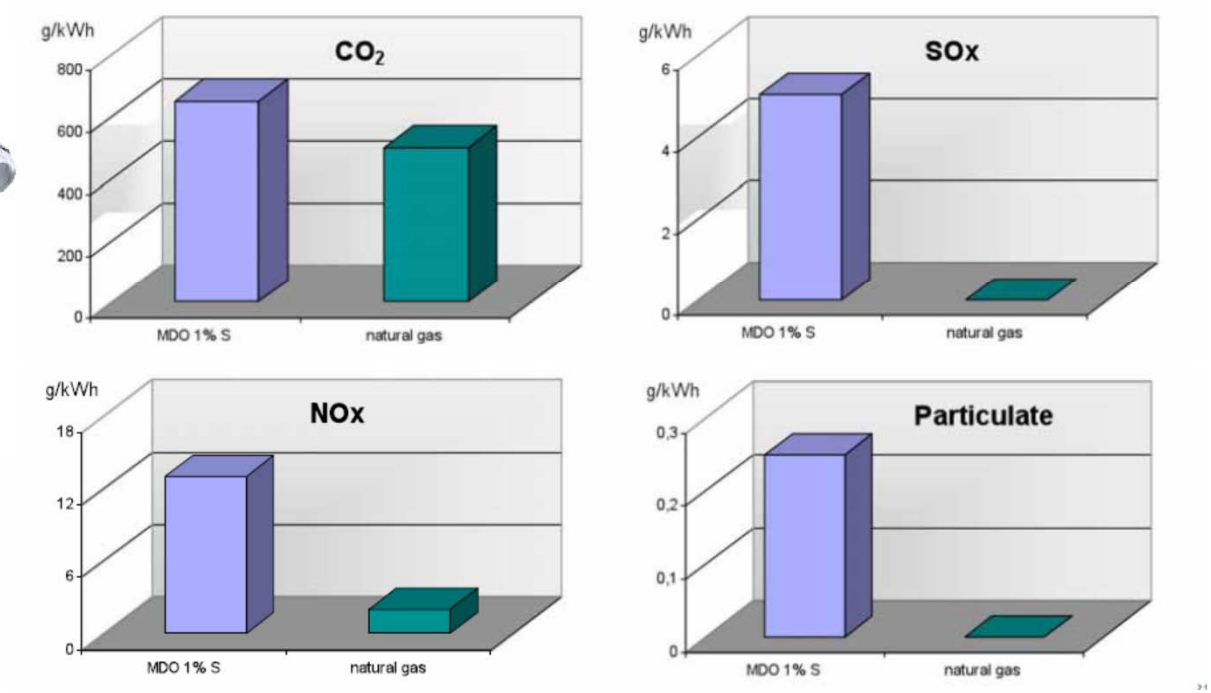
Direct Water injection



③ ECA, Operation with LNG

Rolls-Royce
Spark Ignited Gas Engine

Emissions - MDO versus Natural gas

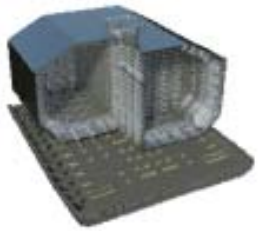


CO2 = △23%, NOx = △92%, SOx = △100%, PM = △98%

Effective in abatement for both Emissions & EEDI

ROLLS-ROYS presentation material

④ Topics of LNG as Fuel

Tank Type	Prismatic Tank	Spherical Tank	Cylindrical Tank		Tank Truck
					
IMO Type	B	B or C	C		
Heat Insulation	External		External	Vacuum	Vacuum
Max. Pressure	0.7 bar	1 bar	10 Bar		10 Bar
Space efficiency	High	Low	Medium		Low/Medium
Gas Delivery	Pumping Out		Pressure Built-Up Type		
Design Cost	High	Medium	Low	Low	-
BOG Treatment	Necessary		Not Necessary		
Suitable Cap.	>5,000m3	>5,000m3	30-1,000m3	30-1,000m3	< 100m3
Cost	High	High	Medium	Medium	Low/Medium

④ Topics of LNG as Fuel

LNG Fuel engine

	Gas Engine	Dual Fuel diesel	Dual Fuel diesel	Steam Turbine
	4 Cycle	4 Cycle	2 Cycle	
Pilot fuel	Spark igniter	Micro pilot fuel	Micro pilot fuel	--
LNG Tank required	2-tanks or more	1-Tank		
NOx-Tier III	Meet	Meet	Additional treatment unit	Meet
Stand-by propulsion	Needs	--	--	--
Emergency	Change over to stand-by propulsion	Change over to H.F.O.	Change over to H.F.O.	Change over to H.F.O.
Remarks	Methane slip 1～2%	Methane slip 1～2%	Gas burning >15% load	Limited operator

LNG Bunkering

Tank Lorry onboard

Tank Lorry

Bunkering Tanker

LNG Terminal

⑤ LNG Fuel Ship in Europe

Figure 9 RoRo concept with LNG as fuel

Project development: Crowley, Glosten & Rolls Royce

RoRo cargo vessel on order for delivery in 2011 (Rolls-Royce Marine design).

List of LNG fuelled ships

Ships in operation

Year	Type of ship	Ship name	Owner	Engine
2000	Car/Passenger ferry	Glutra	Fjord1	Mitsubishi
2003	Offshore vessel	Viking Energy	Eidesvik	Wärtsilä DF
2003	Offshore vessel	Stril Pioner	Simon Møkster	Wärtsilä DF
2004	LNG tanker	Pioner Knutsen	Knutsen OAS	Mitsubishi
2006	Car/Passenger ferry	Bergensfjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Stavangerfjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Raunefjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Mastrafjord	Fjord1	Rolls Royce
2007	Car/Passenger ferry	Fanafjord	Fjord1	Rolls Royce
2008	Offshore vessel	Viking Queen	Eidesvik	Wärtsilä DF
2009	Car/Passenger ferry	Moldefjord	Fjord1	Mitsubishi
2009	Car/Passenger ferry	Tideprinsen	Tide Sjø	Mitsubishi
2009	Car/Passenger ferry	Tidekongen	Tide Sjø	Mitsubishi
2009	Car/Passenger ferry	Tidedronningen	Tide Sjø	Mitsubishi
2009	LNG tanker	Coral Methane	Anthony Veder	Rolls Royce
2009	Offshore vessel	Viking Lady	Eidesvik	Wärtsilä DF
2009	Patrol vessel	Barentshav	REM	Mitsubishi
2010	Car/Passenger ferry	Fannefjord	Fjord1	Mitsubishi
2010	Car/Passenger ferry	Romsdalsfjord	Fjord1	Mitsubishi
2010	Car/Passenger ferry	Korsfjord	Fjord1	Mitsubishi
2010	Car/Passenger ferry	Tresfjord	Fjord1	Rolls Royce
2010	Car/Passenger ferry	Selbjørnsfjord	FosenNamsos	Mitsubishi
2010	Patrol vessel	Bergen	REM	Mitsubishi
2010	Patrol vessel	Sortland	REM	Mitsubishi
2011	Product tanker	Bit Viking	Tarbit Shipping	Wärtsilä DF
2011	Car/Passenger ferry	Boknafjord	Fjord1	Rolls Royce

26 ships in operation

Confirmed order

Year	Type of ship	Ship name	Owner	Engine
2011	Offshore vessel	TBD	DOF	Wärtsilä DF
2011	Offshore vessel	TBD	Solstad	Wärtsilä DF
2011	RoRo ship	TBD	Seacargo	Rolls Royce
2012	Bulk ship	TBD	NSK Shipping	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Car/Passenger ferry	TBD	Torghatten Nord	Rolls Royce
2012	Offshore vessel	TBD	Eidesvik	Wärtsilä DF
2012	Offshore vessel	TBD	Eidesvik	Wärtsilä DF
2012	Offshore vessel	TBD	Olympic Shipping	Wärtsilä DF
2012	Offshore vessel	TBD	Island Offshore	Rolls Royce
2012	Offshore vessel	TBD	Island Offshore	Rolls Royce
2012	RoRo ship	TBD	Seacargo	Rolls Royce
2013	RoPax	TBD	Viking Line	Wärtsilä DF
2013	RoRo ship	TBD	Norlines	Rolls Royce
2013	RoRo ship	TBD	Norlines	Rolls Royce

17 ships on order

⑤ LNG Fuel Ship in Europe （Feeder）

⑥ LNG Fuel Ship in Japan （Japanese Government）

（1） Japan Ship Technology Research Association (JSTRA)

① “Framework for energy efficiency improvement in international marine Business”
Survey of LNG fuel supply infrastructure.

② “LNG fuel tank Committee”
Make a proposal for IGF code reflect HAZID results of experimental LNG fuel ship design.

（2） Ministry of Land, transport and Tourism：

2012 Synthetic research in LNG fuel ships

Research	Contents	
Safety Standards	1.Hard	Design standard of High pressure gas supply system (Mini. plant examination)
		Bunkering manual to prevent excess pressurization, i.e. Roll-Over
	2. Soft	Normal operation, Maneuvering (Crew line-up)
		Ship to Ship （Hard ware）
		Safety & Disaster prevention
		Bunkering: Ship to Ship （Berthing & Anchoring）
		Bunkering: Pipe Line
		Bunkering: Lorry
		Inspection standards
	3. Survey	International Strategy
		GHG reduction

⑥ LNG Fuel Ship in Japan （Concept design）

MITSUBISHI HEAVY INDUSTRIES, LTD.

By Ship-owner

MOL ISHIN-II Ferry

・4Cyc. DFE-CRP Pod

・LNG Tank：Type-C

K-LINE 2000 PCTC

・4Cyc. Gas engine x 2 ＋ 1 CPP

・LNG Tank ： Type-C

By Ship yard

IHI-MU 10,000TEU C/ S

・2Cyc. DF Diesel x 2

・LNG Tank ： SPB

KHI 9,000TEU C/S

・2Cyc. DF Diesel x 1

・LNG Tank ： IMO type-B

MES LNGC “Double Eco Max”

・147,000m3、155,000m3、180,000m3

・2Cyc. DF Diesel x 2

OSHIMA

“OHBC ECO-Ship 2020”

・4Cyc. Gas engine x 2 ＋ 2 Shaft

・LNG Tank ： Type-C

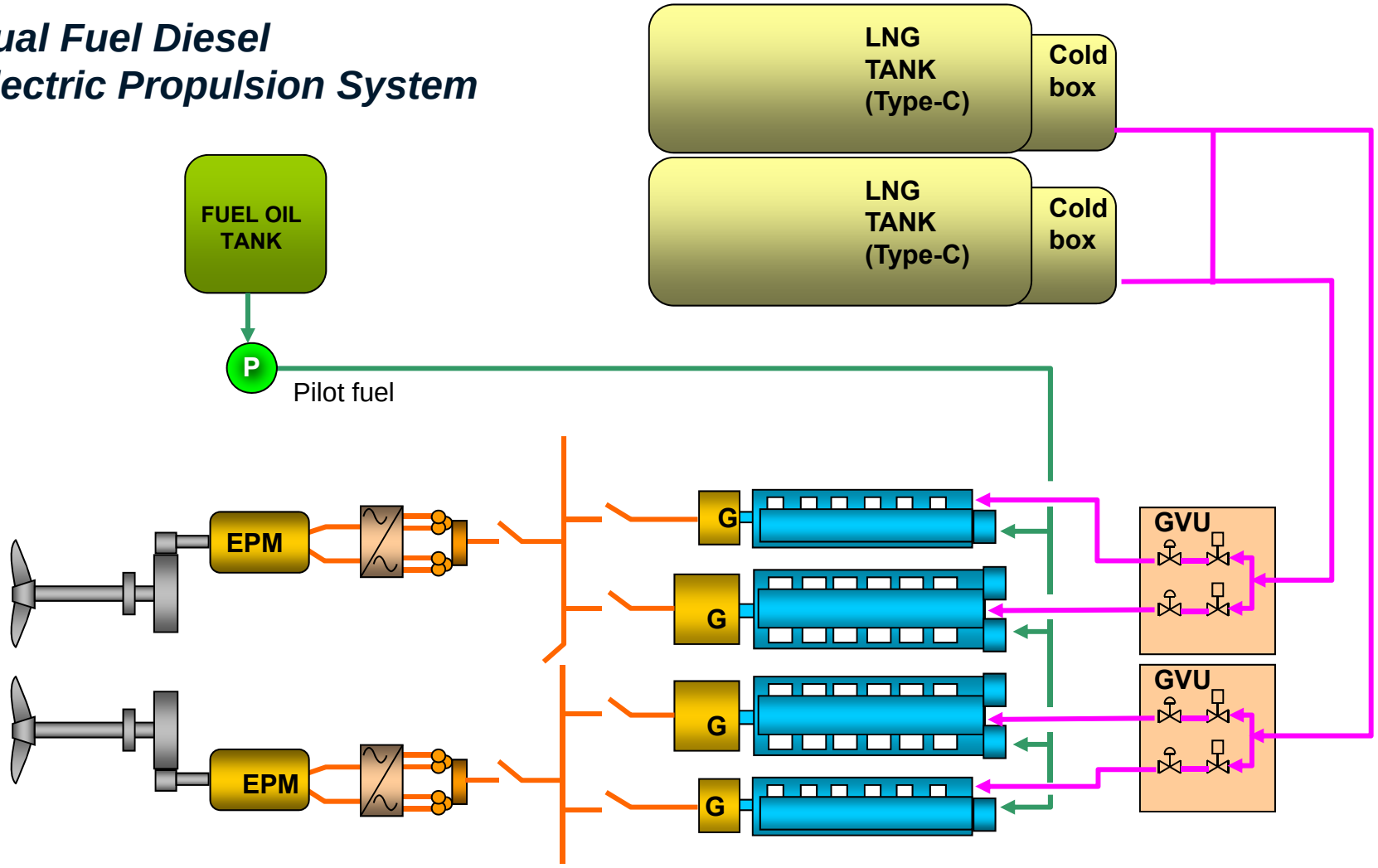
Potential Vessel with LNG as Fuel

Kind of Vessel	Operation route	ECA, SECA	Potential of LNG as Fuel	Remarks
RORO/ROPAX	Japan domestic			
	Europe	✔	✔	
PCTC	Europe – Asia	✔		Short-term operation in ECA/SECA. Circumstances alter Mediterranean sea.
	North America – Asia	✔	✔	Cheaper LNG come form shale gas will be supplied by Ship to Ship bunkering procedure.
	Europe	✔	✔	
Container Ship	Europe – Asia	✔		Short-term operation in ECA/SECA. Circumstances alter Mediterranean sea.
	North America – Asia	✔	✔	Cheaper LNG come form shale gas will be supplied by Ship to Ship bunkering procedure.
	North and South	✔	✔	
VLCC	PG - World wide	Few		
Bulk Carrier	World wide	Few		

⑦ LNG Fuel Ship by MHI（ROPAX + eGF）

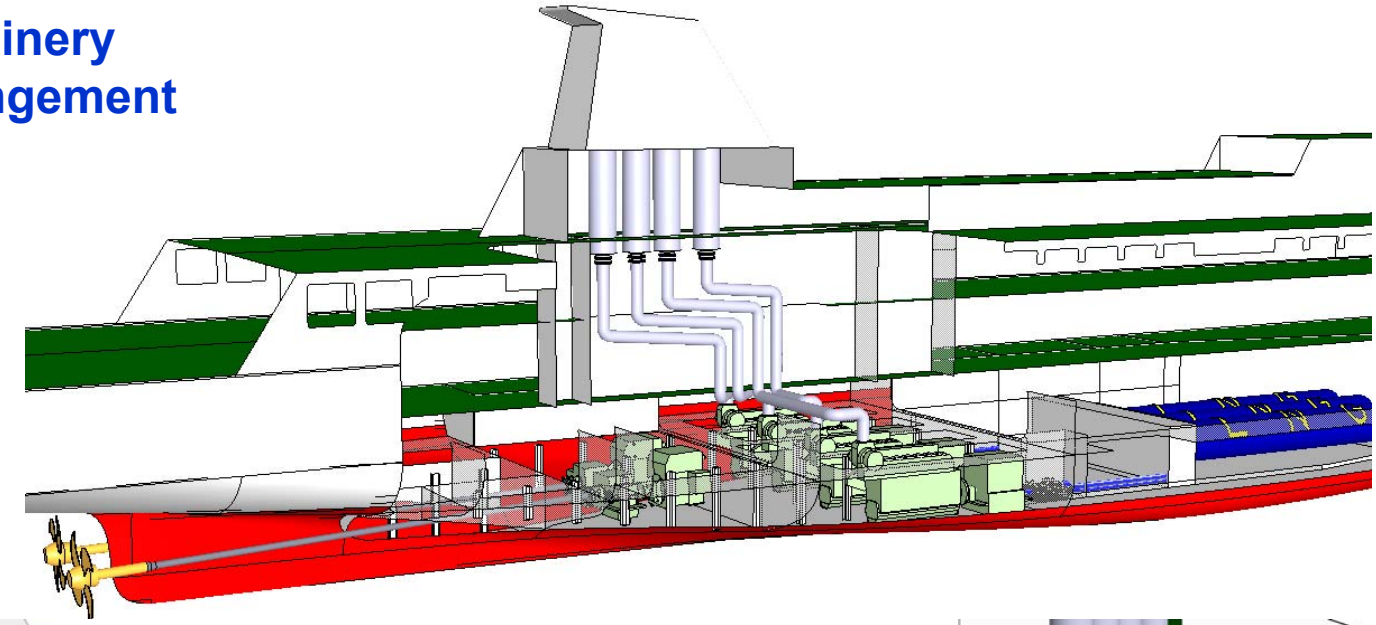
⑦ LNG Fuel Ship by MHI （ ROPAX + eGF ）

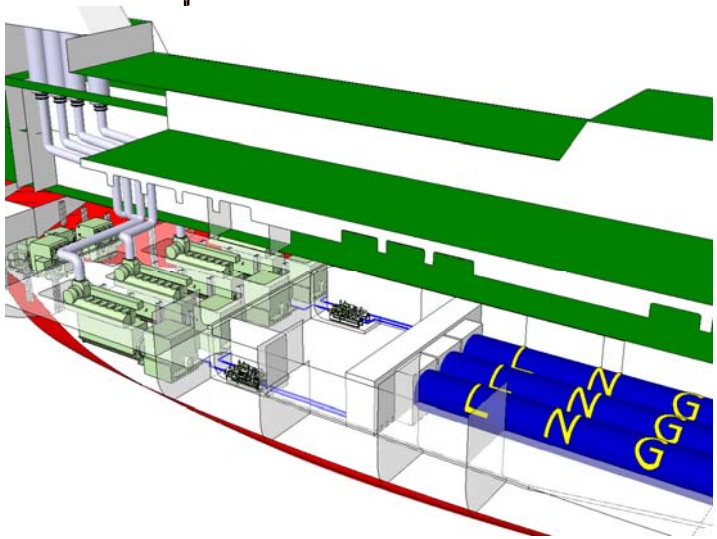
Dual Fuel Diesel
Electric Propulsion System

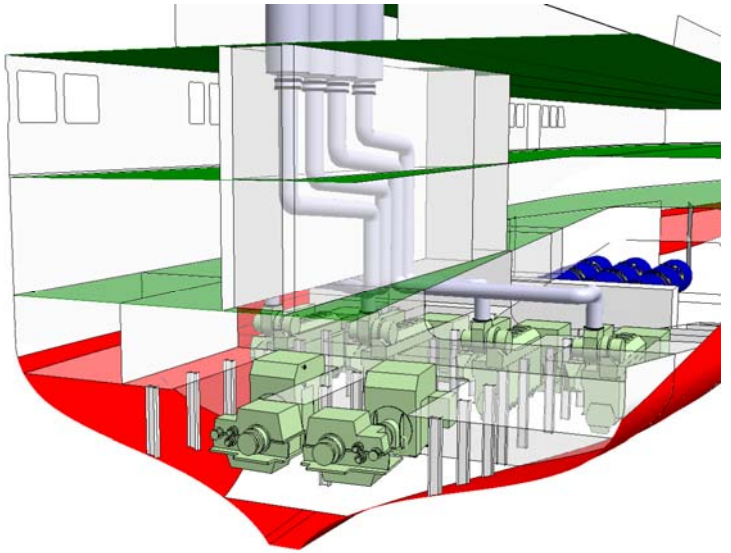


⑦ LNG Fuel Ship by MHI（ROPAX + eGF）

Machinery Arrangement







⑦ LNG Fuel Ship by MHI（ROPAX + eGF）

ROPAX Emission calculation (HFO.：3% S、MDO:0.5%)				
		Conventional Twin CPP Diesel Driven	**4Cyc. DFDE with LNG as fuel**	
PAX		600		
Trailers / Cars	12m Trailers	155		
	Cars	50	--	
Vessel speed		23 kts		
Main propulsion eingine		12,000 kw x 2sets	--	
Main generator		--	8,400 kw x 2sets	
Auxiliary generator		1,270 kw x 3sets	5,400 kw x 2sets	
Operation hours / Voyage		19.5 hrs		
Voyage days / year		300 days		
Fuel consumption / year	FO. (k-ton/y)	26	0.2	
	LNG (k-ton/y)	--	23	
Emission	CO2 (k-ton/y)	82	62	**-25%**
	NO x (ton/y)	1,398	233	**-83%**
	SO x (ton/y)	1,432	28	**-98%**

⑦ LNG Fuel Ship by MHI（ ROPAX + eGF ）

MITSUBISHI HEAVY INDUSTRIES, LTD.

Confirmation of DF engine load limitation based on the LNG property, imported to Japan

Property (mol %)	1	2	3	4	5	6	7	8	9	10
Methane	90.16	87.33	89.88	90.5	88.34	90.95	96.69	92.26	89.53	90.76
Ethane	5.41	8.39	6.58	5.12	7.09	5.56	1.97	4.87	6.36	5.62
Propane	3.16	3.33	2.36	2.84	2.77	2.49	0.34	1.87	2.82	2.39
n-Butane	0.46	0.48	0.63	0.81	0.74	0.48	0.08	0.42	0.6	0.51
i-Butane	0.64	0.39	0.41	0.63	0.74	0.5	0.07	0.37	0.55	0.47
n-Pentane	0	0	0	0.02	0.01	0	0	0.01	0	0
i-Pentane	0	0.01	0	0.04	0.03	0.01	0	0	0.02	0.01
Hexane	0	0	0	0	0	0	0	0	0	0
Nitrogen	0.16	0.09	0.14	0.04	0.28	0.01	0.85	0.2	0.12	0.22
Carbon dioxide	0	0	0	0	0	0	0	0	0	0
Oxygen	0	0	0	0	0	0	0	0	0	0
Average molecular weight liquid	0	0	0	0	0	0	16.58	17.61	0	4.27
Liquid density	459.97	465.29	457.53	459.55	465.74	454.1	439.3	447.8	460.36	456.16
BTU/SCF	1121.7	1142.82	1117.3	1125.505	1137.2	1111.8	1026	1100	1126.1	1110.29
	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
MJ/m3	44.4	45.23	44.22	44.55	45.01	44	40.61	43.54	44.57	43.94
Calculated methane number	**70.6**	**69.1**	**71.5**	**69.6**	**68.4**	**72.4**	**89.8**	**75.5**	**70.2**	**72.5**
Derating Ratio (%) (975kW/cyl)	9.4%	11.1%	8.5%	10.4%	11.6%	7.6%	0%	4.5%	9.8%	7.5%

No derating is required (100% output is possible), please fill in 0%.
Derating is required 10% (max. output is 90%), please fill in 10%.

⑦ LNG Fuel Ship by MHI（ ROPAX + eGF ）

Preparation work before & after regular Dry Dock inspection

Operation：

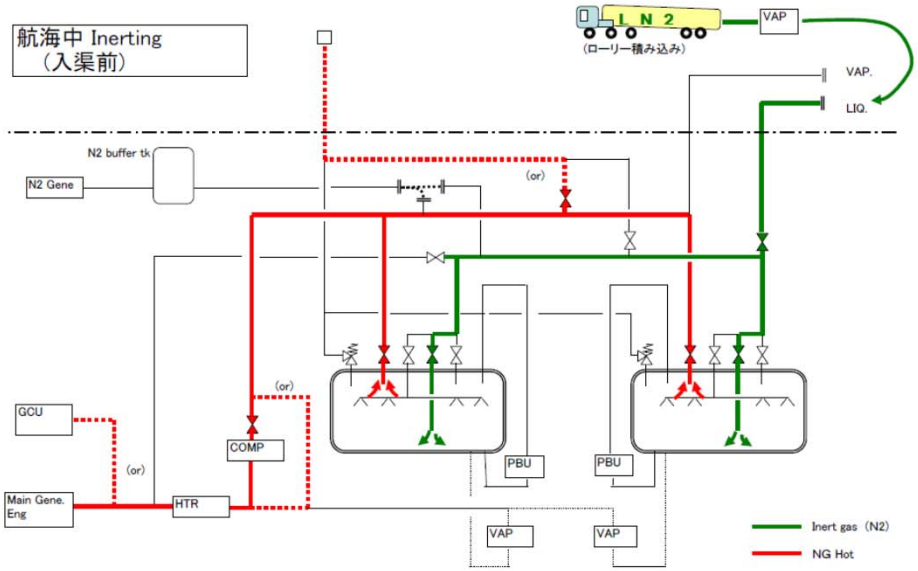
1. LNG tank warm-up
2. Inerting
3. Aeration

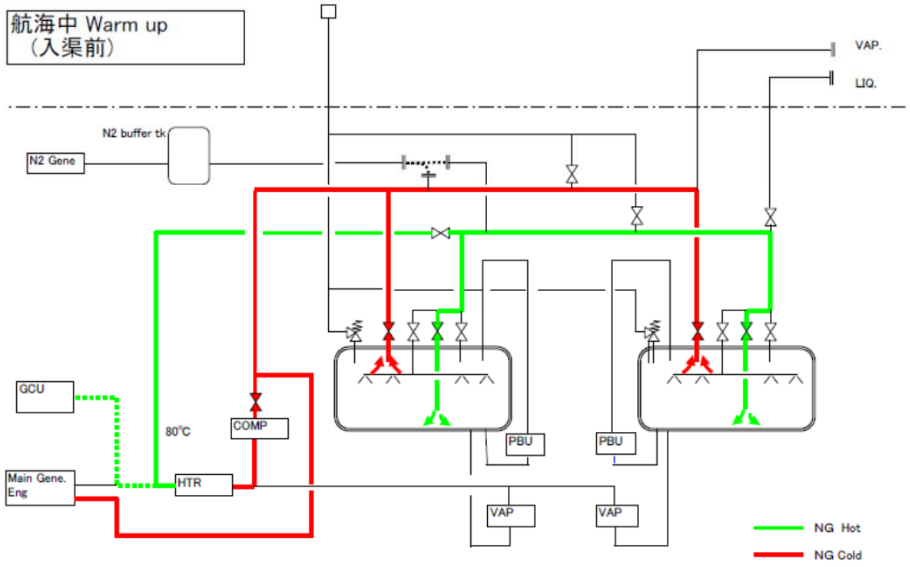
Dry dock

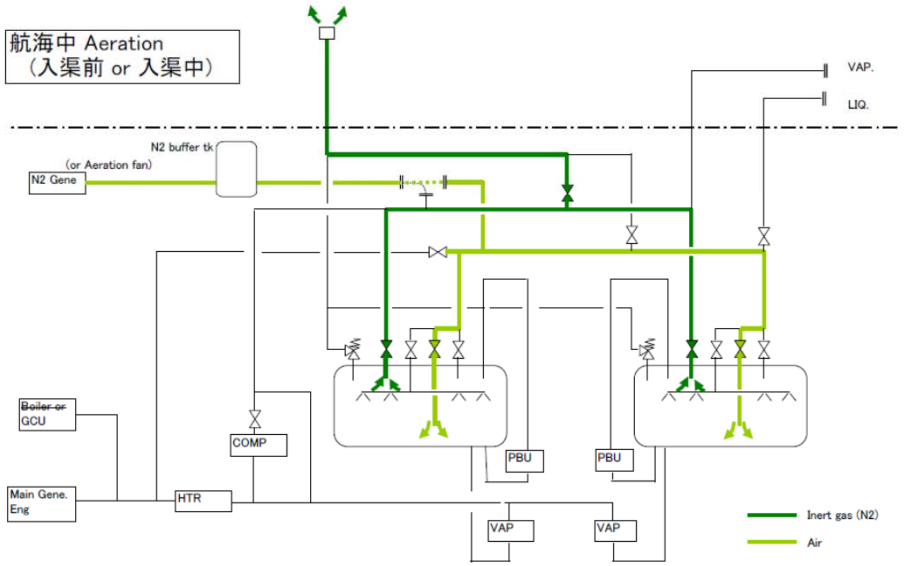
4. Inerting
5. Cool down
6. Initial LNG filling

Considering Equipments：

Compressor / Heater / GCU / N2 Gene.

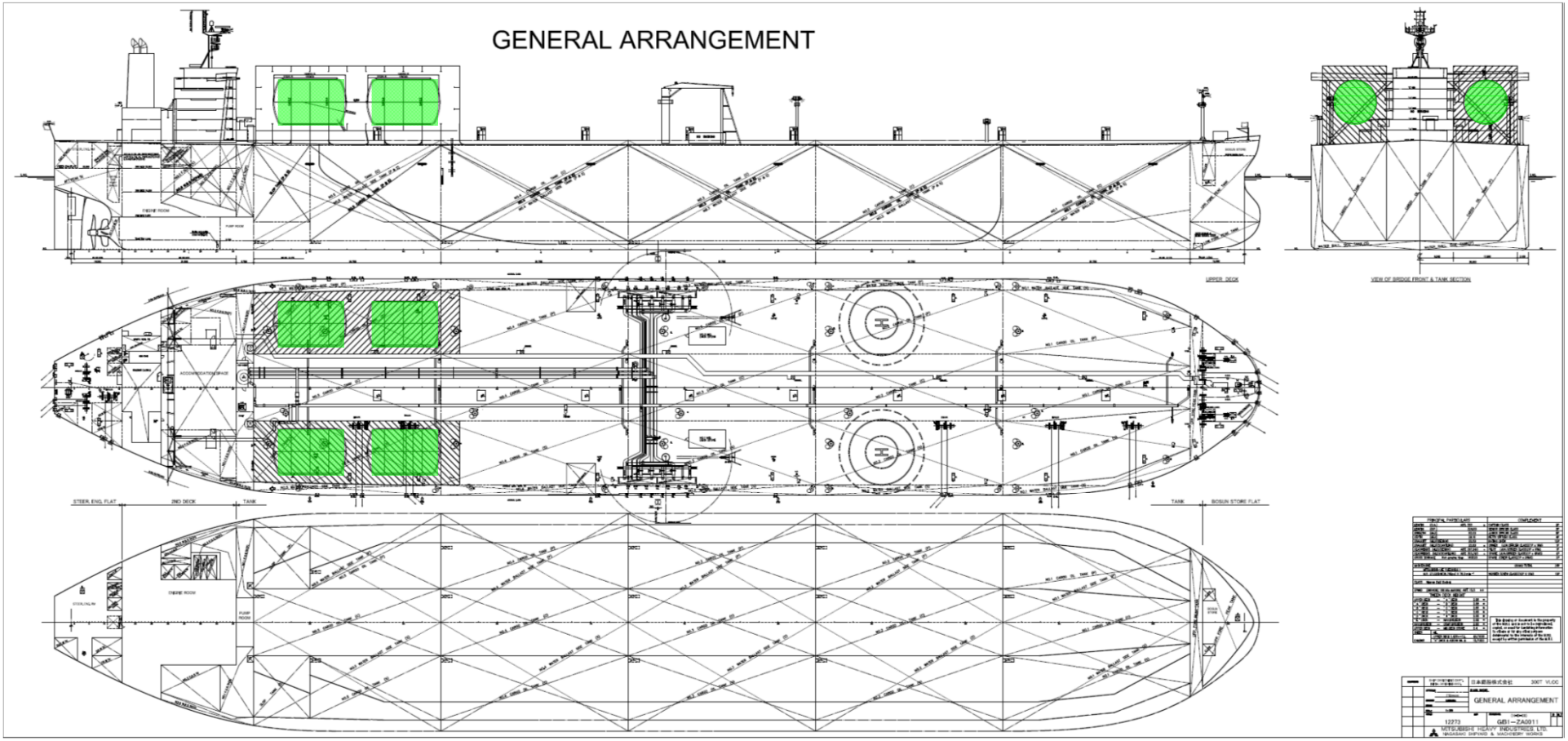




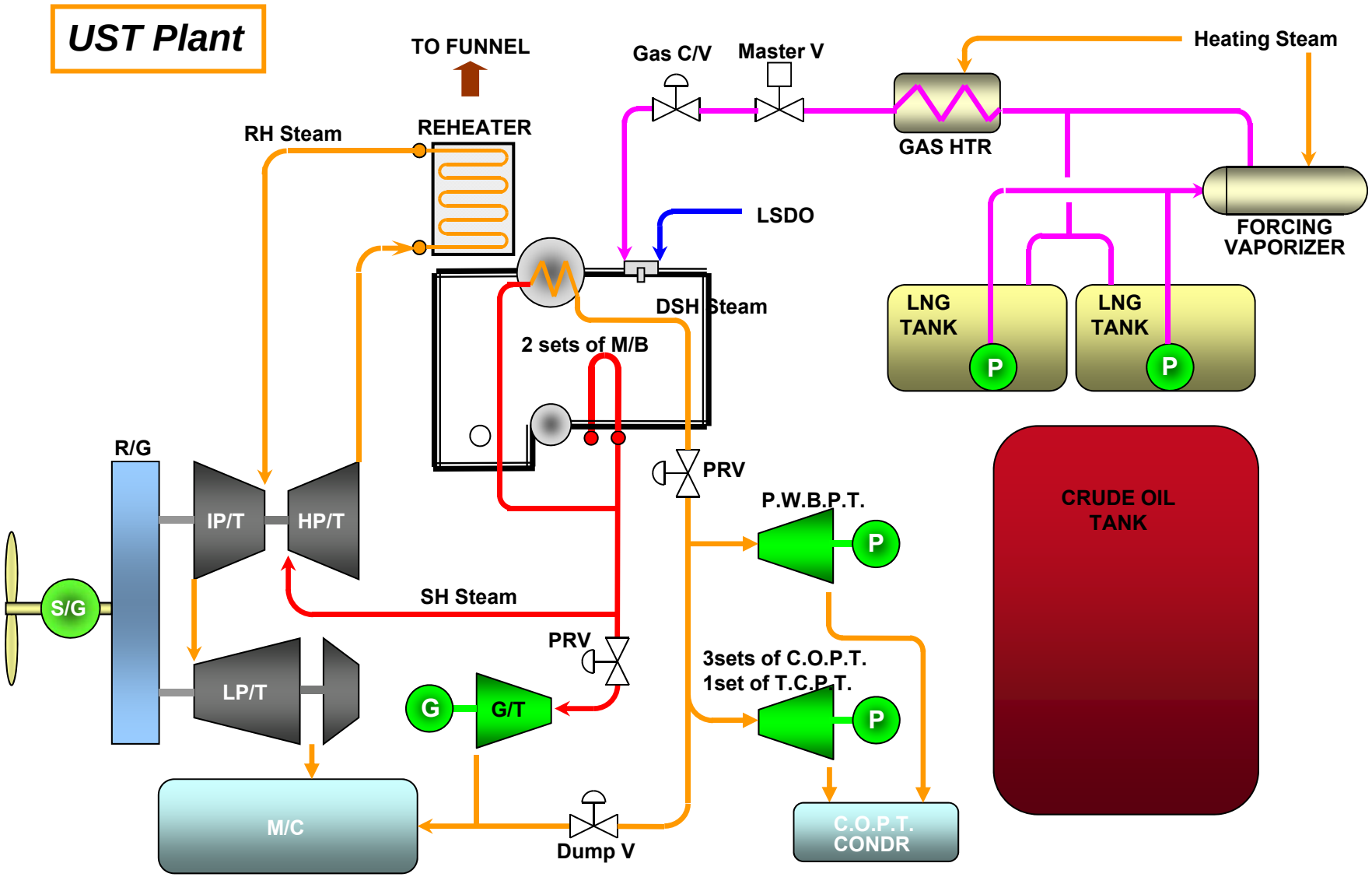


⑦ LNG Fuel Ship by MHI （ VLCC + eGF ）

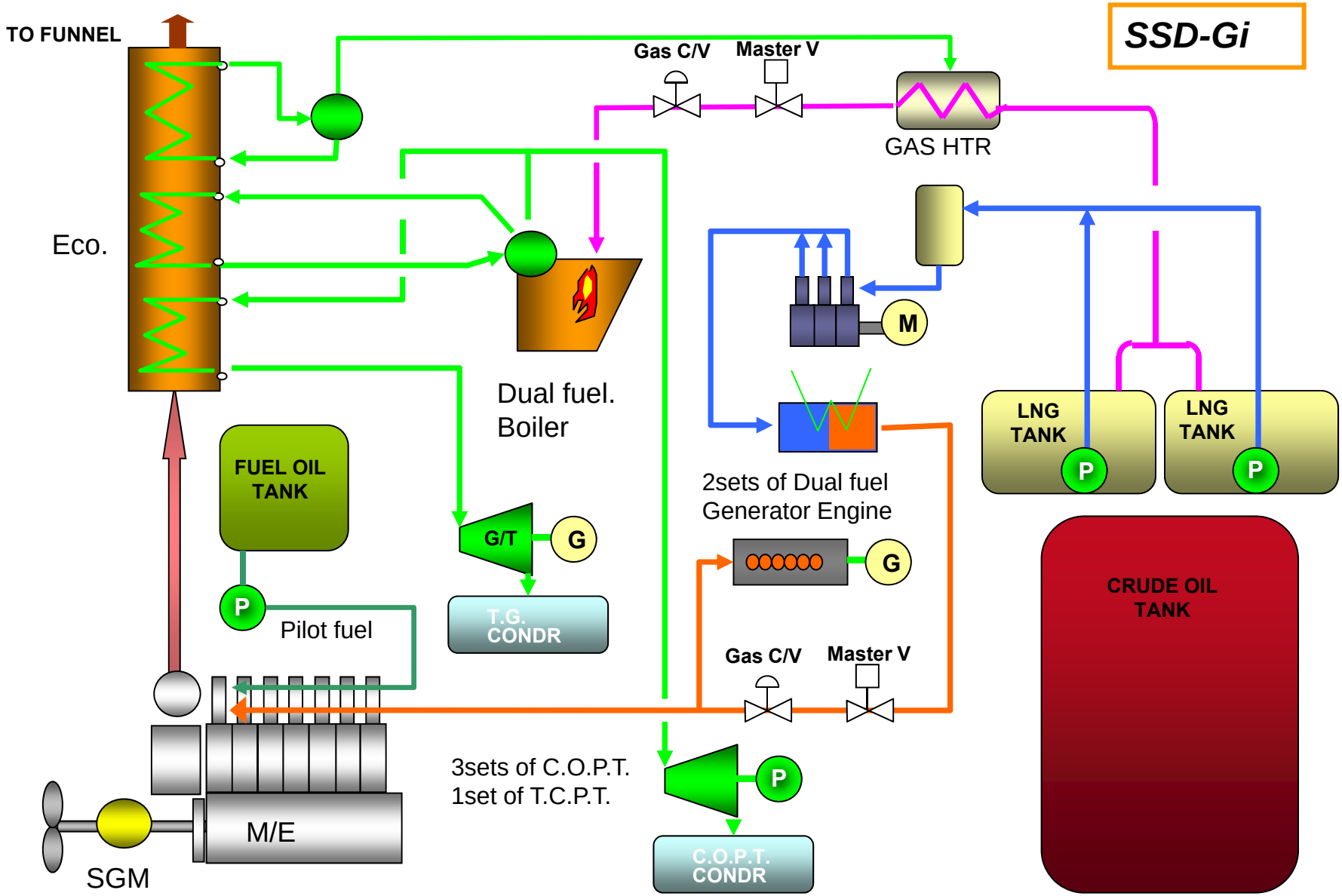
300kDWT、15.5knots、PG ←→ Japan



⑦ LNG Fuel Ship by MHI (Concept design: VLCC)



⑦ LNG Fuel Ship by MHI（Concept design：VLCC）



⑦ LNG Fuel Ship by MHI（Concept design：VLCC）

VLCC Emission calculation		Conventional Diesel	UST Plant		SSD-Gi	
Vessel speed		15.5 kts				
Propulsion power		27000 kw x 1 set				
Elect. Gene.	T/G	1,100kw x 1set	900kw x 1set		2,000kw x 1set	
	D/G	1,100 kw x 2sets	1,100 kw x 2sets		1,400 kw x 2sets	
	SGM		1,100 kw x 1set		1,000kw x 1set	
Cargo capacity		355,000	355,000		355,000	
Voyage days / year		300 days				
Fuel consumption	FO. (ton/day)	90	--		5.2	
	LNG (ton/day)	--	108.0		81.8	
Emission	CO2 (k-ton/y)	84,605	89,100	+5%	72,401	-14%
	NO x (ton/y)	1,913	33	-93%	1,672	-13%
	SO x (ton/y)	1,811	0	-100%	145	-92%

HFO.：3% S、MDO:0.5%

SSD-Gi will required additional treatment unit to meet NOx Tier-III

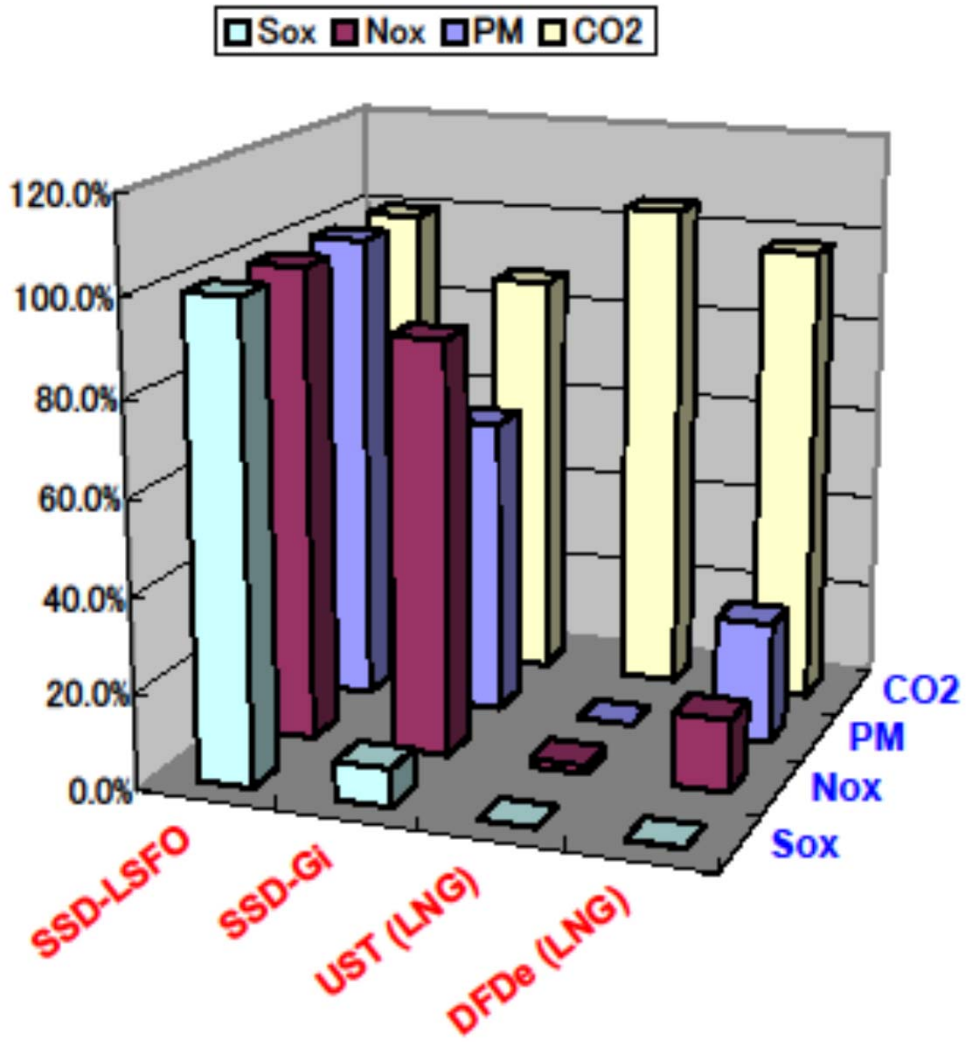
⑦ LNG Fuel Ship by MHI (Concept design: VLCC)

MITSUBISHI HEAVY INDUSTRIES, LTD.

VLCC Emission calculation						H.F.O.: 3% S、MDO: 0.5% S
Main Propulsion		Slow-speed Diesel (H.F.O.)	DF Slow-speed Diesel (LNG) Plant-A		DF Slow-speed Diesel (LNG) Plant-B	
Vessel speed		15.5 kt				
Propusion power		27,000 kw x 76 rpm			25,000 kw x 63 rpm	
Electric. Gene.	T/G	1,100kw x 1set	2,000kw x 1set		--	
	STG	--	--		2,000kw x 1set	
	D/G	1,100 kw x 2sets	1,400 kw x 2sets		1,400 kw x 2sets	
	SGM		1,000kw x 1set		1,000kw x 1set	
Cargo capacity		355,000	326,000		326,000	
Voyagedays / year		300 days				
Fuel consumption	FO. (ton/day)	90	5.2		5.5	
	LNG (ton/day)	--	81.8		66	
Emission	CO2 (k-ton/y)	84,605	72,401	-14.4%	59,649	-29.5%
	NO x (ton/y)	1,913	1,672	-12.6%	1,548	-19.1%
	SO x (ton/y)	1,811	145	-92.0%	135	-92.6%

SSD-Gi will required additional treatment unit to meet NOx Tier-III

Comparison of Emission



SSD-Gi ： Minimum CO2

(NOx tier-III： Additional Equipment)

4Cycle DFDE：Fulfill NOx tier-III / SOx

UST ：CO2 slightly increase,
Almost zero of NOx / SOx / PM

(Comparison with conventional diesel engine)

SSD: Slow Speed Diesel

LSFO: Low Sulfur Fuel Oil

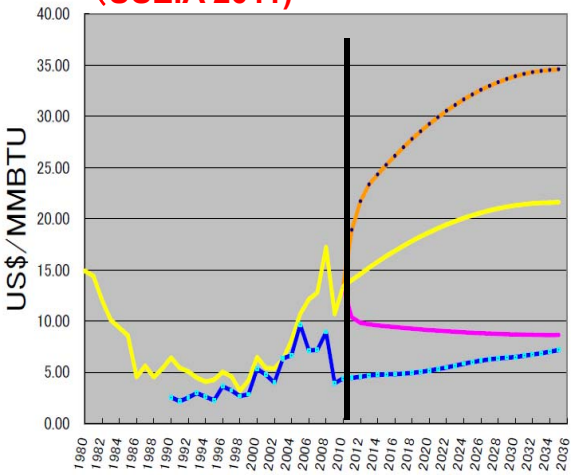
Gi: Gas injection

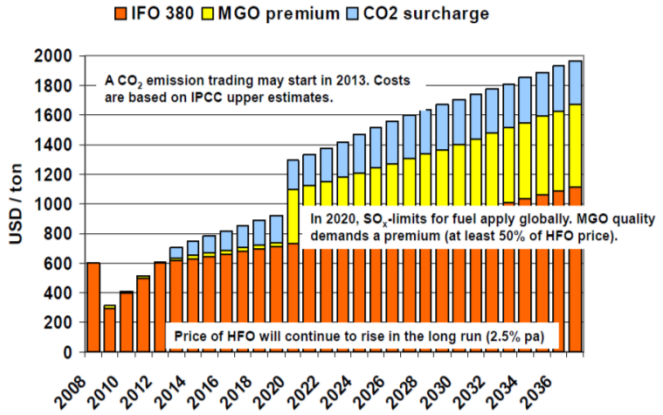
UST: Ultra Steam Turbine Propulsion system

DFDe: 4Cycle Dual Fuel Diesel
Electric Propulsion system

⑦ LNG Fuel Ship by MHI (Bunker Price)

Trend data (NG and Crude oil)
(USEIA 2011)





Ref. Germanischer Lloyd AG

*1 :	Index : HFO x 1.31
*2 :	49.10MJ/kg
*3 :	1MBTU=1,055.056MJ
*4 :	80¥/US$

Equal value calculation of LNG price against H.F.O. price in Japan
(ROPAX + eGF)

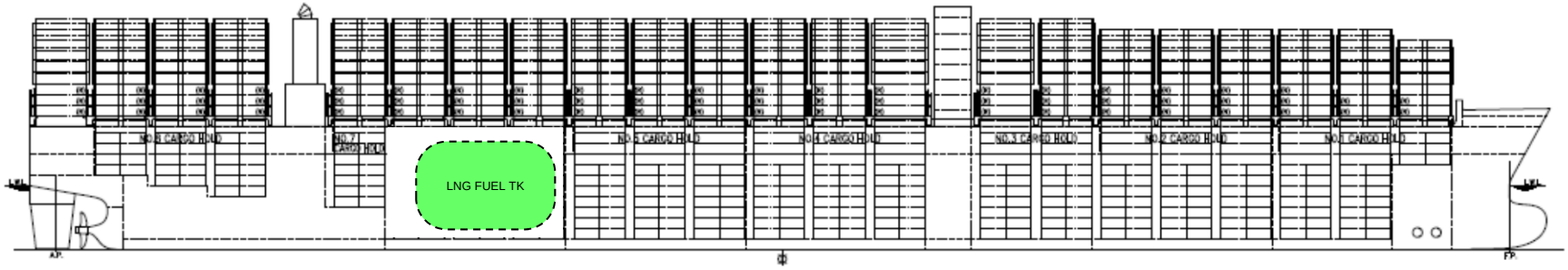
H.F.O. charges			Equal value calculation of LNG						
H.F.O. consumption			MDO (Pilot oil) consumption			Equal price of LNG			
		①			②	③	④		
Unit ¥	Consumption	Charge	Unit ¥	Consumption	Charge	(①−②)	Consumption	Unit price 1	Unit price 2
(¥/MT)	(ton/y)	(M¥/y)	(¥/MT) *1	(ton/y)	(M¥/y)	(M¥/y)	(ton/y)	(円/MT) (③/④)	($/MMBTU) *2、*3、*4
45,000	9,116	410.2	58,950	79	4.7	410.2	8,136	50,420	13.5
46,000	9,116	419.3	60,260	79	4.8	414.6	8,136	50,956	13.7
50,000	9,116	455.8	65,500	79	5.2	450.6	8,136	55,387	14.9
55,000	9,116	501.4	72,050	79	5.7	495.7	8,136	60,925	16.4
60,000	9,116	547.0	78,600	79	6.2	540.8	8,136	66,464	17.9
65,000	9,116	592.5	85,150	79	6.7	585.8	8,136	72,003	19.3
70,000	9,116	638.1	91,700	79	7.2	630.9	8,136	77,541	20.8

⑦ LNG Fuel Ship by MHI （ Container Ship + eGF ）

14,000TEU Container ship, 23knots, Asia-Europe

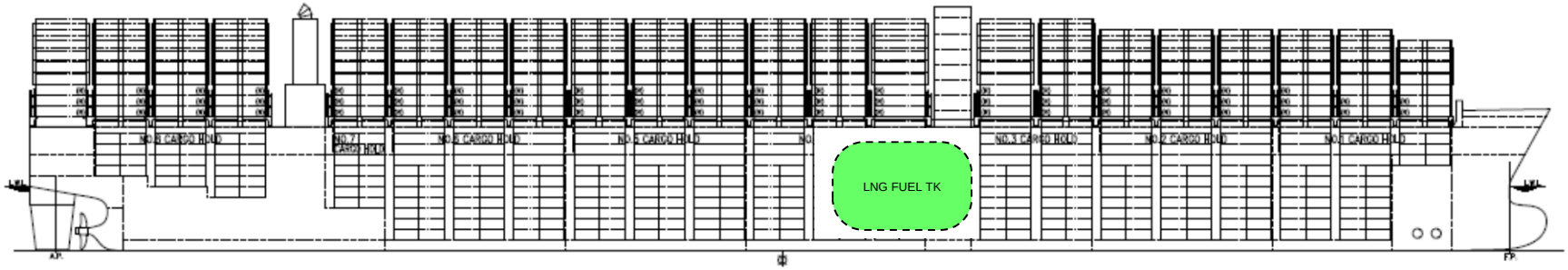
Arrange – 1: -800TEU for all route

-330TEU for the present ECA and the Mediterranean Sea



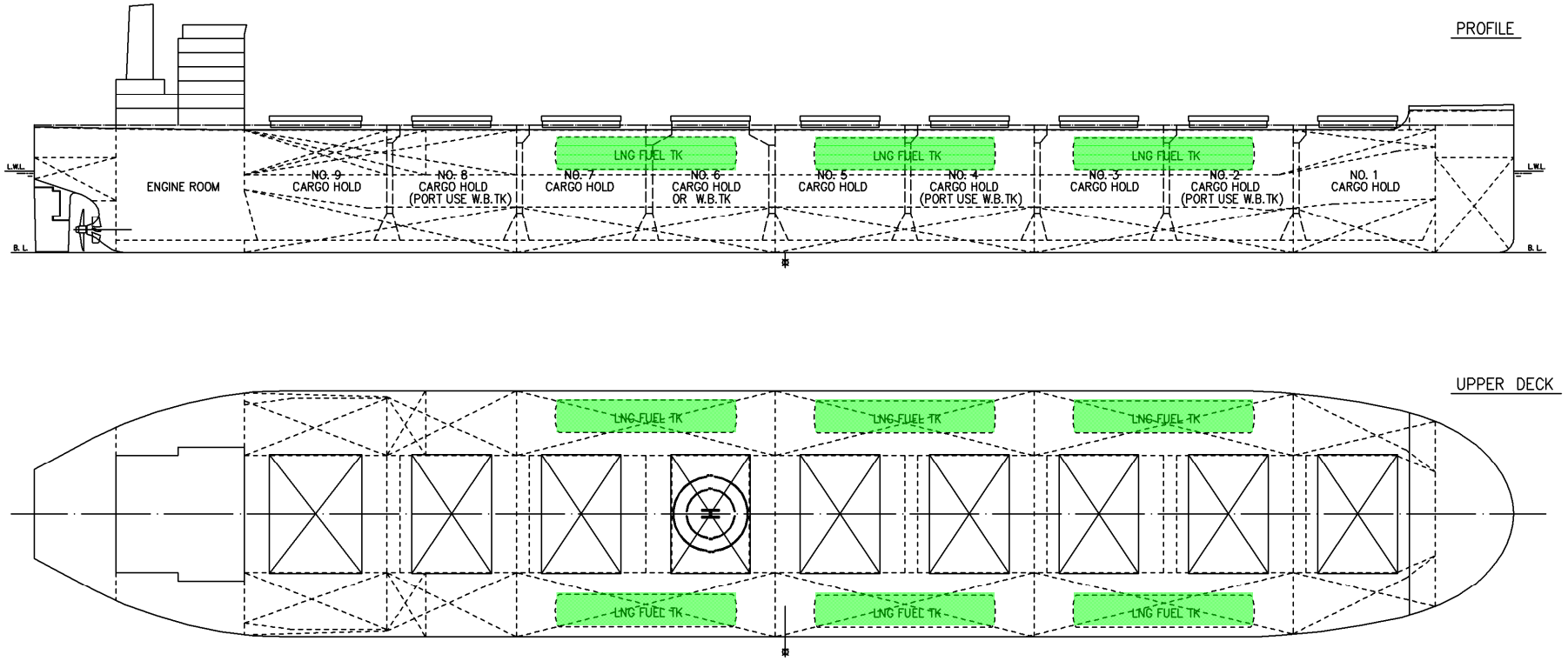
Arrange – 2: -480TEU for all route

-180TEU for the present ECA and the Mediterranean Sea



⑦ LNG Fuel Ship by MHI （ ORE CARRIER + eGF ）

205 Ore Carrier, 14.2 knots, Brazil -Asia

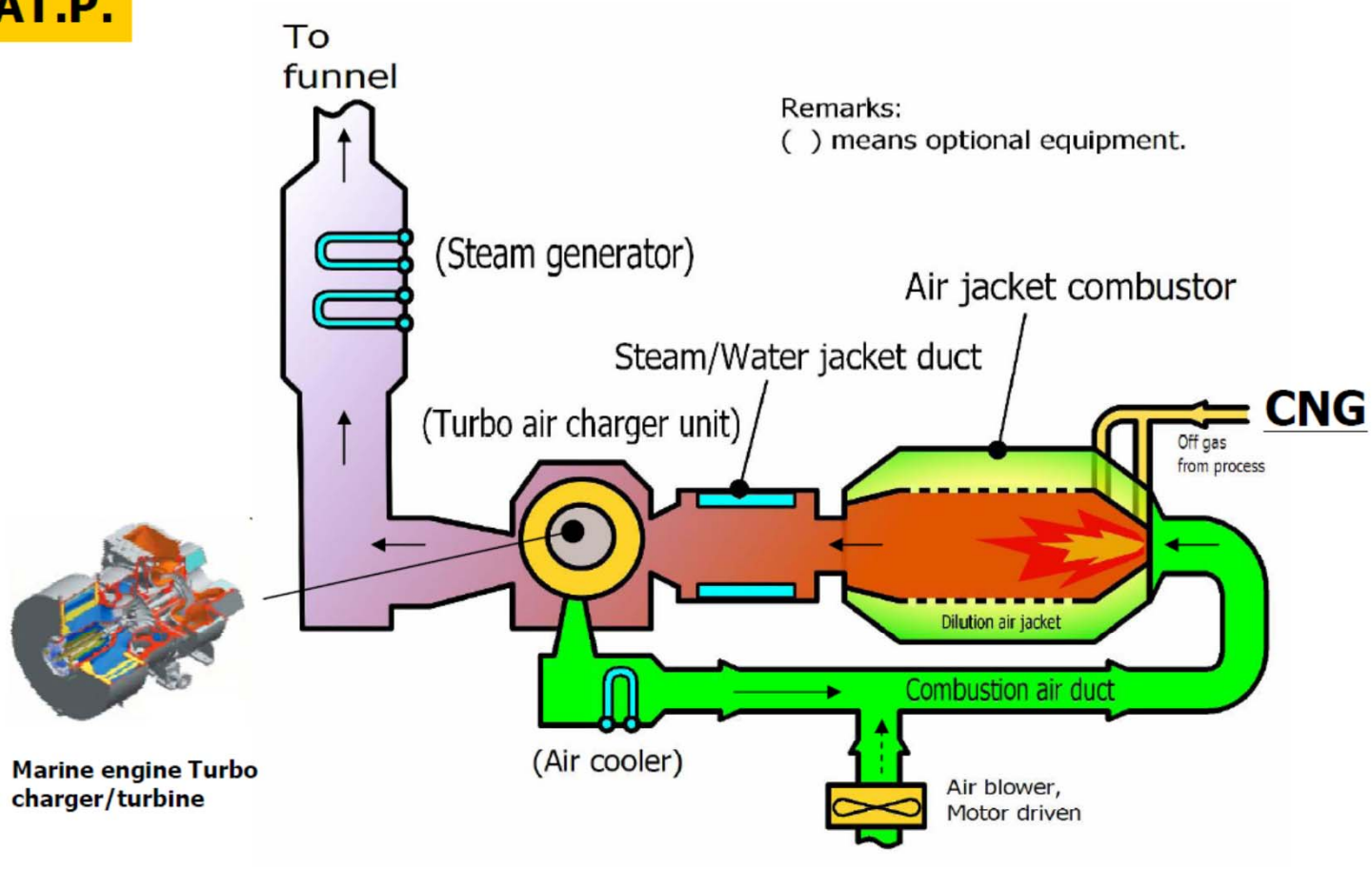


⑦ LNG Fuel Ship by MHI（LNG Bunker Ship + eGF）

5,000m3 LNG Bunker ship

PAT.P.

Compact Gas Combustion Unit



Process diagram

⑧ MHI Gas Ship Equipments

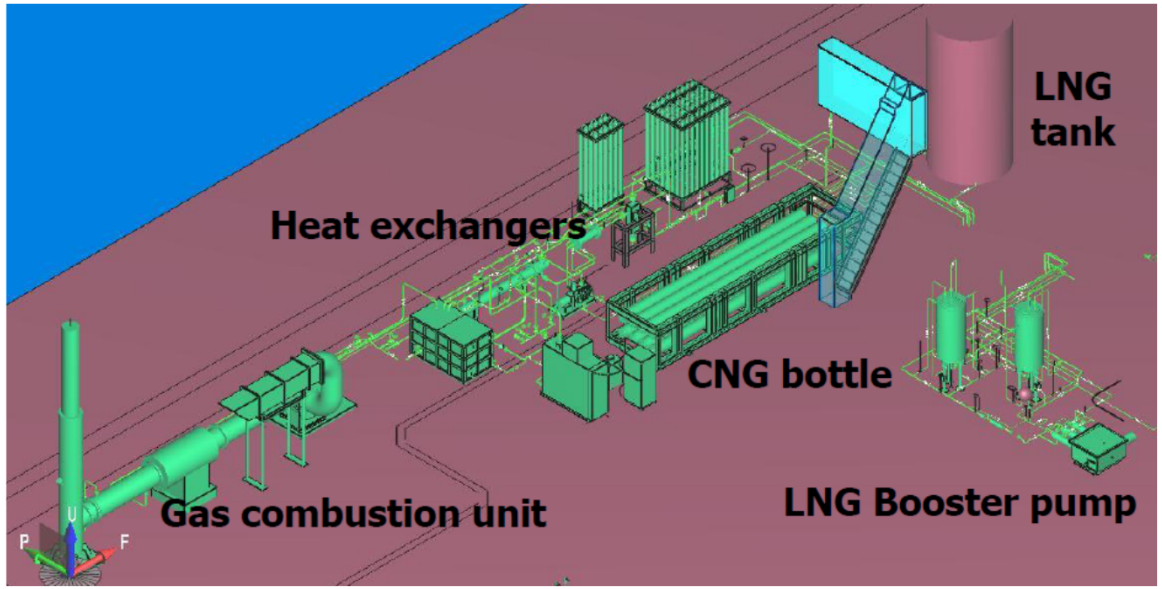
MHI 30MPa LNG Fuel supply Unit

1. Demonstration Plant at MHI Nagasaki R&D center

a. LNG Tank
b. LNG Booster pump
c. Heat exchanger
d. Gas combustion unit
e. CNG bottle

2. Delivery Record

1) MES Tamano Works, ME-GI FAT Facility



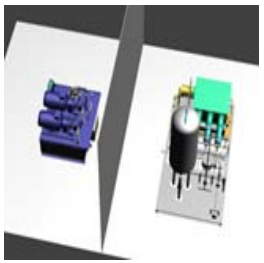
⑧ MHI Gas Ship Equipments

Gas ship Equipment Module and System -GEMS-

Applicable

No.	MHI Gas Ship Equipment	LNGC	LPGC	LNG fuel ship	FSRU	Local LNG Supply chain Floater	FLNG
(1)	30MPa LNG fueling unit						
(2)	1MPa BOG fueling unit						
(3)	LNG (LPG) re-liquefaction unit						
(4)	Re-gasification unit						
(5)	Gas Combustion Unit (GCU)						
(6)	Double wall tank						

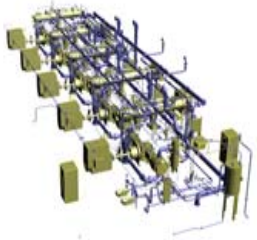
(1)



(2)

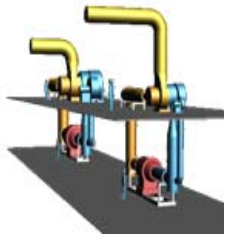
(3)【LNG】

(3)【LPG】



(4)

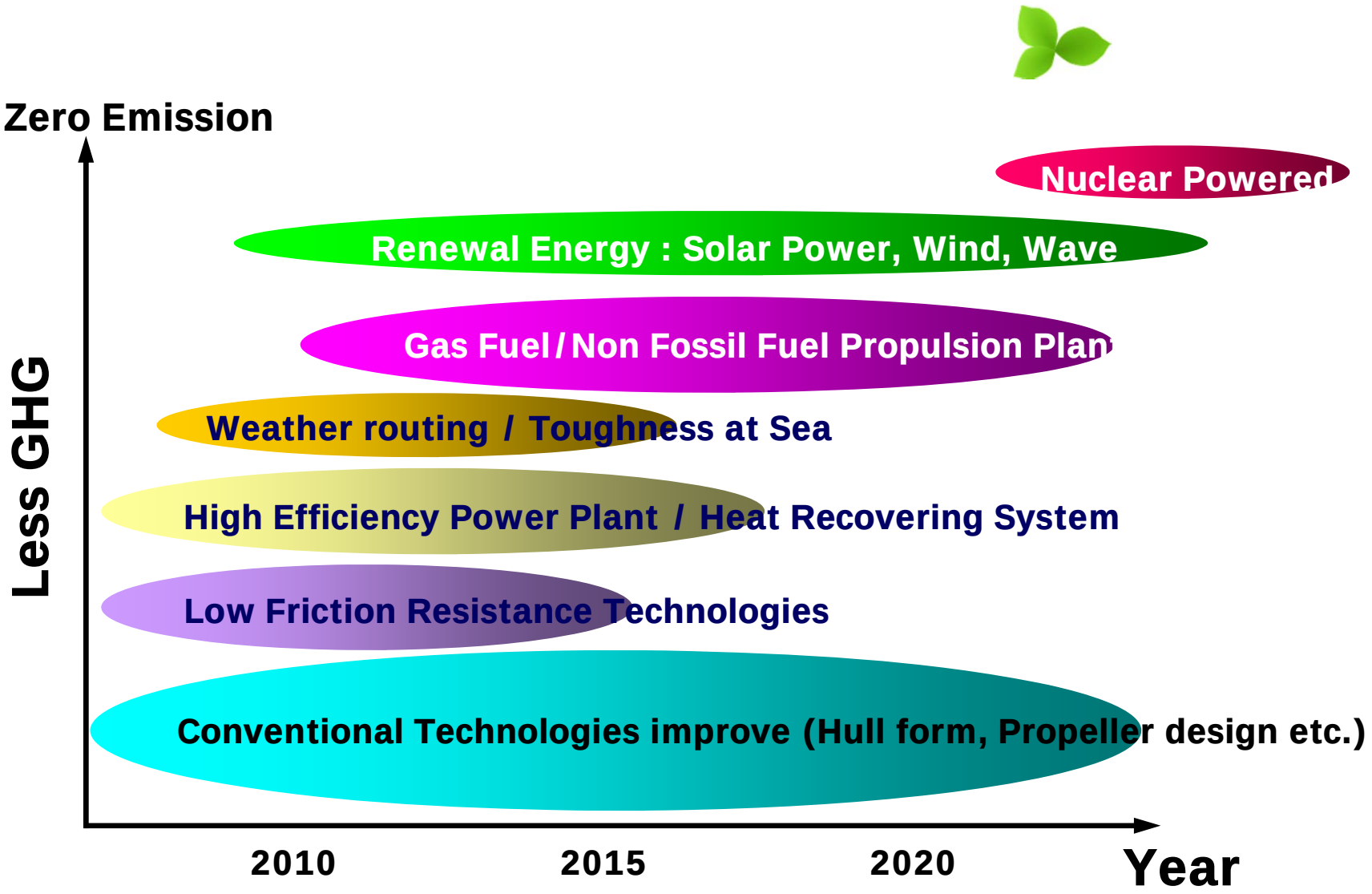
(5)



(6)

BOG; Boil Off Gas
FSRU: Floating Storage and Regasification Unit

Road Map for Reduction of GHG



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Thanks for your attentions!