July 2014

Development of Natural Gas Fuelled Ships (Natural Gas Engines) in the World

(Introduction of R&D on marine natural gas engines supported by ClassNK)

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Motivation for natural gas fueled ships

Regulation of Exhaust Emissions

- ECA (SOx 2015～, NOx 2016～)
- Global SOx regulation, 2020 (2025)～

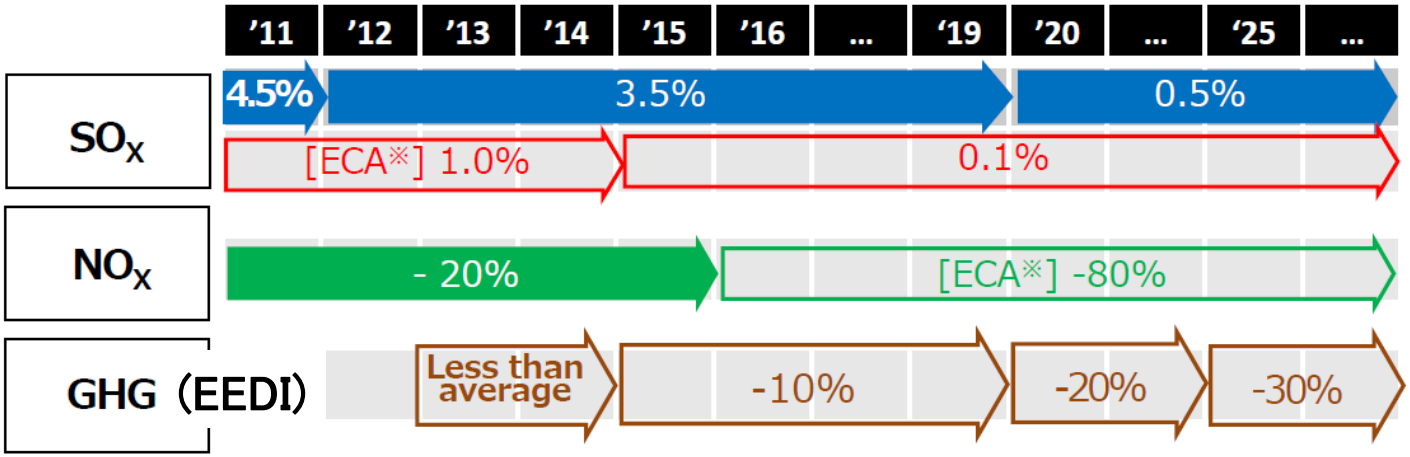
(Global cap for sulfur% of marine fuel)

Regulation of CO2 ：Green House Gas (GHG)

- **EEDI** (Energy Efficiency Design Index) : **CO2 g／ton･mile**

$$= \frac{\text{Engine Power (kW)} \times \text{SFC (g/kWh)} \times C_F}{\text{DWT (ton) x Speed (mile/h)}}$$

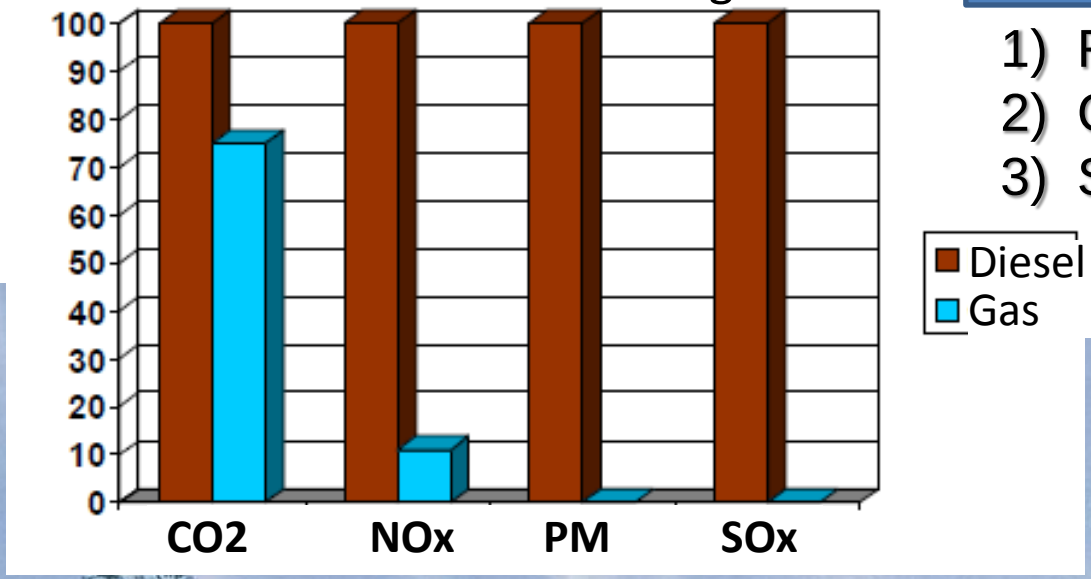
- • 2015～ -10%, 2020～ -20%, 2025～ -30%



Marine diesel oil • • $C_{16}H_{34}$ · · 16 CO_2 +17 H_2O + Q

Natural gas • • 12 CH_4 · · 12 CO_2 +24 H_2O + Q

Effect on emissions reduction by changing the fuel from diesel oil to natural gas



Issues to overcome for introducing LNG fueled ship

1) Regulation
2) Cost (initial and operation)
3) Supply Infrastructures

Natural gas fueled ships in service

About 40 ships in North Europe driven by medium-speed 4-stroke lean-burn type gas engines (ferry, off-shore supply vessel, etc.).


Bergensfjord/ Fjord 1 (130m x 20m, DNV)

フェリー


Viking Energy/ Eidesvik (95m x 20m, DNV)

オフショア支援船


Bit Viking/ Tarbit Shipping (177m x 26m, GL)

ケミカルタンカー

重油バンカー船 @オランダ・ロッテルダム港


Høydal/ Nordnorsk Shipping (70m x 16m, DNV)

貨物船（水産飼料運搬）

クルーズフェリー及び世界唯一のLNGバンカー船
@スウェーデン・ストックホルム港


EcoNuri/ Incheon Port Authority (36m x 8m, KR)

観光船 @韓国・仁川港


Barentshav/ Norwegian Coast Guard (93m x 17m, DNV)

沿岸警備船

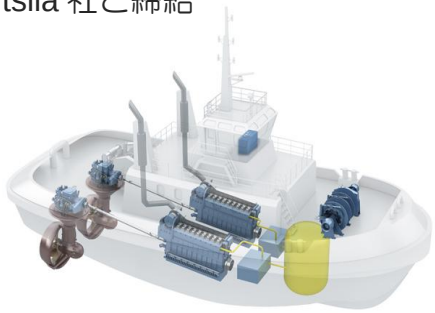

Francisco/ Buquebus (99m x 26m, DNV)

高速フェリー @豪州にて海上公試
（アルゼンチン⇔ウルグアイ航路に投入予定）

Natural gas fueled ships from now

including the first ship driven by a low-speed 2-stroke natural gas engine.

- ドイツのEMS社がワッデン海のフェリー”Ostfriesland”をDFエンジンに換装する契約をWärtsilä 社と締結



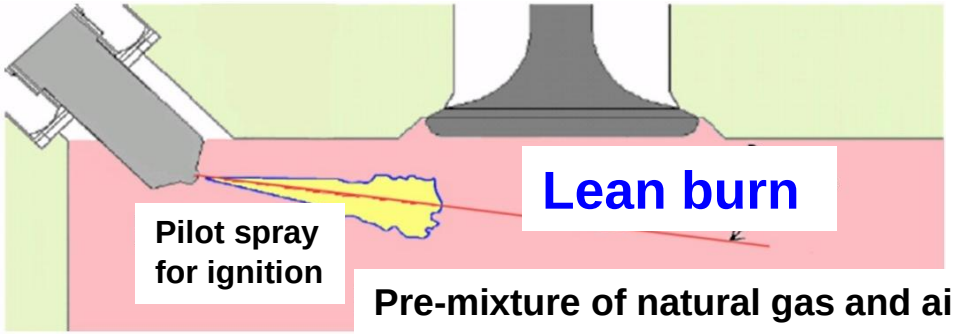
- 負荷変動の激しいタグボートをLNG燃料化する計画も浮上

- 米国内航船社TOTE社がMANの低速エンジンを搭載した3,100TEUのコンテナ船を発注（フロリダ⇔プエトリコ航路に投入予定）

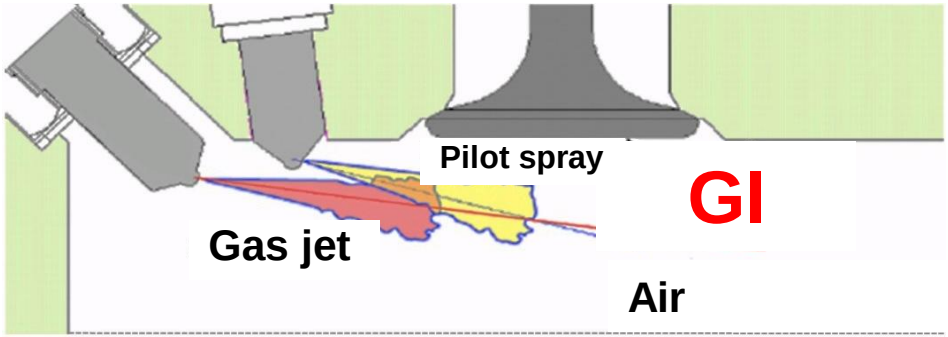
- 米国のHarvey Gulf社が６隻のオフショア支援船を発注
- LNG燃料供給設備の建造も計画（ルイジアナ州ポート・フォーチョン）

- 米国内航船社Horizon Line社が蒸気タービン船２隻のDFエンジンへの換装を計画

Two types of gas engine combustion



Lean burn type : Natural gas pre-mixed combustion like a gasoline engine



GI (Gas Injection) type : Natural gas diffusive combustion like a diesel engine

'Dual-fuel (DF)' and 'Mono-fuel' are another categorization.

Only **DF** type is referred in this presentation.

DF has such a merit that the fuel can be changed from natural gas to diesel fuel instantly when some abnormal combustion or leakage has occurred.

Merits and problems to be solved for two types of gas engine

Lean burn type

(Combustion is 'flame propagation' from pilot-fuel to gas-air pre-mixture.)

Merits

- **Low pressure gas supply**
  (only 5-6 bar for medium-speed and 10 ? bar for low-speed engine.)
- **Low NOx emission**
  (TierⅢ regulation can be cleared without any additional measure.)

Problems to be solved

- **Possibility of abnormal combustion like knocking**
  (Combustion is sensitive to the **Methane Number** (**MN**).)
- **Methane slip** (Cancellation of Green House Gas reduction)

GI (Gas Injection) type

(Diffusive combustion of high pressure gas jet in air ignited by pilot fuel.)

Merits

- **Free from knocking**
  (Insensitive to MN and high compression ratio is possible.)

Problems to be solved

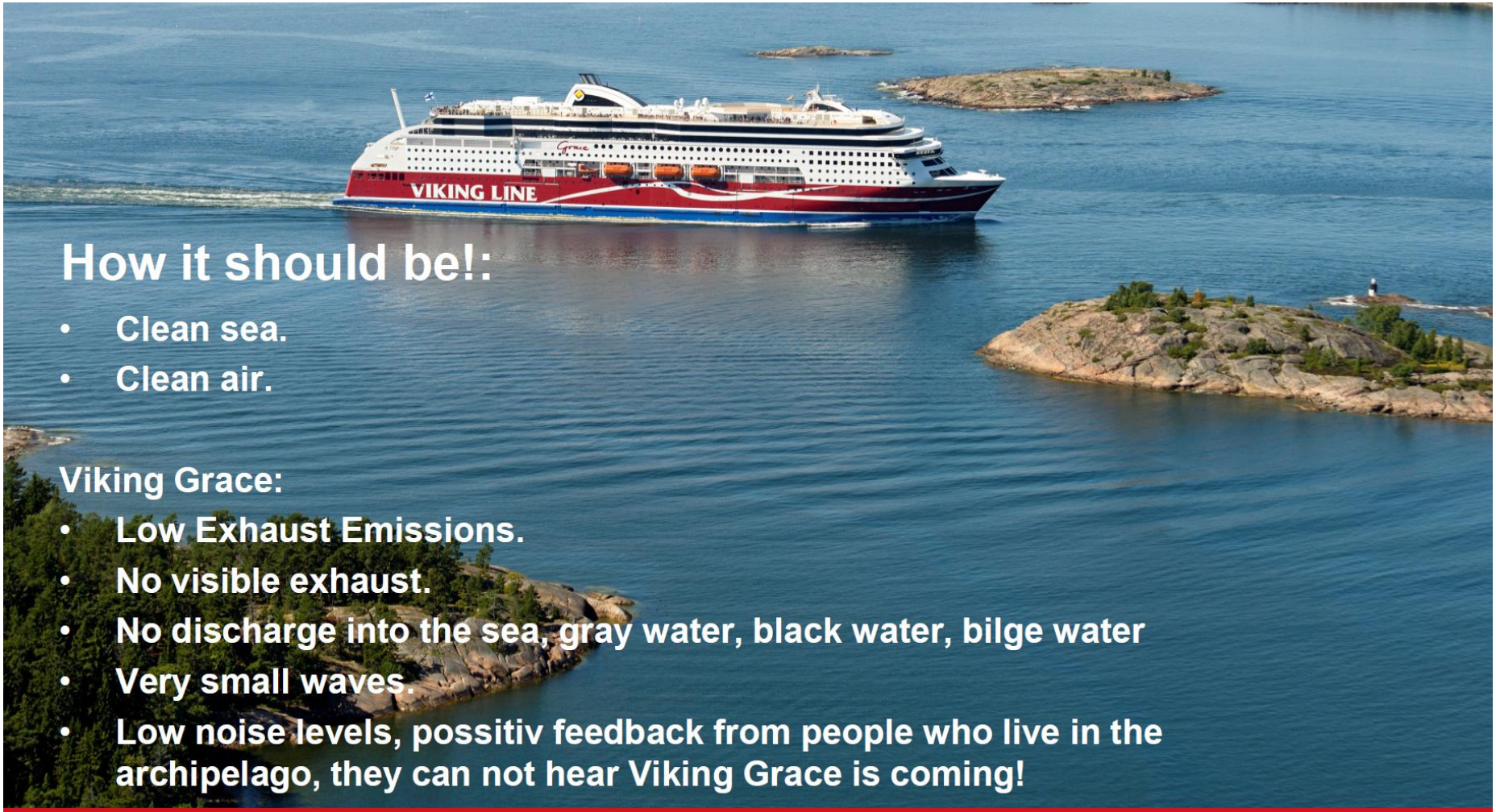
- **Higher NOx** than the lean burn type
- **Work to generate the high pressure** (for example, to 300 bar) **gas**

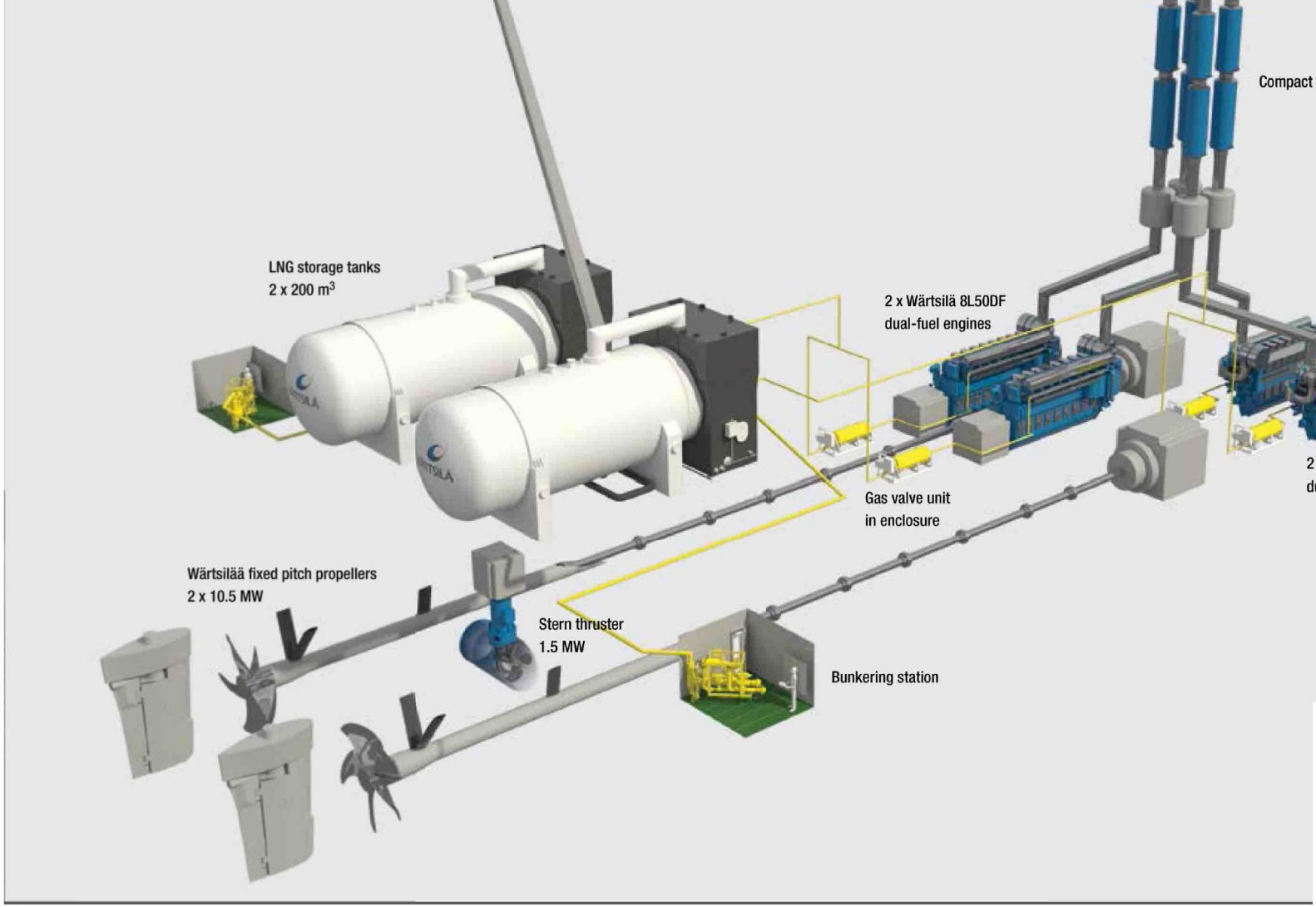
An example of lean burn type natural gas engine application

Ferry 'Viking Grace' (60,000 GT) in the Baltic Sea

(Medium-speed 4-stroke lean-burn engine + Electric propulsion 21 MW for 23 kt)

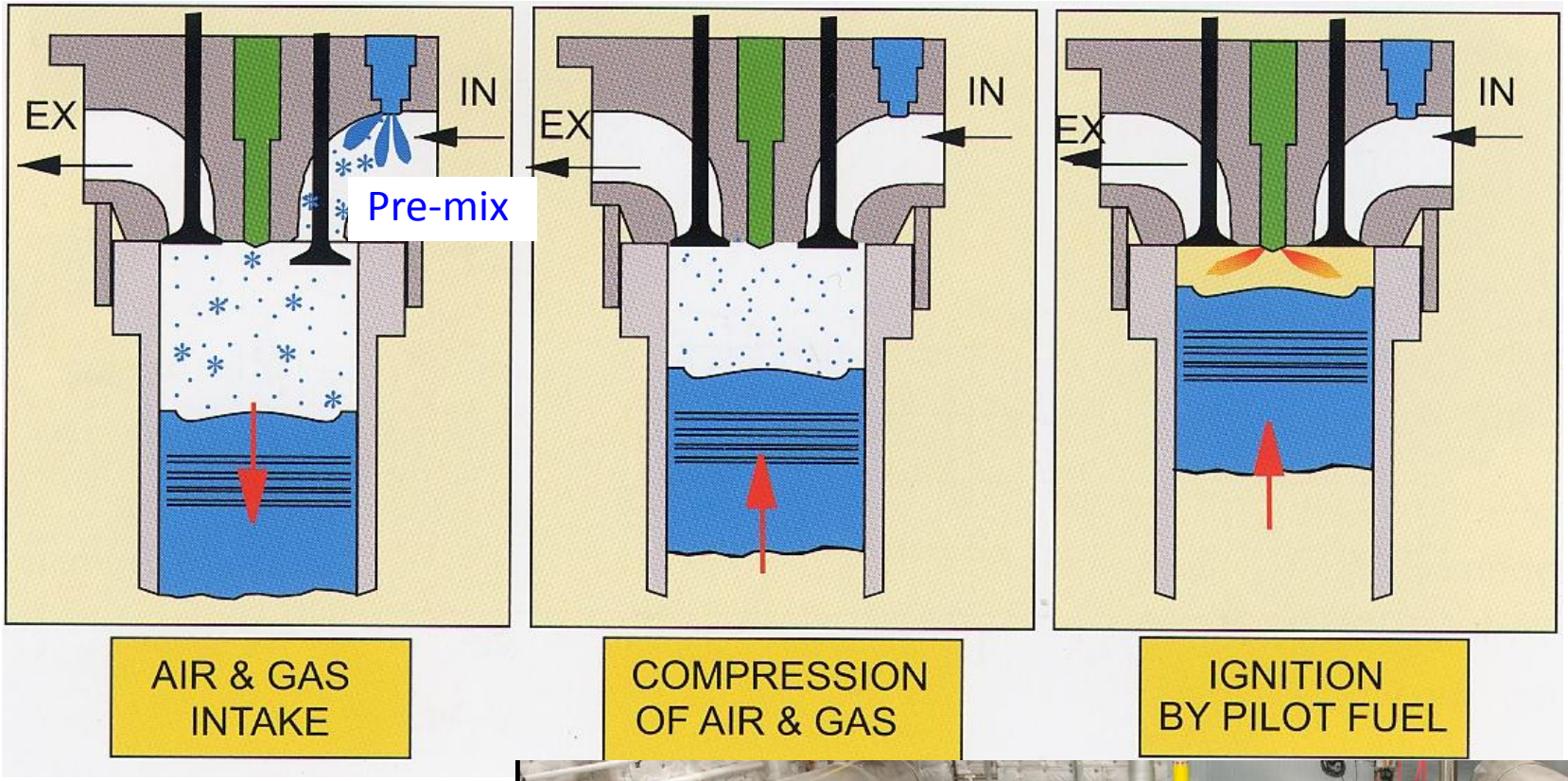
Calm sea condition in the Baltic sea (no load-fluctuation to cause knocking from propeller side) and high MN of fuel gas in Europe make stable gas operation possible.



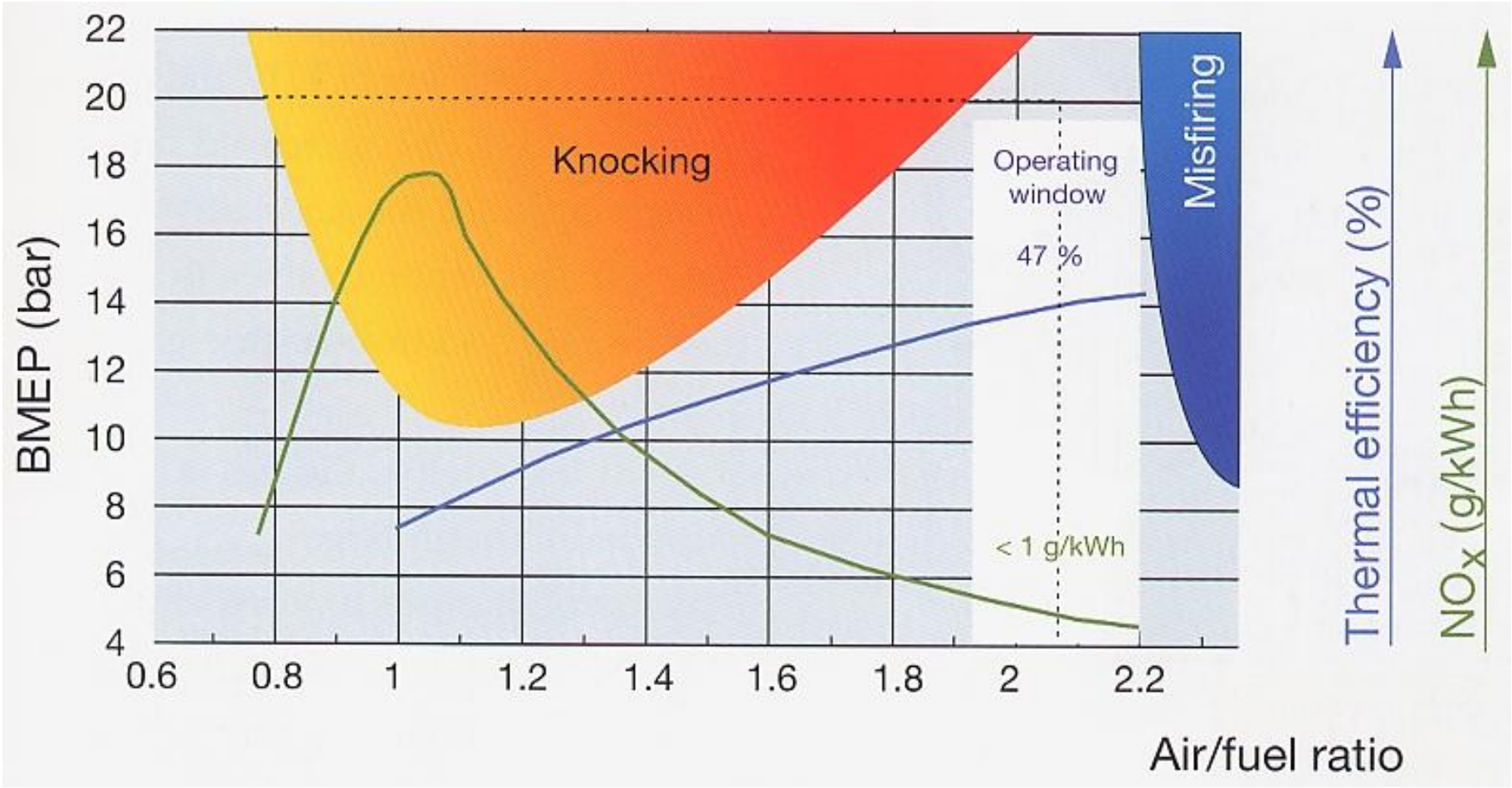


Propulsion system for Viking Grace

Function of medium-speed lean-burn gas engine



Wartsila 50DF
（950 kW/cyl.）
for Viking Grace
（Wartsila社資料）



Possibility of abnormal combustion for lean burn gas engine

Wartsila社資料

Viking Energy

（Platform supply vessel at the North Sea）

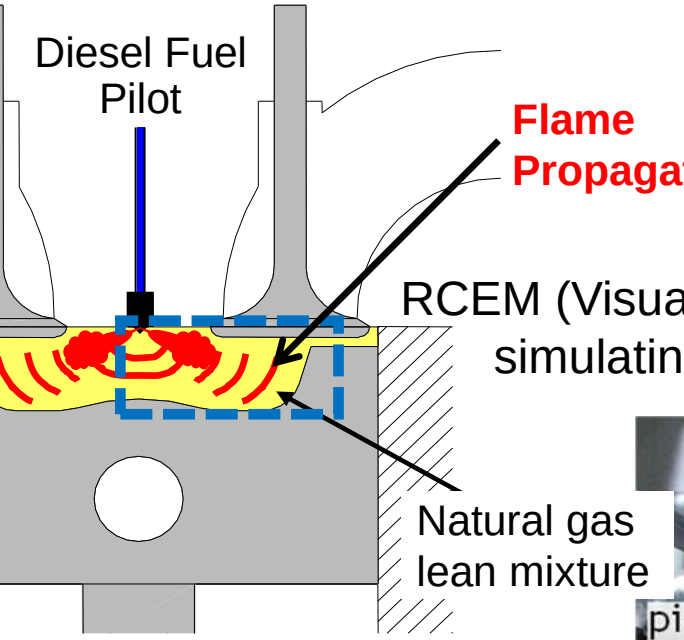
・・Wartsila 32DF + Electric propulsion

- Escape from knocking caused by load fluctuation by availing DF system (Switching to diesel fuel from gas mode)

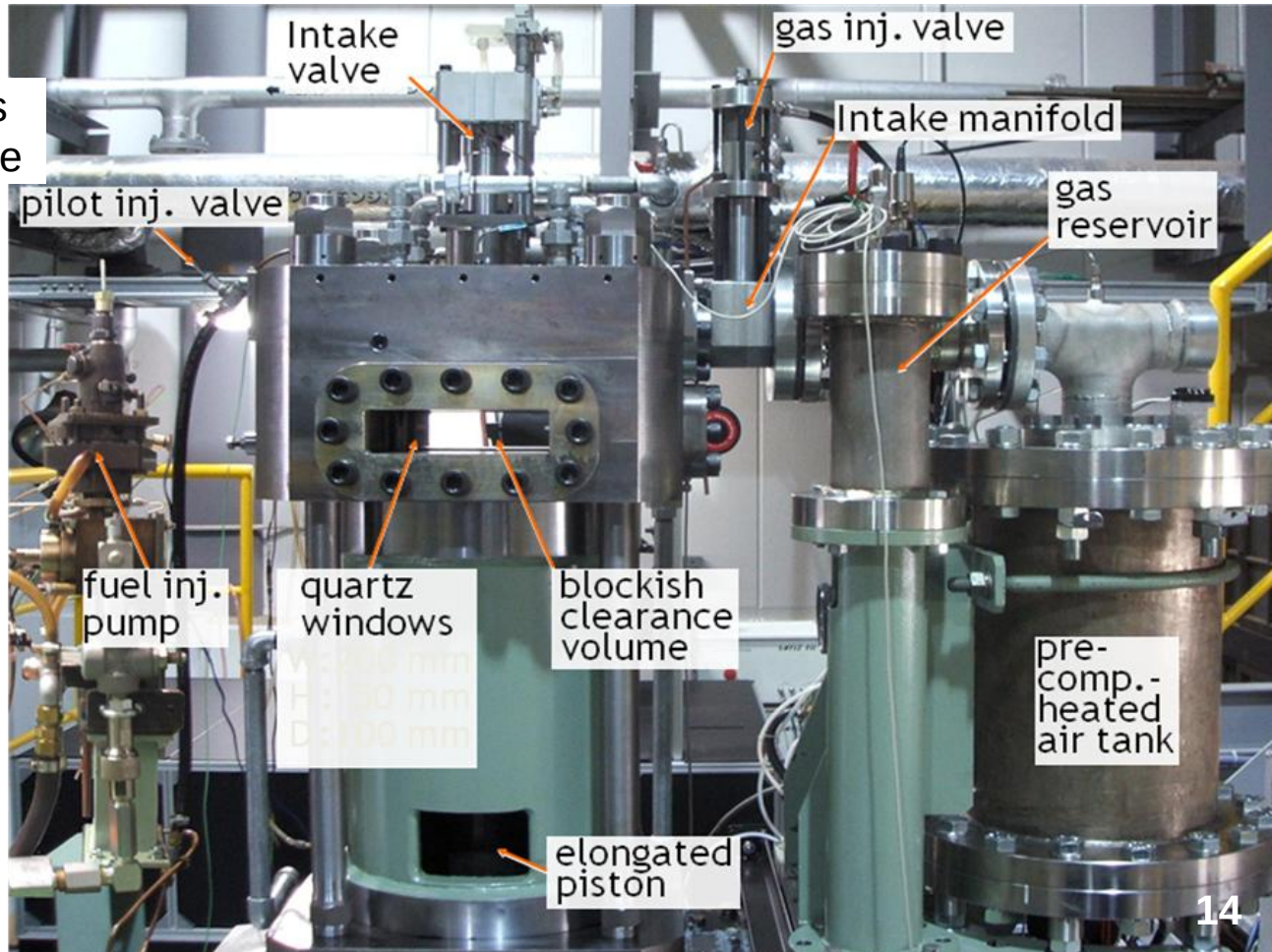
Function of liquid fuel injector for DF engine

(for Wartsila DF engines • •Wartsila社資料）

The smaller holes are used for pilot injection at gas mode.
When emergency has occurred at gas mode, fuel gas is stopped and full amount of heavy fuel injection starts from the larger holes.

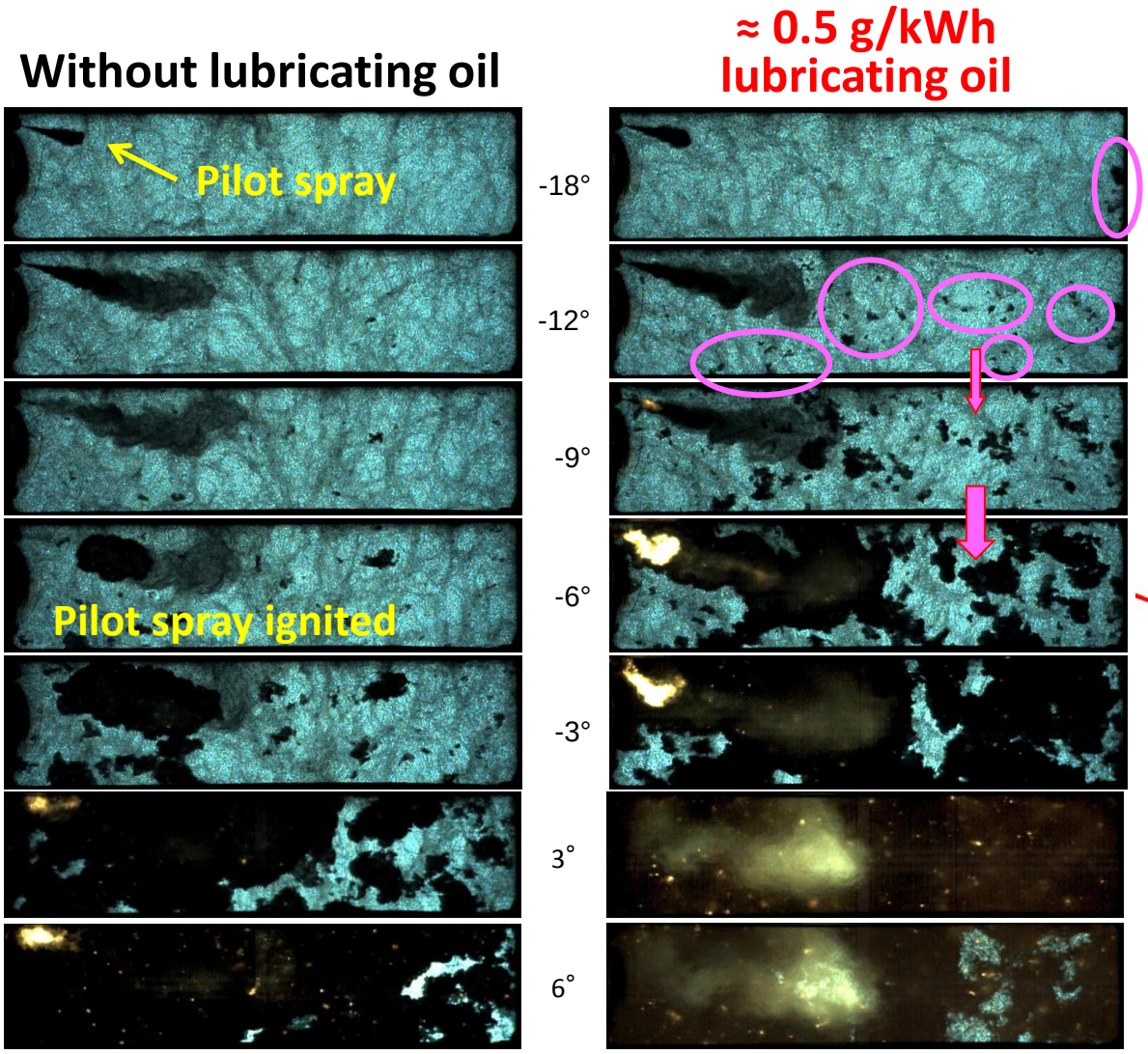


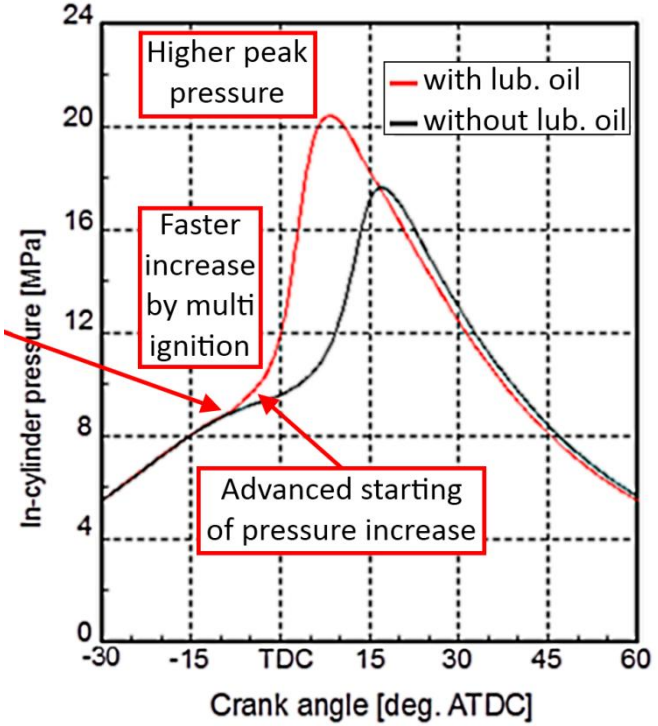
RCEM (Visual apparatus with 200 mm wide window) is simulating a half of combustion chamber of a gas engine.



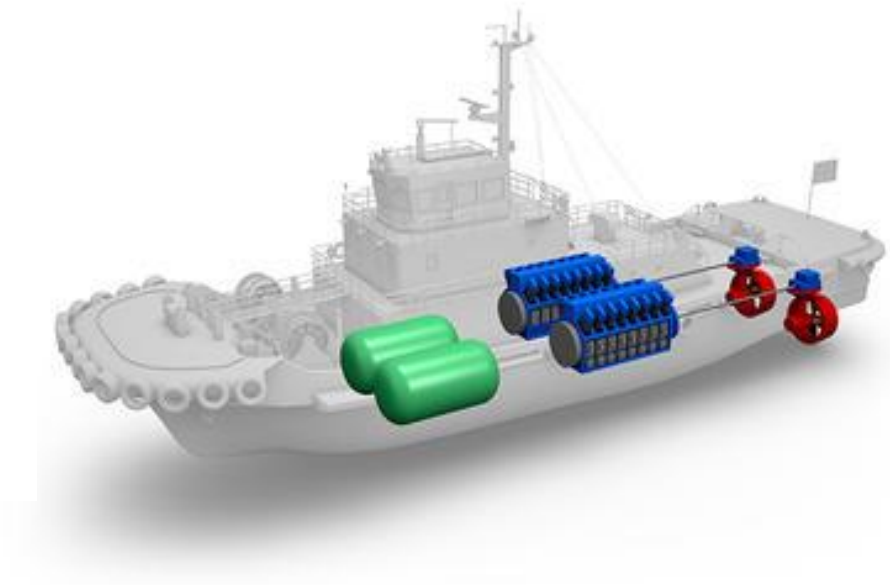
Fundamental study on lean burn gas combustion

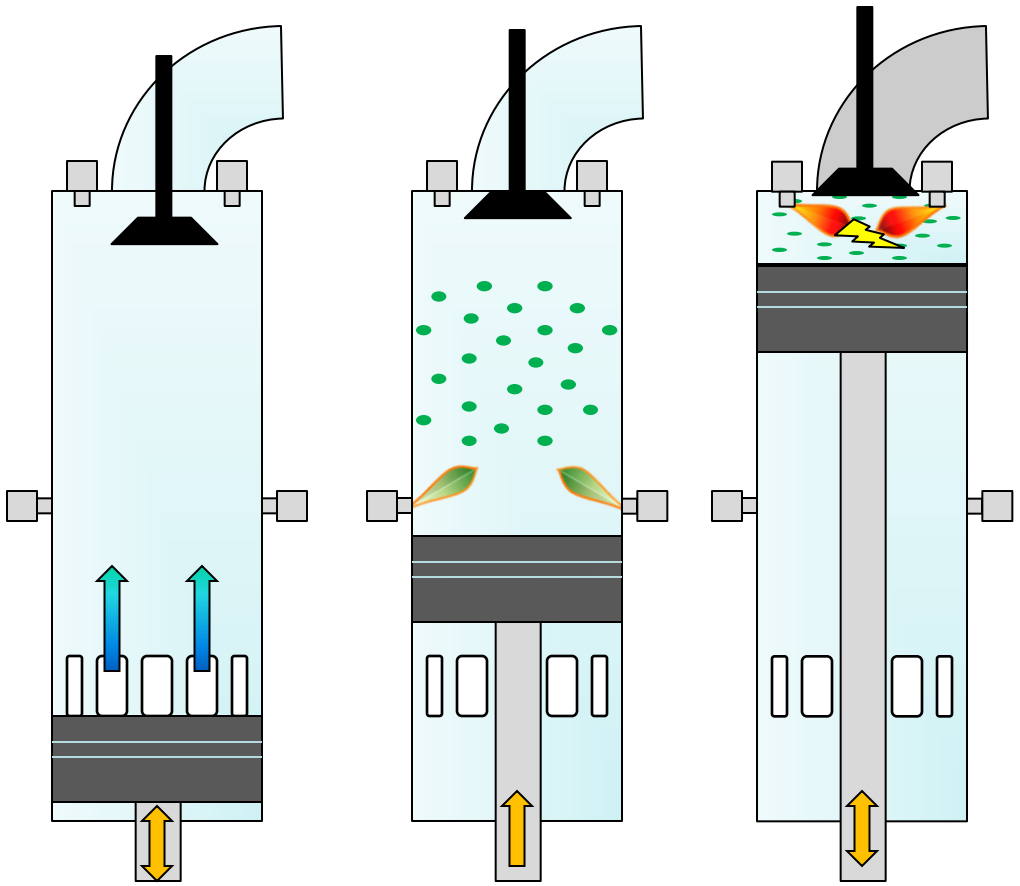
Possibility of abnormal combustion caused by lubricating oil ignition





- Development of LNG-fuelled tug-boat by NYK Group • • 2013～
  （ClassNK is supporting the development of not only the vessel itself but also the medium-speed DF engines）





Pro's:

- low pressure (LP) gas <10 bar
- IMO Tier III NOx compatible without after treatment
- high efficiency (> diesel)
- successfully developed for 4-stroke engines by Wärtsilä

Con's:

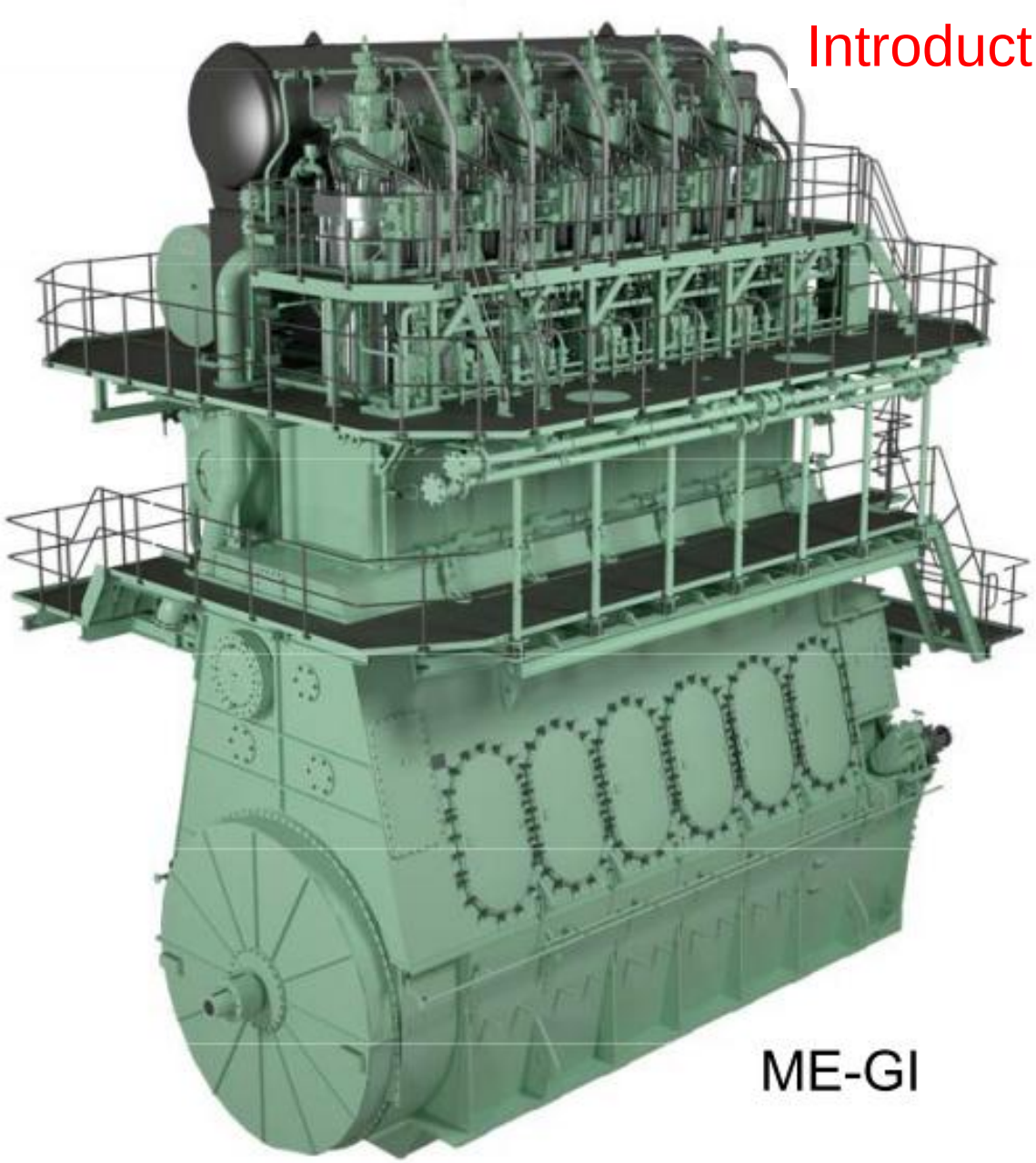
- unknown concept for 2-stroke
- output limited by knocking?
- hydrocarbon (HC) emissions?

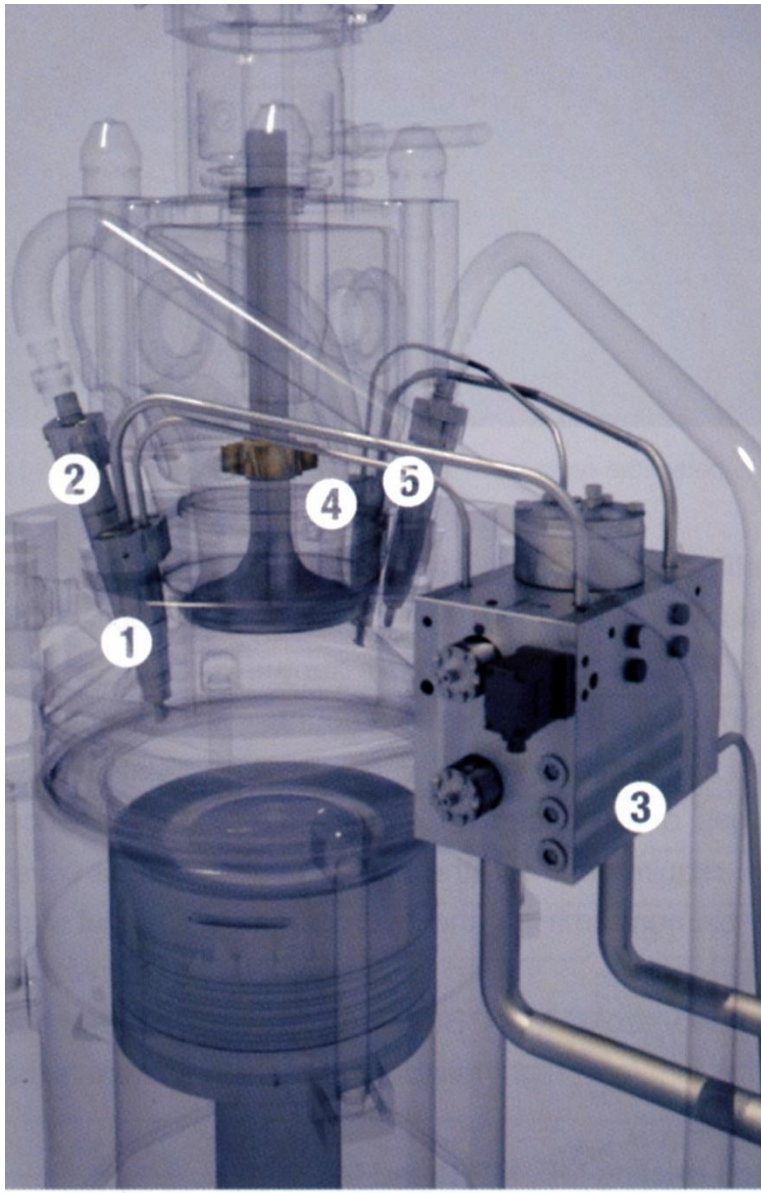
'Lean-burn' combustion for low-speed 2-stroke engines

2-stroke gas concepts – Low pressure DF

(Wartsila Technical Seminar 2011)

Introduction of GI type combustion

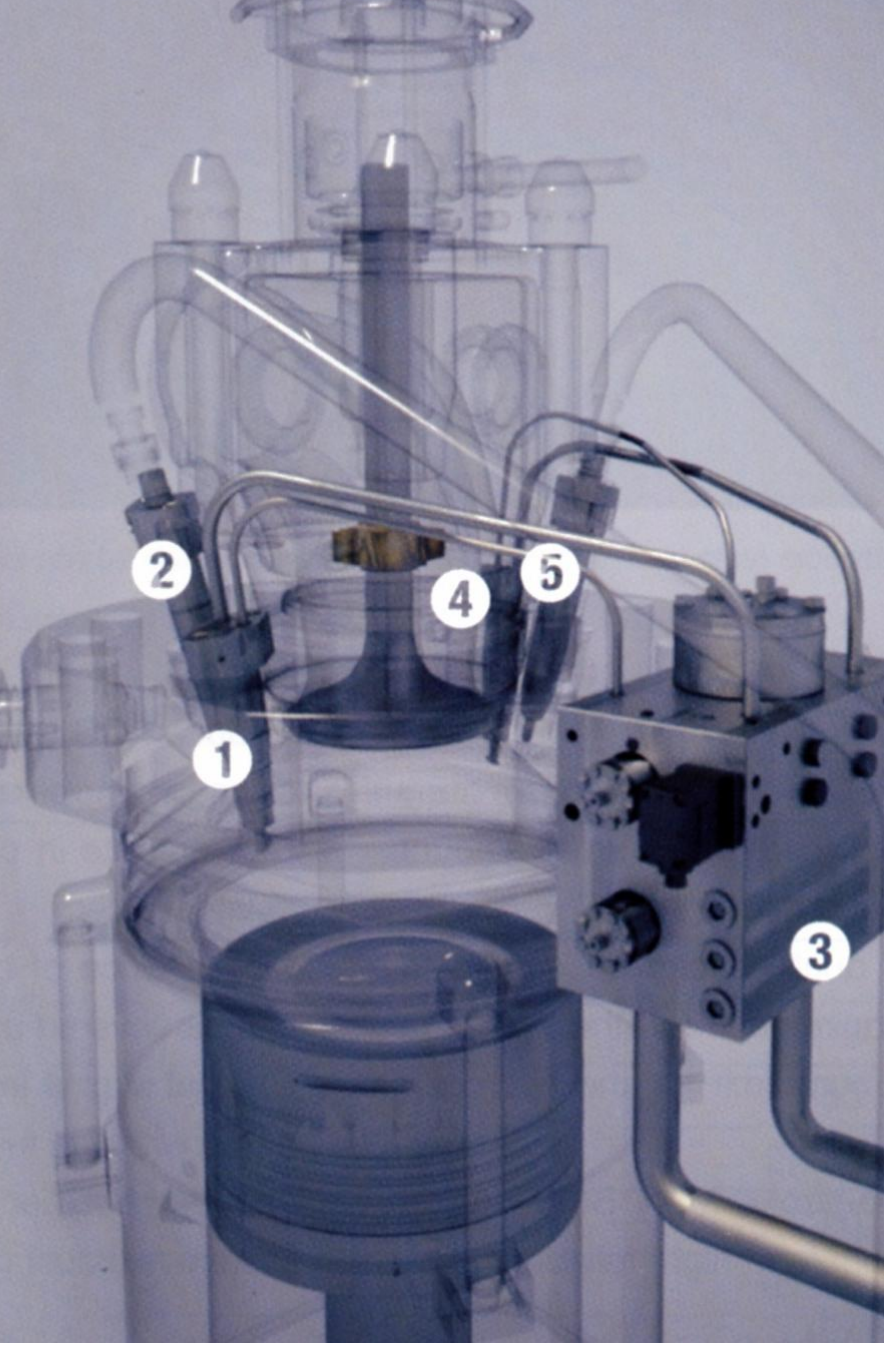


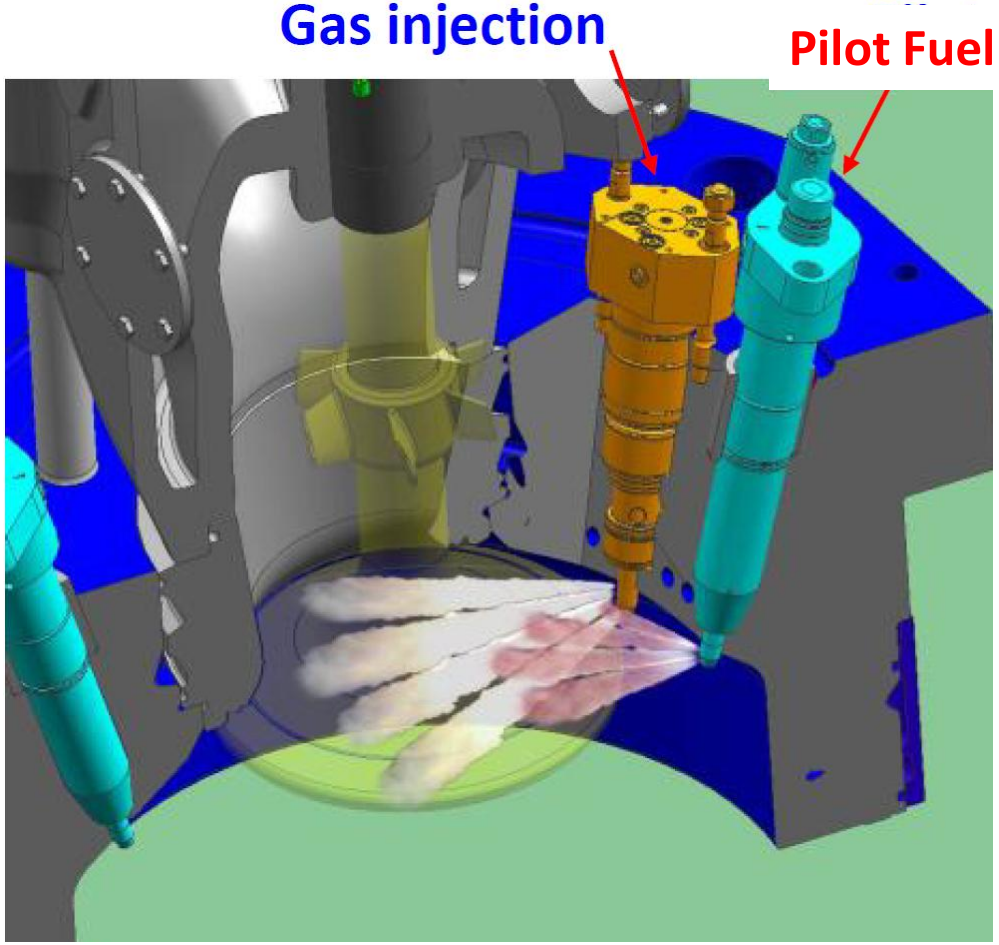


1. Gas injection valve, 2. Fuel valve, 3. Gas control block (GCB), 4. Sealing oil, 5. Pilot oil i.e. HFP or DO

MAN D&T 社資料

GI combustion

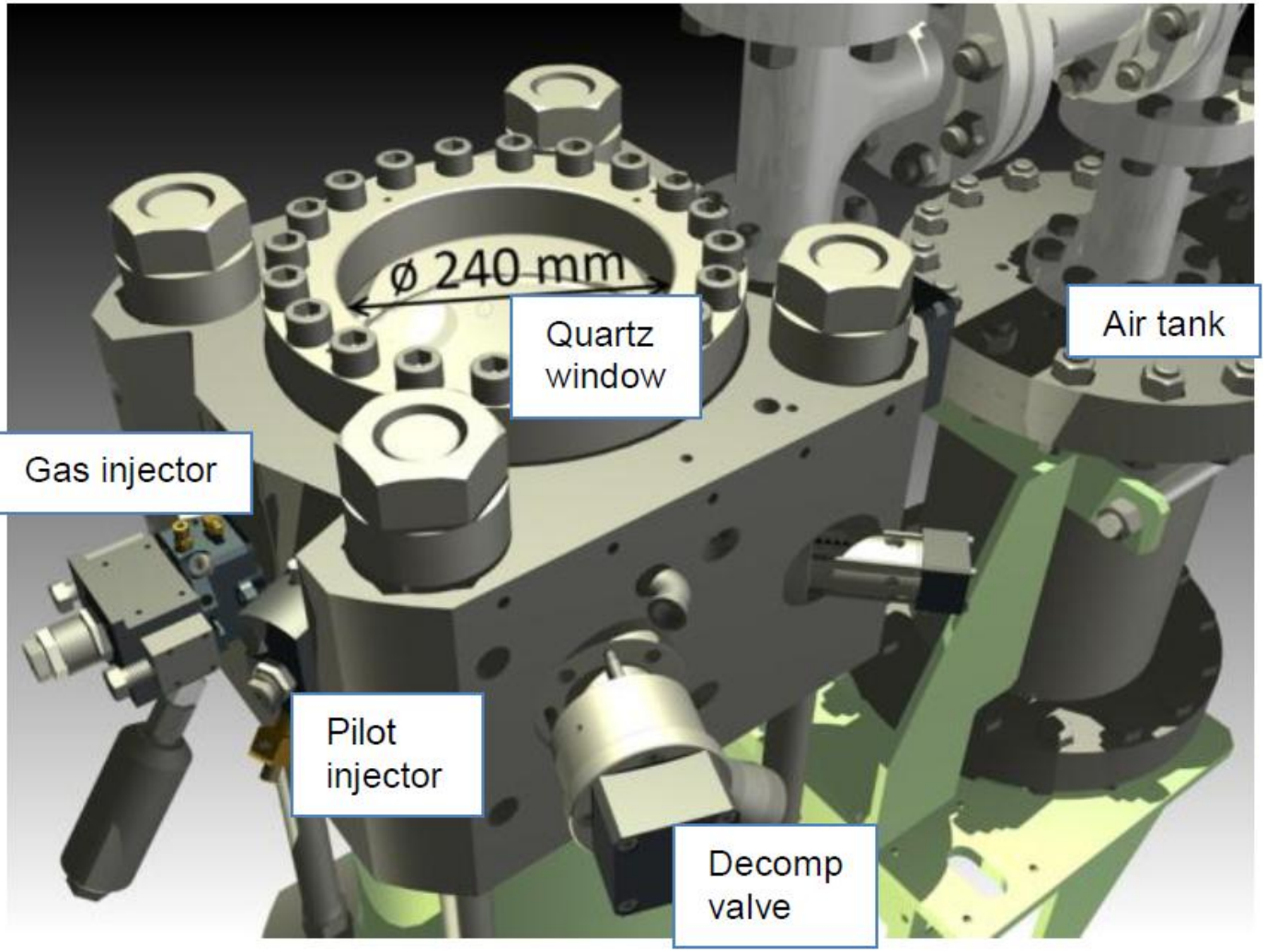


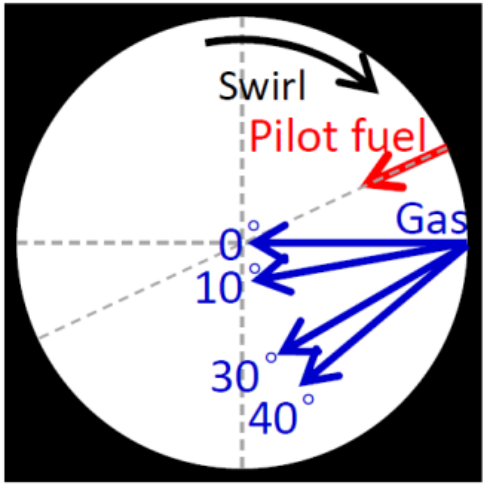


A low-speed marine two-stroke-cycle GI engine

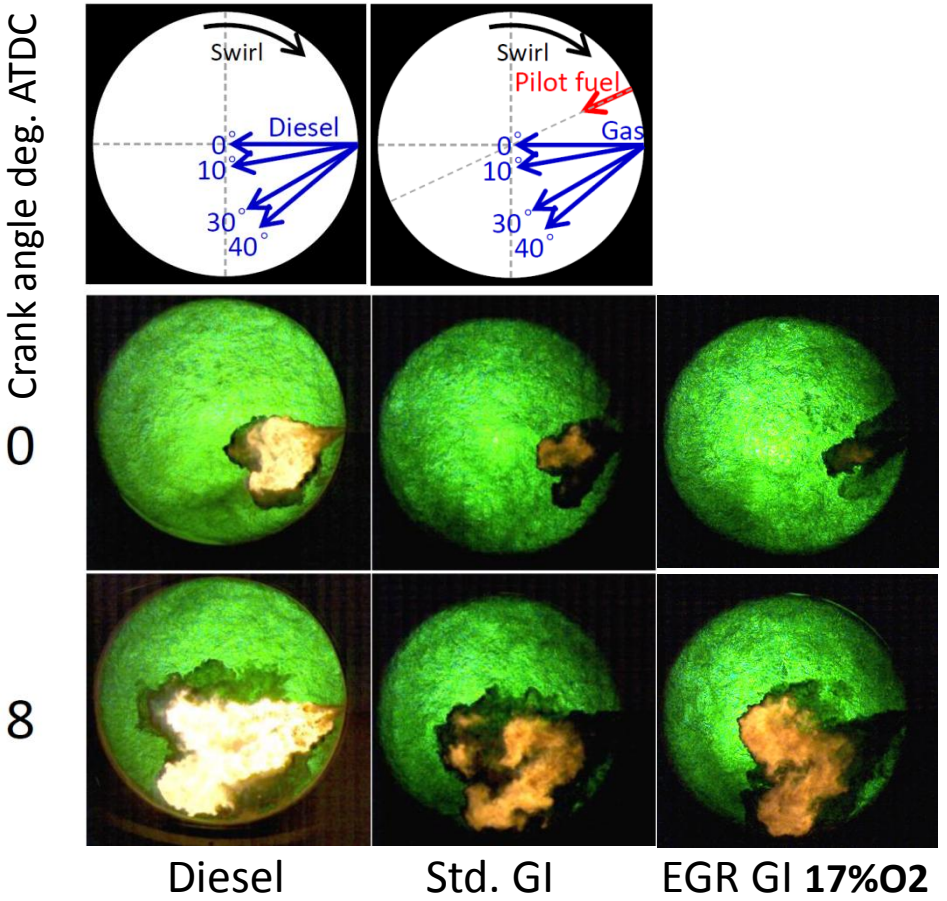
Fundamental study on GI combustion

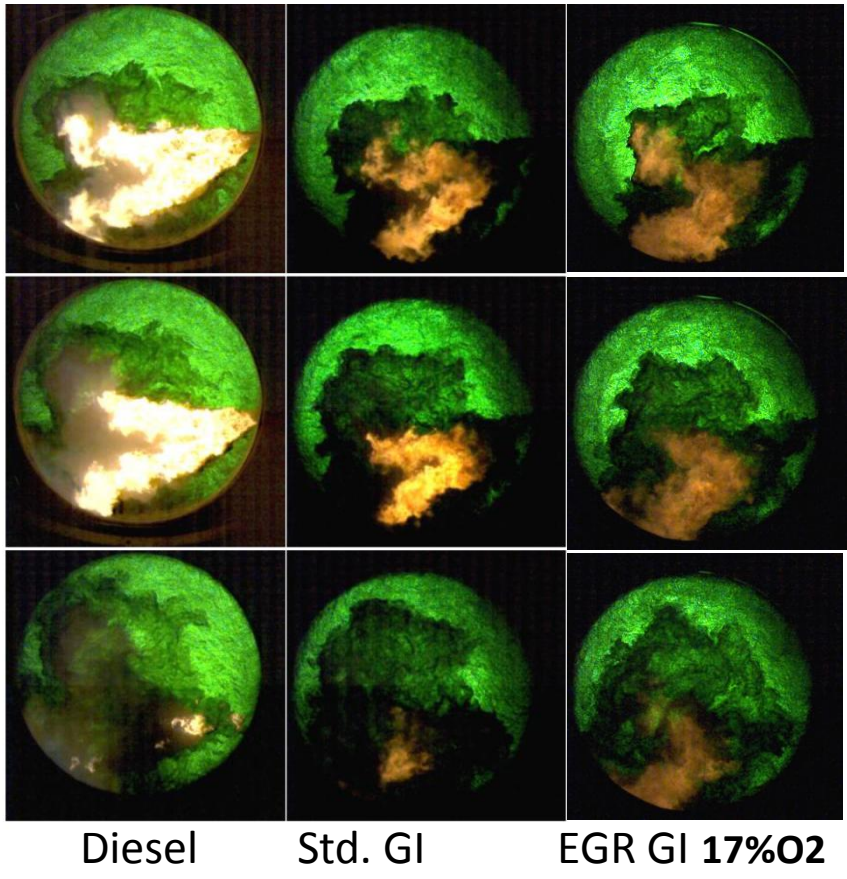
RCEM (Visual apparatus with 240 mm dia. window) is simulating a GI gas engine combustion.



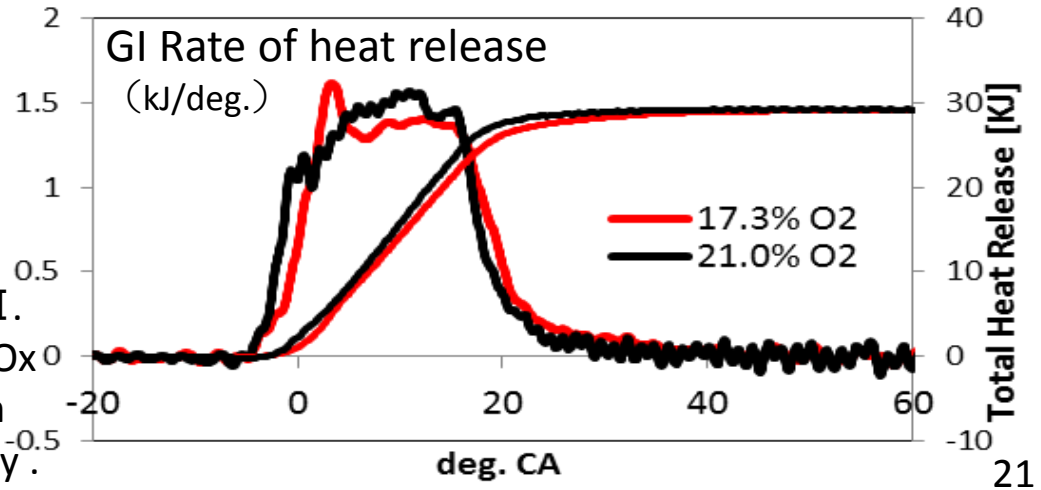


Mirror on top of piston for Schlieren technique





Emissions	Diesel	Std. GI	EGR GI
CO[ppm]	17	30	45
NOx[ppm]	499	300	44



EGR（or SCR）is necessary for GI to clear TierⅢ.
EGR condition is simulated by 17% O2 air and NOx is reduced to 10% of diesel mode with minimum sacrifice of combustion in this fundamental study.

Merits and problems to be solved for two types of gas engine

Lean burn type

(Combustion is 'flame propagation' from pilot-fuel to gas-air pre-mixture.)

Merits

- **Low pressure gas supply**
  (only 5-6 bar for medium-speed and 10 ? bar for low-speed engine.)
- **Low NOx emission**
  (TierⅢ regulation can be cleared without any additional measure.)

Problems to be solved

- **Possibility of abnormal combustion like knocking**
  (Combustion is sensitive to the **Methane Number** (**MN**).)
- **Methane slip** (Cancellation of Green House Gas reduction)

GI (Gas Injection) type

(Diffusive combustion of high pressure gas jet in air ignited by pilot fuel.)

Merits

- **Free from knocking**
  (Insensitive to MN and high compression ratio is possible.)

Problems to be solved

- **Higher NOx** than the lean burn type
- **Work to generate the high pressure** (for example, to 300 bar) **gas**

国土交通省 Ministry of Land, Infrastructure, Transport and Tourism

Review Committee for Comprehensive Measures toward Disseminating/Promoting LNG fuelled Ships

Secretariat : Japan Ship Technology Research Association

【Chairperson】 Dr. Koji Takasaki, Professor, Kyushu University

【Committee members】

Dr. Hayama Imazu, Professor Emeritus, Tokyo University of Marine Science and Technology
Dr. Masataka Fujino, Professor Emeritus, University of Tokyo
Dr. Kenkichi Tamura, Senior Director for Research, National Maritime Research Institute

Nippon Kaiji Kyokai (ClassNK)
Japanese Shipowners' Association
Cooperative Association of Japan Shipbuilders
Japan Gas Association
Shipbuilders' Association of Japan
Japan Ship Machinery & Equipment Association

Review Committee for Fuel Transfer

Secretariat: Japan Ship Technology Research Association

Chairperson:
Dr. Kenkichi Tamura
Senior Director for Research
National Maritime Research Institute

Review Committee for Safety of Navigation

Secretariat: Japan Association of Maritime Safety

Chairperson:
Dr. Hayama Imazu
Professor Emeritus, Tokyo University of Marine Science and Technology

Review Committee for Maritime Disaster Prevention

Secretariat: Maritime Disaster Prevention Center

Chairperson:
Dr. Masataka Fujino
Professor Emeritus
University of Tokyo

Directions on survey policies, review and summarization of survey results with cooperation from key figures in relevant fields, industry organizations, Ministry of Economy, Trade and Industry, Japan Coast Guard and other relevant ministries and agencies

Implementation of survey and review projects by the survey/review consortium
(Survey implementation bodies: Japan Marines Science Inc., Mitsubishi Heavy Industries, Ltd.)

Technical cooperation

ClassNK NIPPON KAIJI KYOKAI

Abundant knowledge of classification society.

(e.g. review of classification codes, inspection etc.)

Collaboration

JSTRA Japan Ship Technology Research Association

Coordination of projects associated with compliance with IMO and ISO.

Introduction of **Review Committee for comprehensive measures toward disseminate/promote LNG fuelled ships • • 2012**

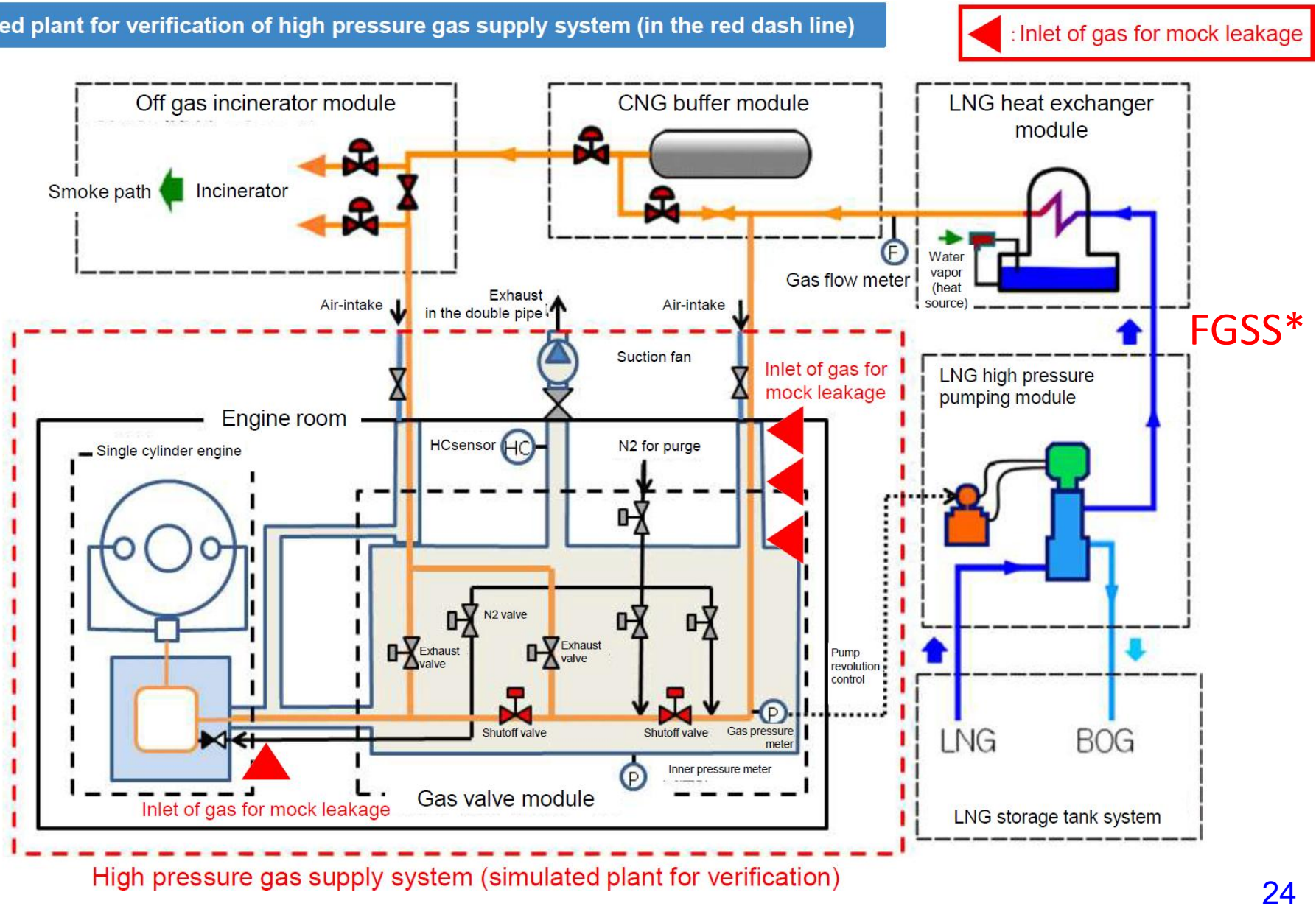
Examples of activities by the national committee

・Development of FGSS and engine room safety system for a low-speed GI type main engine

*FGSS: Fuel Gas Supply System

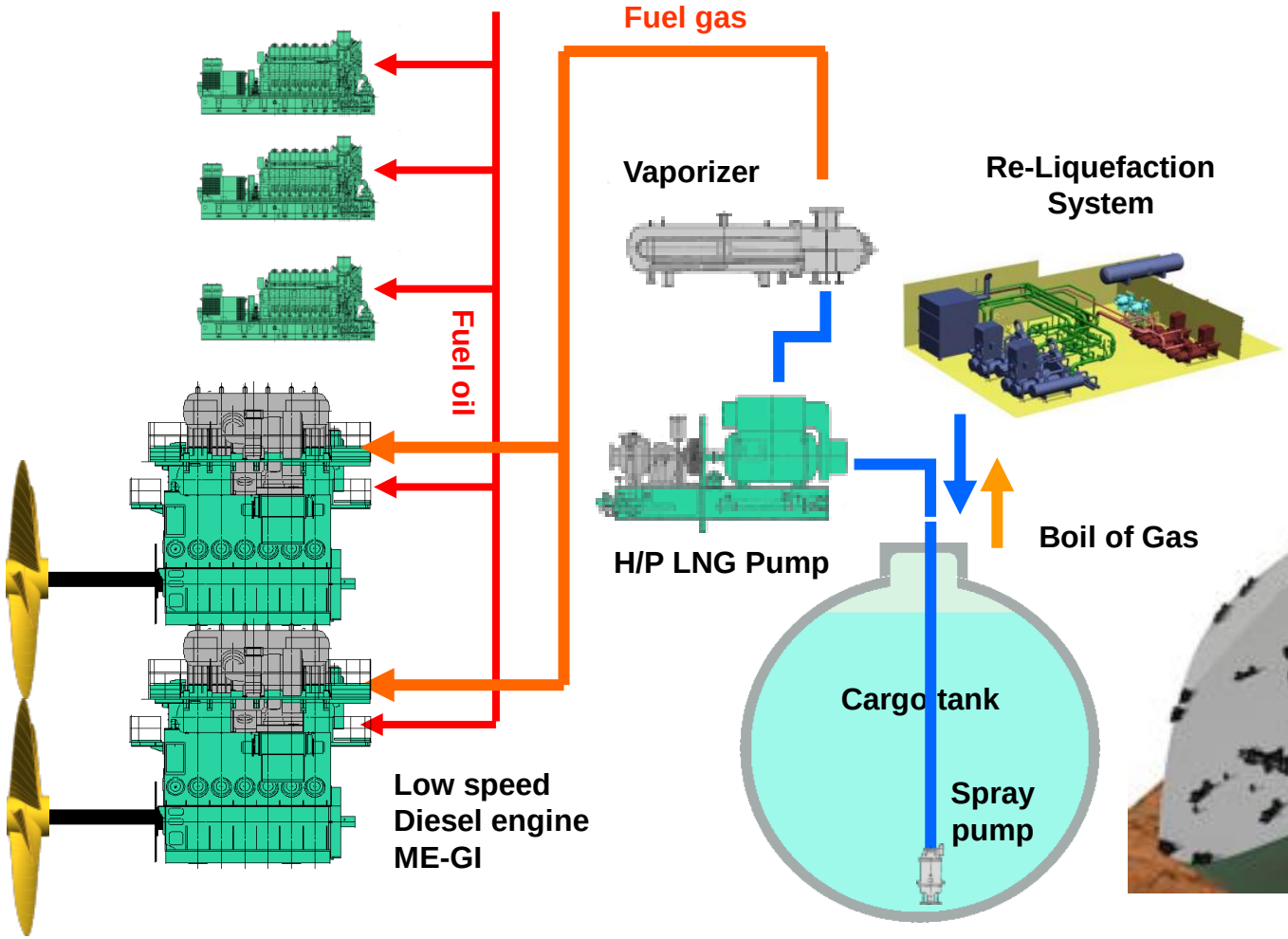
・・300 bar (30 MPa) gas is generated by high press. LNG pump.

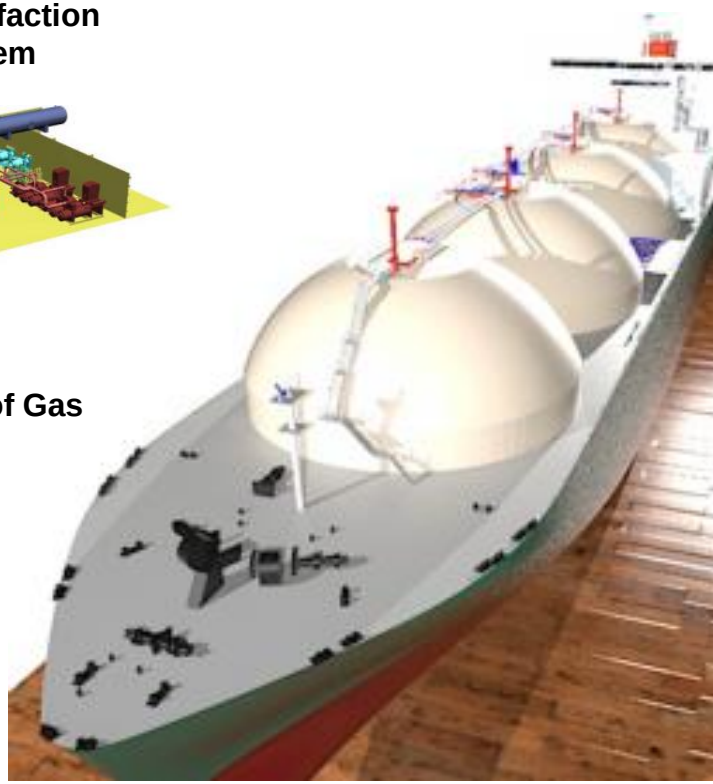
Simulated plant for verification of high pressure gas supply system (in the red dash line)



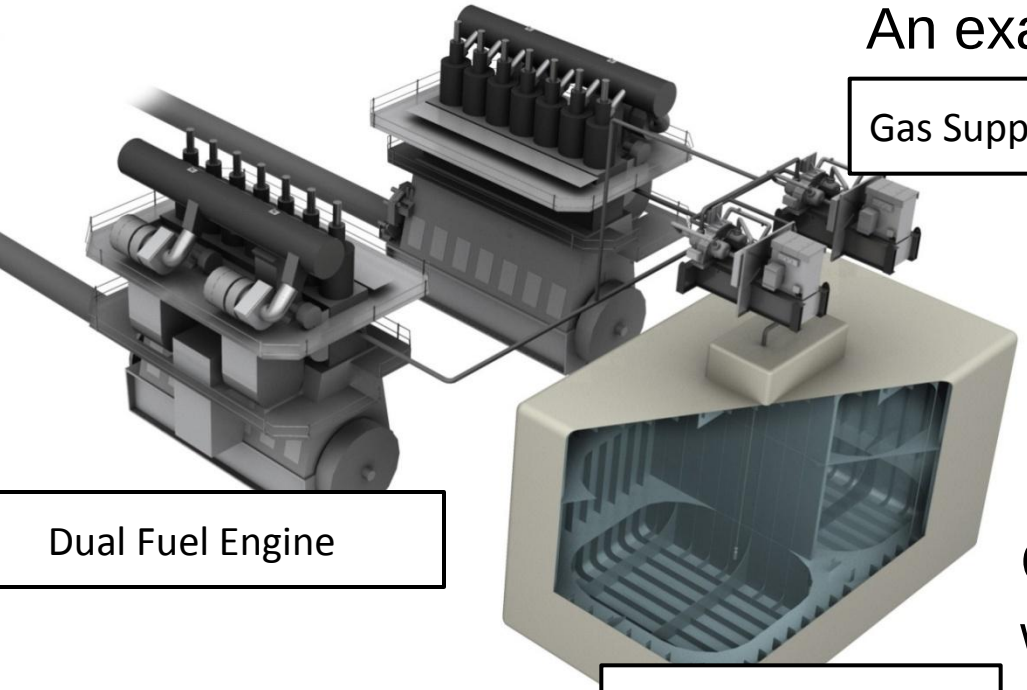
An example of installation of FGSS : Double Eco Max LNGC

- Highly Efficient Dual-Fuel Slow-Speed Electronic-Controlled Diesel Engine (ME-GI)
- Compact Fuel Gas Supply System with Liquefaction Plant
- Efficient and Redundant Ship by Twin Screw Propulsion





An example of installation of FGSS



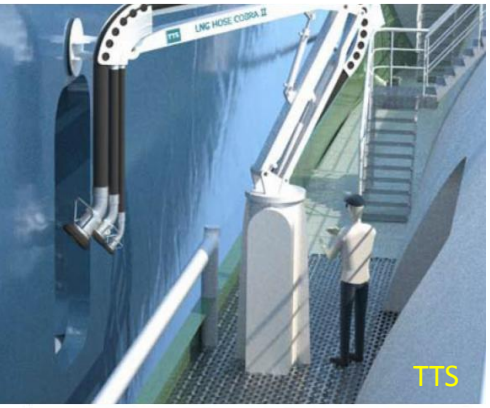
Gas Supply System

Dual Fuel Engine

IHI-SPB LNG Tank

Container vessel (JMU)

with originally designed LNG tank



LNG transfer arm

LNG transfer hose

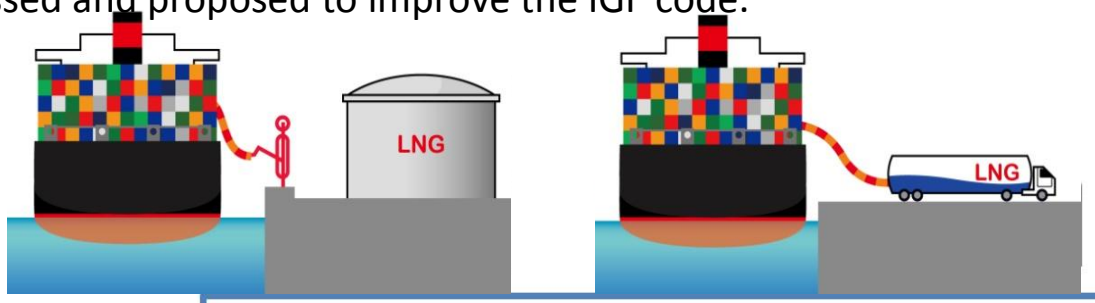
Hose saddle

Drip tray

Water curtain

In the committee, many subjects on the safety of facilities for LNG bunkering have been discussed and proposed to improve the IGF code.

Fender (pneumatic fender)



Emergency shut down system (ESDS)
Emergency breakaway device (ERS, DBC)

Emergency release coupling (ERC), a device installed in ERS

Coupling with a function to prevent leakage (DBC)
Note: Can be used for hoses with a small diameter

Note: In case where BAC is used, it is necessary to review measures to ensure that ESD operates before detaching BAC and take appropriate measures.

13

ClassNK is playing a leading role in this area.

Thank you for your kind attention