LPG Combustion Solution Using Gas Reformer

November 7th, 2019

DAIHATSU DIESEL MFG.CO.,LTD

Today's Contents

1．The Possibility of LPG as Marine Fuel

2．LPG Reformer

3．Gas Fuel Ship System
Configuration Example
Using LPG Reformer

4．Summary

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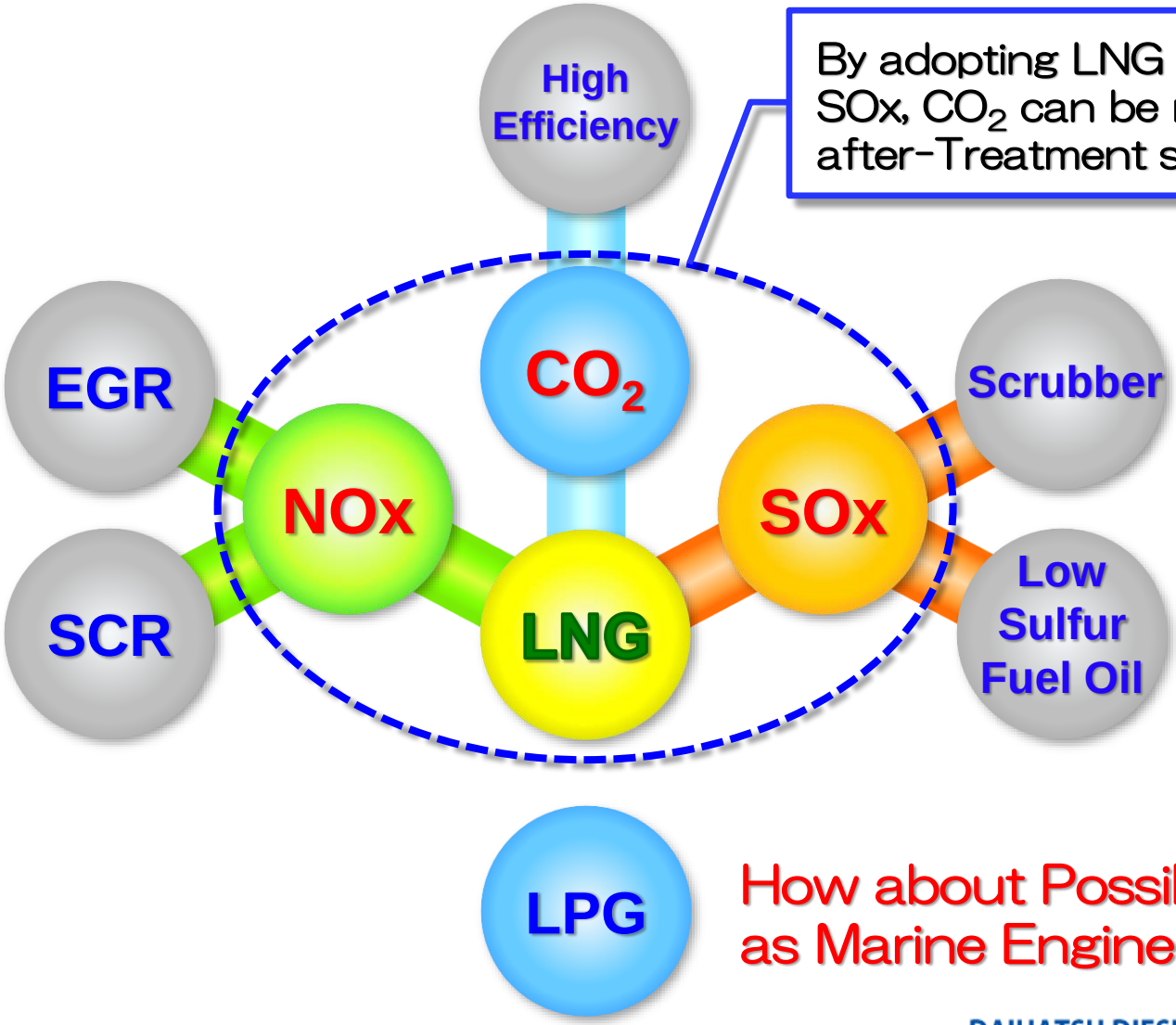
1．The Possibility of LPG as Marine Engine Fuel

Compliant Technology for Marine Engines



How about Possibility of LPG as Marine Engine Fuel ?

1．The Possibility of LPG as Marine Engine Fuel

Characteristics of LNG and LPG

Items			Unit	LNG (Methane)	LPG (Propane)
Conditions	Normal Temp. Normal Pressure		—	Gas	Gas
	Normal Temp. High Pressure.（1.8 MPa）		—	Gas	Liquid
	Low Temp.（about -42 ℃） Normal Pressure		—	Gas	Liquid
	Cryogenic Temp. （about -160 ℃）		—	Liquid	Liquid
Lower Heating Value		Liquid	MJ/kg	50.0	46.4
		Gas	$MJ/m^3_{(N)}$	35.9	93.2
Density		Liquid	kg/m^3	426 (@Boiling Point)	585 (@Boiling Point)
		Gas	$kg/m^3_{(N)}$	0.72	2.01
Gasification Volume			—	× 600	× 300
Methane Number（MN）			—	100	35
Boiling Point			℃	-161.5	-42.1

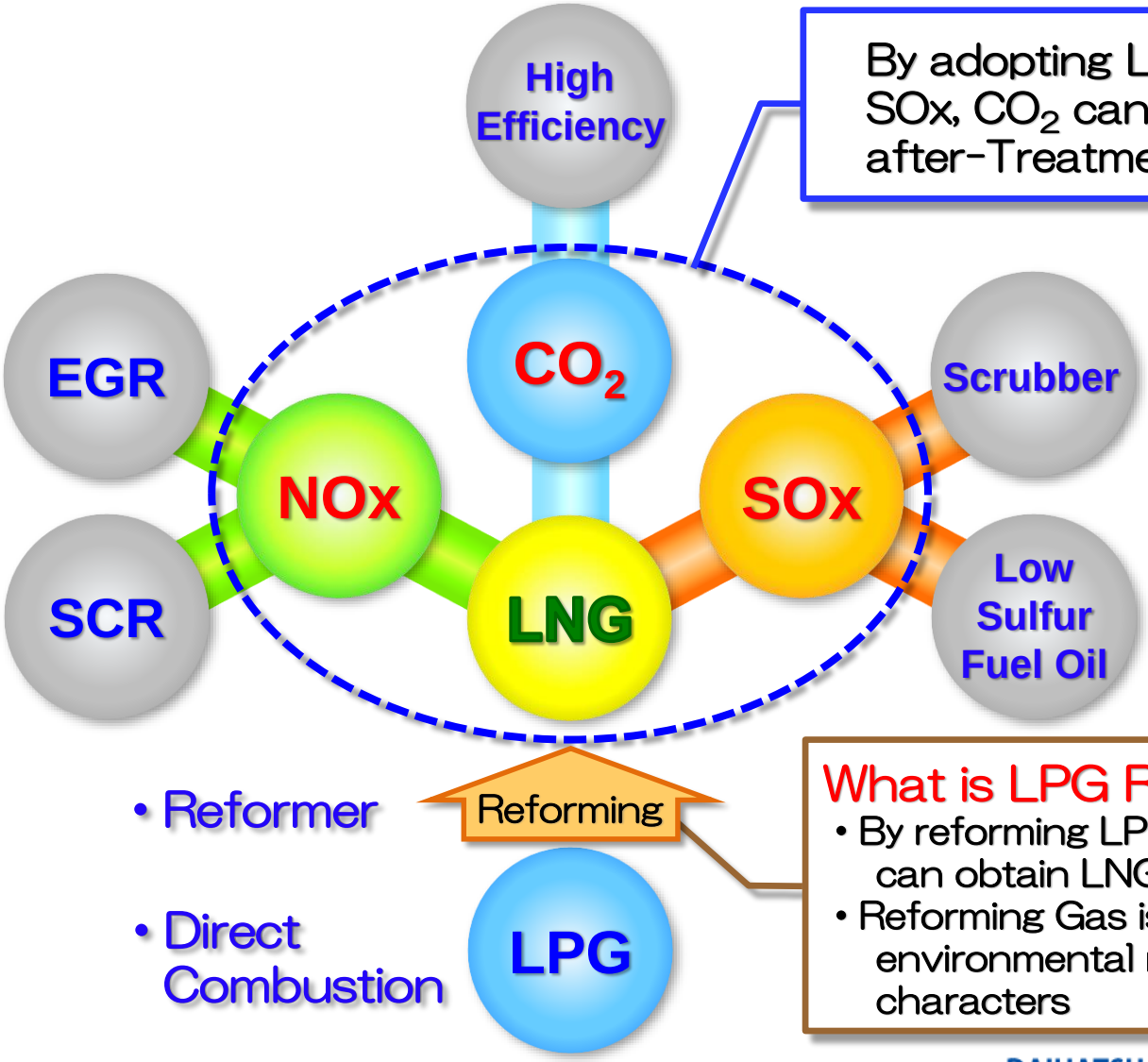
1．The Possibility of LPG as Marine Engine Fuel

Comparison for LNG and LPG for Marine

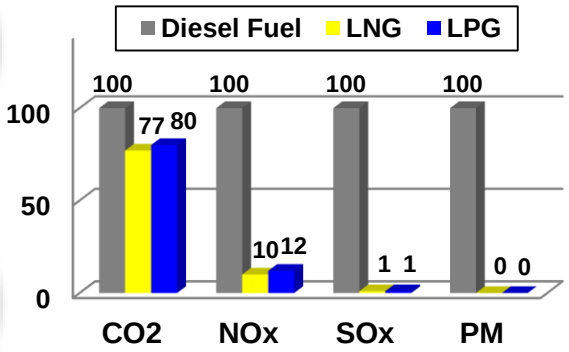
	LNG	LPG
Fuel Gas Quality	Varies by Regions	Homogeneous all over the world
Fuel Gas Supply Points	Limited	• Possible to use existing Supply Equipment • Possible to use existing Small Type Barge Vessel
Long Term Storage	Not Suitable (Processing of Boil off Gas)	Suitable
Handling	With Extreme Care (Cryogenic Temperature)	Relatively easy
Initial Cost	Large	Medium
Density（Gas）	0.72 (Lighter than Air)	2.01 (Heavier than Air)
Methane Number (MN)	100	35

1. The Possibility of LPG as Marine Engine Fuel

Compliant Technology for Marine Engines



By adopting LNG as Gas Fuel, NOx, SOx, CO_2 can be reduced without after-Treatment system



- Reformer
- Direct Combustion

Reforming

What is LPG Reformer ?

- By reforming LPG to LNG equivalent Gas, it can obtain LNG equivalent performance
- Reforming Gas is capable to comply with environmental regulation as equal as LNG characters

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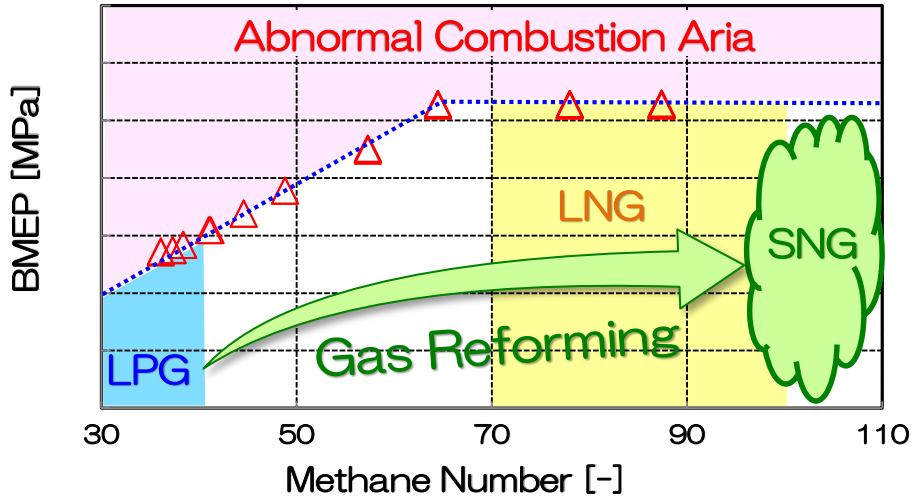
1．The Possibility of LPG as Marine Engine Fuel

Measures for Using LPG as Marine Fuel

Combustion Type		Operation Performance
Direct Combustion Use LPG Directly	Gas Injection	• No Load Limitation • After-Treatment is Necessary to Satisfy IMO Tier 3 of NOx Emission by Gas Mode Operation
	Premixed Lean Burn	• Limitation of Engine Load (Methane Number of LPG is Lower than LNG)
Reformer Reforming LPG to SNG	Premixed Lean Burn	• No Load Limitation (Methane Number of SNG is over 65) • SNG can be Easily Manufactured by Reforming



※ SNG : Synthetic Natural Gas

※ Methane Number (MN) is Anti-Knocking Index of Gas Fuel (MN : High→ Knocking : Low)

※ Daihatsu Diesel's Dual Fuel Engine Compatible with City Gas 13A (Methane Number : 65)

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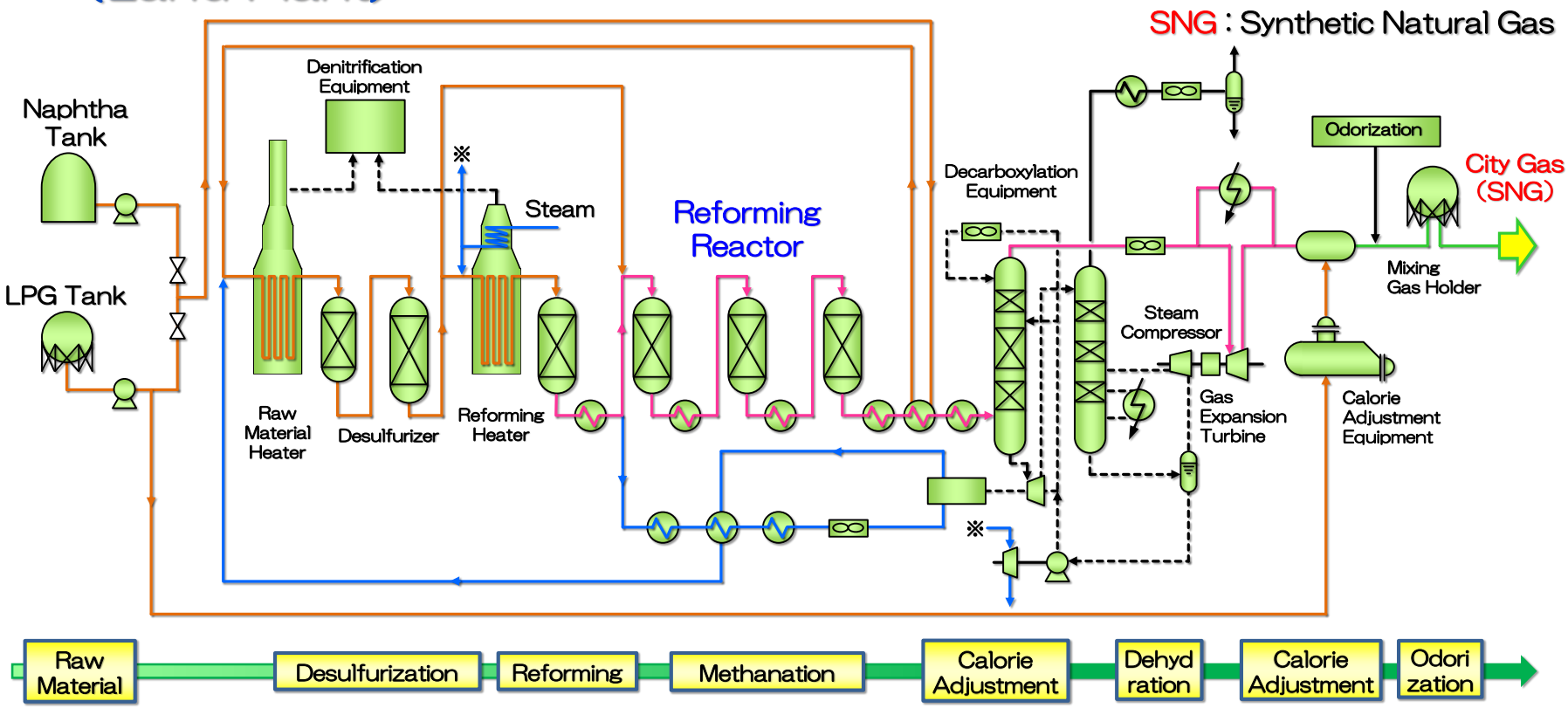
2. LPG Reformer

Equipment Configuration of Common Reformer (Land Plant)



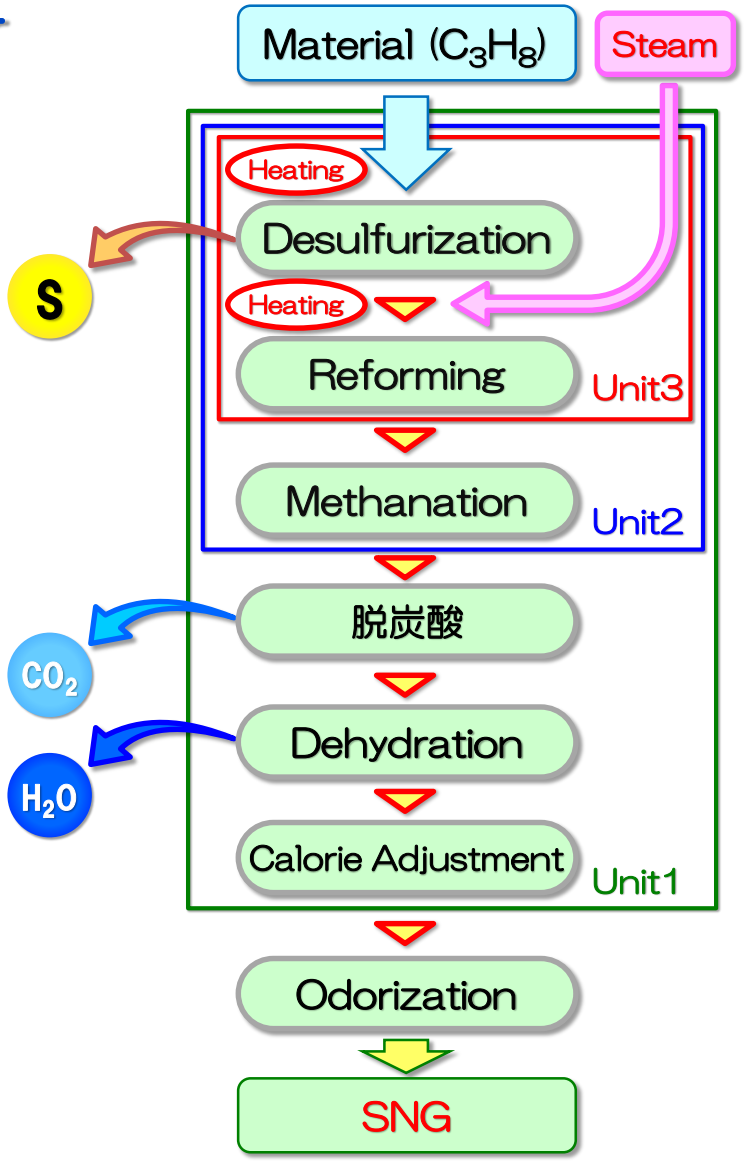
- Techniques for reforming LPG into highly pure methane have been practically used since 1970's.
- It has been used for the purpose of supply stability at the beginning of LNG introduction and risk avoidance of LNG facilities
- Review challenges and solutions for shipboard installation.

2. LPG Reformer

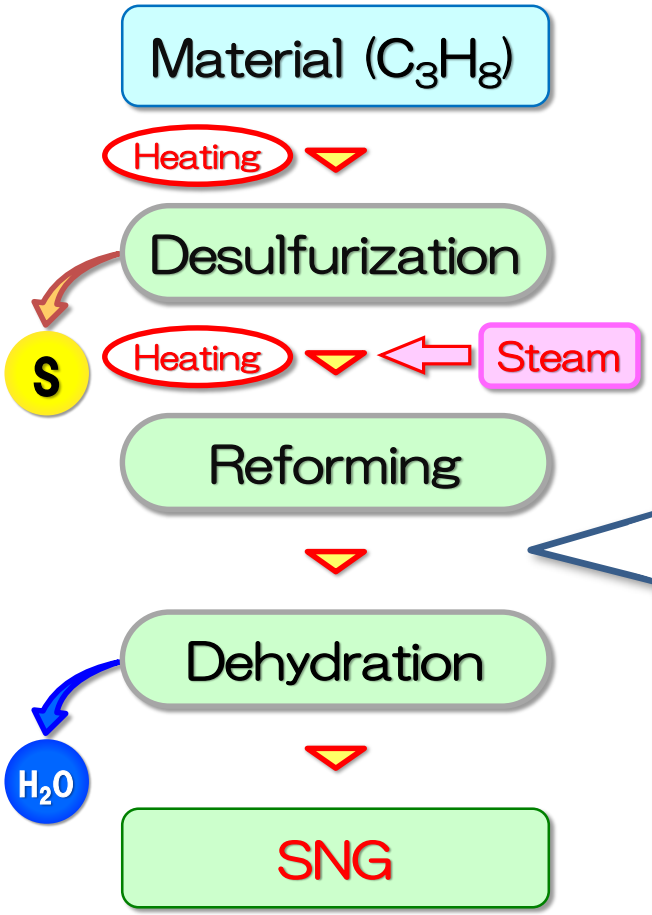
Examination of LPG Reformer Design Concept

1. Simplification of Reforming System.
2. Lower Heating Value of Reforming Gas.
3. Anti-Knocking Performance (Methane Number)
4. Applicability for Gas Fuel Engines.

Equipment configuration		Material (Propane)	Unit 1	Unit 2	Unit 3
Gas Composition	Propane (C_3H_8)	100 %	7 %	0 %	0 %
	Methane (CH_4)	0 %	92 %	77 %	68 %
	Carbon Dioxide (CO_2)	0 %	0 %	22 %	20 %
	Others	0 %	1 %	1 %	12 %
Methane Number (MN)		34	75	120	108
Lower Heating Value [$MJ/m^3_{(N)}$]		93.2	40	28	27



Principle of LPG Reformer



Main Chemical Reaction of Reforming

- Steam Reforming Reaction

$$C_3H_8 + 3H_2O \xrightarrow{\text{(Steam)}} 3CO + 7H_2$$

- CO Denaturalization Reaction

$$CO + H_2O \xrightarrow{\text{(Steam)}} CO_2 + H_2$$

- Methanation Reaction

$$CO + 3H_2 \rightarrow CH_4 + H_2O$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

2. LPG Reformer

For Reference

Utility

LPG Reformer : 4,000[kW]

	Flow		Pressure		Temp.	Remarks
			Input	Output		
Material (Propane)	425	Nm^3/h	800 [kPa(G)]	-	60℃	Above Condensation Temp.
SNG (Reforming Gas)	1,440	Nm^3/h	-	600 [kPa(G)]	45℃	
Steam	1,017	Nm^3/h	900 [kPa(G)]	-	-	Saturation Temp. About 40% can be recovered with Dehydration Process drain water
	817	kg/h				

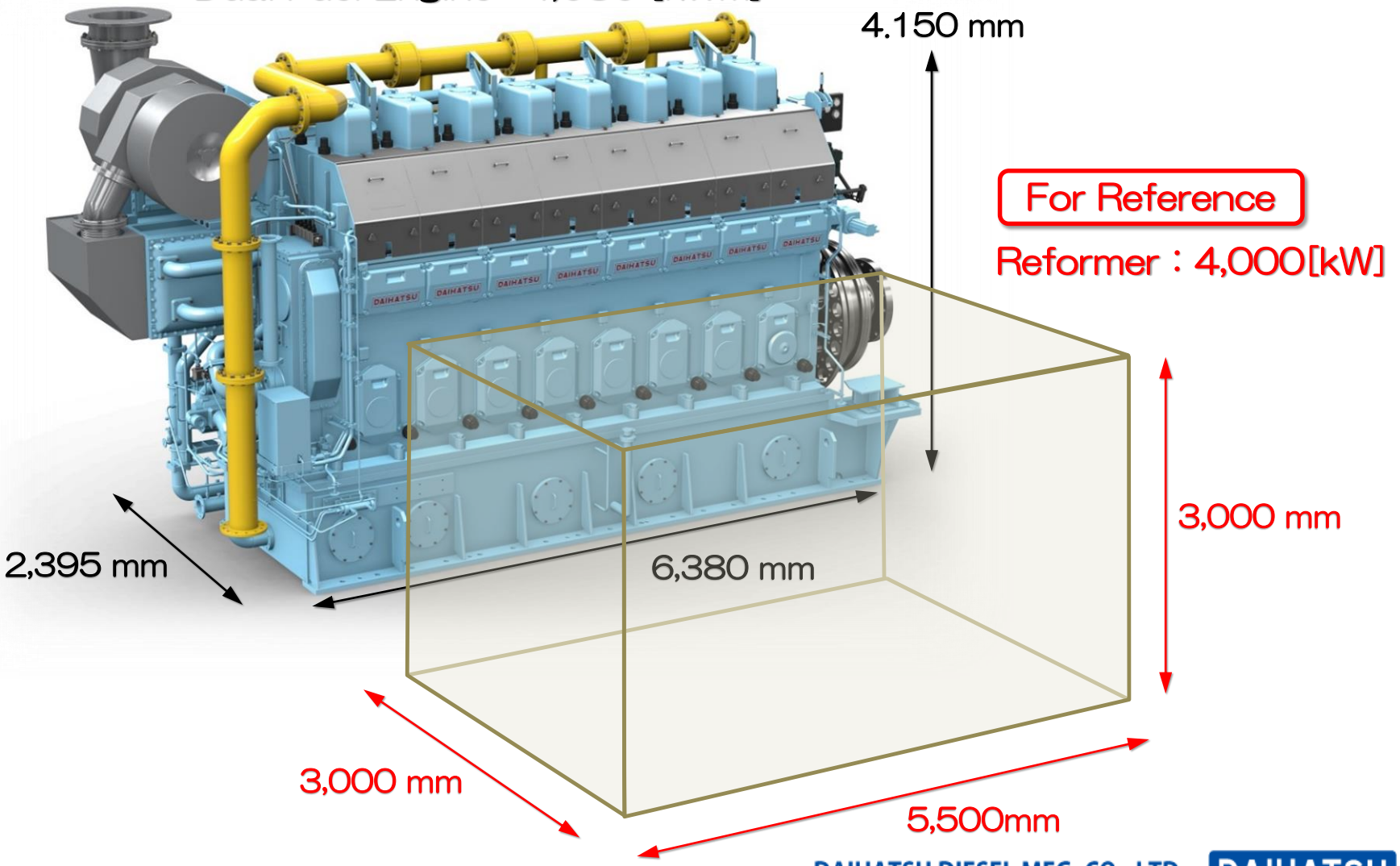
※ Purge Gas (Mixed Gas of 95% N_2, 5% H_2, 950 [kPa (G)]) : Use about 48 [Nm^3] per time

2. LPG Reformer

For Reference

LPG Reformer Size

Dual Fuel Engine : 4,080 [kWm]



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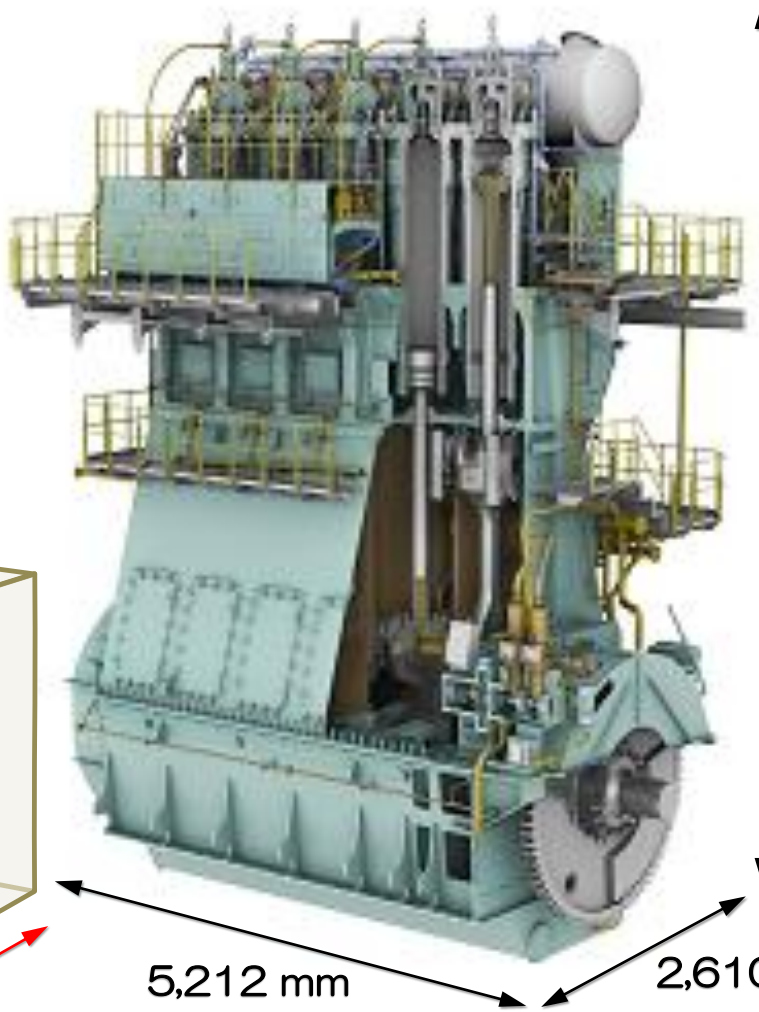
2. LPG Reformer

For Reference

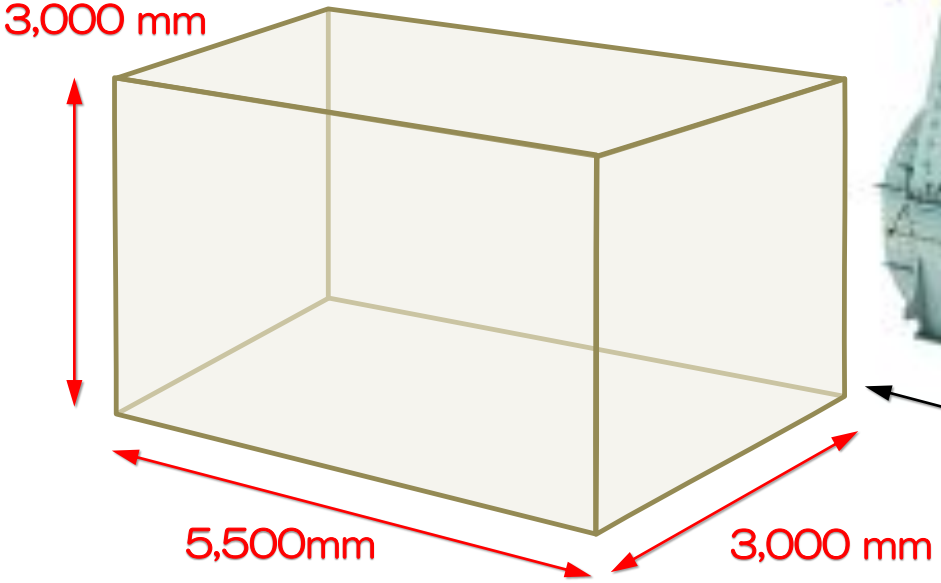
LPG Reformer Size

Dual Fuel Engine
6X40DF 4,000 [kWm]



For Reference

Reformer：4,000[kW]

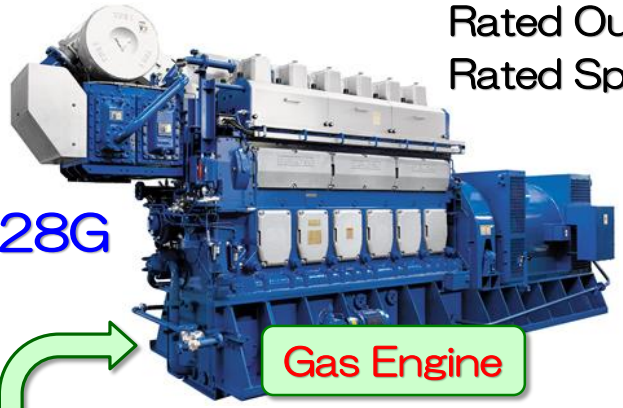


2. LPG Reformer

Verification Test System for LPG Reformer

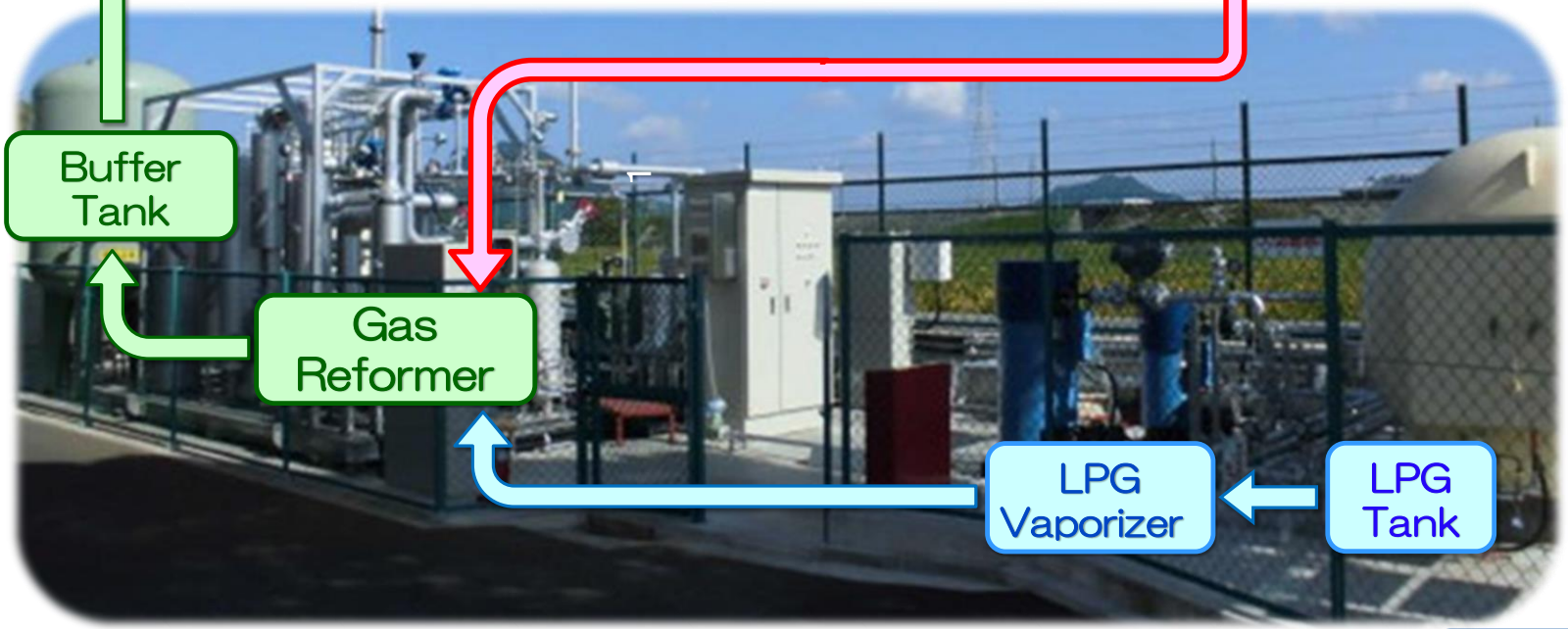
Rated Output : 1500 [kWe]
Rated Speed : 720 [min^{-1}]

6GK28G



Gas Engine

Steam Boiler



Buffer Tank

Gas Reformer

LPG Vaporizer

LPG Tank

2. LPG Reformer

AiP : Approval in Principle

NIPPON KAIJI KYOKAI

Document No: KF19MQ3007 Date: 20 September 2019

Approval in Principle

OSAKA GAS CO., LTD
LPG REFORMER UNIT FOR GAS ENGINE

Nippon Kaiji Kyokai (Class NK) has examined the documents specified in the annex of this letter based on the relevant requirements in "*ClassNK Guidelines for Ships Using Low-Flashpoint Fuels (Methyl/Ethyl Alcohol / LPG)*" , "*Part N; Ships carrying liquefied gases in bulk*" and "*Part GF; Ships using low-flashpoint fuels*" of the Society's Rules and Guidance for the Survey and Construction of Steel Ships incorporating "*International Code for a Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)*", *IMO Res. MSC.5(48) as amended by IMO Res. MSC.370(93)* and "*International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code)*", *IMO Res. MSC.391 (95)*, and found that the principle design of the system is feasible as a basic concept.

Accordingly, Approval in Principle is hereby granted.

Conditions on this approval are set out in the Annex to letter KF19MQ3007.

(Takeshi Shimada)
General Manager of Machinery Department
NIPPON KAIJI KYOKAI

September 2019
Obtained Approval in Principle of LPG Reformer Unit for Gas Engine
(Class NK)

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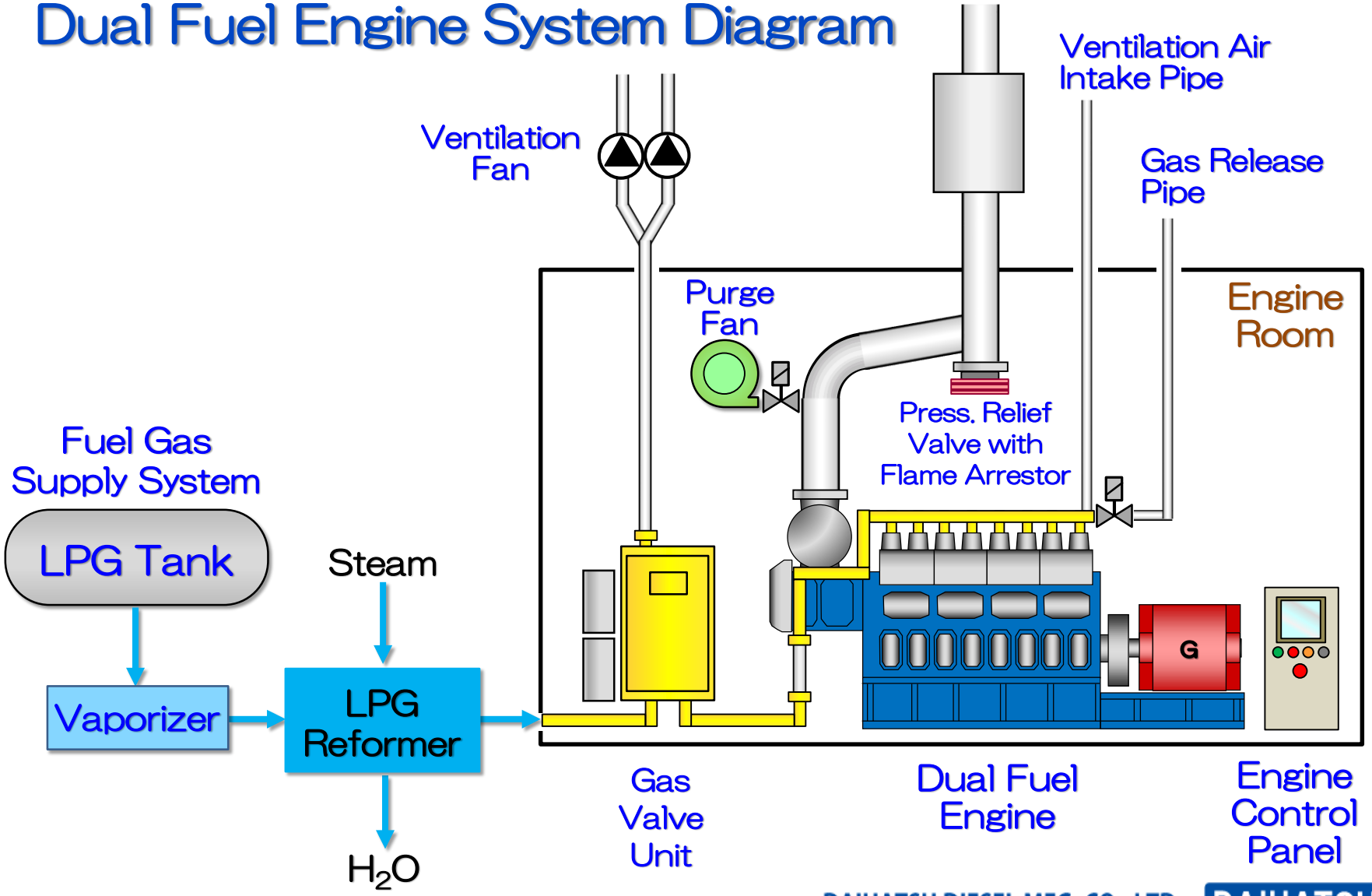
3. Gas Fuel Ship System Configuration Example Using LPG Reformer

Dual Fuel Engine System Diagram



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For Reference

3. Gas Fuel Ship System Configuration Example Using LPG Reformer

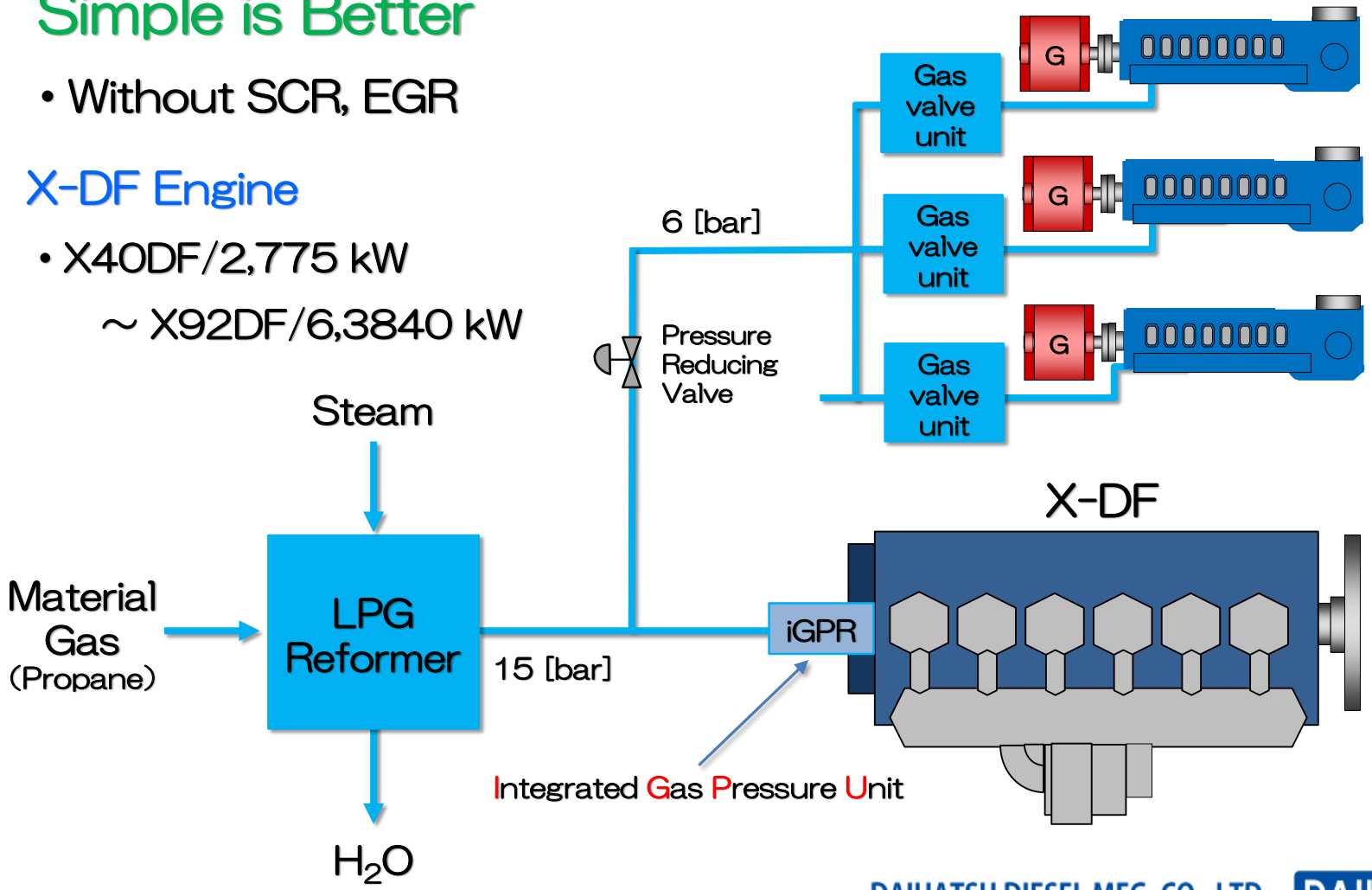
Dual Fuel Engine System Diagram (X-DF + Reformer)

Simple is Better

- Without SCR, EGR

X-DF Engine

- X40DF/2,775 kW
  ～ X92DF/6,3840 kW



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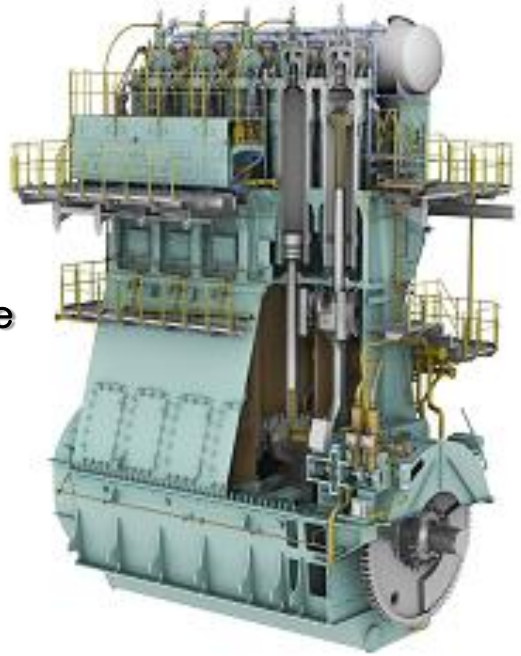
3. Gas Fuel Ship System Configuration Example Using LPG Reformer

Advantages of X-DF + Reformer



（1）Proven and Reliable System

（2）Simple Arrangement in the Engine Room

- Not need for Exhaust Gas Aftertreatment Equipment
  → Reduction of CAPEX, Reduction of Engine Room Space
- The Reforming Gas is used for the Main Engine（X-DF）and Auxiliary Engine（DF-Engine）
  → Simple Piping, Environmental Measures
- Low Pilot Fuel Consumption （MGO）
  → Study of Dual Fuel (LPG + MGO)
  → Not need for Compatible Oil Heaters, Cleaners, etc.
  → Reduction of CAPEX, Reduction of Engine Room Space and Easy to handling
- BoG can be Used for Auxiliary Engine（DF-Engine）
- Low Pressure Piping （Main Engine：15 [bar], Auxiliary Engine: 6 [bar])
  → Easy Construction for New Shipbuilding and Periodic Inspections
- The Reforming Gas is Lighter than Air
  → Improved Safety, Not Need for Additional Safety Equipment（Reduce CAPEX）

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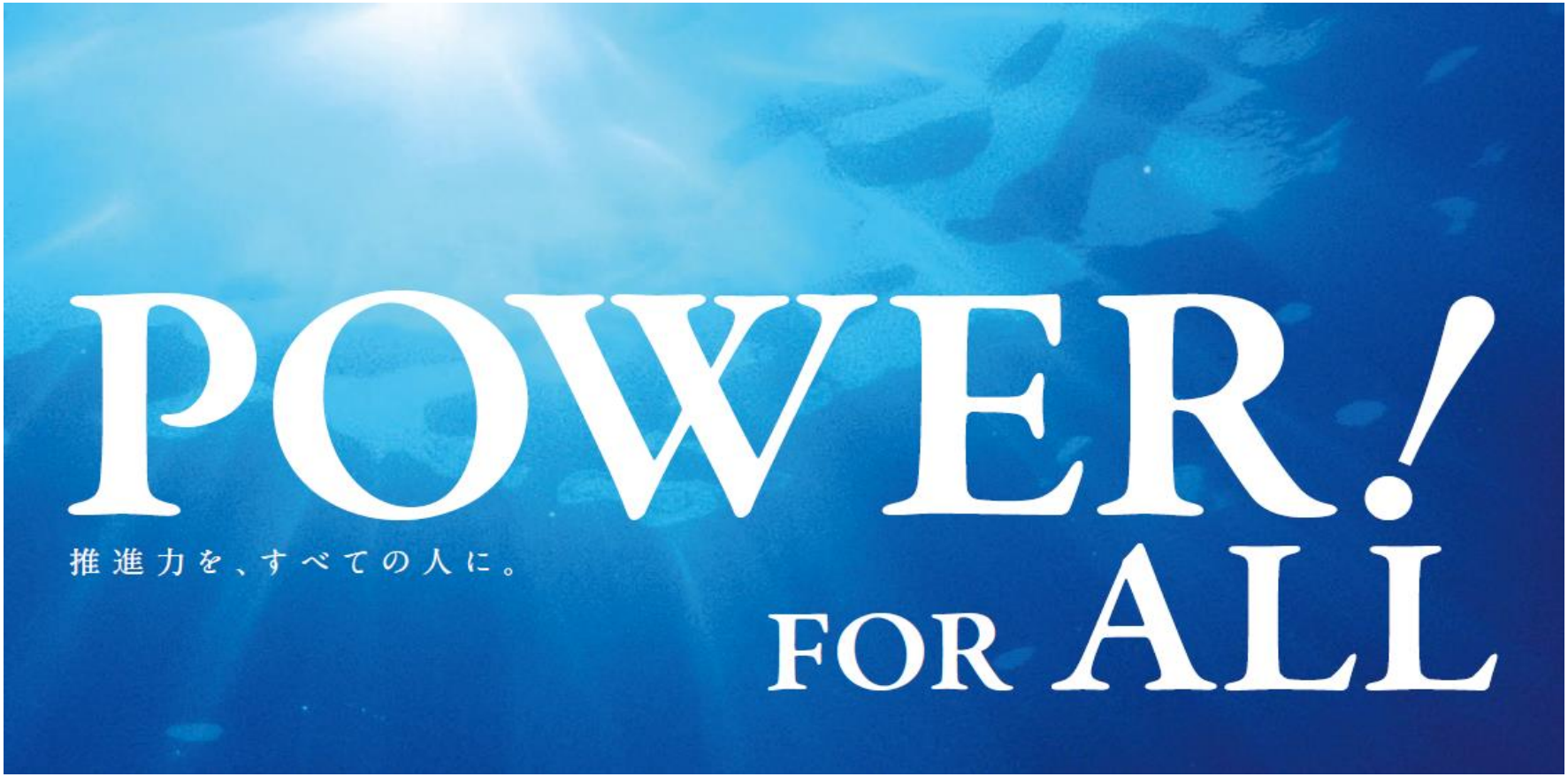
4. Summary

- DDK have Downsized the Gas Reformer Equipment Considering Shipboard Installation and Confirmed that the Reformed Gas Achieves almost the same Engine Performance as LNG.
- By using the LPG Reformer, it is Possible to Achieve IMO Tier 3 of NOx without Using the Exhaust Gas Aftertreatment Device in Gas Mode.
- By using the LPG Reformer, Main Engine and Auxiliary Engine Systems can be Realized in Simple and Space Saving.



Thank you very much for your attention!

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