DAIHATSU DIESEL MFG. CO., LTD. DAIHATSU

Technical Management Division
Technical Department 3
Hiroaki Heima

Latest Solution for Utilizing Various Types of Gas Fuel in DAIHATSU DIESEL

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1. Company Introduction

2. Global Trend

3. Motivation

4. Gas Reformer

5. Development Schedule

6. Evaluation of Engine Performance

7. Conclusion

1. Introduction of DAIHATSU Group

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1907 HATSUDOKI Manufacturing Co., Ltd

Manufactured 6.0hp GAS Engine

1951 DAIHATSU Motor Co., Ltd

The production of diesel engine for diesel locomotive of Japan National Railways

Development of the world's smallest displacement diesel engine for of passenger car

1966 Daihatsu Diesel MFG Co., Ltd.

DAIHATSU Group Philosophy

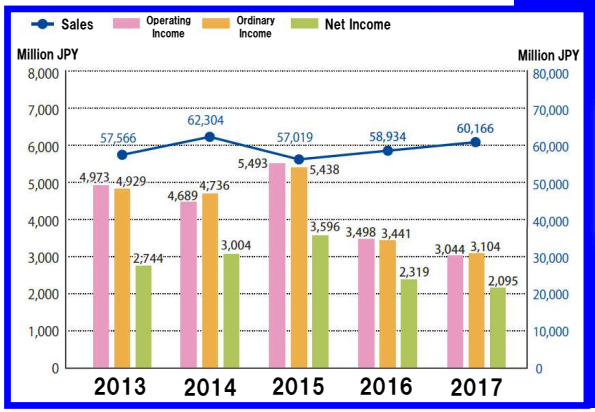
The DAIHATSU Group
aims to establish itself as
"a global loved around the world" and as
"a corporate group with confidence and pride"
through meeting the challenge of innovative
automobile manufacturing
at the forefront of our era.

HATSUDOKI: Mover , Engine / 発動機 / 发动机

Main Products Passenger Car

Ayla

Mira



Main Products : Diesel Engine for Marine Use
Gas Engine & Gas Turbine for Land Use

1. History of DAIHATSU DIESEL GAS Engine

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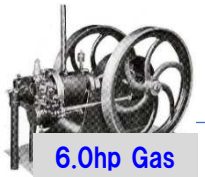
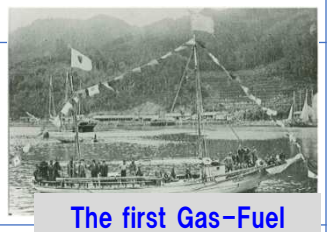
Year	Event	Remarks
1907	6.0hp Gas Engine was manufactured in MOVER (HATSUDOUKI) MFG. Co., Ltd	 6.0hp Gas Engine
1908	15.0hp Gas engine was installed to Passenger boat in Nagasaki, Japan The first Gas-Fuel Engine ship in Japan.	 The first Gas-Fuel Engine ship
1966	Established DAIHATSU DIESEL MFG Co., Ltd	
1983~	Launched Spark Ignition type GAS Engine with Three-way Catalyst	 GK28G - Shin Umeda Bld. Osaka
2005	Developed Lean burn Gas engine with Micro-Pilot ignition system Launched "MD20G", "MD36G", "GK28G" .	
2013	Developed Dual Fuel Engine "DE28DF" with Micro Pilot ignition system.	 DE28DF
2017	First Commercial Dual Fuel Engine was Shipped to our Customers.	

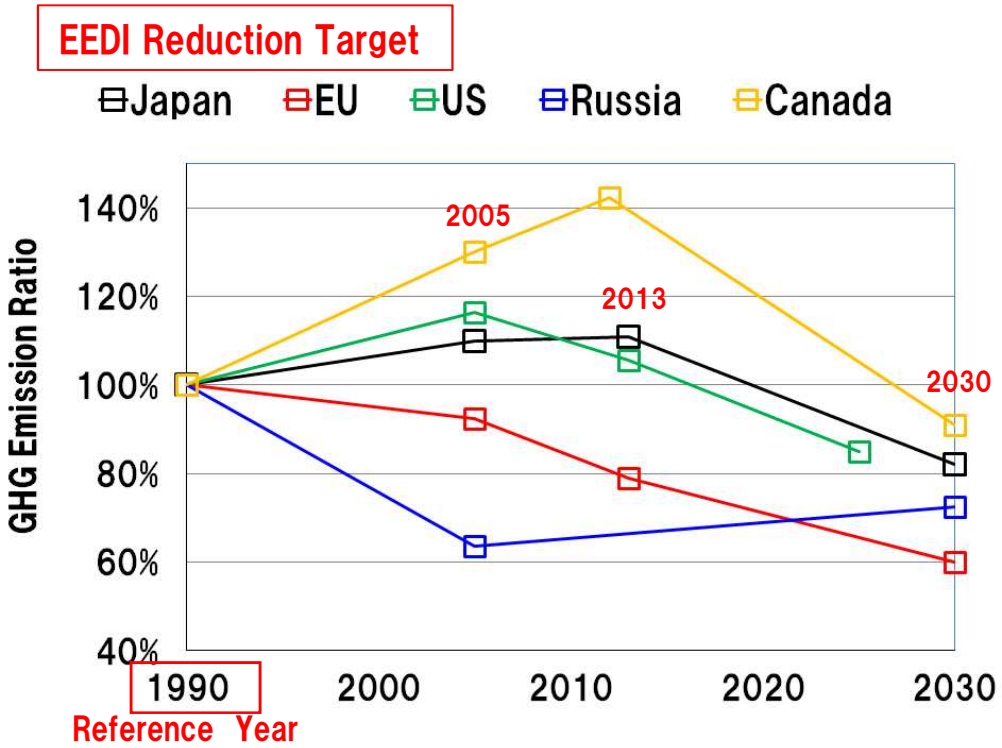
2. Global Trend

Reduction of GHG regarding Paris Agreement

◆ *The Paris Agreement*

A) Holding the increase in the global average temperature to well below 2 ℃ above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 ℃ above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.

B) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production.



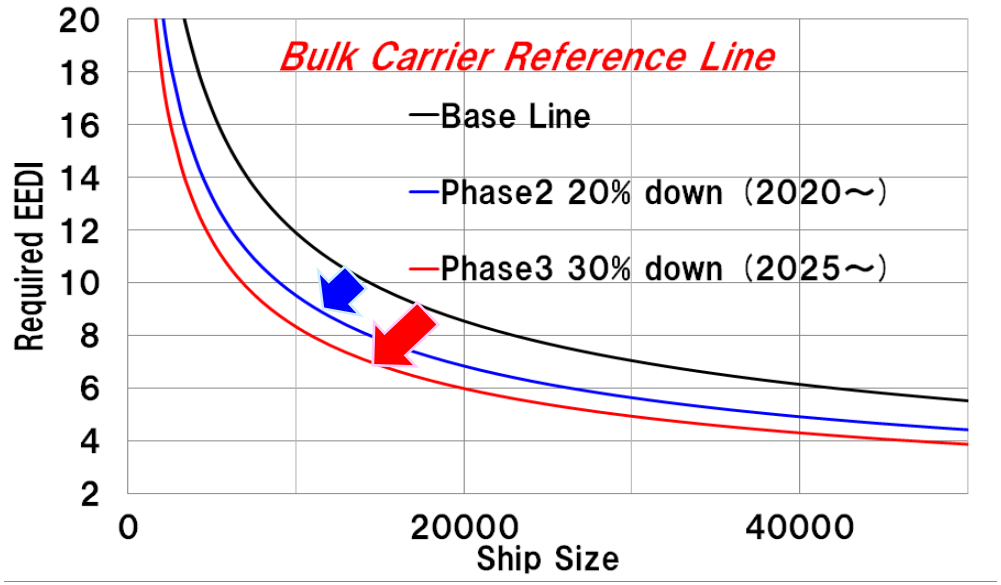
Individual countries achieve individually determined goal for GHG reduction.
Engine Manufacturers have to offer the solution to reduce GHG emission.

2. Global Trend -Ocean Ship Industry-

Required EEDI

◆*Reference to http://www.imo.org/*

A) The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI. This was the first legally binding climate change treaty to be adopted since the Kyoto Protocol.



$$EEDI(\mathrm{g/ton\ mile}) = \frac{CO_2\ conversion\ Factor \times Fuel\ Consumptio(\mathrm{g/kWh}) \times Output(\mathrm{kW})}{DWT(\mathrm{ton}) \times ShipSpeed(\mathrm{mile/h})}$$

Generally... Ship Speed decreases by about **15%** in order to reduce **30% reduction of EEDI**.

According to Required EEDI, Engine Manufacturers need to reduce CO_2 emission.

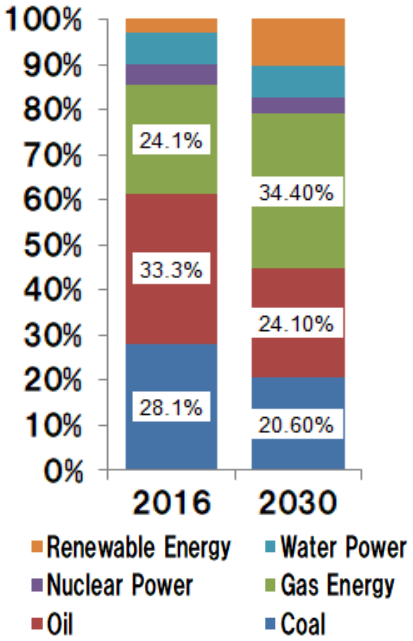
2. Global Trend

Global Energy Sources

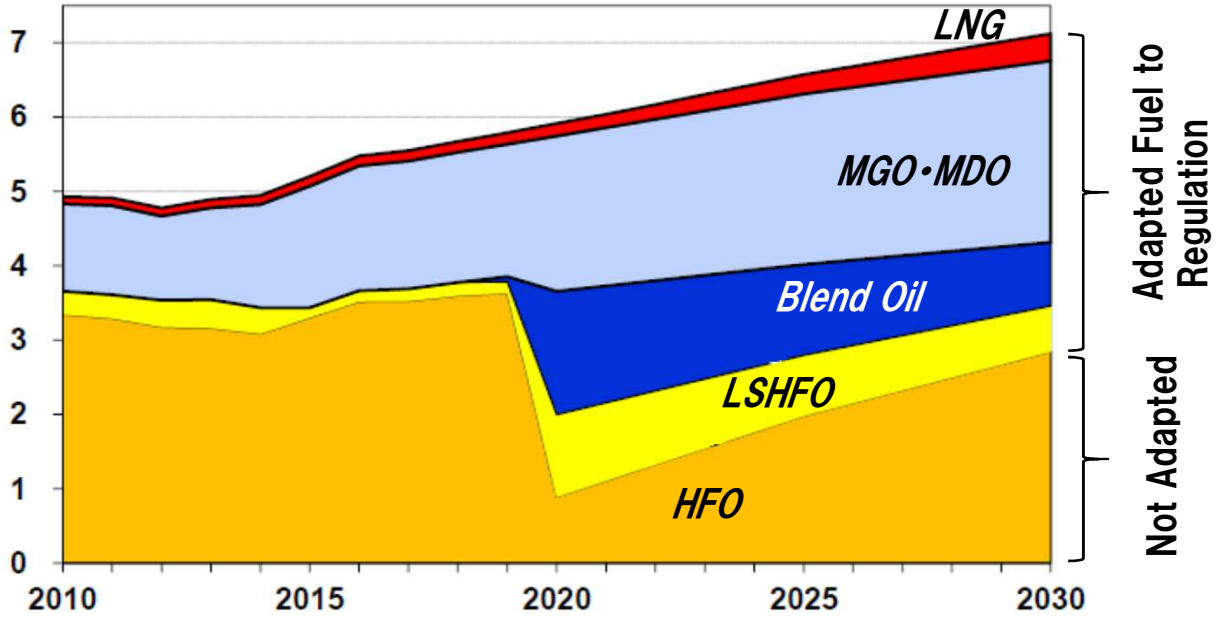
Gas Energy Trend

LNG will occupy more than 10% in Adapted Fuel.
And other gas will be utilized as Ship Fuel.

Global Energy Trend



Fuel Trend in Ships Industry



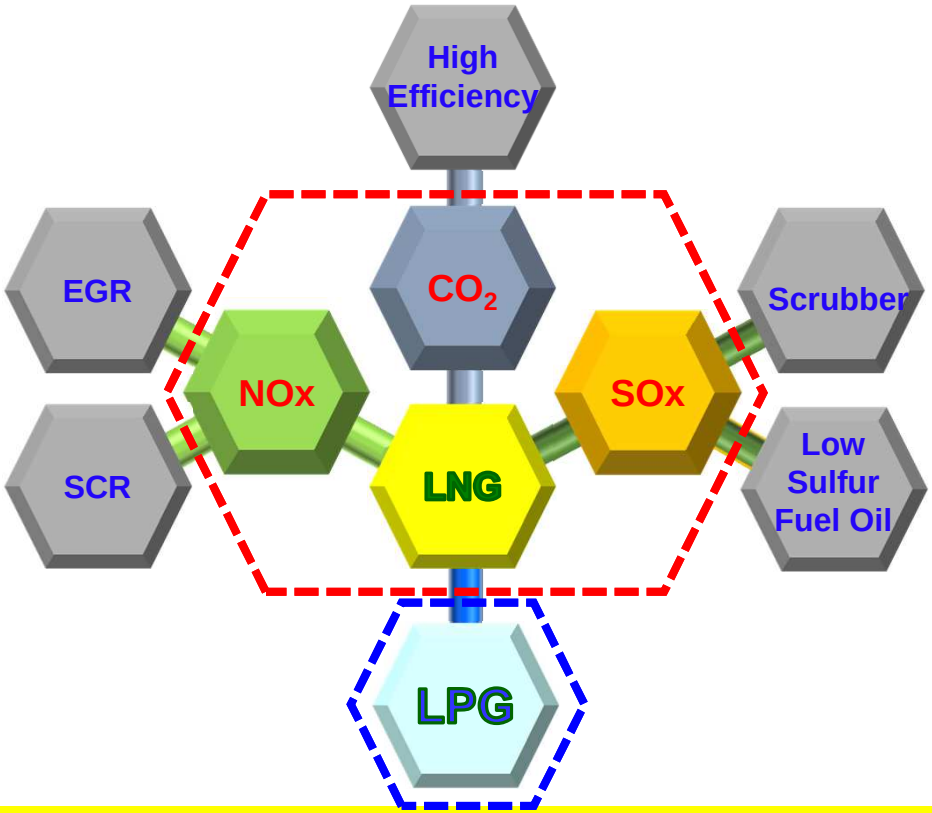
PIRA Energy: How The IMO is Not Making Shipping Great Again

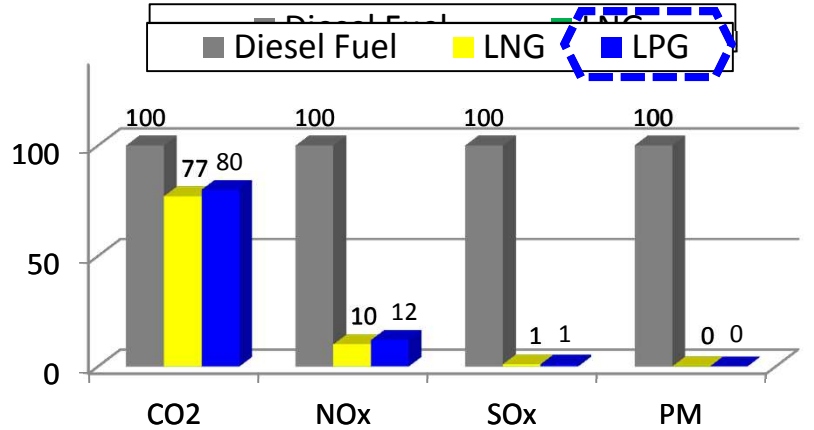
http://www.enecho.meti.go.jp/about/whitepaper/2018html/2-2-2.html

As a global trend, Gas Energy Demand will increase definitely.
DDK is developing utilized technology for various types of Gas Fuel to meet Global Needs.

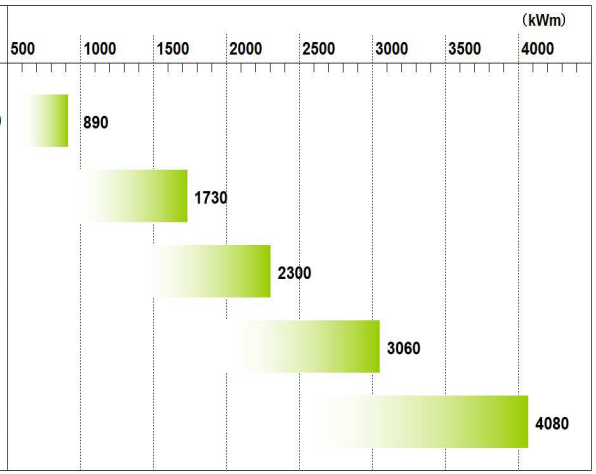
3. Motivation

Ship Engine Applied Environmental Regulations





Engine Type	Bore x Stroke	Speed
6DE20DF	φ205 x 300	900/1000
6DE28DF	φ280 x 390	720/750
8DE28DF	φ280 x 390	720/750
6DE35DF	φ350 x 440	720/750
8DE35DF	φ350 x 440	720/750



DDK is looking into the technical possibility of applying LPG as the marine fuel

3. Motivation

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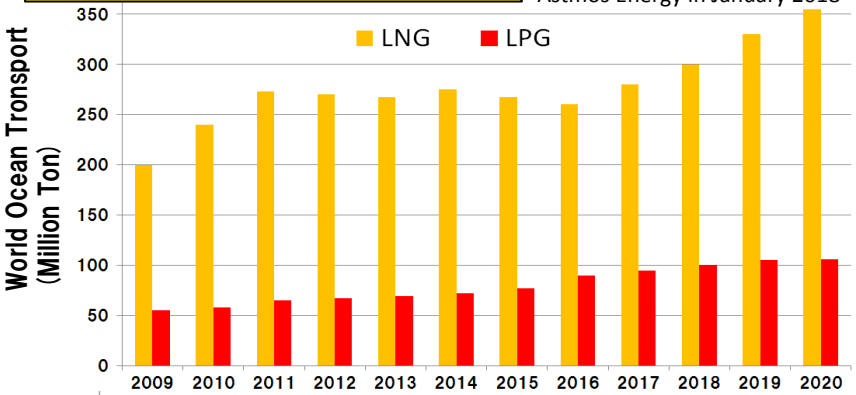
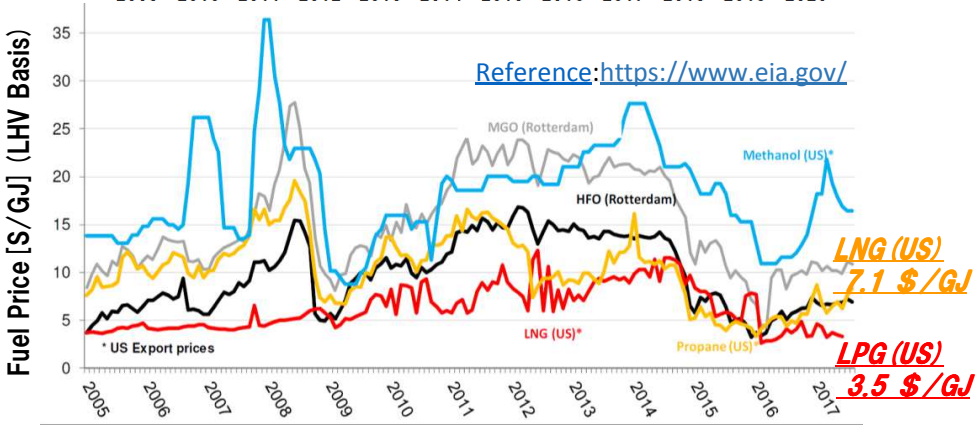
Utilizing LPG as Ship's Fuel

Reference
Quote material of
Astmos Energy in January 2018



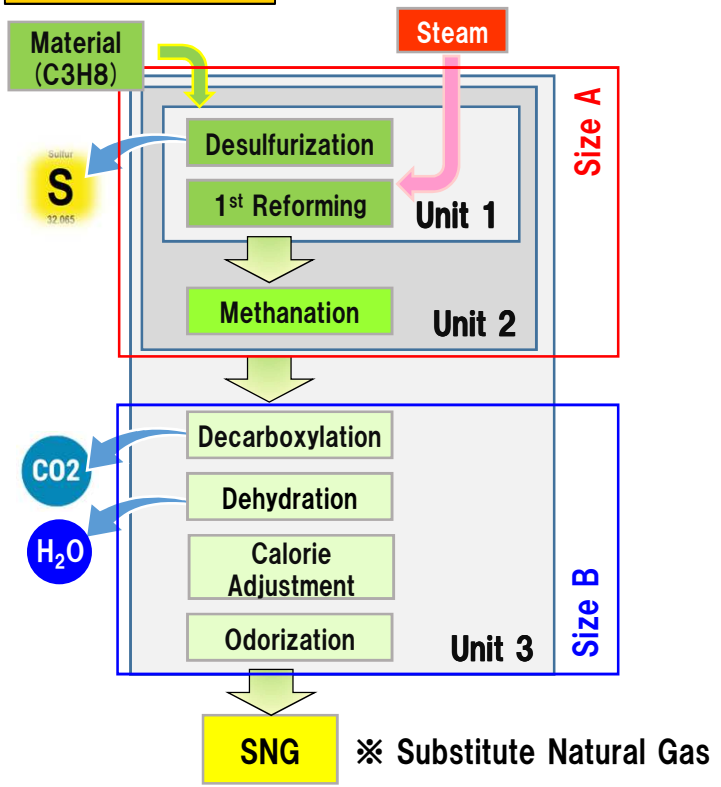


	LNG	LPG
Quality	Depend on Site	Uniform
Supply Chain	Very Limited	Utilize Conventional Site
Boiling Point	−161.5 [℃]	−42.1 [℃]
Storage In the long term	Not Appropriate •How to deal BOG •MN reduction	Easy
Handling	Difficult	Easy
Gas Density	0.72 (lighter than Air)	2.01 (Heavier than Air)
Methane Number	65～102	34(Propane)

DDK researched how to utilize both LNG and LPG in the same engine by reforming gas.

4. Gas Reformer

General Process

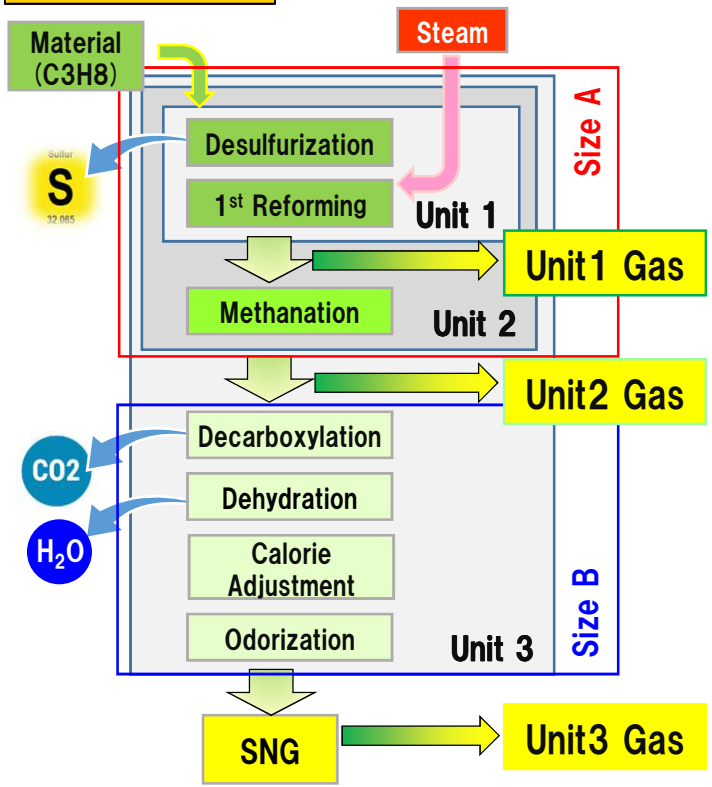


※ Substitute Natural Gas

DDK and Osaka Gas investigated Configuration Unit in order to minimize existing Gas Reformer

4. Gas Reformer

General Process



Study of Reformer Design Concept

1. Simplification of the reforming equipment configuration ➡ Unit1 or Unit2
2. Gas composition of reforming process ➡ Chose Unit1
3. Fuel suitability for Gas engine ➡ Check in Eng Test

Configuration		Propane	Unit 1	Unit 2	Unit 3
Gas Composition	C_3H_8	100 %	0 %	0 %	7 %
	CH_4	0 %	68 %	77 %	92 %
	CO_2	0 %	20 %	22 %	0 %
	Other Gas	0 %	12 %	1 %	1 %
Methane Number		34	108	120	99
Lower Heating Value [MJ/kg]			27	28	49

DDK and Osaka Gas studied the relationship between the Engine combustion and the gas composition.
Unit1 was chosen as Prototype Gas Reformer.

4. Gas Reformer

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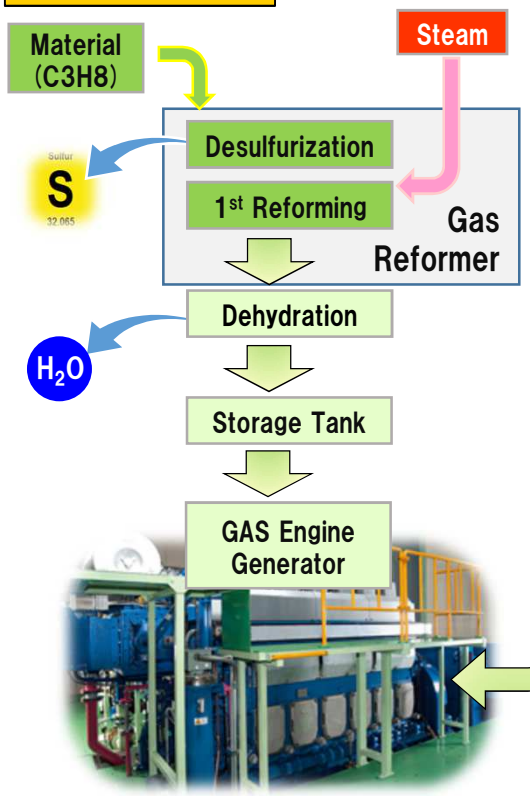
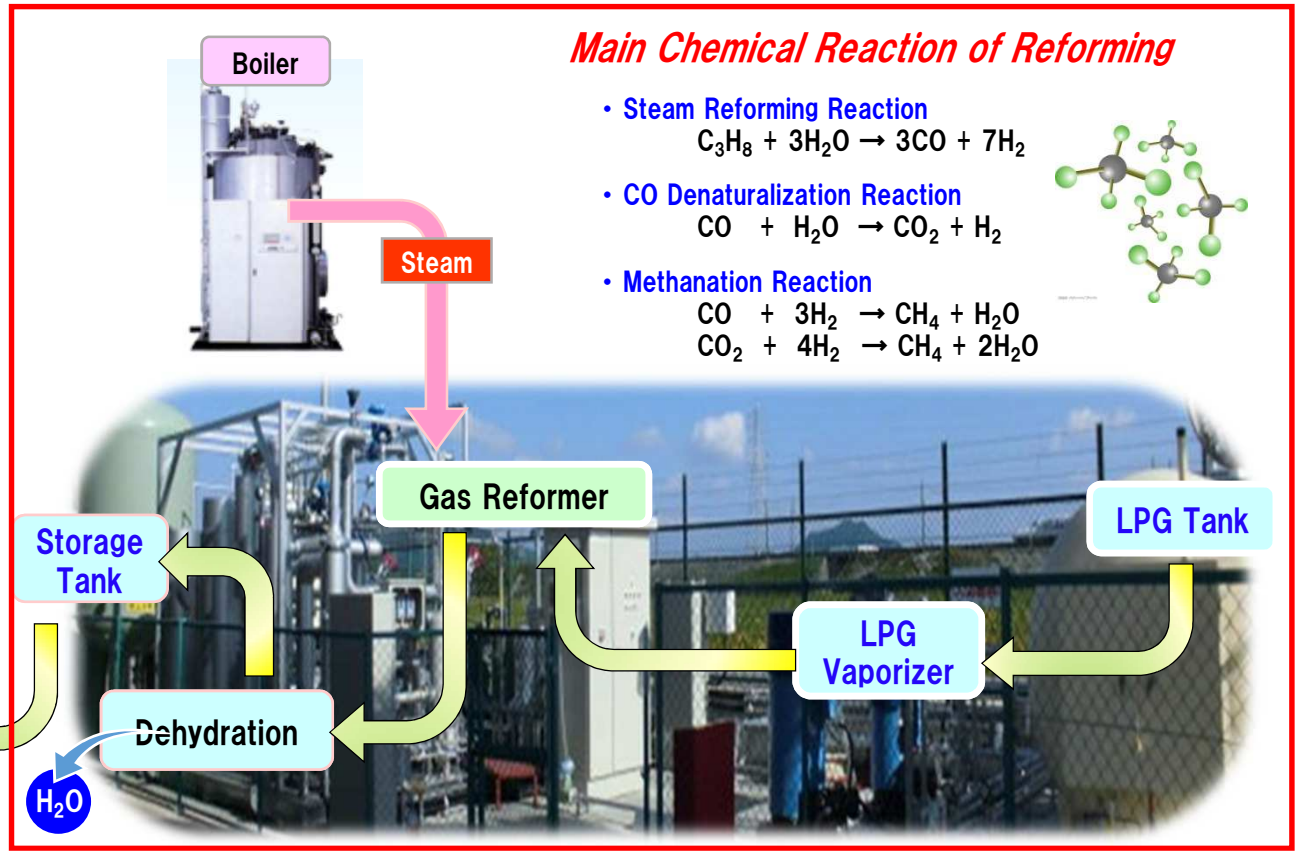
General Process





Main Chemical Reaction of Reforming

- Steam Reforming Reaction
  $C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2$
- CO Denaturalization Reaction
  $CO + H_2O \rightarrow CO_2 + H_2$
- Methanation Reaction
  $CO + 3H_2 \rightarrow CH_4 + H_2O$
  $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

The prototype gas reformer was installed at DDK Moriyama Factory and conducted reformed gas evaluation test with factory power generator.

5. Development Schedule

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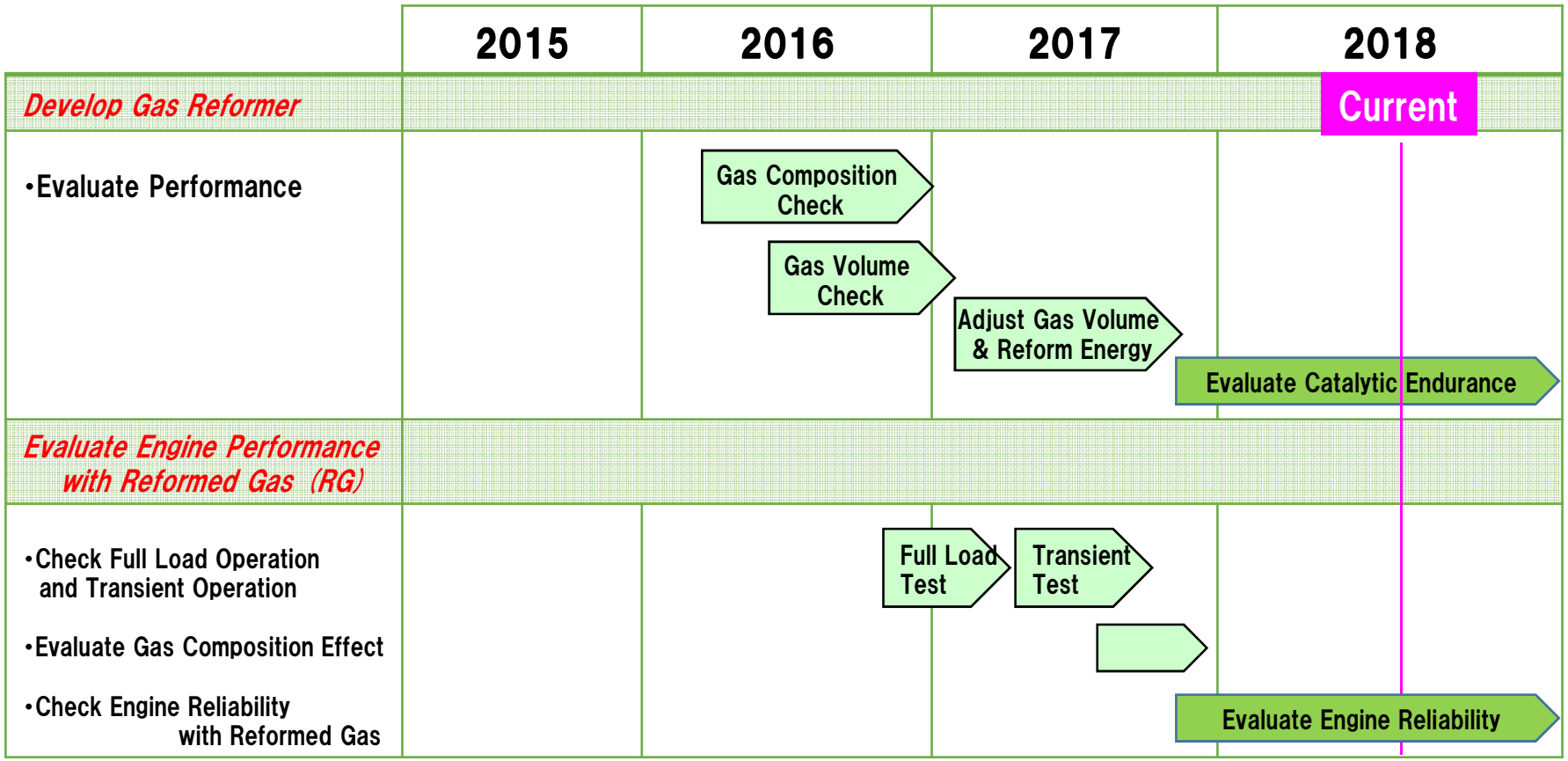


Various practical operation evaluation was carried out, and future long-term durability evaluation is ongoing.

6. Evaluation of Engine Performance

1. Gas Engine Test

Testing Gas

- City Gas and Reformed Gas were used

Test Purpose

1. Confirm the influence of reformed gas on operability of gas engine.
2. Evaluate for Deterioration Characteristics of Reforming Catalyst in the future term.

City Gas

&

Reformed Gas

2. Gas Composition Test

Testing Gas

- Change mixing ratio of methane and propane respect to engine load.

Test Purpose

1. Optimize the amount of Reformed Gas Volume according to Engine Load to reduce Reforming Energy.

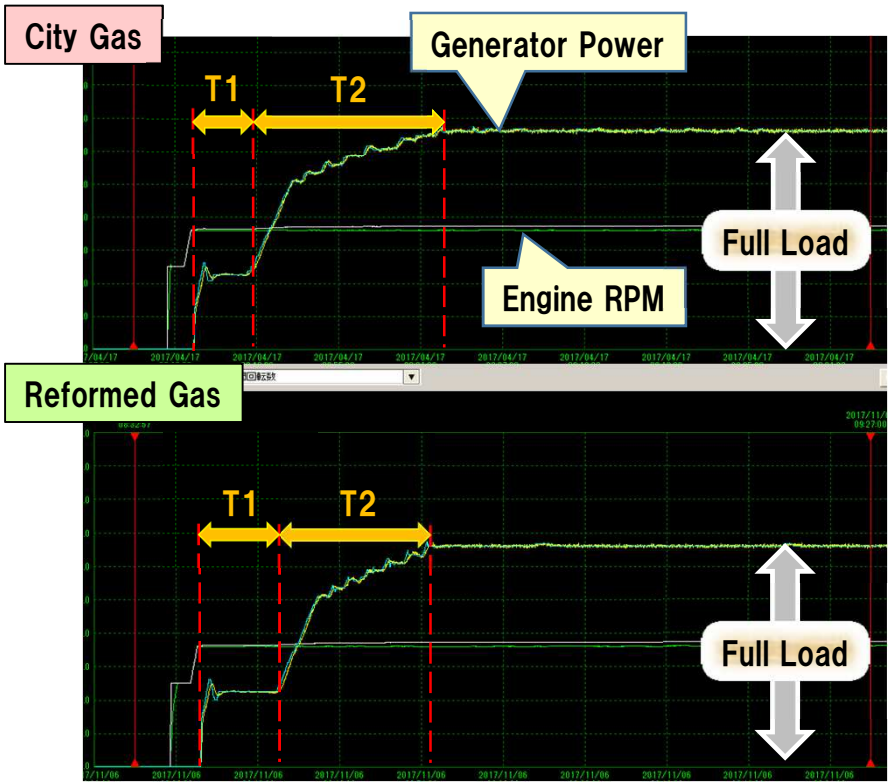
2. Risk Assessment of Leaking LPG into Engine directly in case something wrong with Gas Reformer.

Confirm combustion characteristics by changing the mixing ratio CH_4 and C_3H_8

DDK confirmed the reliability of Reformed Gas and the effect of mixing ratio through these Tests

6. Evaluation of Engine Performance

Engine Start ⇒ Steady Operation under Full Load



	Reformed Gas	City Gas
T1	120%	100%
T2	70%	100%

- Time period T1 is 20% longer than that of City gas.

  ⇓

  The lubrication temperature is lower during gas reforming test.

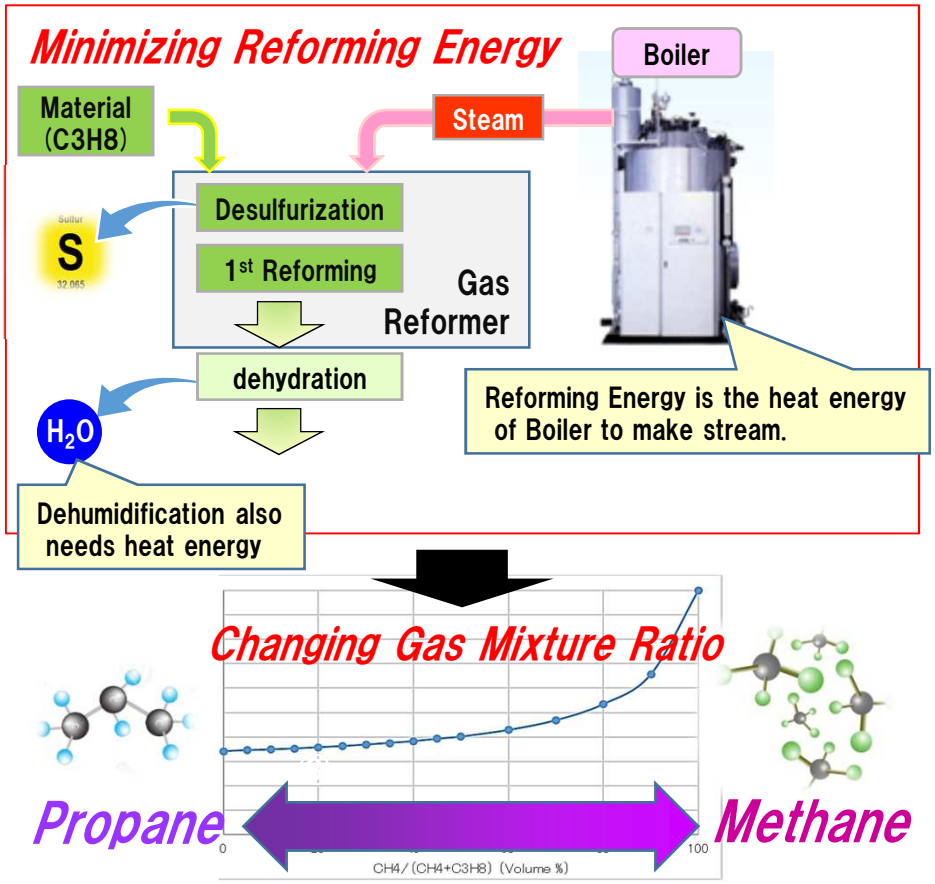
- Time period T2 is 30% shorter than that of City gas.

  ⇓

  High MN gas makes it possible to raise Engine Load quickly.

Start-up characteristic is slightly different because of the difference of initial lubrication oil temperature.
DDK confirmed the Reformed Gas contained 20% of CO_2 can be used as the same with Japanese City Gas.

6. Evaluation of Engine Performance



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Confirm combustion characteristics by changing the mixing ratio CH_4 and C_3H_8

DDK confirmed the combustion characteristics by changing Mixing Ratio of methane and propane.

7. Conclusion

1. Regarding the effective use of LPG which accounts for approximately 23% in the world ocean transport volume, DDK confirmed that reformed gas achieve the almost same output performance in case of using LNG.

2. By optimizing the system composition, We carried out downsize the Gas Reformer equipment considering shipboard loading.

3. DDK grasped the characteristics of MN in the low load region in the lean burn combustion and the influence on the combustion stability.

4. And now, reliability evaluation is ongoing in the long-term operation and the evaluation of deterioration characteristics of catalyst are also in progress.

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Thank you for your Attention