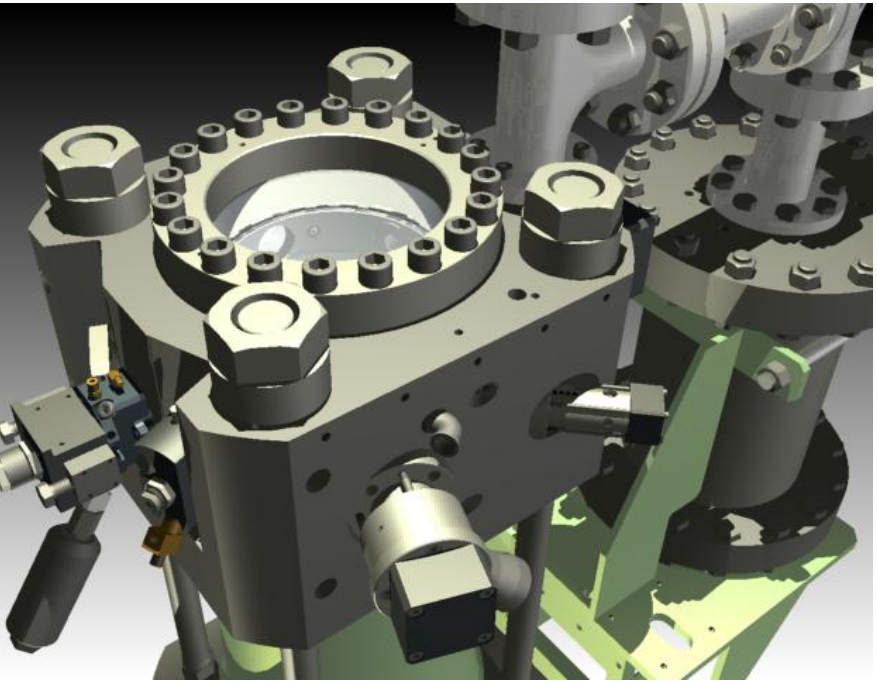
ClassNK Seminar 3. Nov. 2015

Joint Industry Collaboration Projects at Maritime Energy Test Bed

Key-technology for marine natural gas engine development

How academic or fundamental research work could contribute to marine industries ?



Prof. Dr. Koji Takasaki

Technical Adviser for ClassNK

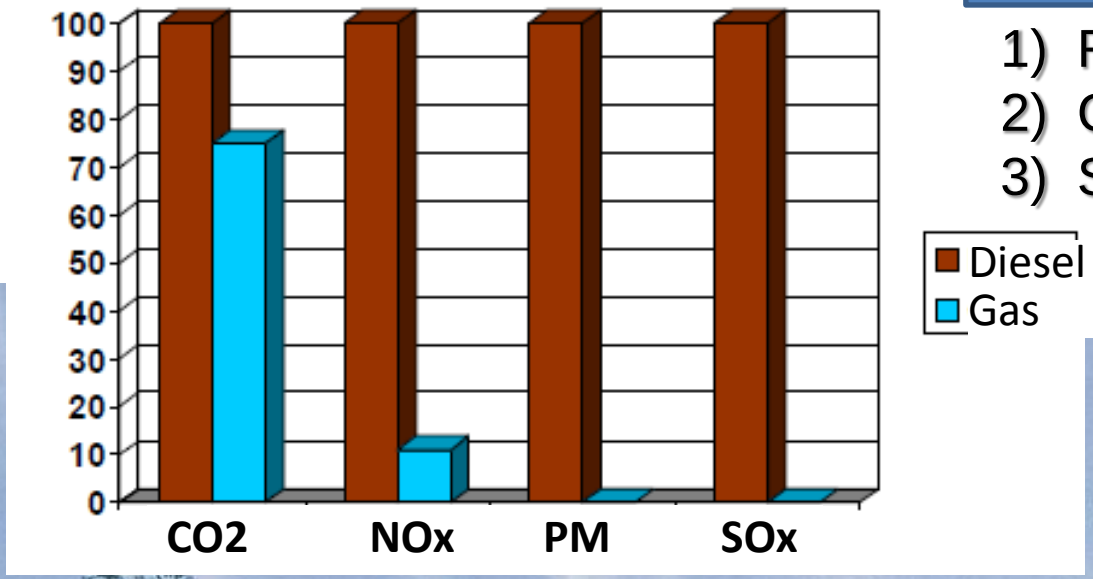
Labo. of Engine and Combustion,
Kyushu University, Japan

Contents

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

‘All-mighty’ effect of natural gas fuelled ship

Natural gas fueled ships in service

About 60 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

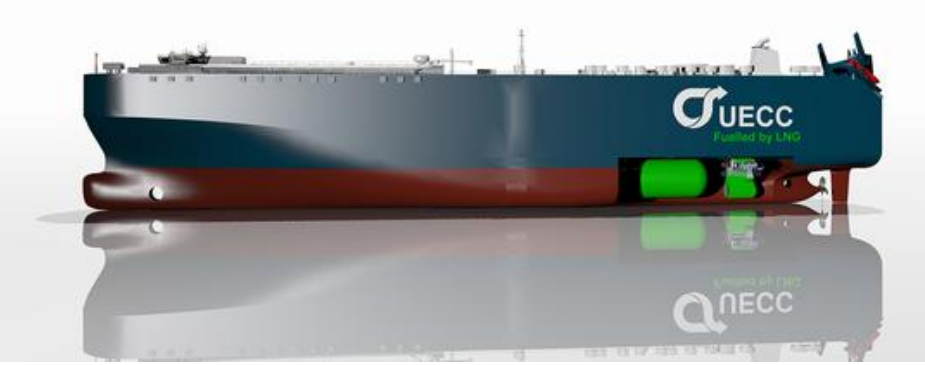
沿岸警備船

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

60 ships are in service plus 80 ships are ordered

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

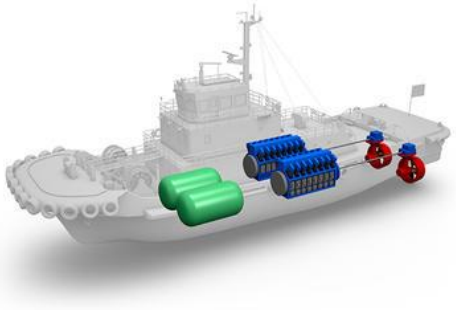


• United European Car Carriers (UECC) jointly owned by NYK and Wallenius Lines has ordered KHI two PCCs propelled by MAN low-speed ME-GI gas (DF) engine. (for voyage in European ECA)

・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）。

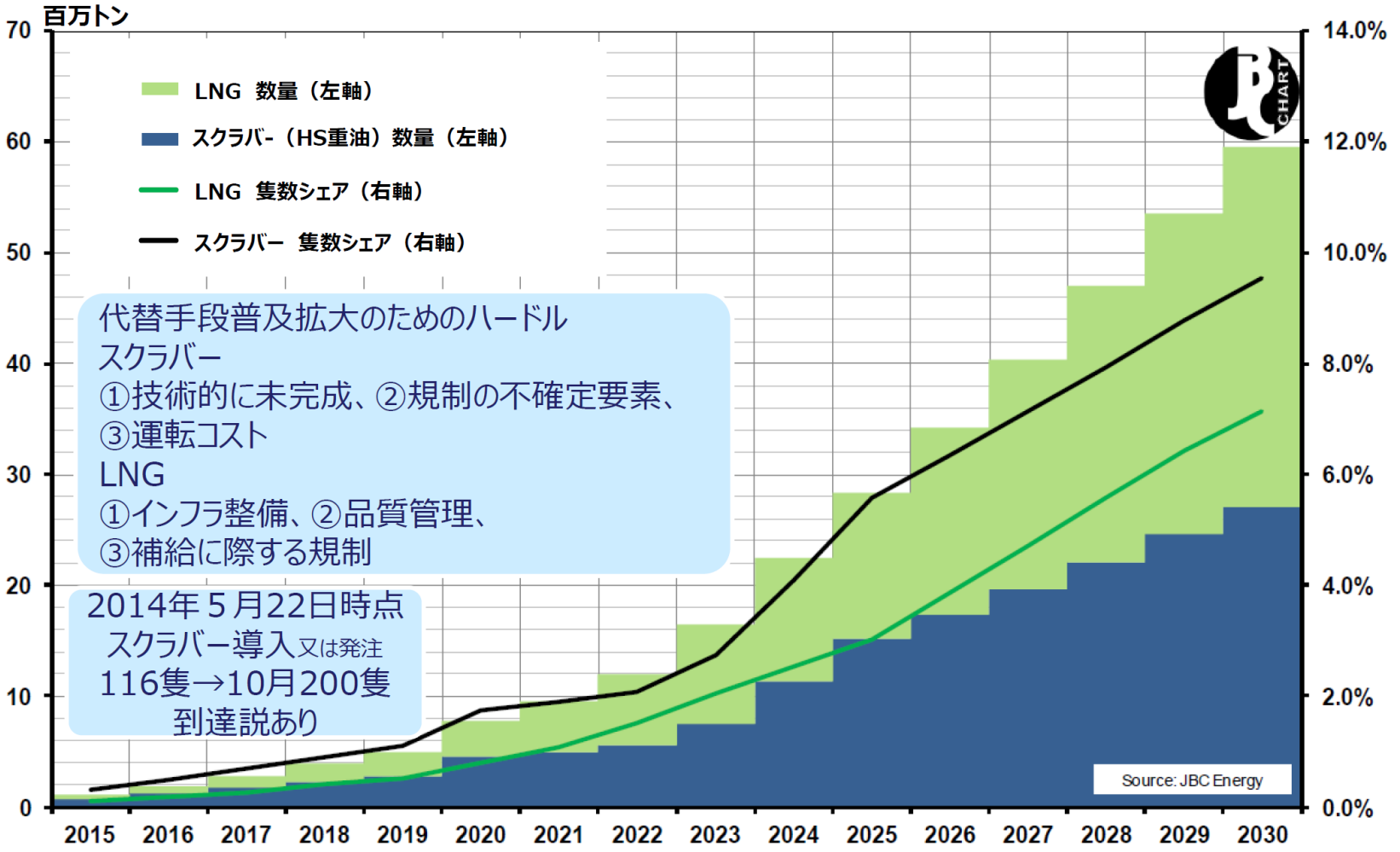
• TOTE Line has ordered 3,100TEU container ships propelled by MAN low-speed ME-GI gas (DF) engine. (Route: Florida⇔ Puerto Rico)

・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）



スクラバー船の隻数シェアの見通しは　2025年：5.8%、2030年：9.8%
LNG船の隻数シェアについては、　2025年：3.2%、2030年：7.3%の見通し

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Estimation

7% of ships in the world will be natural gas fuelled at 2030.
(10% of ships in the world will install Scrubber at 2030.)

35 mil. ton of natural gas will be used as marine fuel at 2030.

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.

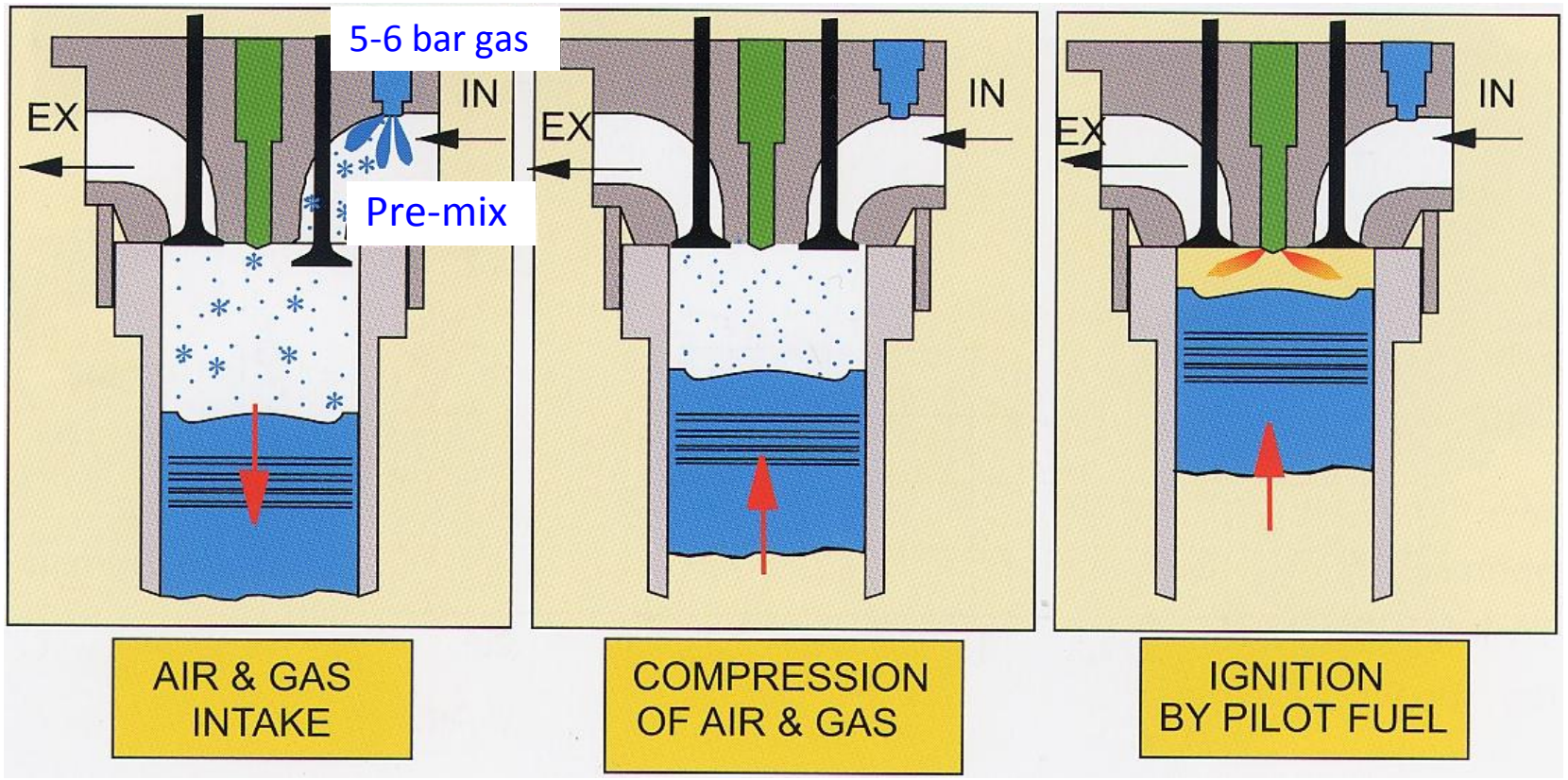
	Lean-burn (pre-mixed) (low-pressure gas supply)	**GI** (Gas Injection) (high press. gas injection)
Medium-speed 4-st.	Currently all	Possible but not yet applied
Low-speed 2-st.	Existing **Otto-cycle** type gas engine	Existing **Diesel-cycle** type gas engine

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.



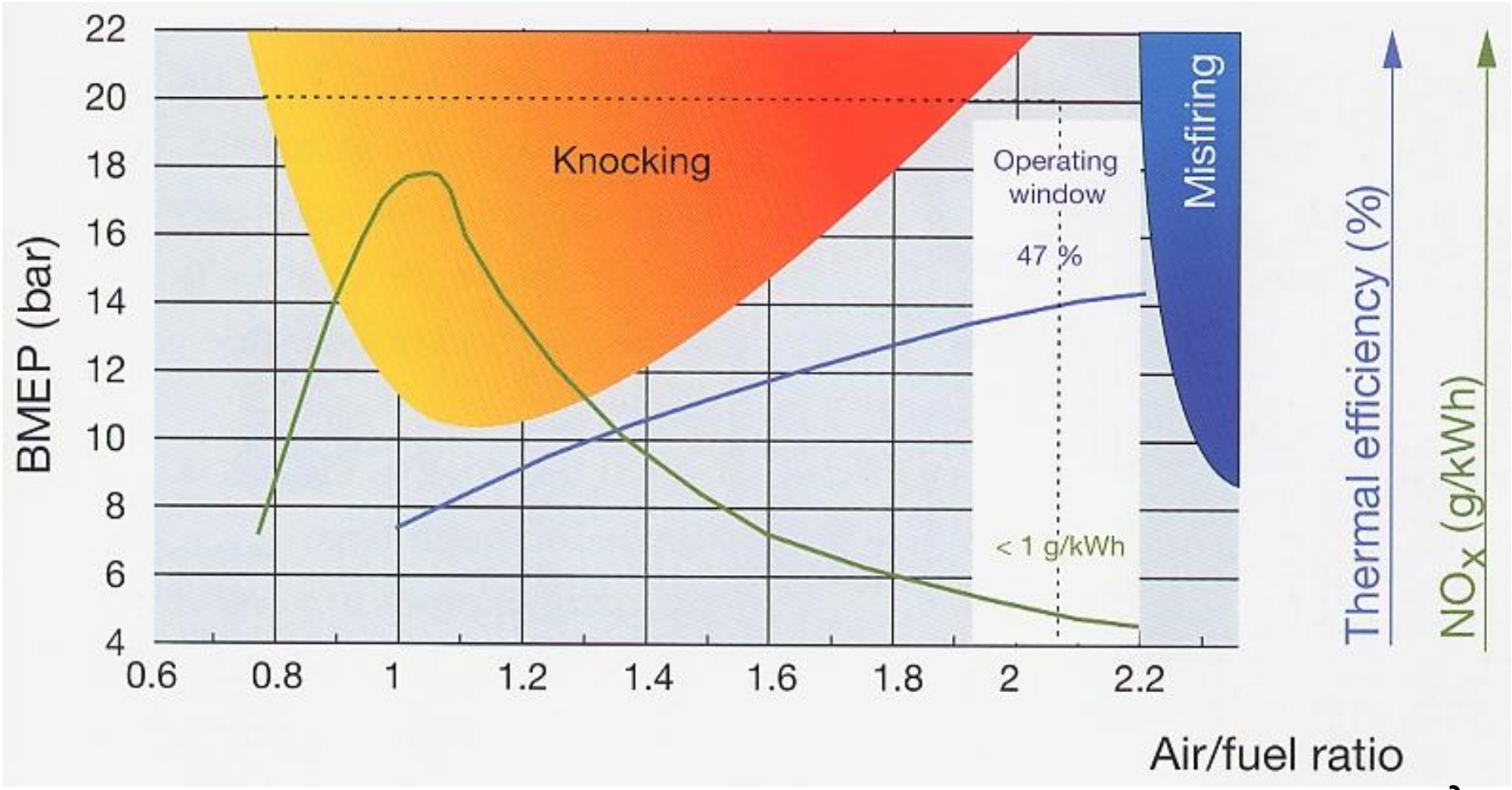
Function of medium-speed lean-burn gas engine

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)

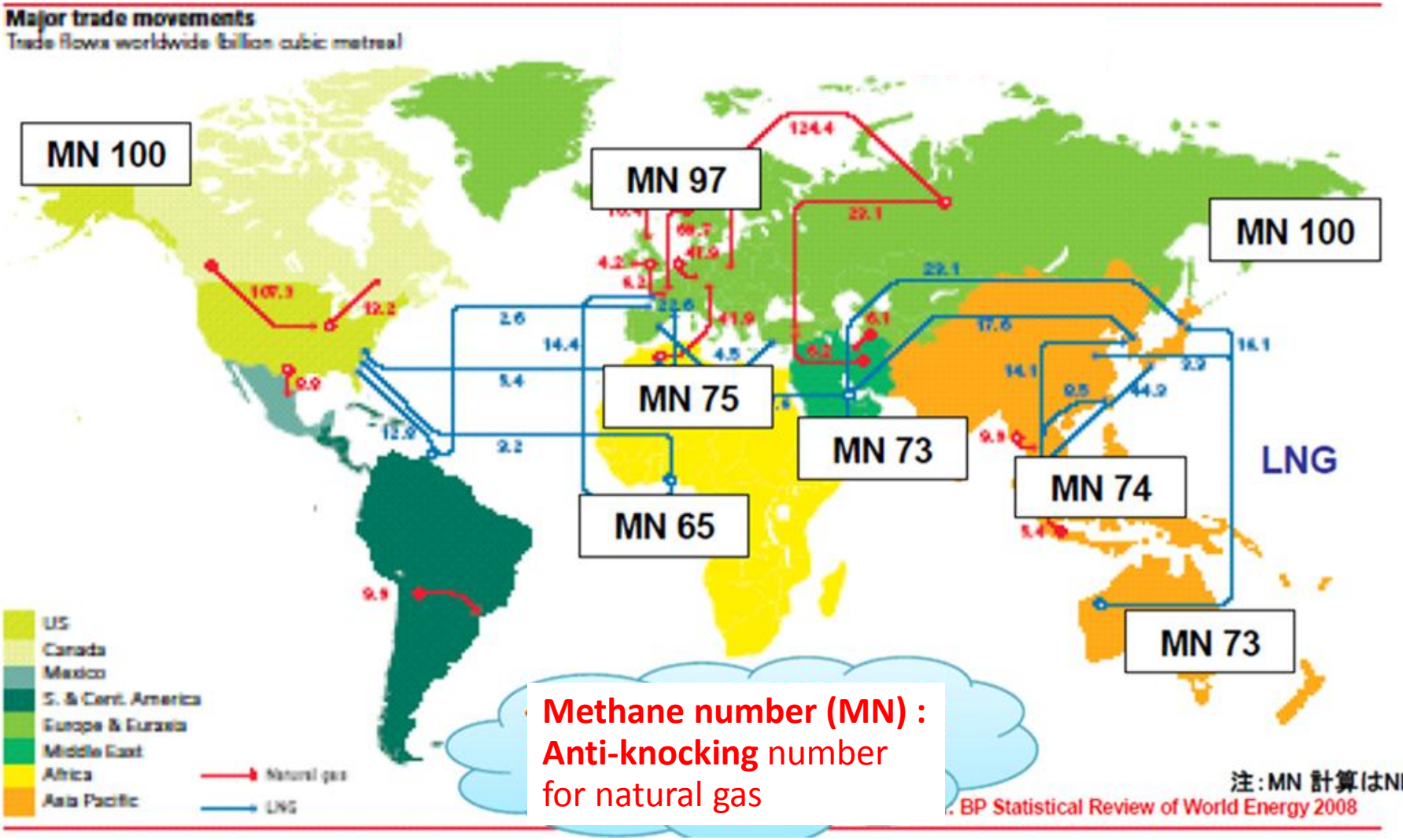


（Excess Air Ratio）**Lambda λ**

Possibility of abnormal combustion for lean burn gas engine

Wartsila社資料

Current Methane Number of natural gas in each area

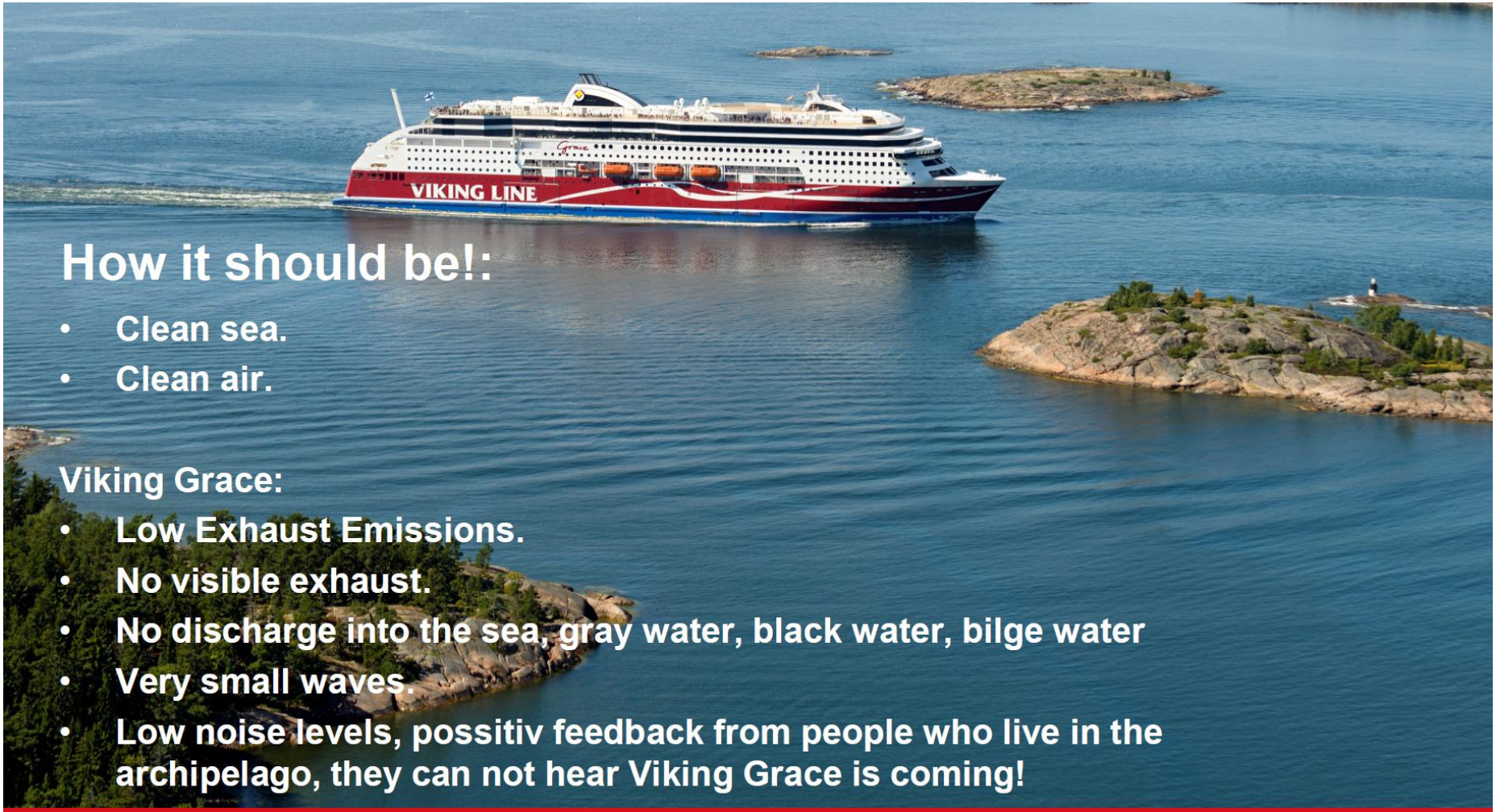


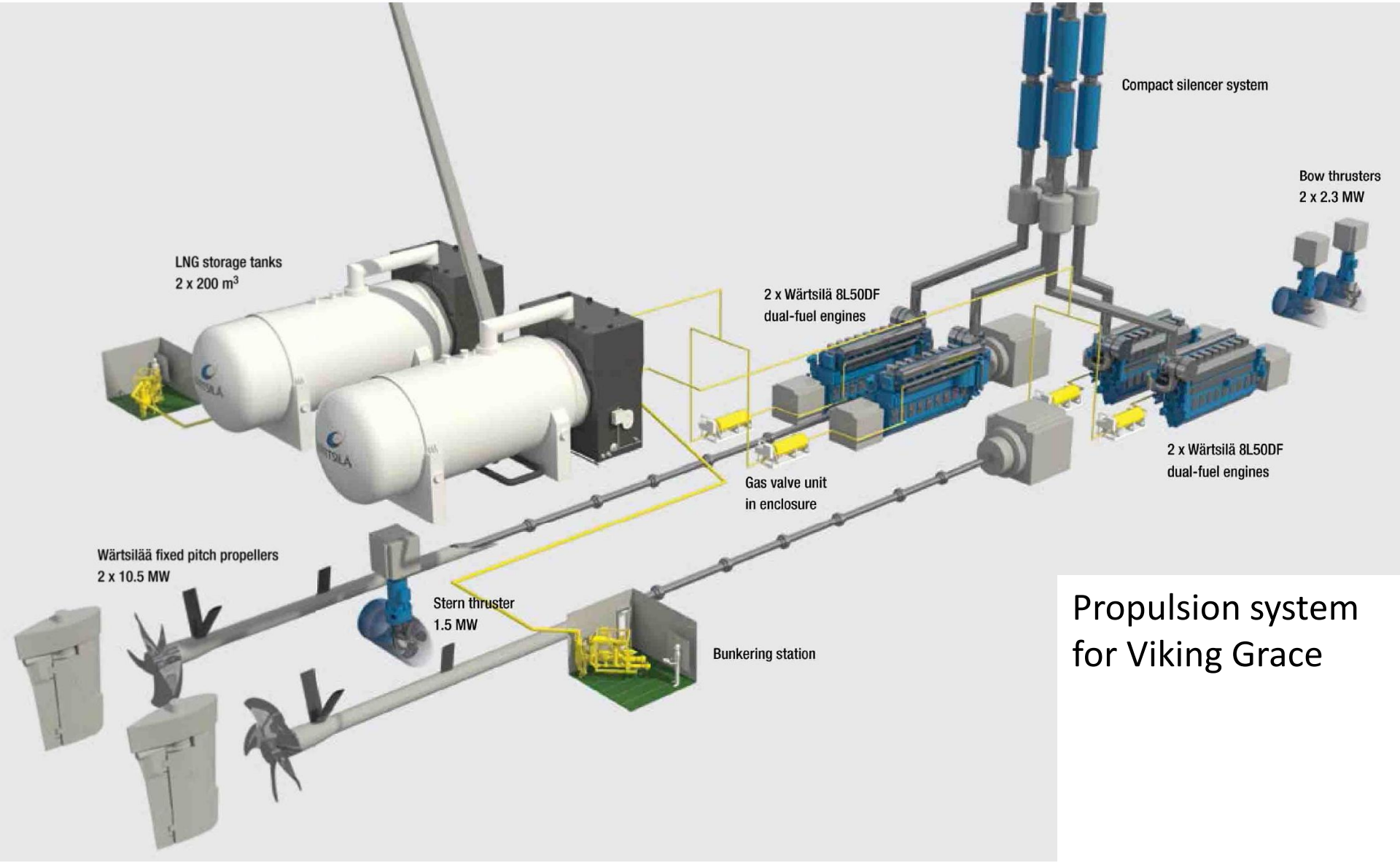
An example of lean burn type natural gas engine application

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

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

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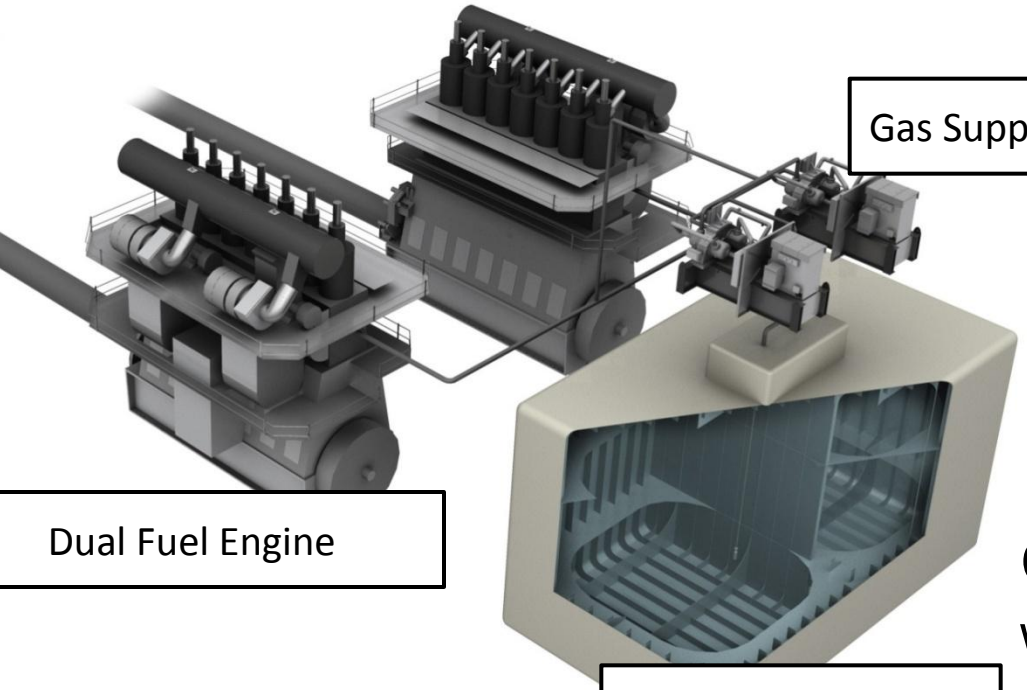
1. Background for development of LNG fuelled ships

2. How the academic research contributes to marine gas engine development?

2.1 Stories for low-speed 2-stroke gas (DF) engines development (Lean-burn and GI type)

3. Support for ship and engine development by ClassNK



Gas Supply System

Dual Fuel Engine

IHI-SPB LNG Tank

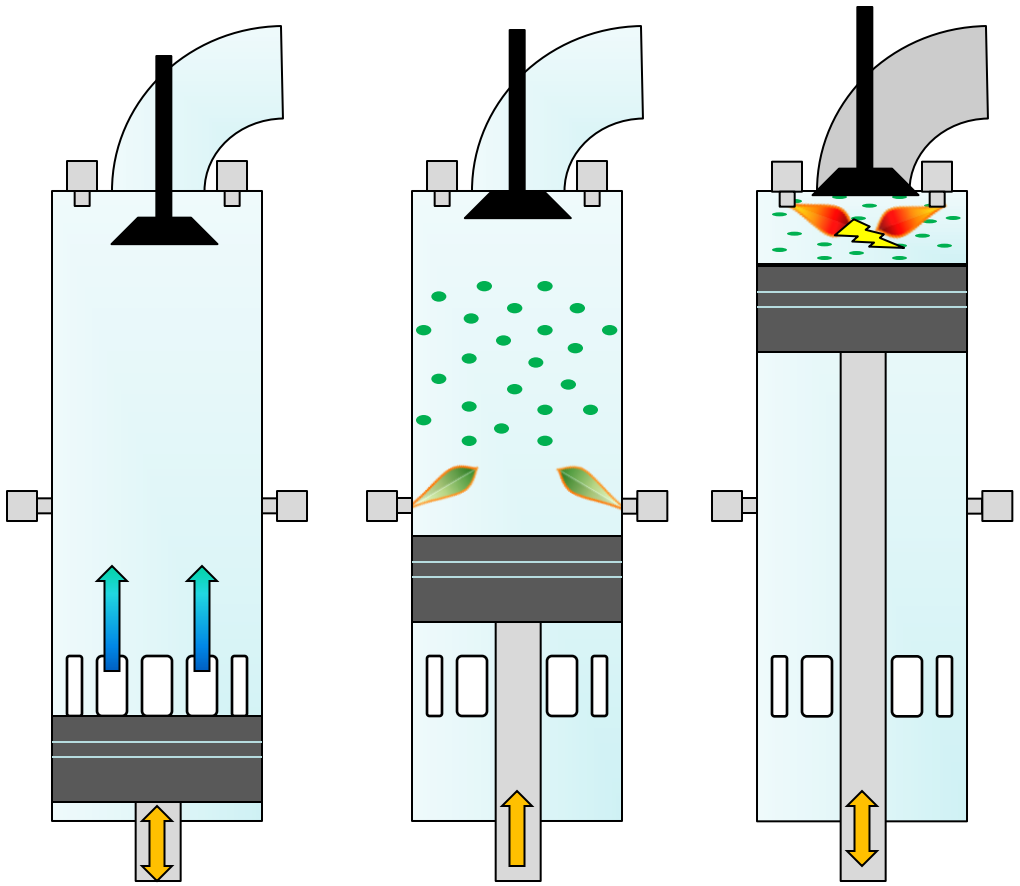
Container vessel (JMU)

with originally designed LNG tank

Introduction of low-speed two–stroke **lean-burn** type (DF) engine development

Low-speed two–stroke lean-burn type test engine (DF) @Diesel United, Japan

6 cylinders
Bore x Stroke:
720 x 3086 mm
MCR: 19350 kW@89 rpm
BMEP: 17.3 bar



Scavenging | Compression/ gas admission | Ignition → expansion

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:

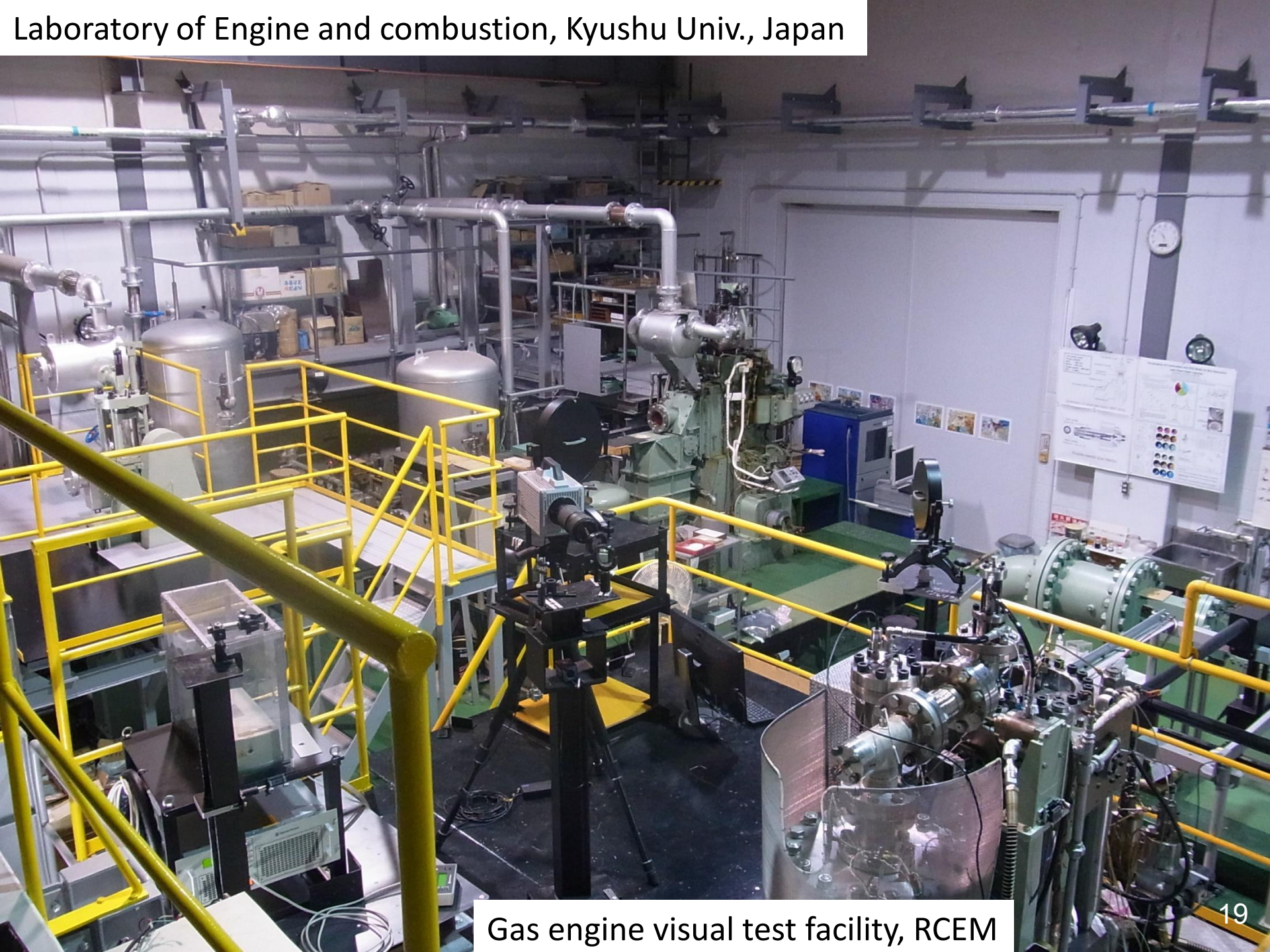
- unknown concept for 2-stroke
- output limited by knocking?
- hydrocarbon (HC) emissions?

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

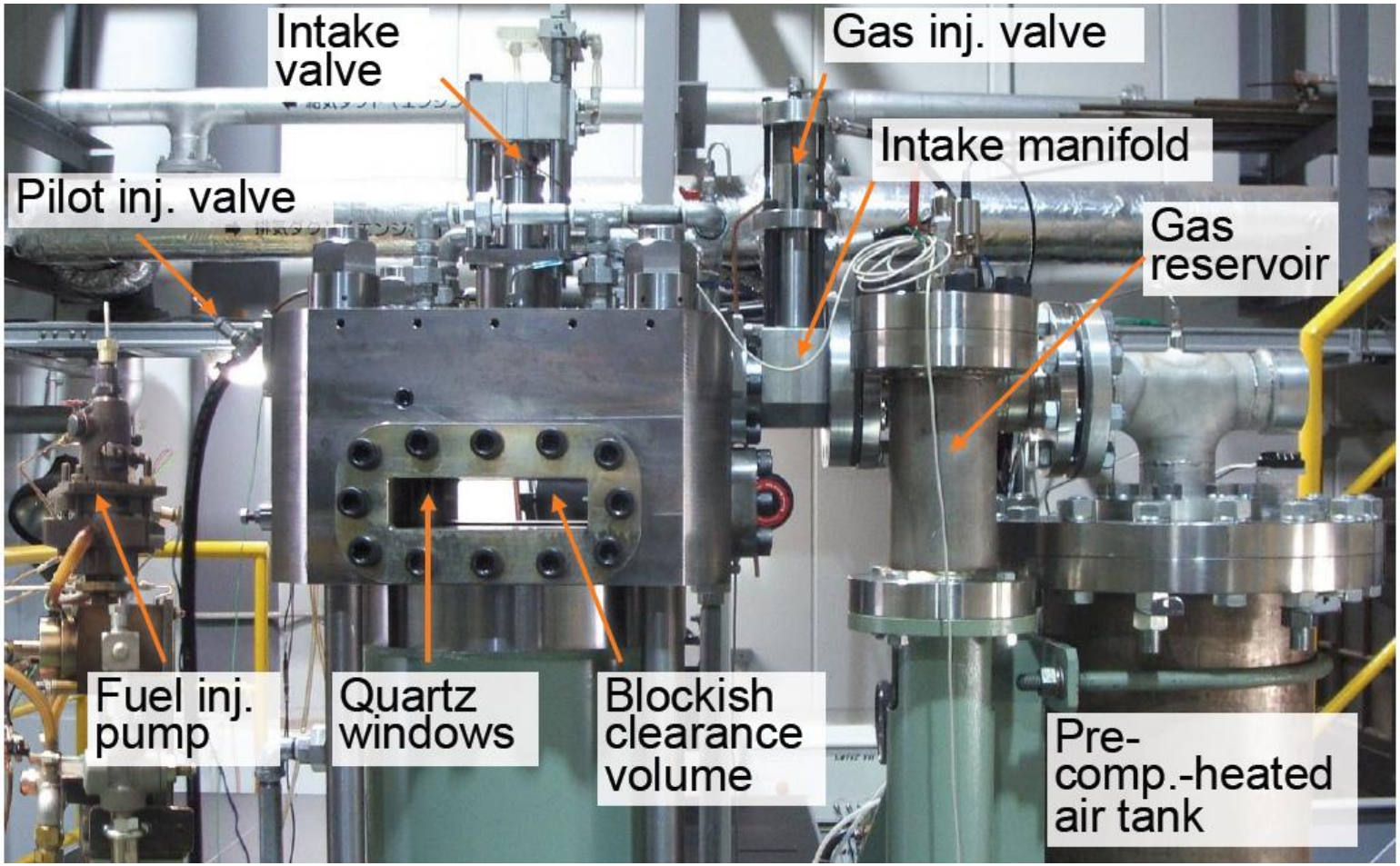
2-stroke gas concepts – Low pressure DF

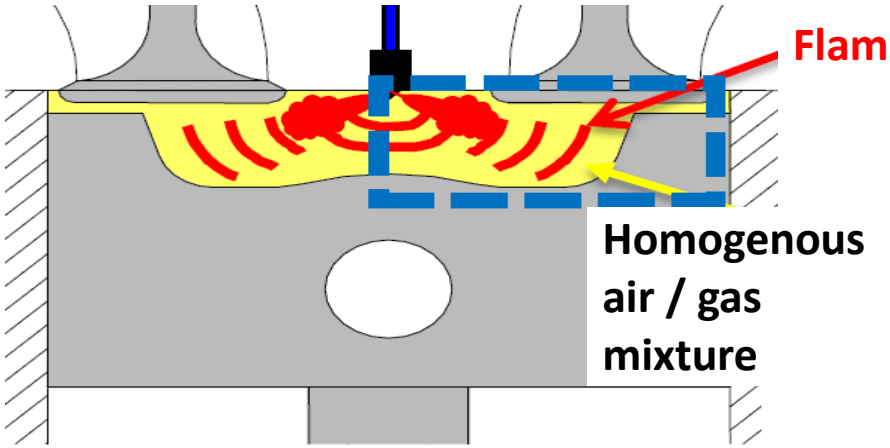
(Wartsila Technical Seminar 2011)

Laboratory of Engine and combustion, Kyushu Univ., Japan



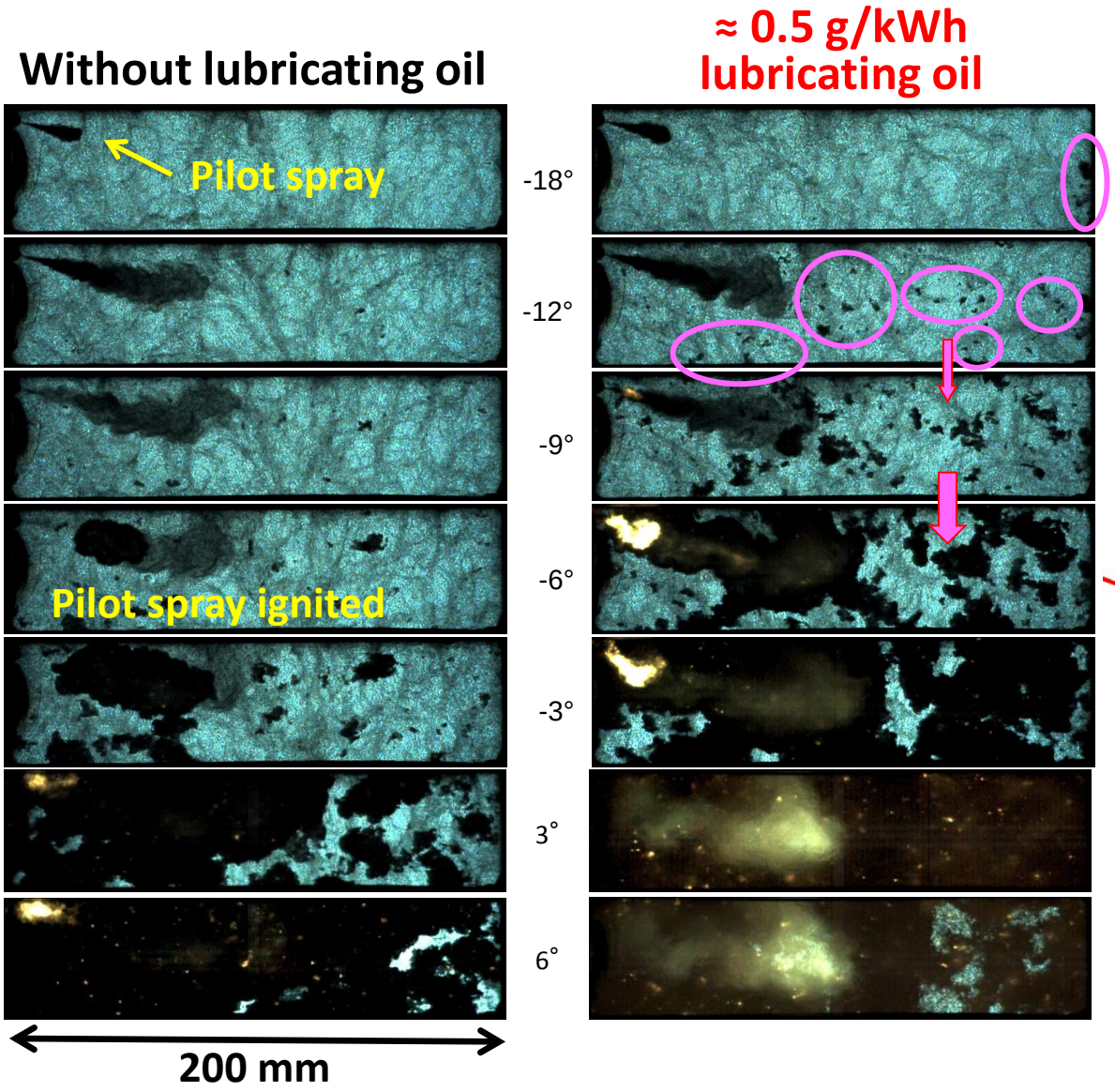
Gas engine visual test facility, RCEM

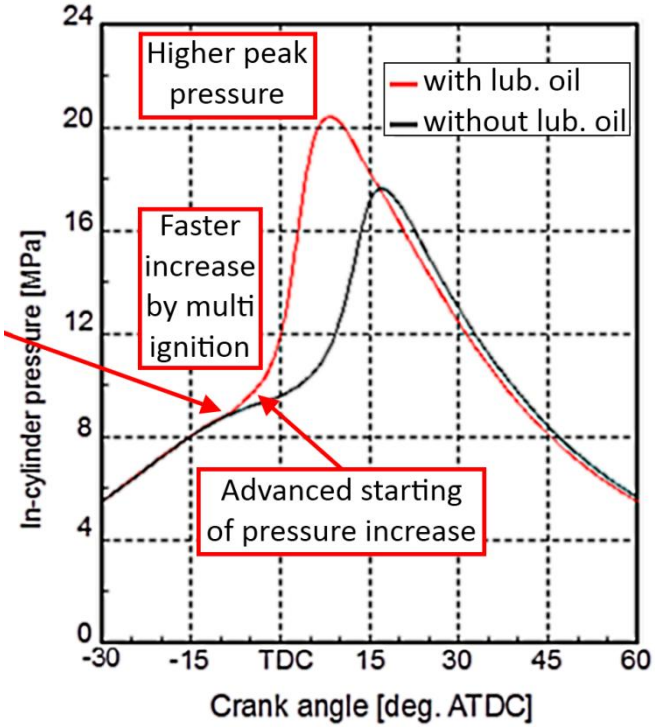


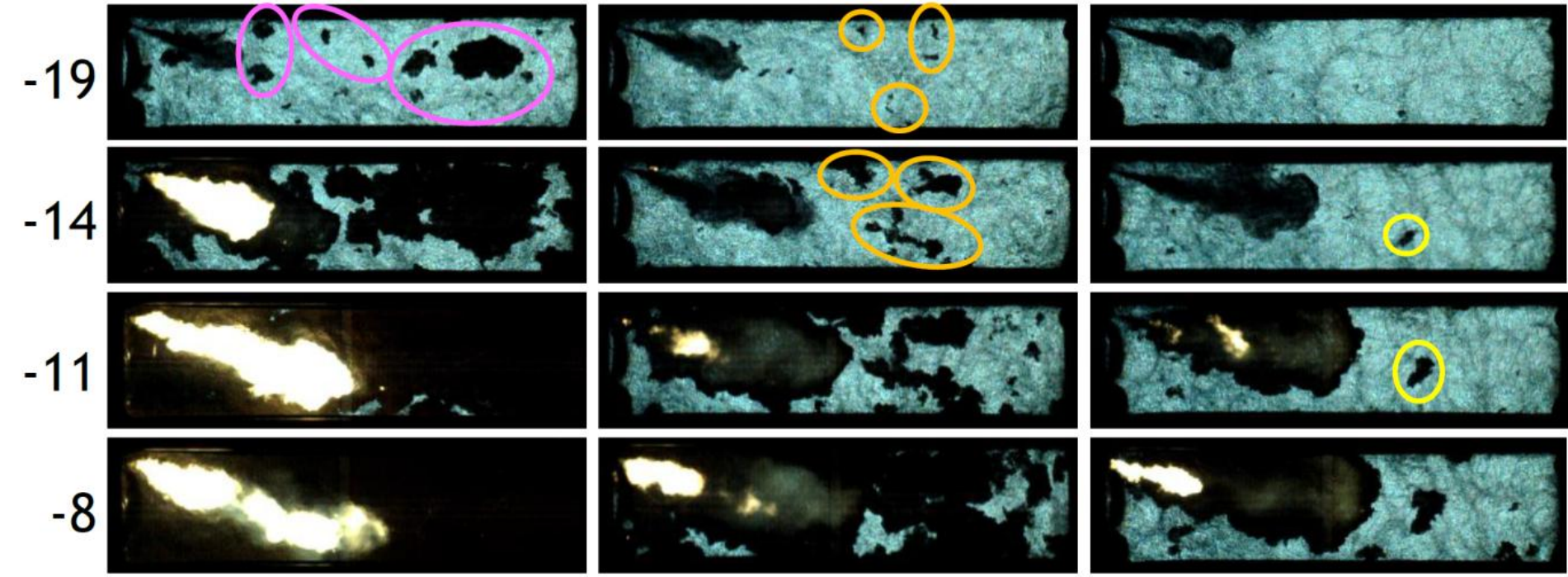


How is the flame propagation and abnormal combustion in lean-burn type gas engine?

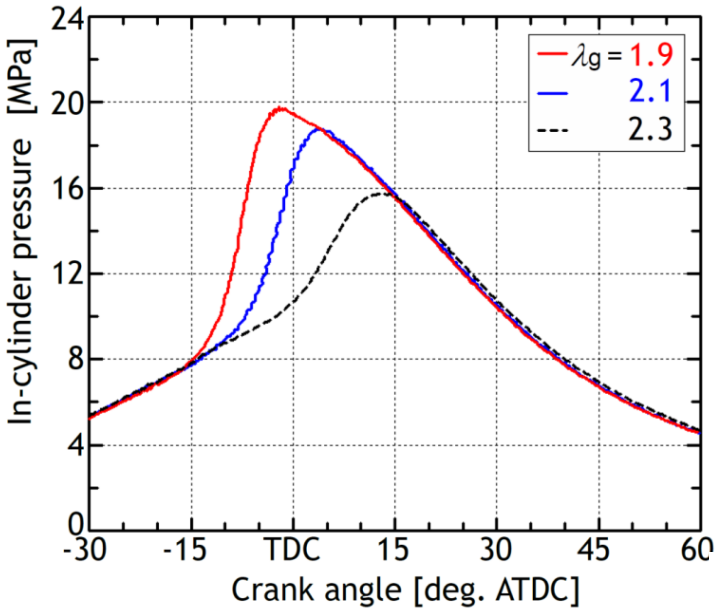
Abnormal combustion caused by lubricating oil







Lub. oil particle could be an origin of self-ignition.
And it grows faster to be big flame in richer mixture.



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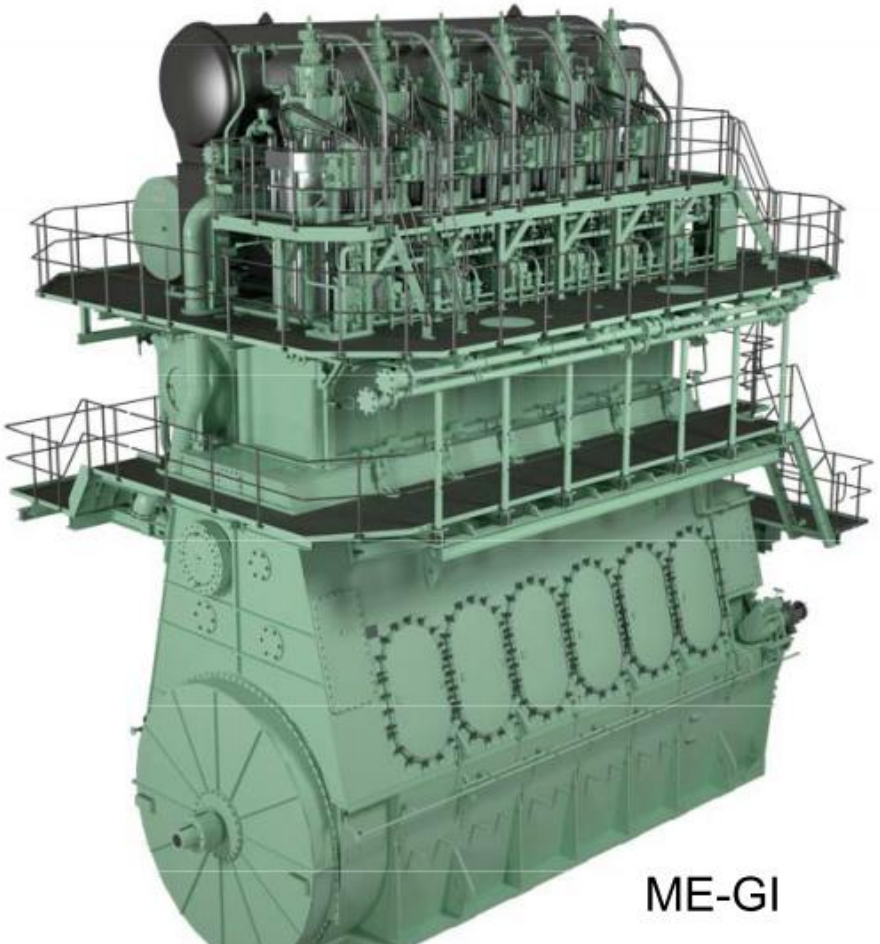
An example of research work by Kyushu Univ.

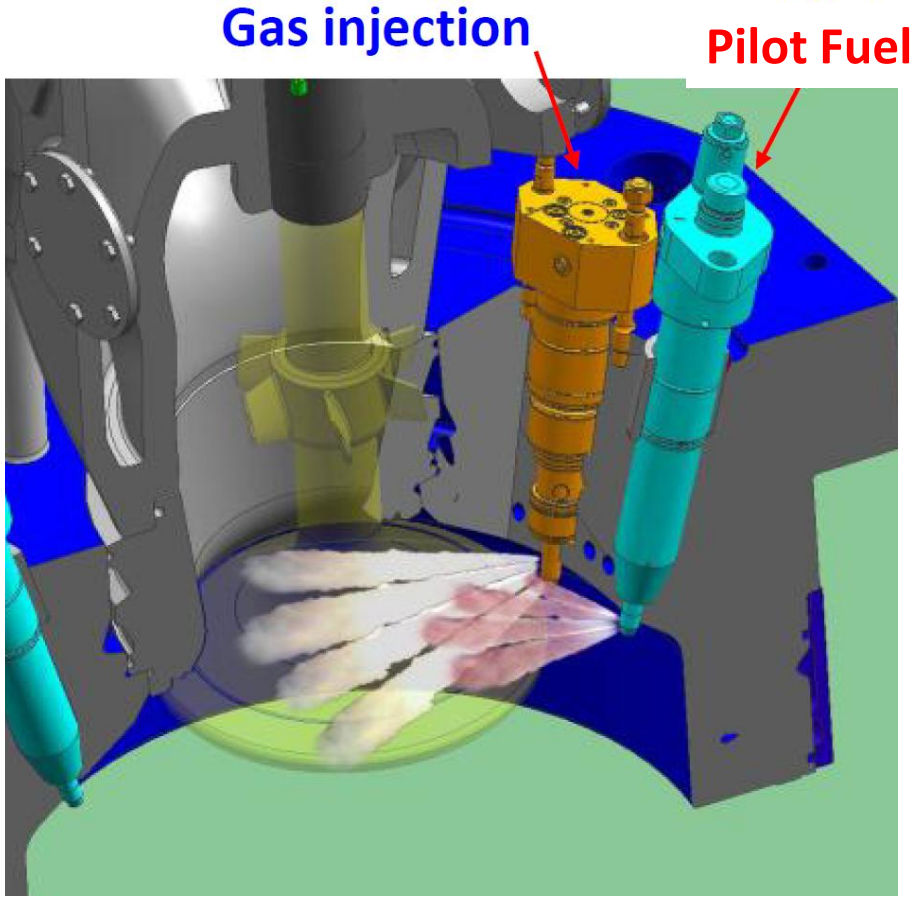
GI (**G**as **I**njection) type combustion • • named ‘Diesel cycle gas engine’

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

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

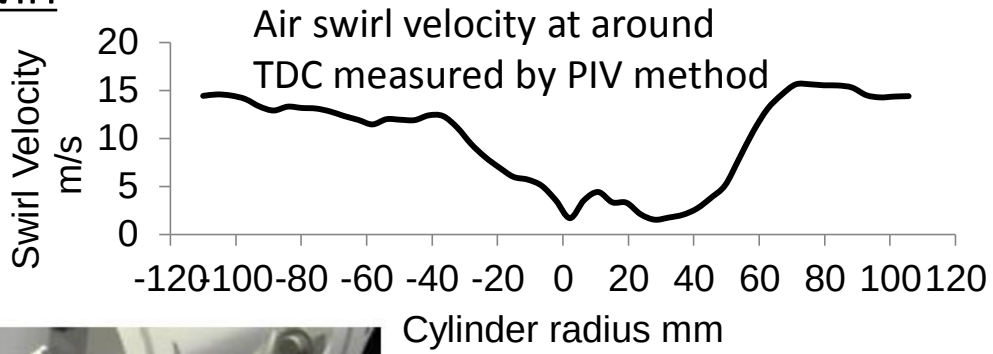
Lower methane slip

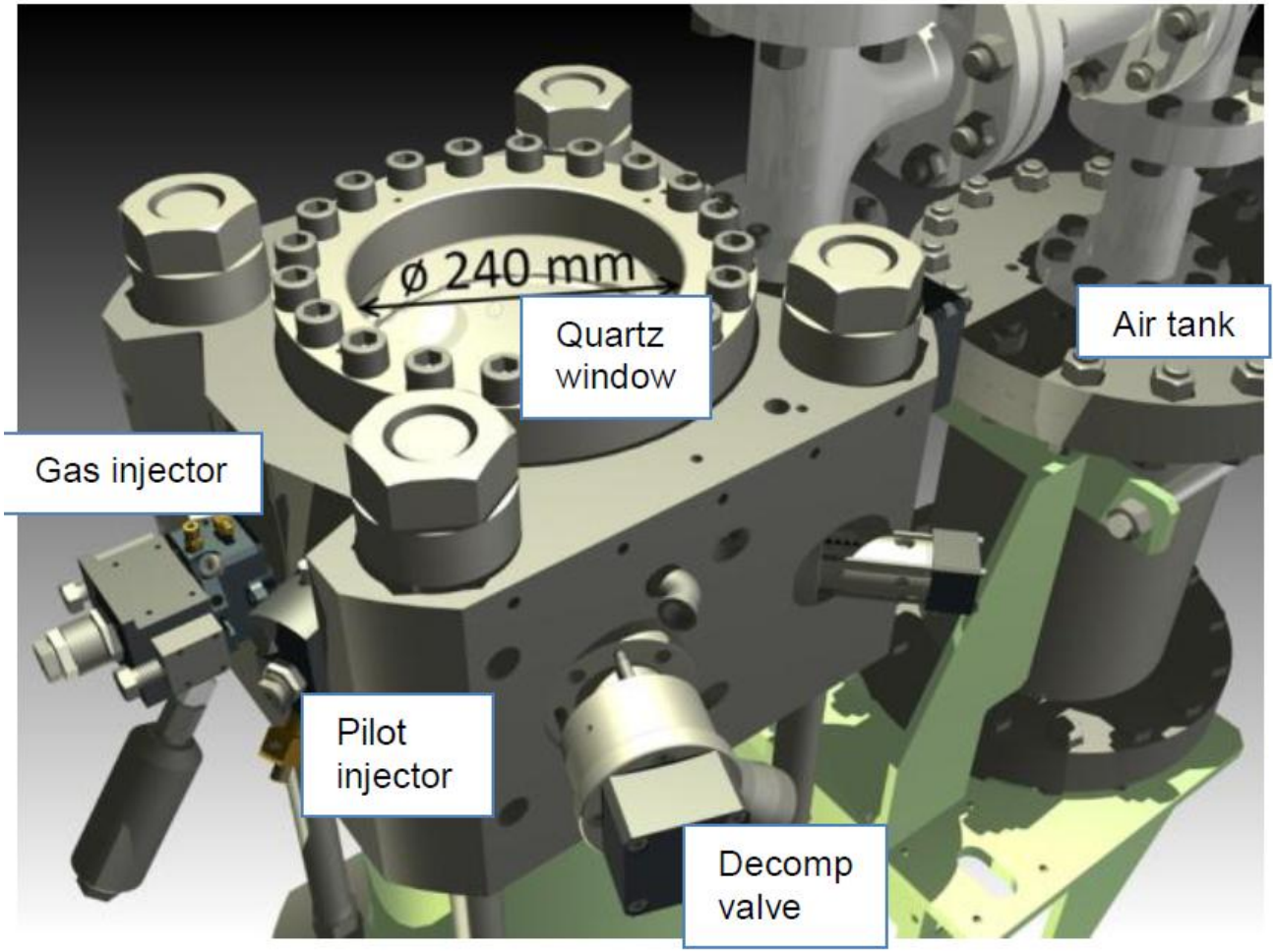


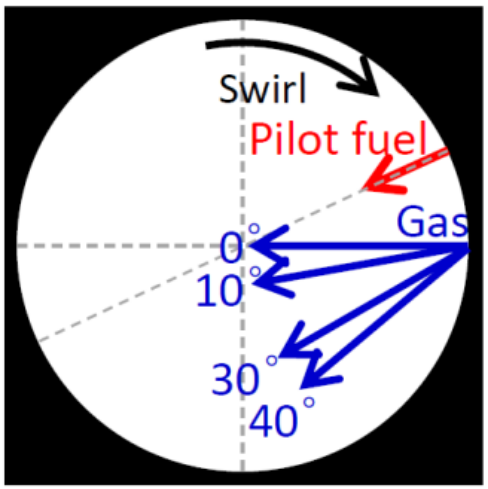


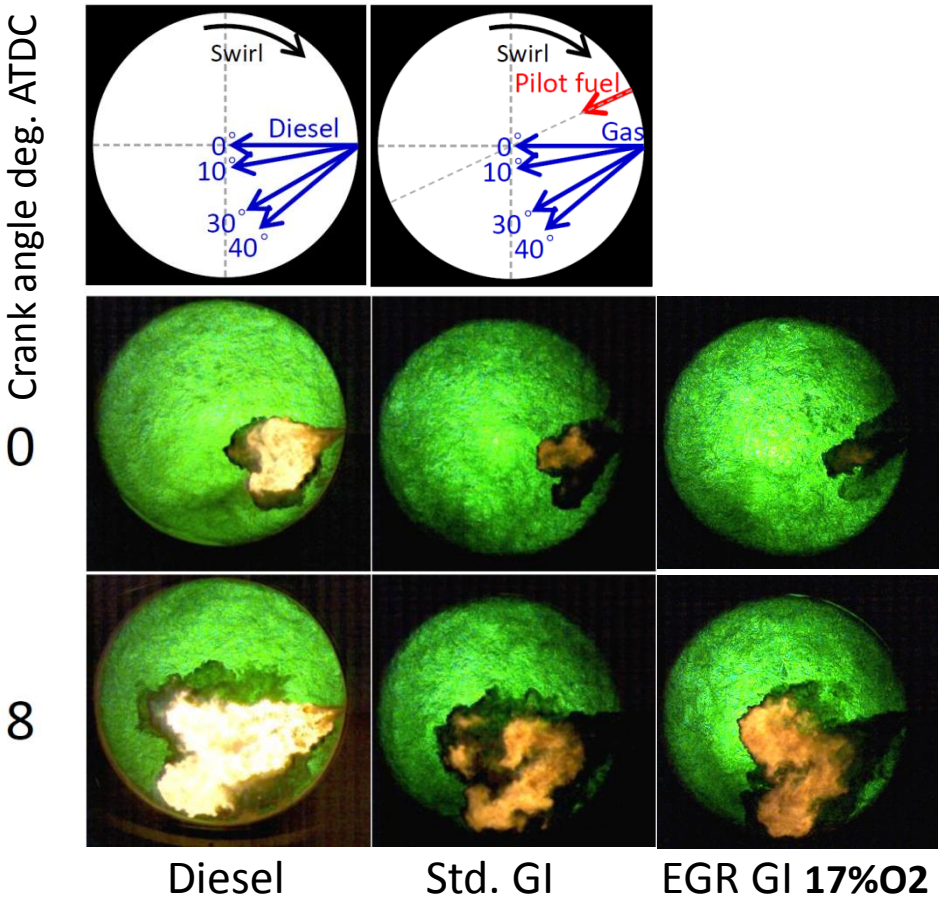
Effect of gas injection pressure on combustion

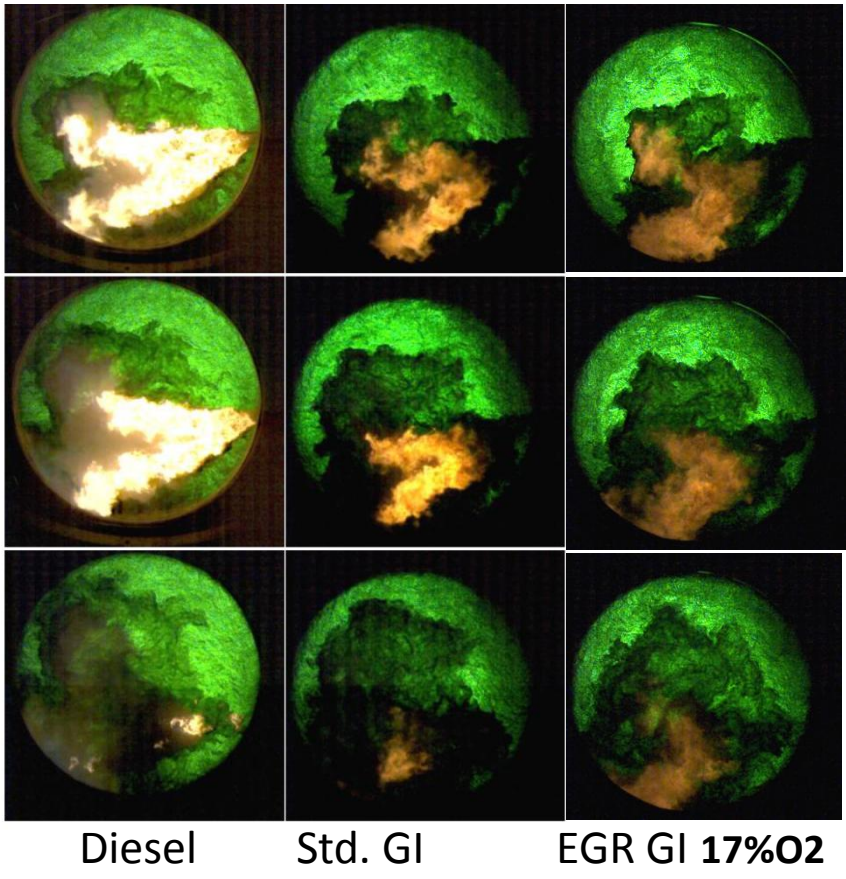
Observation of GI multi flames in air swirl



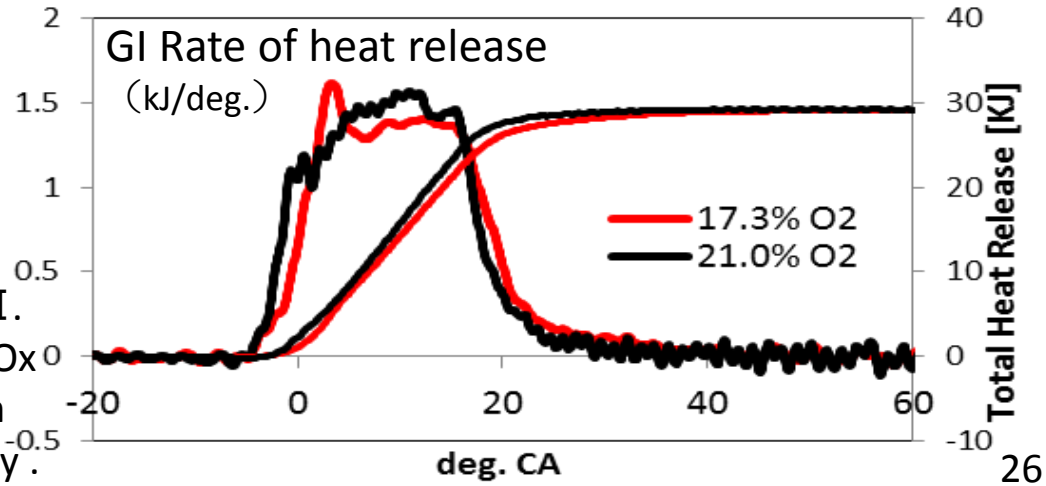








Emissions	Diesel	Std. GI	EGR GI
CO[ppm]	17	30	45
NOx[ppm]	499	300	44



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.

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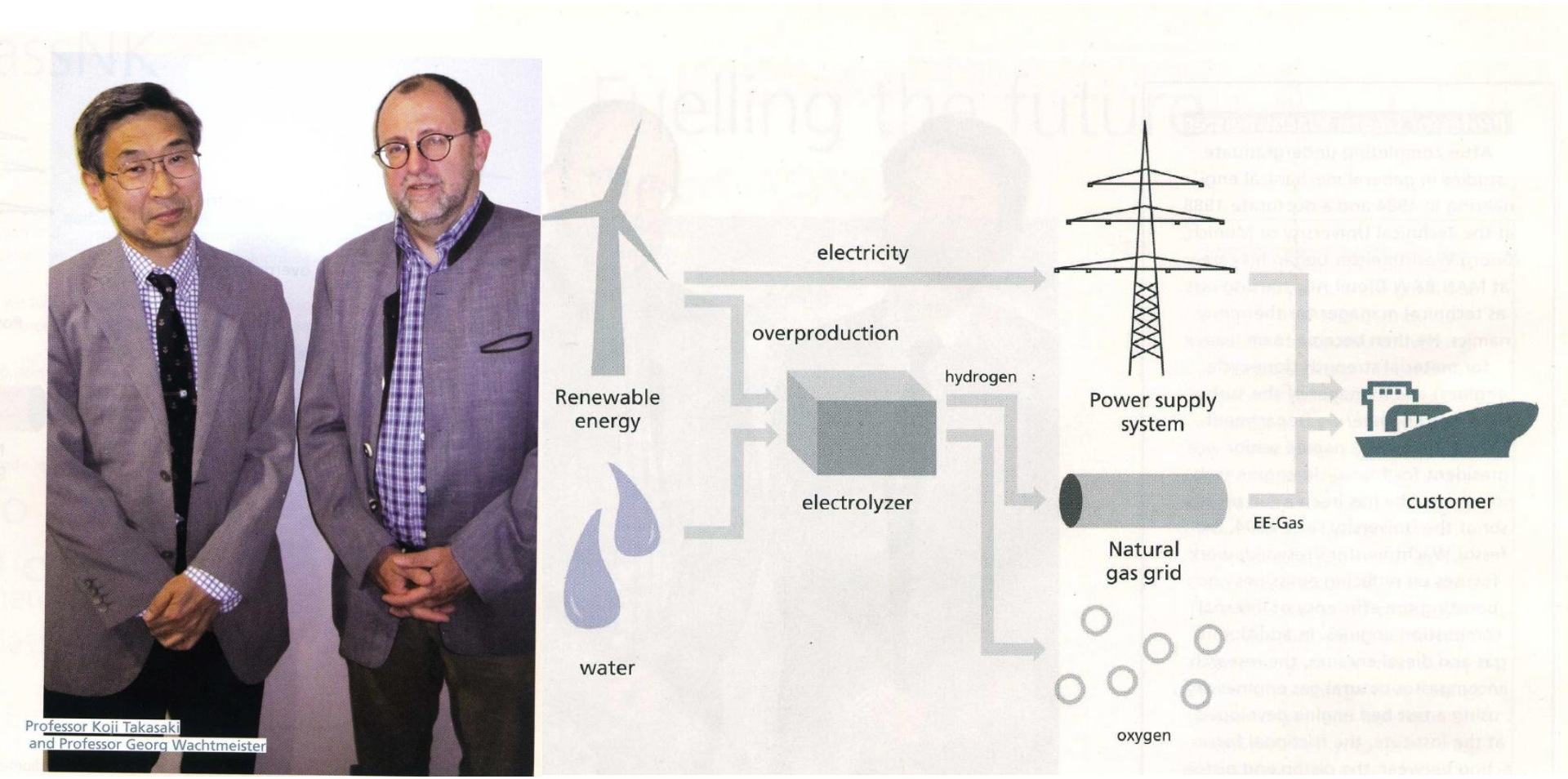
2. **How the academic research contributes to marine gas engine development?**

   2.2 Research theme ‘Hydrogen’ for the future

3. Support for ship and engine development by ClassNK

A joint research project

'**Hydrogen**-admixture to natural gas for gas engines' has started by **ClassNK**, **Technical Univ. of Munich** (Germany) and **Kyushu Univ**..



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

Fuel components

Mix rate of H_2 Vol. %	CH4	H2	80% CH_4- **20% H_2**	70% CH_4- **30% H_2**	50% CH_4- **50% H_2**
Mass % of H_2	0	100	**3**	**5**	**11**
Density (℃, 1atm) [kg/m^3]	0.72	0.09	0.592	0.529	0.403
Theoretical amount of air [m^3N/m^3N]	9.53	2.38	8.100	7.385	5.955
Lower Calorific Value [MJ/kg]	50.10	141.80	52.047	53.492	57.729
Share of calorific value from hydrogen [%]	0	100	**7.0**	**11.4**	**23.2**

Direct

Pc : 8MPa

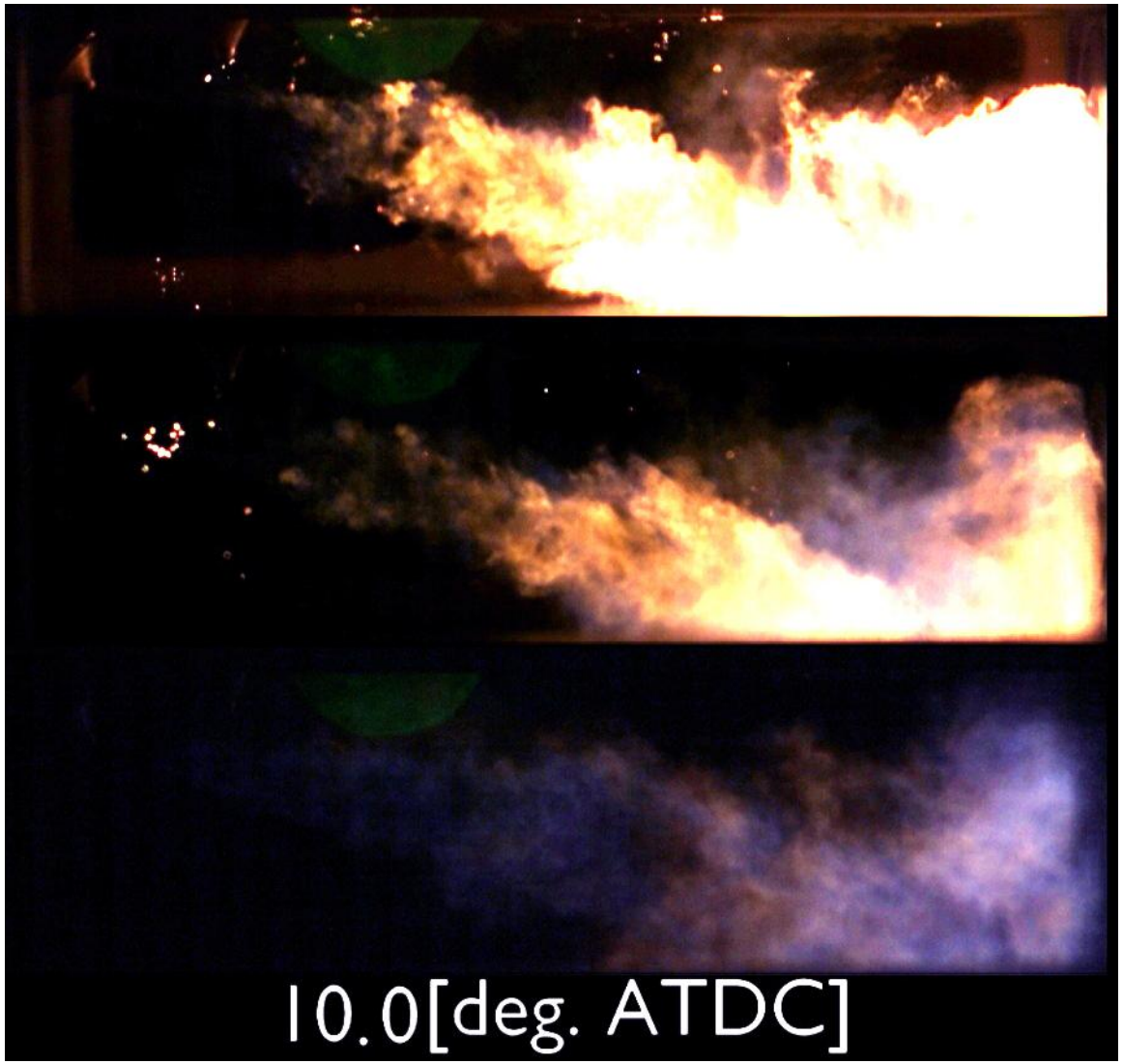
200 mm wide window

No.052 **80%CH_4 - 20%H_2 (F2)**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **26.4**[MPa]

No.043 **70%CH_4 - 30%H_2 (F2)**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **27.6** [MPa]

No.021 **50%CH_4 - 50%H_2 (F2)**
Inj. Hole Dia. 1.2 [mm]
Inj. Press. **30.7**[MPa]

% = vol. %



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Not only the above-mentioned low-speed gas engine development, but also many other projects have been cooperated and supported by 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**

LNG transfer arm

LNG transfer hose

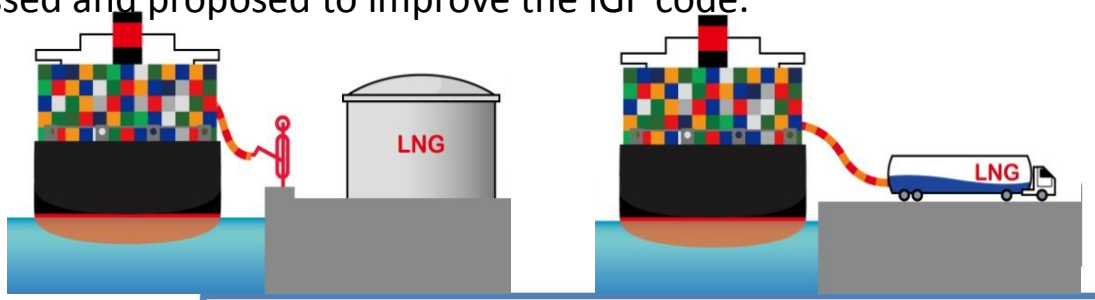
Hose saddle

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.

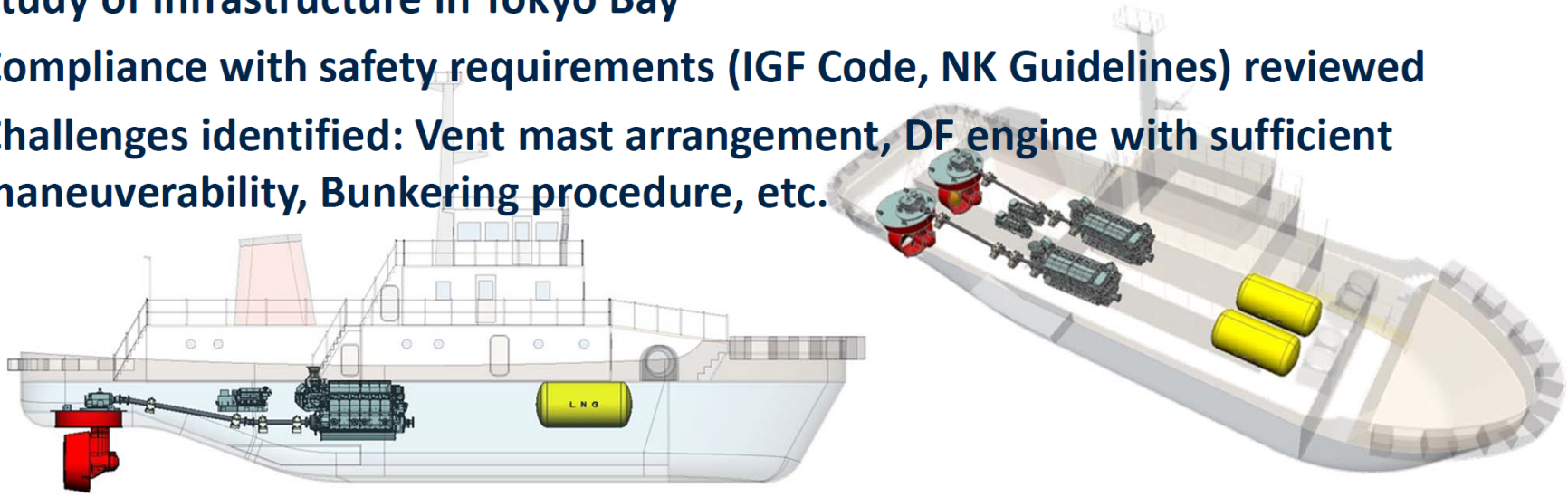

Simulated plant used for the demonstration experiment

- 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

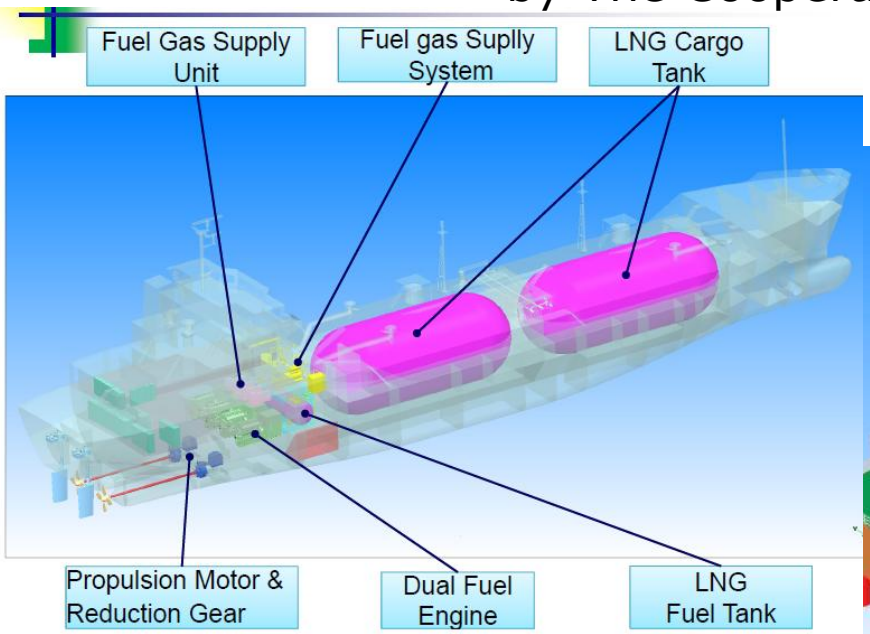
- ✓ **Study of optimum design (comparison in engine type, shafting & propellar, LNG/CNG tank system, etc.)**
- ✓ **Study of infrastructure in Tokyo Bay**
- ✓ **Compliance with safety requirements (IGF Code, NK Guidelines) reviewed**
- ✓ **Challenges identified: Vent mast arrangement, DF engine with sufficient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

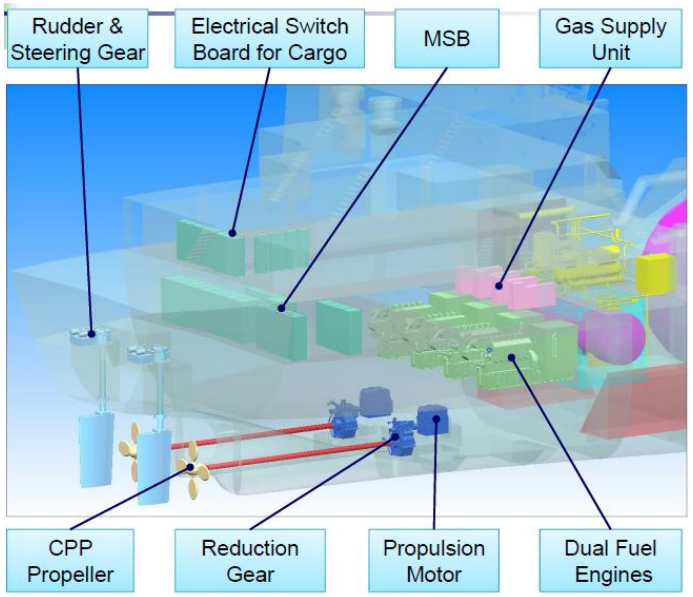


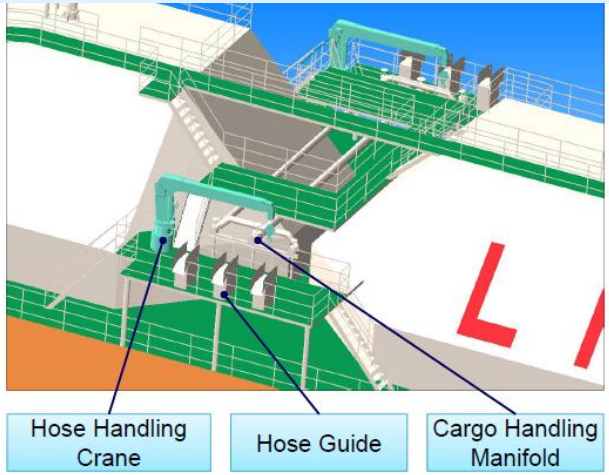
LNG Fuel Tank	25m3 (12.5m3 X 2), bunkering : once a week
Propulsion System	DF Engine (abt.2000kW) & direct coupling with thruster X 2sets

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







Development of marine natural gas engines has been introduced as an example of 'Collaboration'.

ClassNK will contribute as a 'Bridge'.

'Bridge' has two meanings.

Like a bridge of the ship, we can take an extensive view of the world aspect from it.

And connect between not only the academic side and industries like today's example but also between 'Singapore and Japan'.

Thank you for your kind attention