Feb. 13. 2015

Development of LNG Fuelled Ships (Natural Gas Engines) as an Example of Collaboration with Industries + ClassNK + Government + Universities

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1. Background for development of LNG fuelled ships
2. Role of university for collaboration
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Laboratory of Engine and Combustion, Kyushu University, Japan

1. Background for development of LNG fuelled ships・・

SOx regulation

ECA 2015～ **0.1%**

Global Cap
2020（2025）～ **0.5%**
All area other than ECA

（Including Japanese domestic）

EU Directive
EU EEZ 2020～ **0.5%**

(In case that global cap starts from 2025)

Motivation for natural gas fueled ships

Regulation of SOx(PM) and NOx Emissions

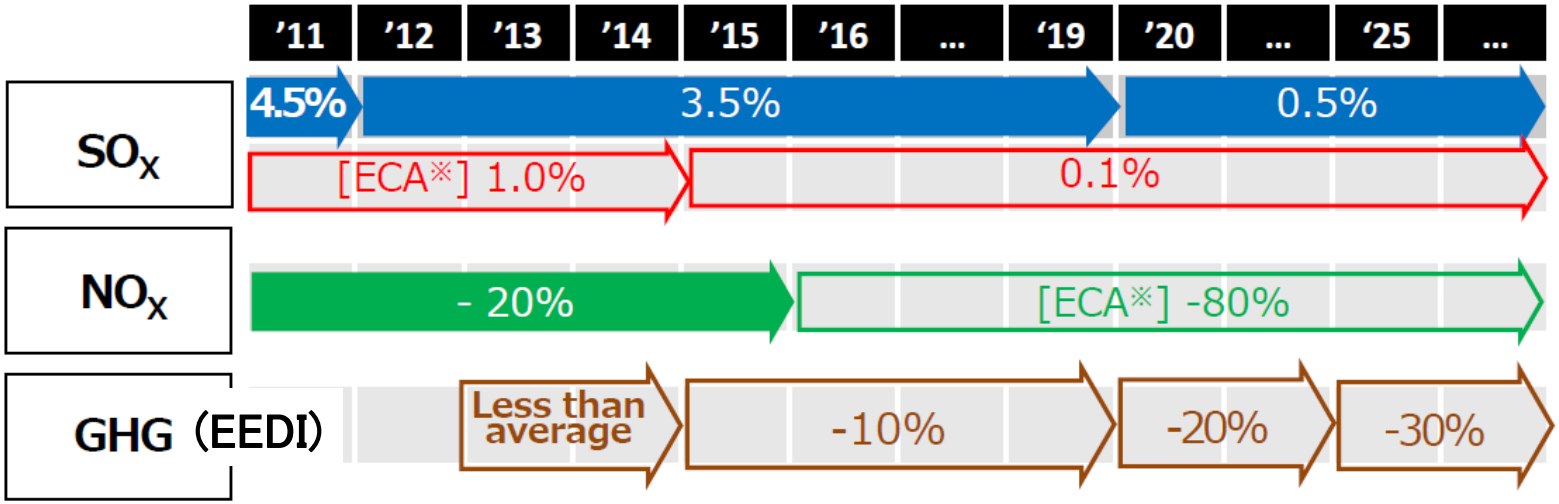
(Black Carbon (BC) in the North-pole area is under discussion)

Regulation of CO2 ：Green House Gas (GHG)

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

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

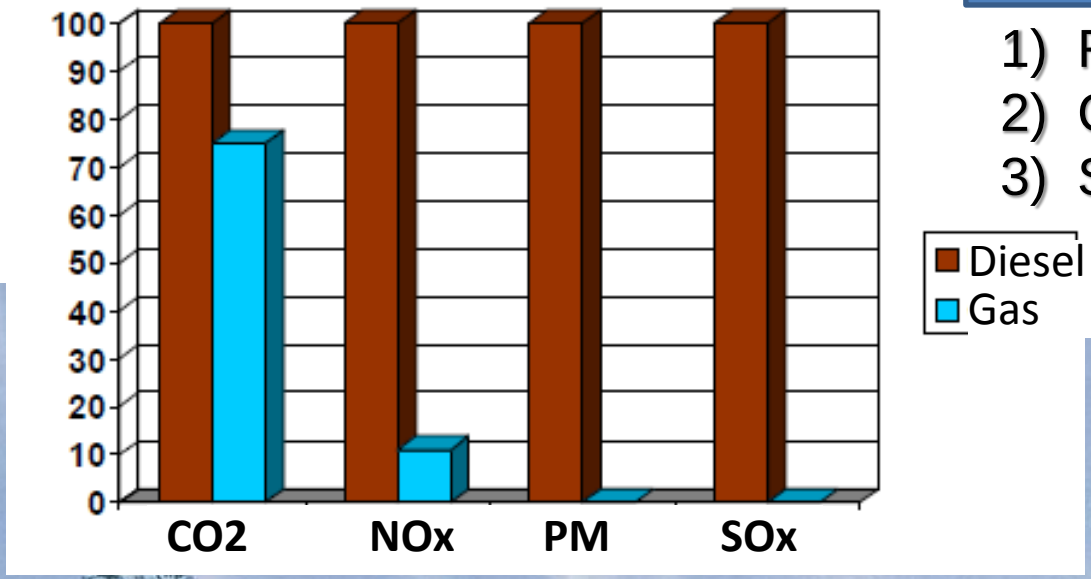
For newly built ships **2015～ -10%, 2020～ -20%, 2025～ -30%**



Marine diesel oil $C_{16}H_{34} + 16\,O_2 \rightarrow 16\,CO_2 + 17\,H_2O + Q$

Natural gas $CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + Q$

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

‘All-mighty’ effect of natural gas fuelled ship

Natural gas fueled ships in service

About 50 ships in North Europe driven by medium-speed 4-stroke lean-burn type gas engines (ferry, off-shore supply vessel, etc.).

フェリー

オフショア支援船

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

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

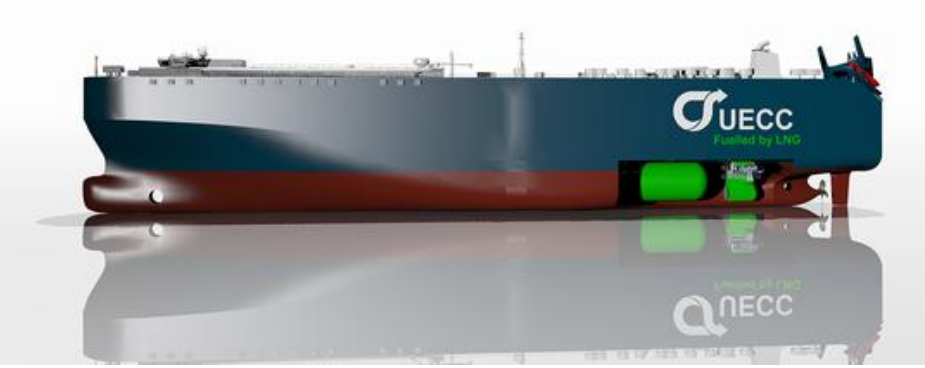
観光船 @韓国・仁川港

沿岸警備船

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）

Natural gas fueled ships from now

including large ships driven by low-speed 2-stroke natural gas engines.

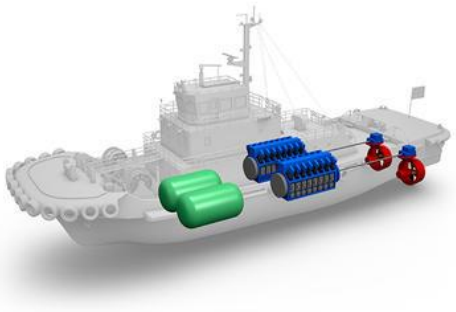


• United European Car Carriers (UECC) jointly owned by NYK and Wallenius Lines has ordered KHI two PCCs propelled by MAN low-speed ME-GI gas (DF) engine. (for voyage in European ECA)

・NYKとWallenius共同出資のUECC社が、MANの低速２ストGI（DF）エンジンを搭載した自動車運搬船を川崎重工に発注（欧州内ECAに投入予定）。

• TOTE Line has ordered 3,100TEU container ships propelled by MAN low-speed ME-GI gas (DF) engine. (Route: Florida⇔ Puerto Rico)

・米国内航船社TOTE社が、MANの低速２ストGI（DF）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）



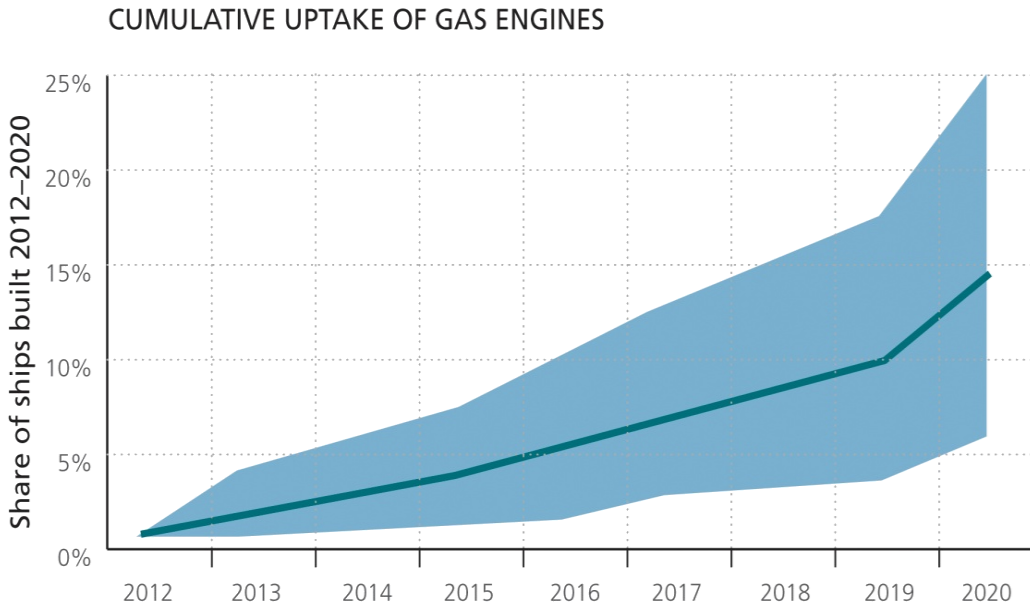
・Development of LNG-fuelled tug-boat by NYK Group・・2013～
（ClassNK is supporting development of not only vessel itself but also medium-speed DF engine）

・負荷変動の激しいタグボートをLNG燃料化（NYKグループ）（政府と日本海事協会の支援）

Another background for LNG fuelled ships • • Price

An estimation • •

About 1000 LNG fuelled ships (14% of newly built ships) will be in service in 2020,
on the assumption that LNG price is 30% cheaper than HFO.



(DNV Report “Shipping 2020”)

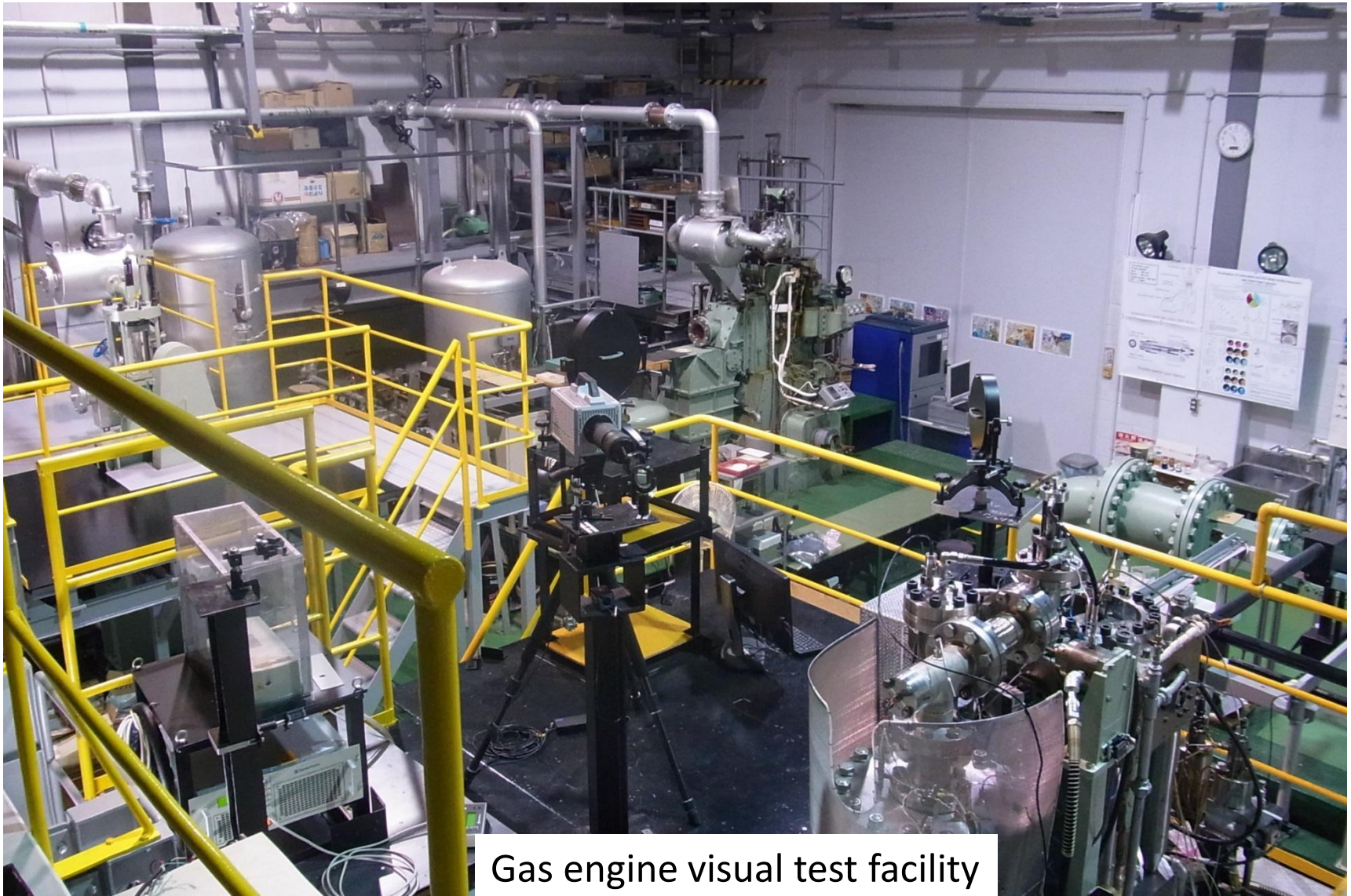
To estimate on growth of LNG fuelled ships, for example by 2030, following new conditions must be considered.

- Global cap will start from 2020? or 2025?
- How would be LNG and bunker liquid fuel price in the future?

(LNG price should be compared with not HFO but **MGO** after the global cap.)

2. Role of University for collaboration

Introduction of fundamental study on natural gas engine combustion by Kyushu University,
for example, '**knocking**' phenomena・・**GI** combustion・・



Gas engine visual test facility

At first, let's see a movie on knocking phenomena in automobile gasoline engine as a reference.

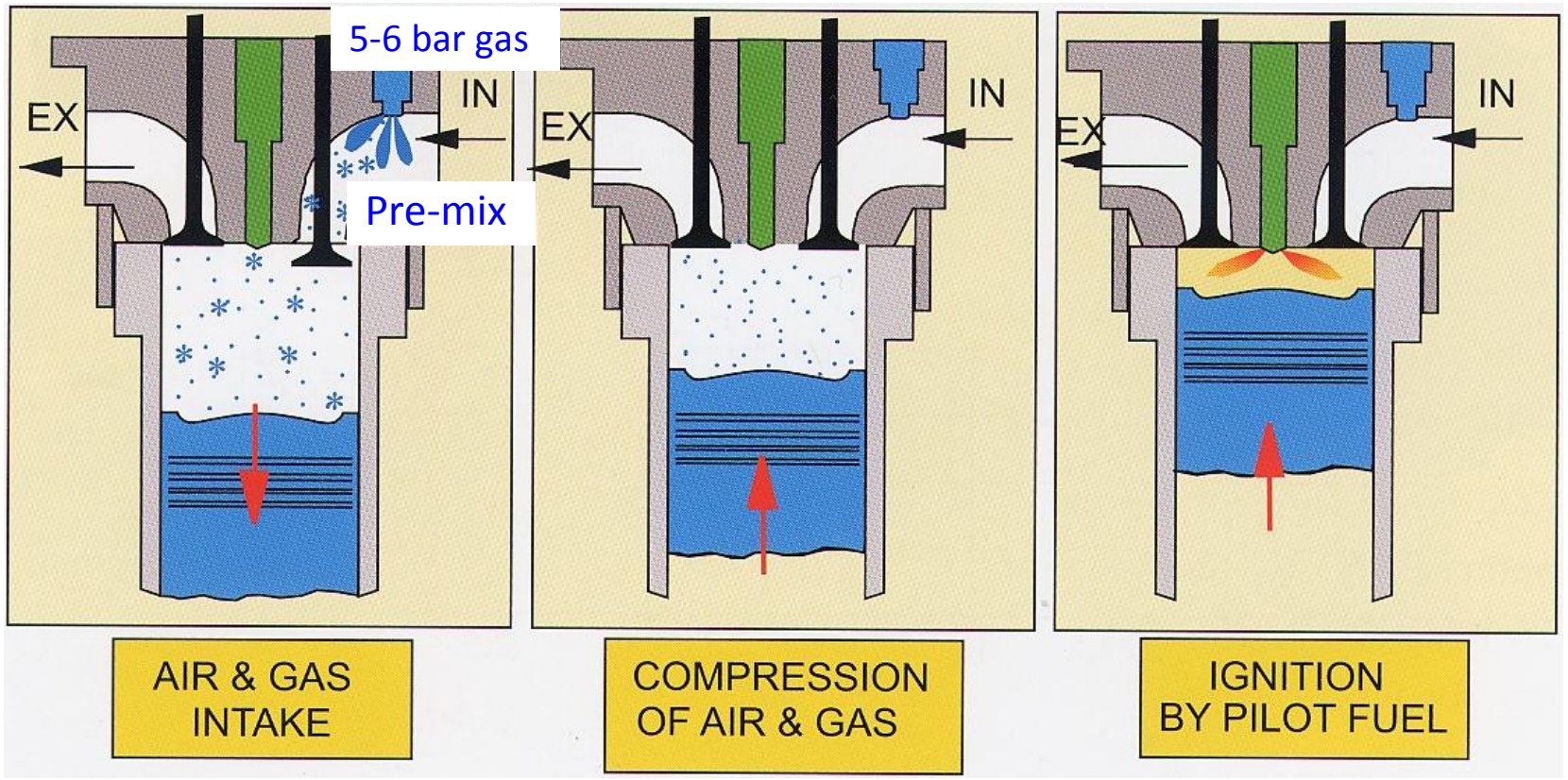
(Gasoline with high 'Octane Number' allows high compression ratio.)

Lean-burn type (**Otto-cycle type**) gas engine (Table 1) has the same combustion style as gasoline engine and suffers **knocking** in rough sea, especially when low 'Methane Number' gas is burned.

Key word :

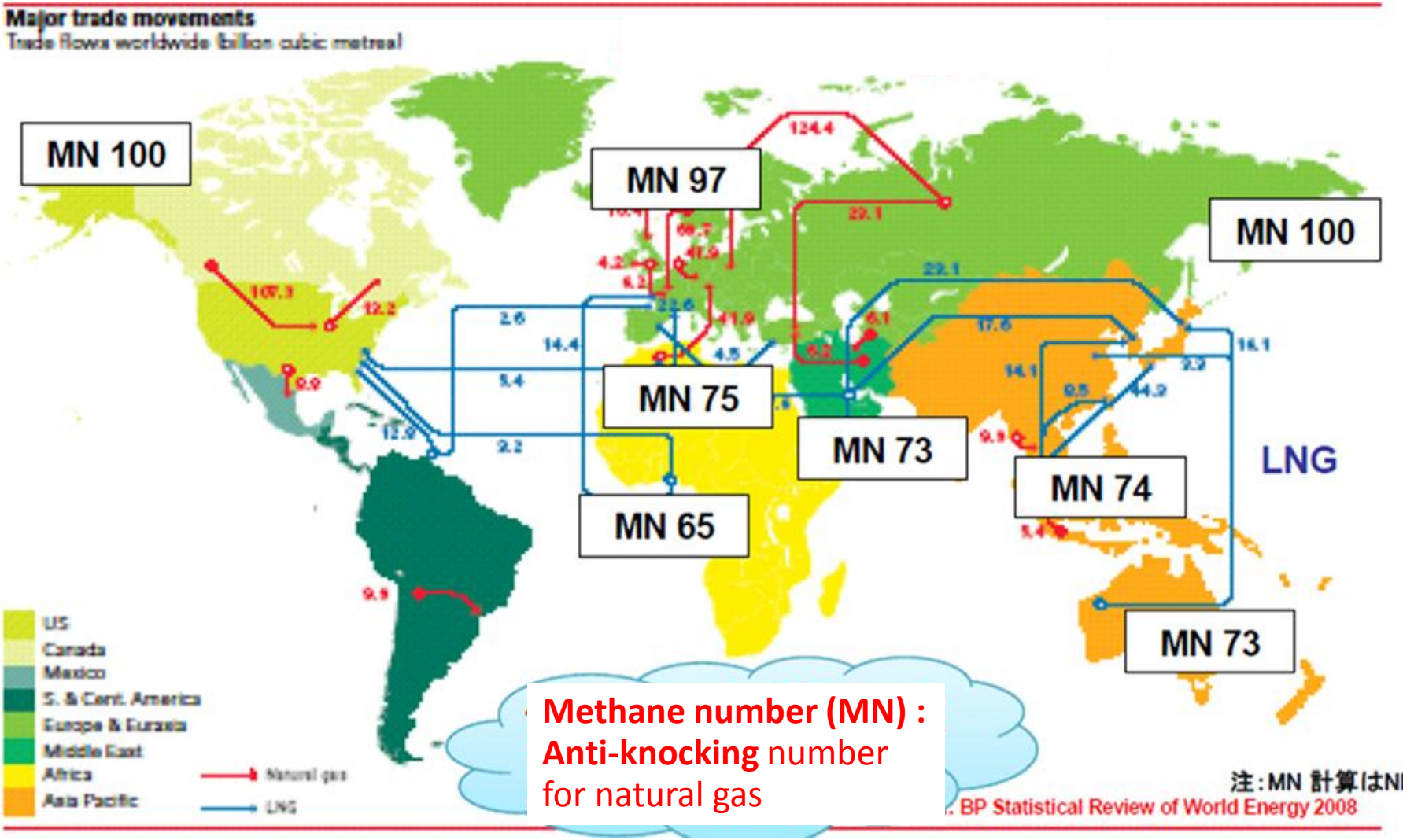
Methane number (MN) : Anti-knocking number for natural gas

To keep safe operation at high load, MN higher than 80 is necessary.

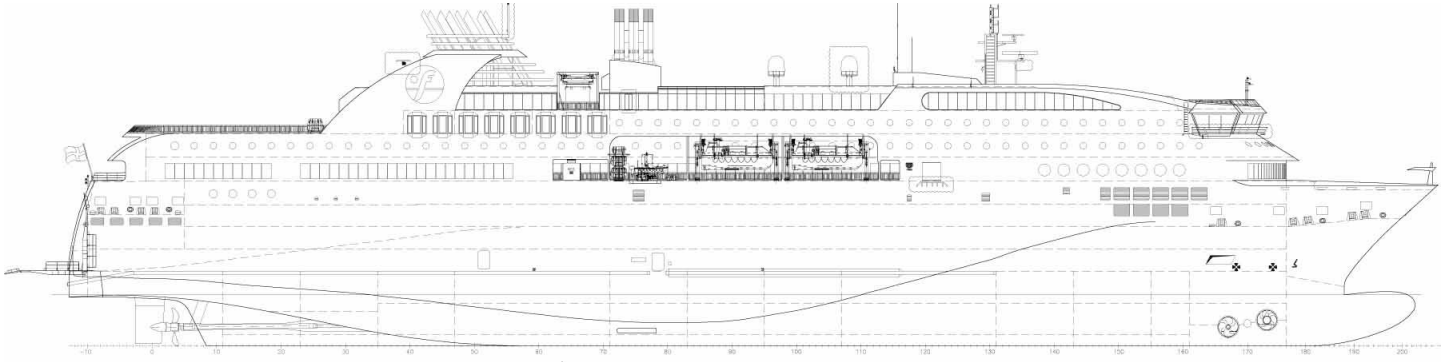


Function of medium-speed lean-burn gas engine

Current Methane Number of natural gas in each area



Ferry ‘Stavanger Fjord’ between Norway (Bergen) and Denmark, (25,000 GT) suffers knocking in rough sea condition in winter, even if high MN gas is burned.



RR B35・40 type mono-fuel gas engine
5400 kW（Pme: 18.7 bar, 750 rpm）
X 4 sets drive two CPPs directly.

Merit of DF (‘Dual Fuel’) engine

(An example of platform supply vessel in rough sea condition in 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)

Table 1 Categorization of main engines (excluding seam turbine for LNGC)

	Direct coupling	Electric drive
Medium-speed 4-st.	Existing	Popular
Low-speed 2-st.	All	Nonexistent

	Mono-fuel	DF（Dual Fuel）
Medium-speed 4-st.	Existing	Popular
Low-speed 2-st.	Nonexistent	All

In case of **DF**, fuel can be switched instantly from gas to heavy fuel in an emergency like heavy knocking or gas-leak.

	Lean-burn (pre-mixed) (low-pressure gas supply)	**GI** (Gas Injection) (high press. gas injection)
Medium-speed 4-st.	Currently all	Possible but not yet applied
Low-speed 2-st.	Existing **Otto-cycle** type gas engine	Existing **Diesel-cycle** type gas engine

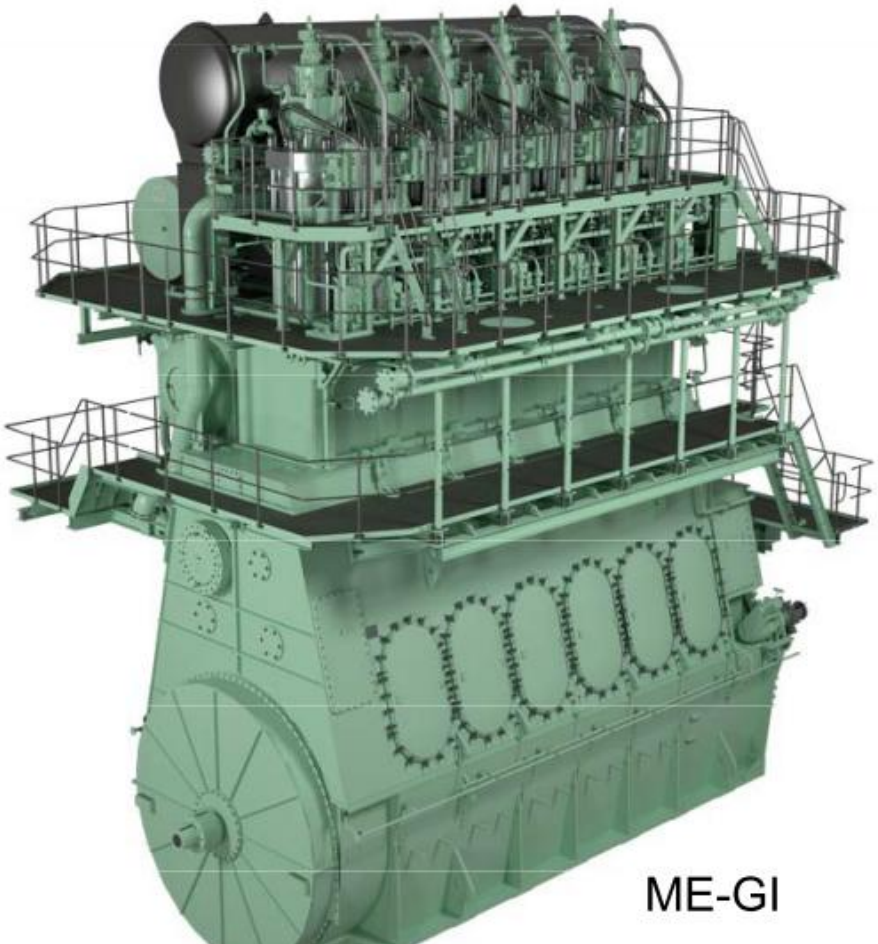
An example of research work by Kyushu Univ.

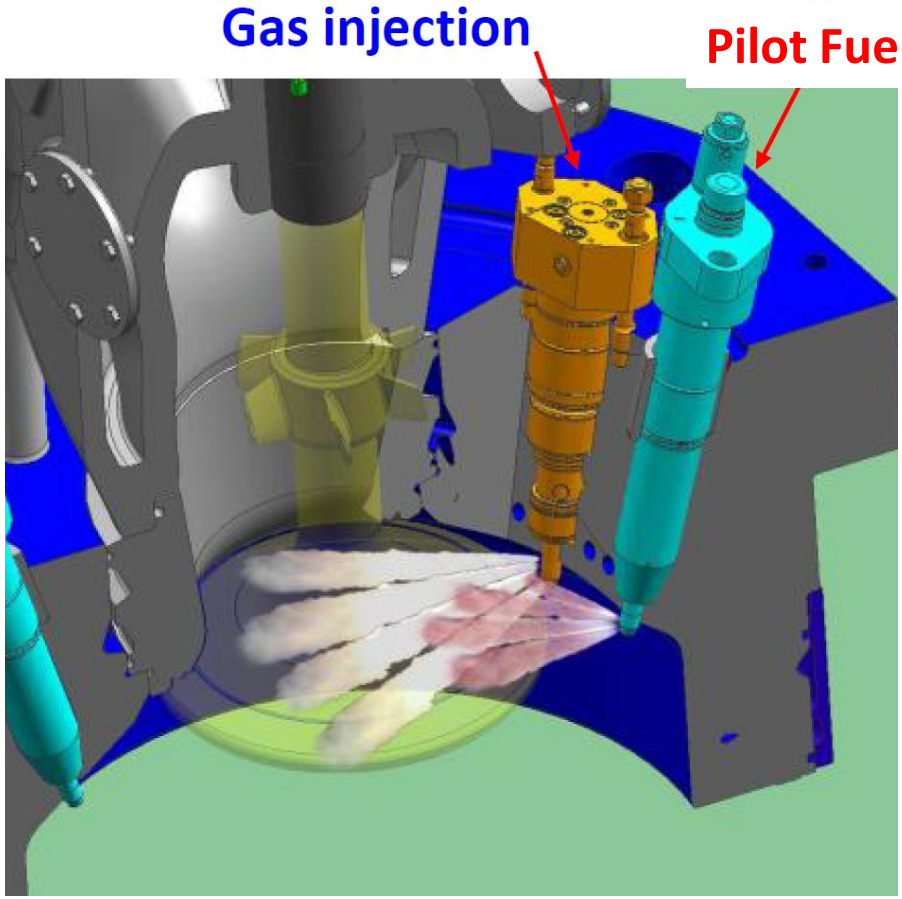
GI (**G**as **I**njection) type combustion • • named ‘Diesel cycle gas engine’

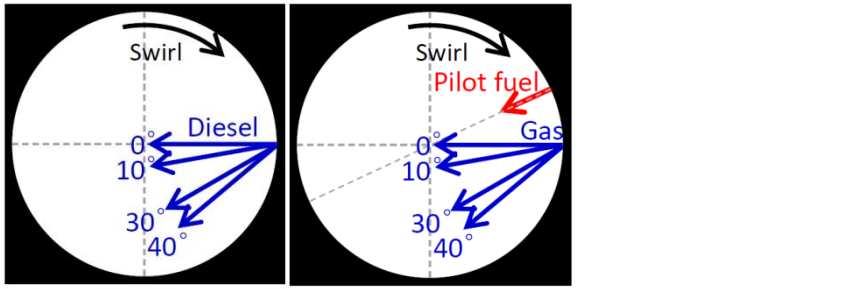
(Diffusive combustion of high pressure gas jet ignited by pilot fuel.)

Merits : Free from knocking & abnormal combustion (Any MN is allowable.)

Lower methane slip







Crank angle deg. ATDC

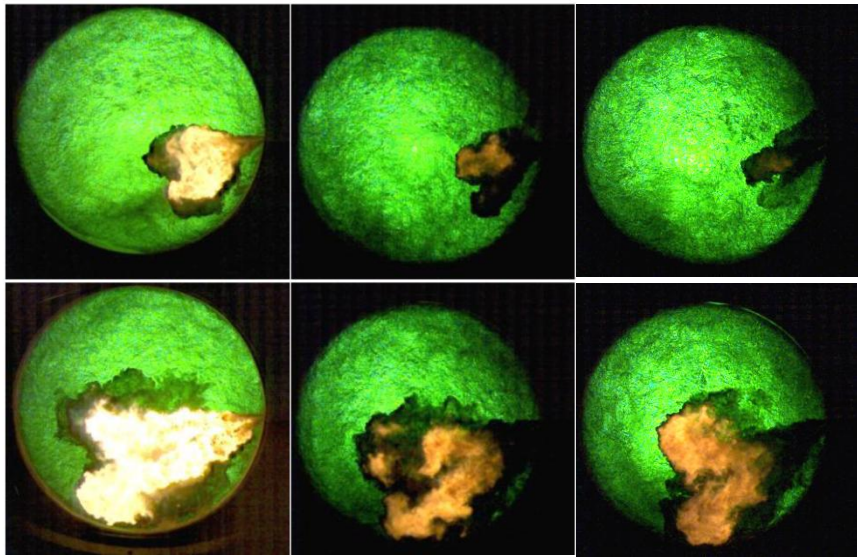
0

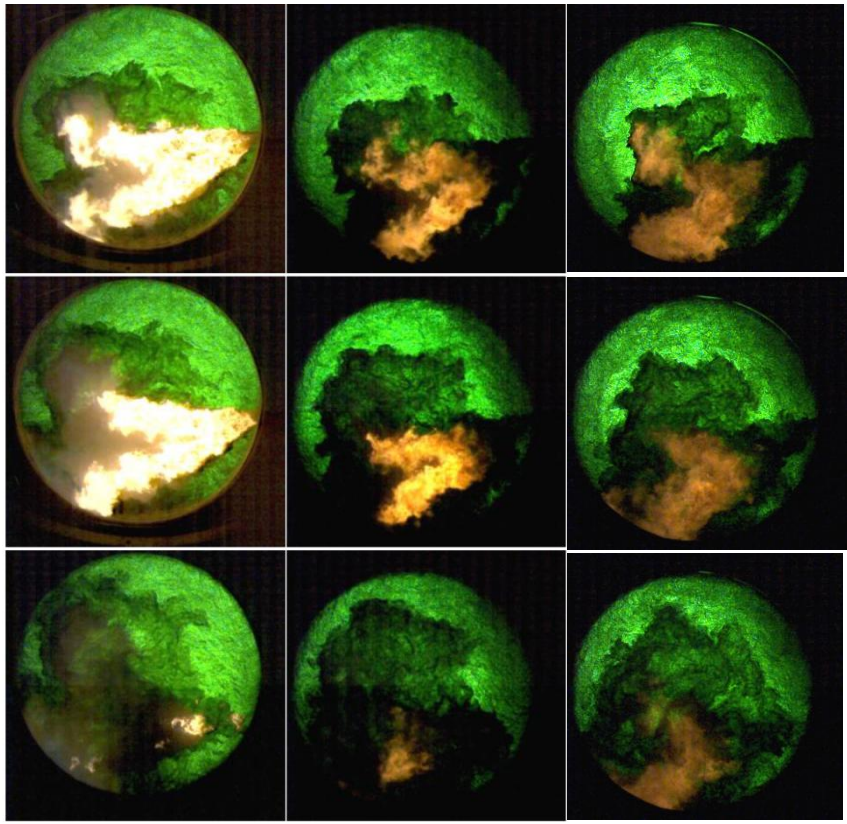
8

12

16

20



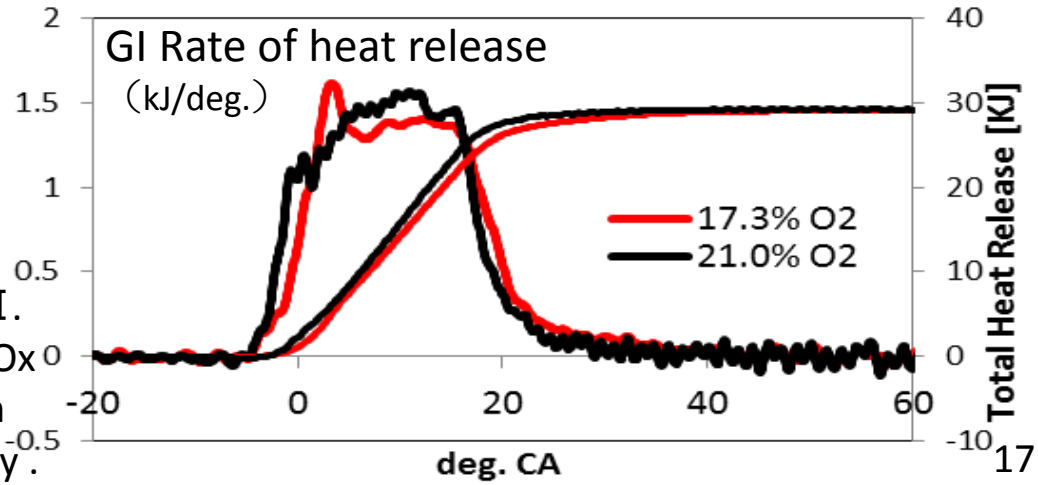


Diesel Std. GI EGR GI **17%O2**

Diesel Std. GI EGR GI **17%O2**

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

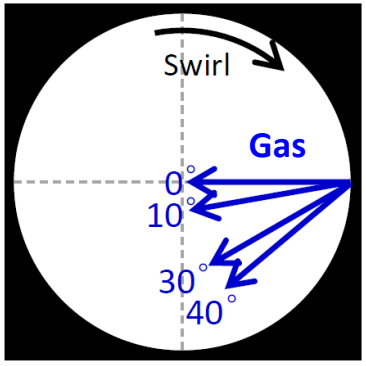
EGR（or SCR）is necessary for GI to clear TierⅢ.
EGR condition is simulated by 17% O2 air and NOx is reduced to 10% of diesel mode with minimum sacrifice of combustion in this fundamental study.



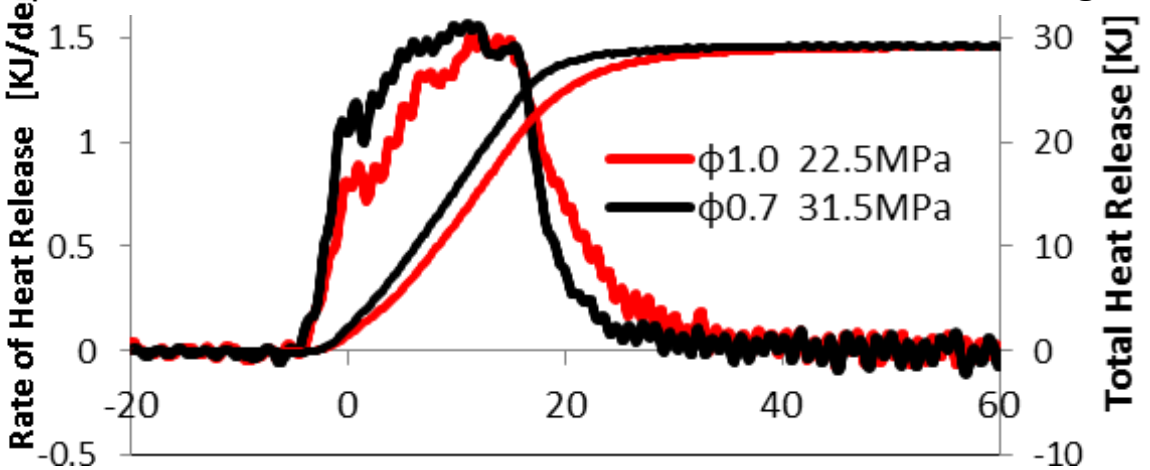
Lower gas pressure case shows longer burn-up length of flame.

d: 4x **ϕ0.7**
31.5MPa

d: 4x **ϕ1.0**
22.5MPa



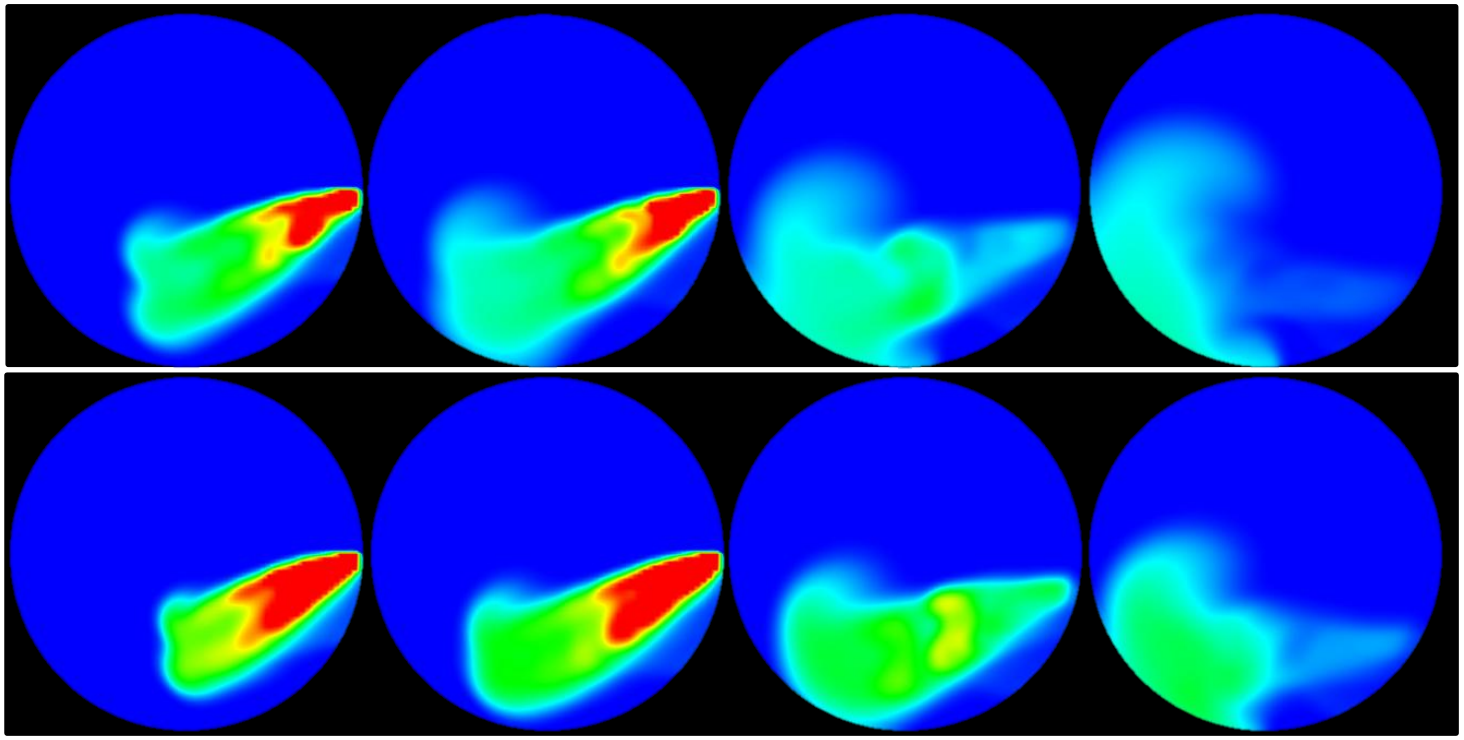
8 12 16 20 [deg.ATDC]

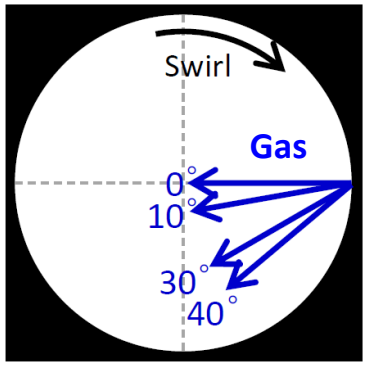


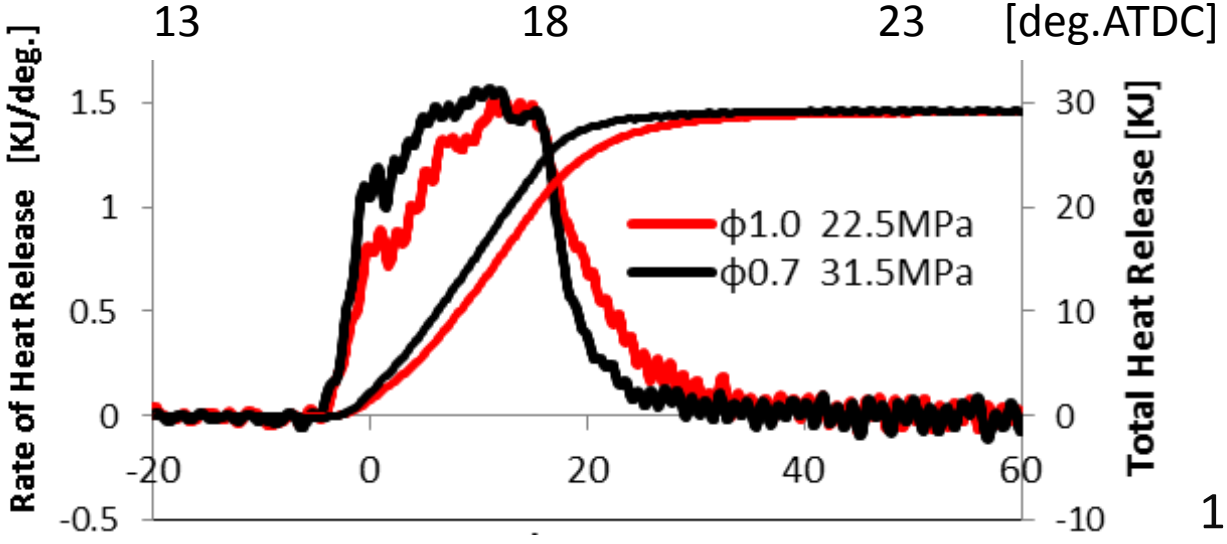
An example of CFD simulation : Visualization of fuel mass fraction in gas jet

d: 4x **ϕ0.7**
31.5MPa

d: 4x **ϕ1.0**
22.5MPa

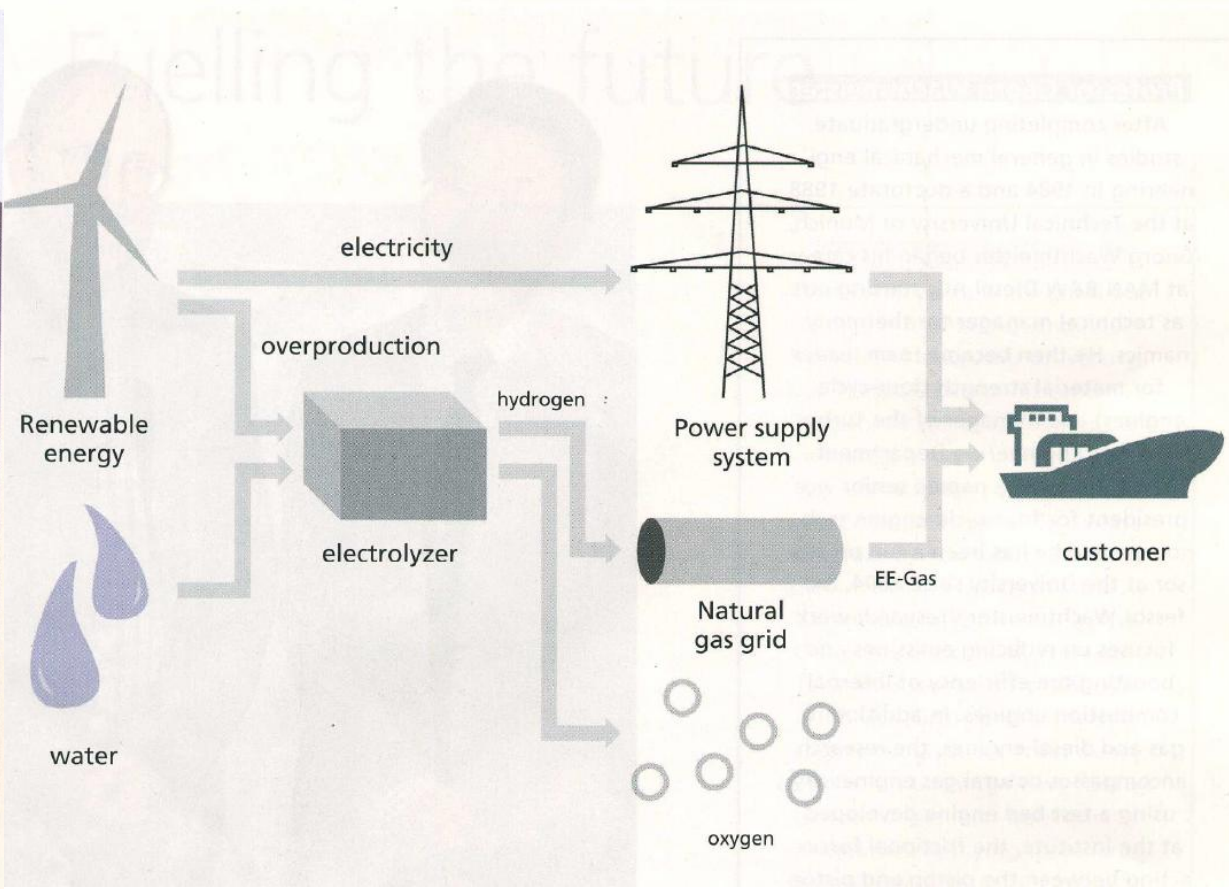






Further research theme ‘Hydrogen-admixture to natural gas for gas engines’ has started in 2014, as a joint research by ClassNK, Technical Univ. of Munich (Germany) and Kyushu Univ..


Professor Koji Takasaki and Professor Georg Wachtmeister



(Promotional supplement in association with ClassNK, the Schiff & Hafen (Ship & Offshore, Sept. 2014)

3. Support for ship and engine development by ClassNK

ClassNK Joint Industry R&D project on LNG fuelled ship (1/2)

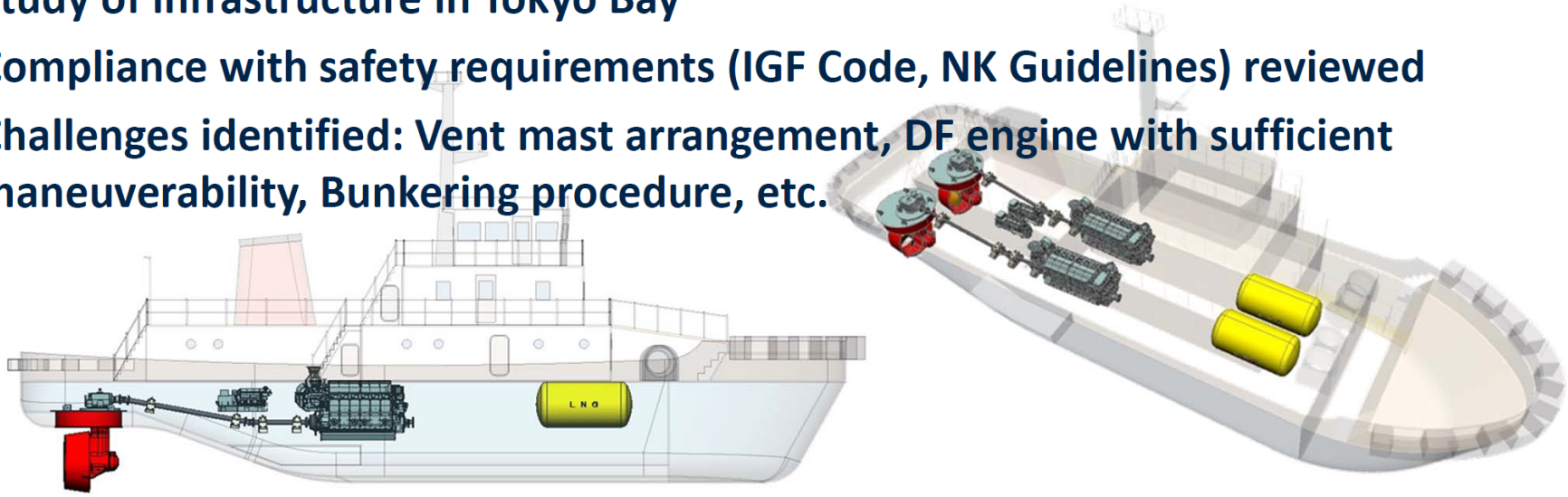
Project	Industry Participants
Prelim. design development of LNG fuelled ships & feed back to IGF Code	JSTRA, IHI MU (JMU), Imabari, KHI, Namura, MES, MHI, Universal, K-Line, MOL, NYK, MTI
Research for practical use of ocean-going LNG fuelled ship	JMS
Research for LNG fuel application on coastal tug boat	JMS, TLT
Preliminary design development for coastal tug boats with LNG fuel system	NYK, Keihin Dock, Niigata Power System
Risk assessment of H.P. fuel gas supply system for low speed DFD	MES, MOL

- Development of LNG-fuelled tug-boat by NYK Group • • 2013～

（ClassNK is supporting the development of not only vessel itself but also its medium-speed DF engines.）

Development of Coastal Tug Boat with LNG fuel system

- ✓ **Study of optimum design (comparison in engine type, shafting & propellar, LNG/CNG tank system, etc.)**
- ✓ **Study of infrastructure in Tokyo Bay**
- ✓ **Compliance with safety requirements (IGF Code, NK Guidelines) reviewed**
- ✓ **Challenges identified: Vent mast arrangement, DF engine with sufficient maneuverability, Bunkering procedure, etc.**



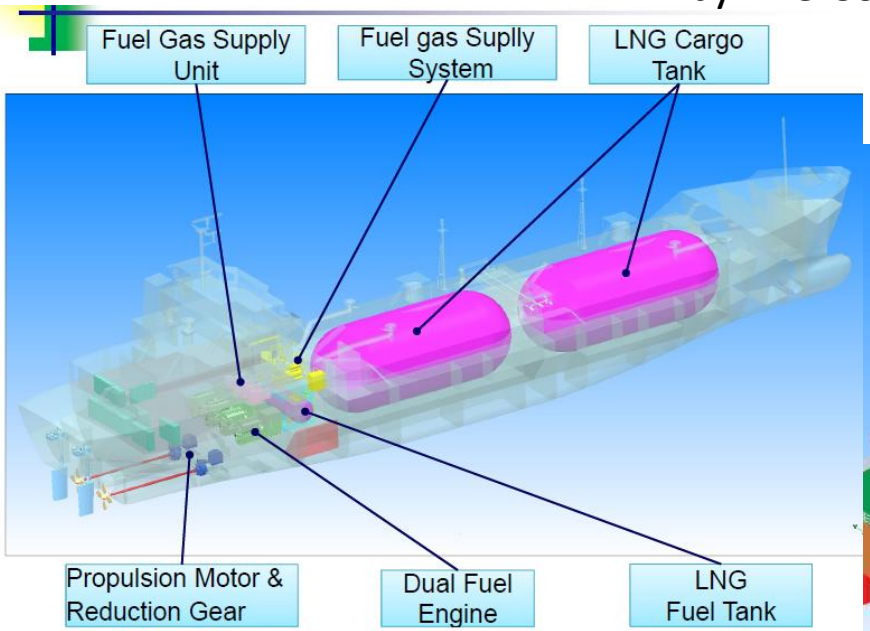
LNG Fuel Tank	25m3 (12.5m3 X 2), bunkering : once a week
Propulsion System	DF Engine (abt.2000kW) & direct coupling with thruster X 2sets

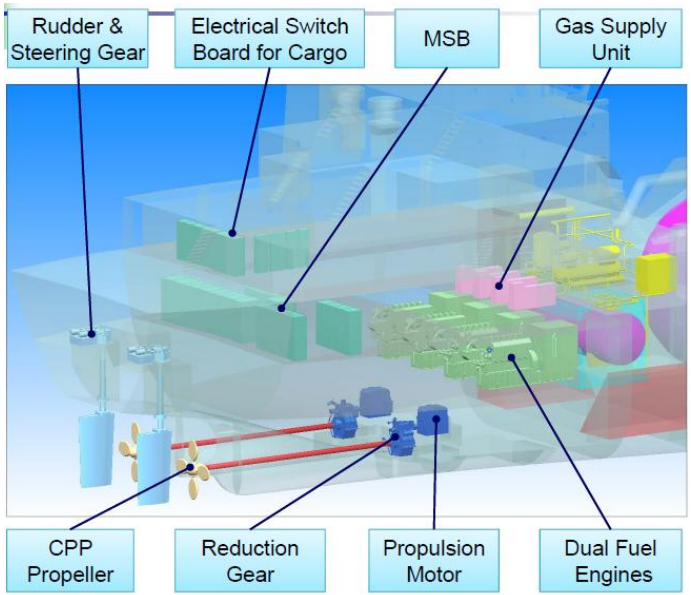
ClassNK Joint Industry R&D project on LNG fuelled ship (2/2)

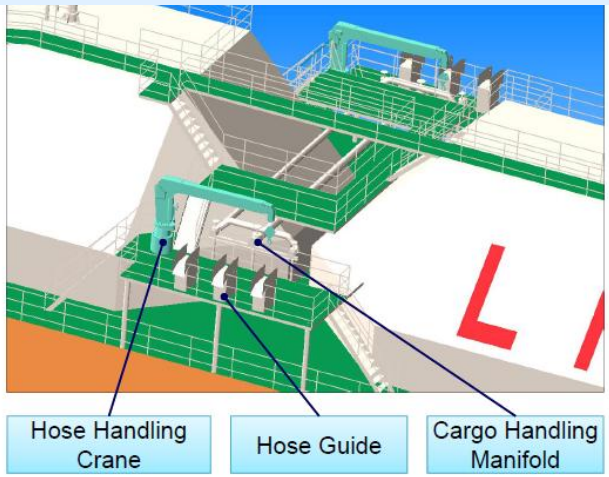
Project	Industry Participants
Research on on-deck arrangement of LNG fuel tank with prismatic type B design	MHI
Feasibility study of varying types and materials of LNG fuel tank	MHI
Prelim. design development of ocean going LNG fuelled ship & bunker ship	MHI, NYK, JMS
Development of 4-stroke marine dual fuel engine	Daihatsu
Development of small scale LNG carrier / bunkering ship with DF Engine	Kobe Senpaku, Higaki, Sanwa Dock, Daihatsu, Izumi Steel, CAJS

Study of Small Scale LNG Carrier /Bunkering Ship with DF Engine

as The ClassNK Joint R&D for Industry Program
by The Cooperative Association of Japan Shipbuilders







(Training for crew is especially important in the side of LNG bunkering ship.)

4. Support by government (MLIT committee) + ClassNK

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**

Major Achievements of Review

国土交通省

1) Safety requirements for high-pressure gas supply system

- Safety requirements for designing high-pressure gas supply system
- Safety requirements for designing high-pressure piping (double pipe)

2) Safety requirements for navigation and port entry/departure of LNG fuelled ships that do not get fuel supply

- Thrash out points to consider
- Research/review of load characteristics of the main engine

3) LNG fuel transfer guideline/operation manual

- Operating procedure/safety measures for LNG fuel transfer
- Installations to be used for LNG fuel transfer
- Determination of safety zones and security zones
- Points to consider during night time
- Points to consider during cargo operations/passenger boarding and disembarking
- Points to consider regarding pressure control of fuel tanks in case of mixing different kinds of LNGs

■ Ship to Ship (StS) transfer

- Safety management system (e.g. collaboration with organizations (inc. private companies) for maritime disaster prevention etc.)
- Operating conditions (e.g. meteorological limitation, condition of oceanographic phenomenon etc.)
- Points to consider regarding operations to berthing/unberthing and mooring

Adoption

4) Measures for navigation safety regarding StS LNG fuel transfer

5) Measures for maritime disaster prevention on StS LNG fuel transfer

■ Shore to Ship transfer

- Safety management system (shore - ship responsibility system)
- Requirements for emergency breakaway device

■ Truck to Ship transfer

- Safety management system (shore - ship responsibility system)
- Requirements for emergency breakaway device

6) Requirements for docking LNG fuelled ships

- Summarization of measures required for docking such as gas free operation etc.
- Handling of vacuum insulated Type C tanks

LNG transfer arm

LNG transfer hose

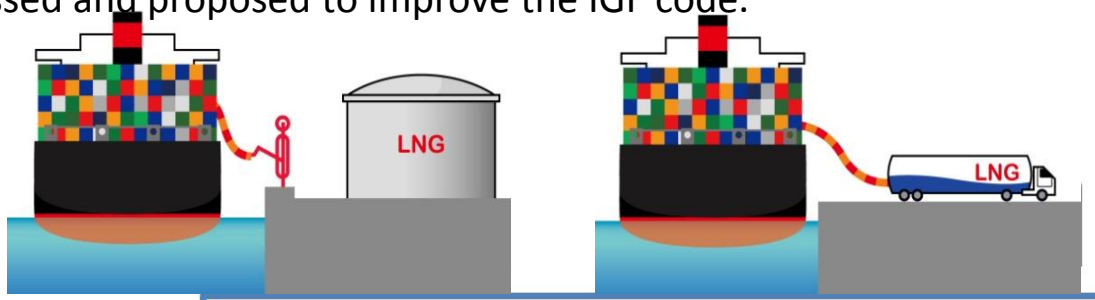
Hose saddle

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.

An example of system development supported by MLIT and ClassNK in the committee

Safety requirements for high-pressure gas supply system

[Background] ⇒Necessity of gas supply at high pressure (approx. 300 bar) for highly energy efficient two-stroke low speed GI engines.

⇒ Necessity of safety measures to handle extremely low-temperature LNG and high-pressure natural gas in the limited space in ships

[Objective] Formulate safety requirements for high-pressure gas supply system (points to consider in designing)

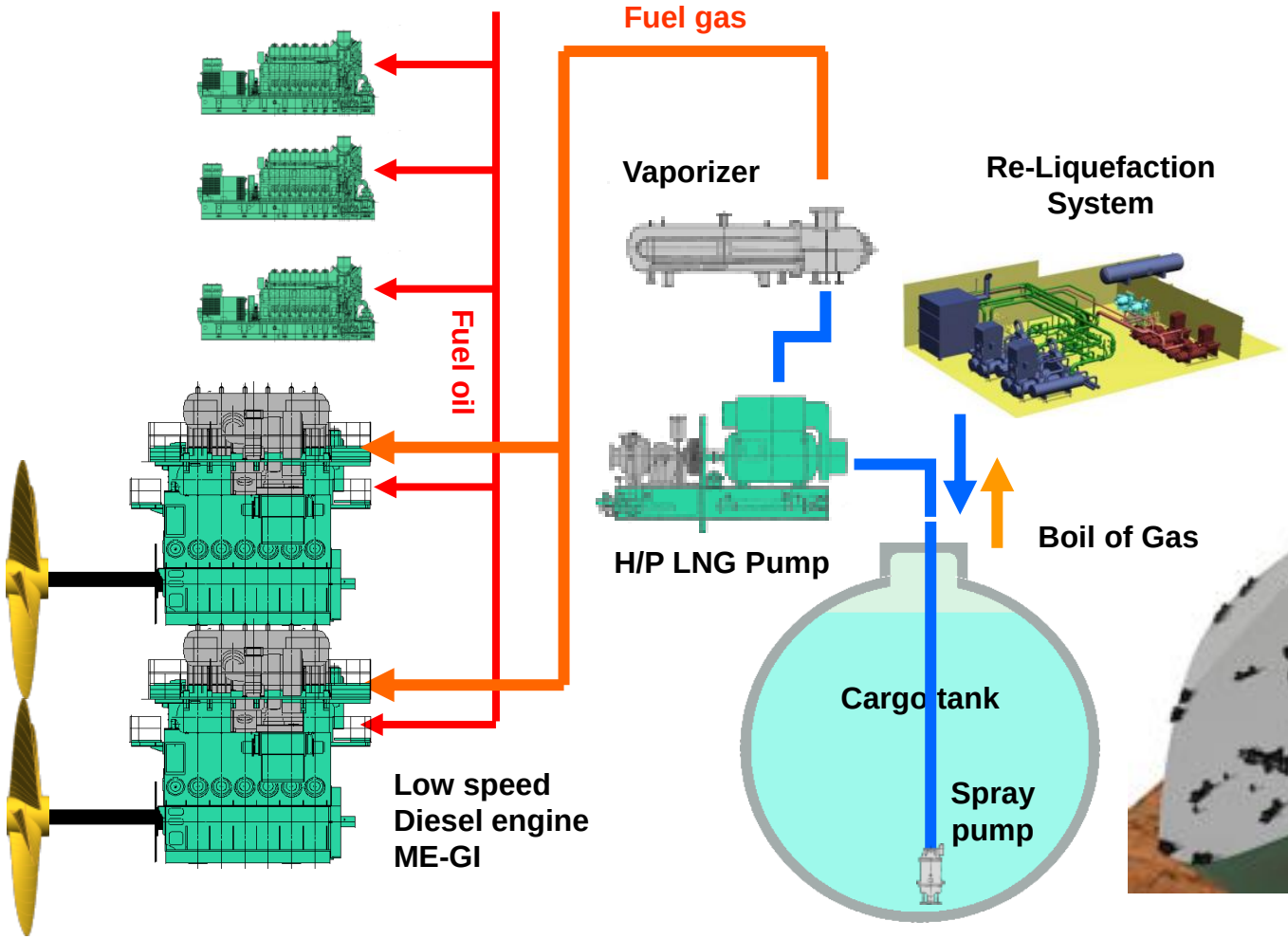
（This system is named FGSS（Fuel Gas Supply System） • • LNG is pumped to 300 bar and evaporated under 300 bar to be injected into GI engine. Pumping work is much smaller than high-press. gas compressor.

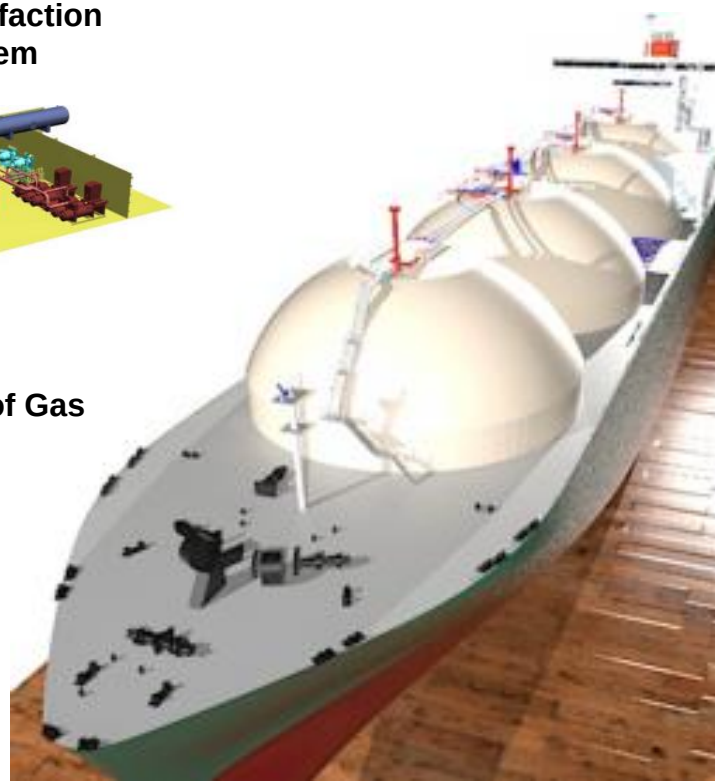

Simulated plant used for the demonstration experiment

An example of installation of FGSS

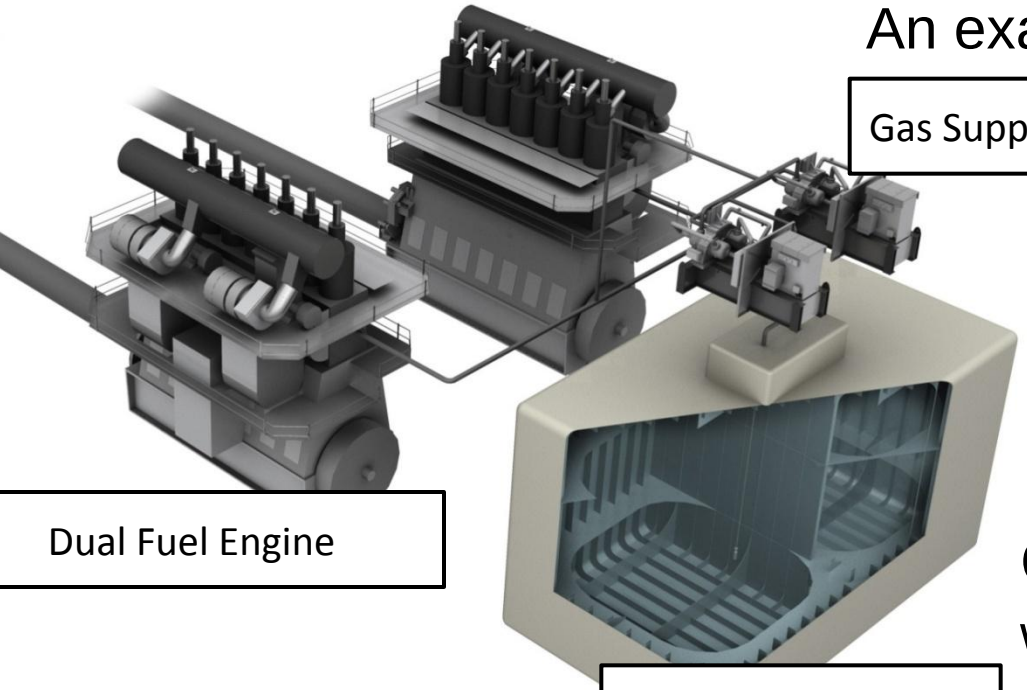
Double Eco Max LNGC MES

- 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

Development of LNG fuelled ships (natural gas engines) has been introduced as an example of 'Collaboration'.

To promote LNG fuelled ships in the world, Singapore is strongly expected as an important LNG bunkering port.

ClassNK will contribute to Collaboration between

'Singapore and Japan'.

(Last, movie on a successful LNG fuelled ferry in Baltic sea・・)

Current Situation & Technical Trends

Construction / Operation Record in North Europe 2/3

Passenger Ferry "Viking Grace" & Bunkering Ship "SEAGAS"

- ✓ **Delivery: Jan 2013, M/E: DFD (Electrical propulsion, Quad-engine, Twin-propeller)**
- ✓ **2 LNG fuel tanks are installed on open deck aft space**

Operating between Turku and Stockholm

Length	50 m	Breadth	11.3 m
Service speed	abt. 12 knot	Bunker Capacity	200m3

Length	214 m	Main engines	4 × Wartsila 8L50DF, 7600 kW per unit
Breadth	31.8 m		
GT	57,000 ton	LNG fuel tanks	2 × Type C cylindrical cryogenic tanks, 2 × 200m³
Service speed	abt. 22 knots		
Passenger	2800		

LNG bunkering for "Viking Grace"

Reference: Viking Grace Home Page

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Thank you for your kind attention