Development of marine natural gas engine

Prof. Dr. Koji Takasaki
Kyushu University, Japan

Contents

1. **Real conditions of natural gas engines in marine use**

2. Special apparatus
   Large sized RCEM: Rapid Compression and Expansion Machine

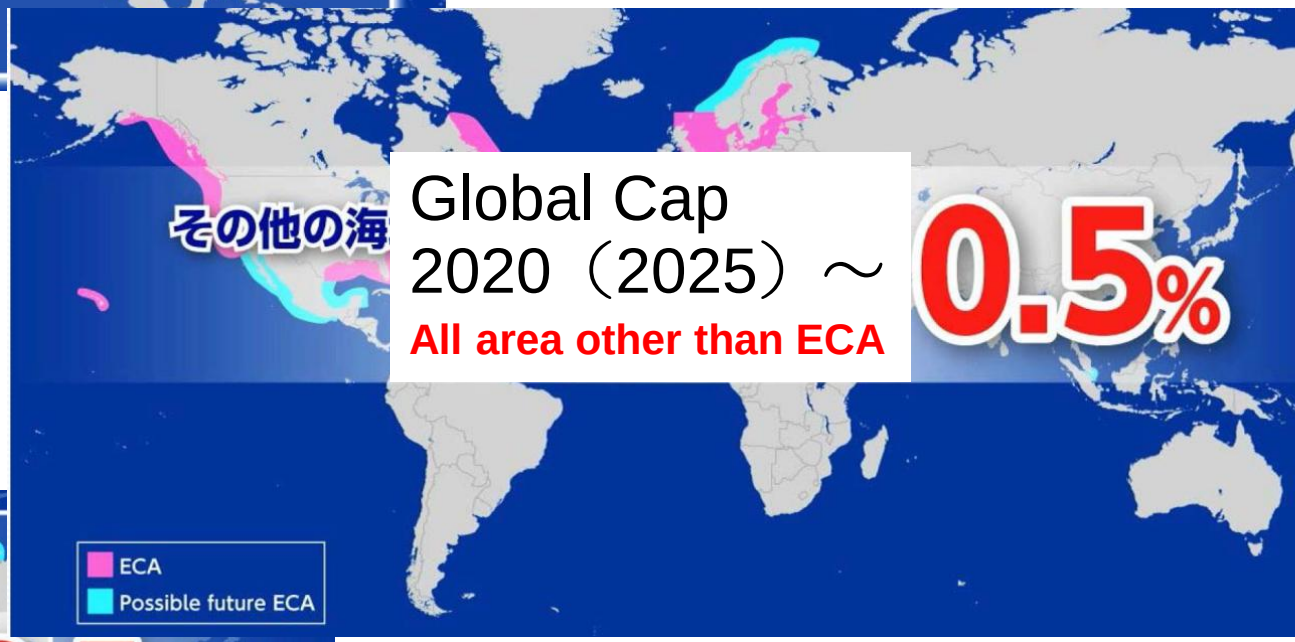
3. Visual study on abnormal combustion in lean-burn gas mode (Otto-cycle type gas engine)

4. Visual study on **GI** (high pressure **G**as **I**njection) combustion (Diesel-cycle type gas engine)

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

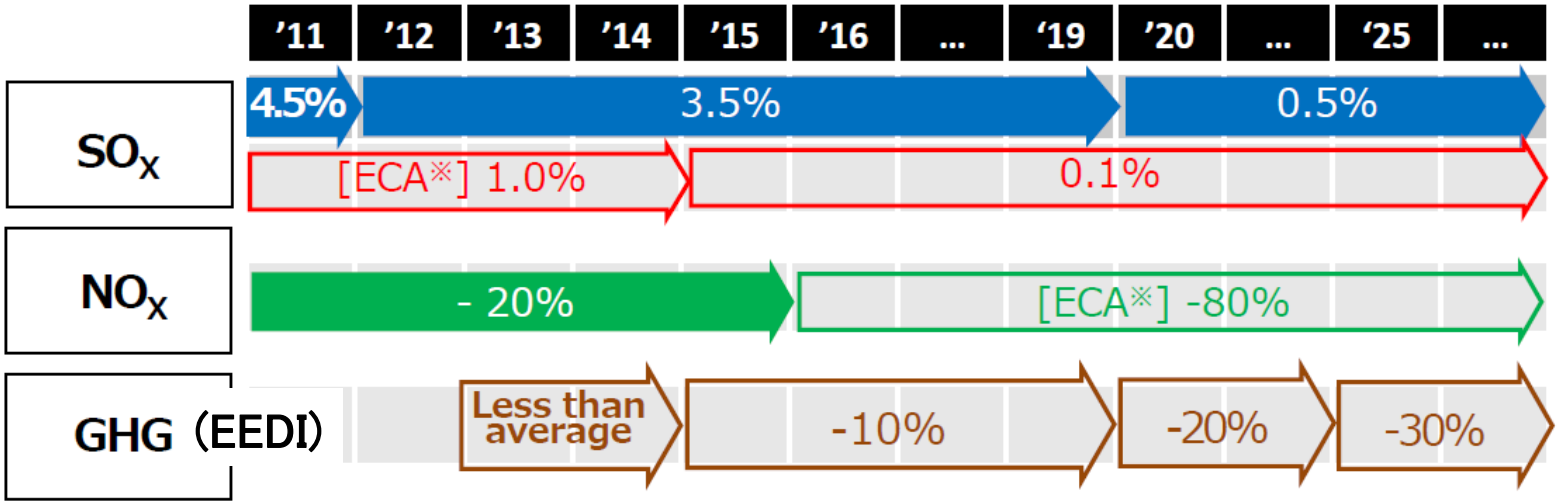
(Black Carbon (BC) in the North-pole area is under discussion)

Regulation of CO2 ：Green House Gas (GHG)

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

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

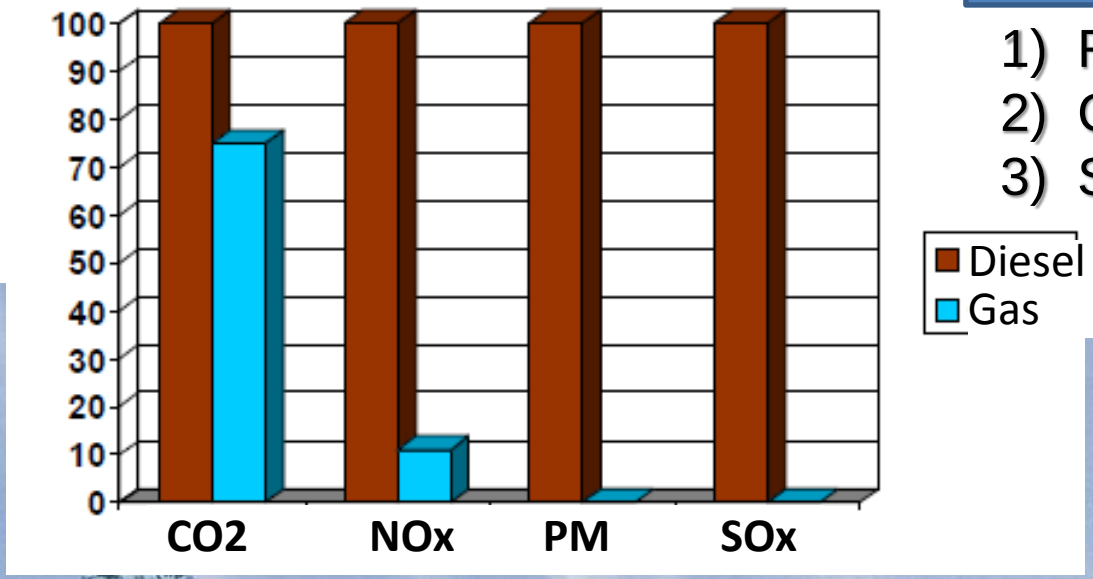
For newly built ships **2015～ -10%, 2020～ -20%, 2025～ -30%**



Marine diesel oil : **C16H34 · · 16 CO2 +17 H2O + Q**

Natural gas : **12 CH4 · · 12 CO2 +24 H2O + Q**

Effect on emissions reduction by changing marine 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

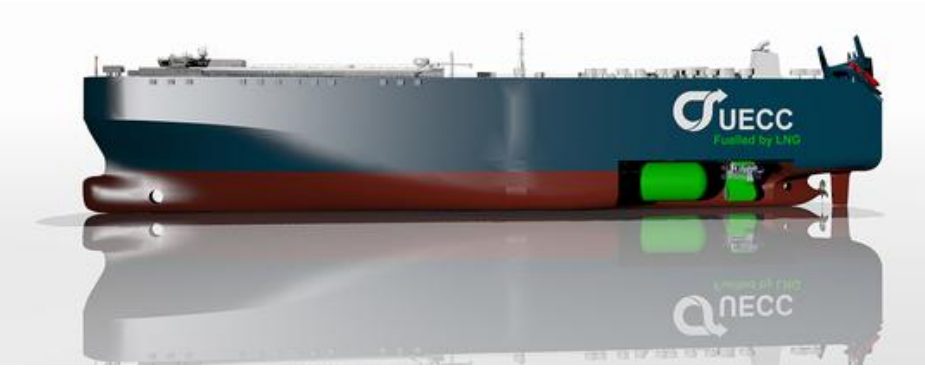
観光船 @韓国・仁川港

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⇔ウルグアイ航路に投入予定）

Natural gas fueled ships from now

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

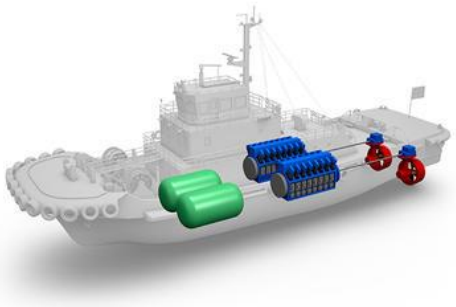


• United European Car Carriers (UECC) jointly owned by NYK and Wallenius Lines has ordered KHI two PCCs propelled by MAN low-speed ME-GI gas (DF) engine. (for voyage in European ECA)

・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～
（MLIT and 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）

Table 1 Categorization of marine gas engines

	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.

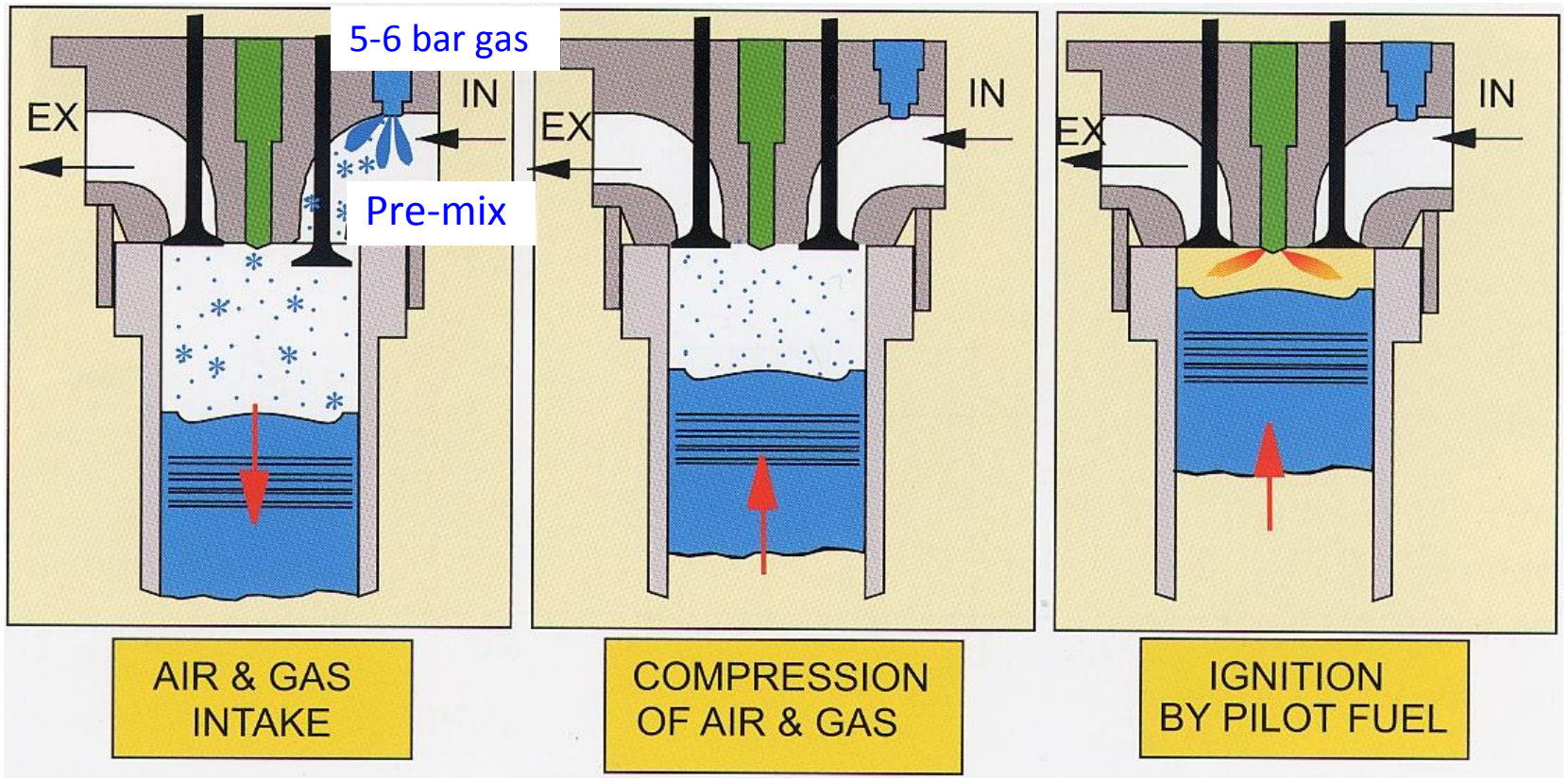
	Lean-burn (pre-mixed) (low-pressure gas supply)	**GI** (Gas Injection) (high press. gas injection)
Medium-speed 4-st.	Currently all	Possible but not yet applied
Low-speed 2-st.	Existing **Otto-cycle** type gas engine	Existing **Diesel-cycle** type gas engine

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

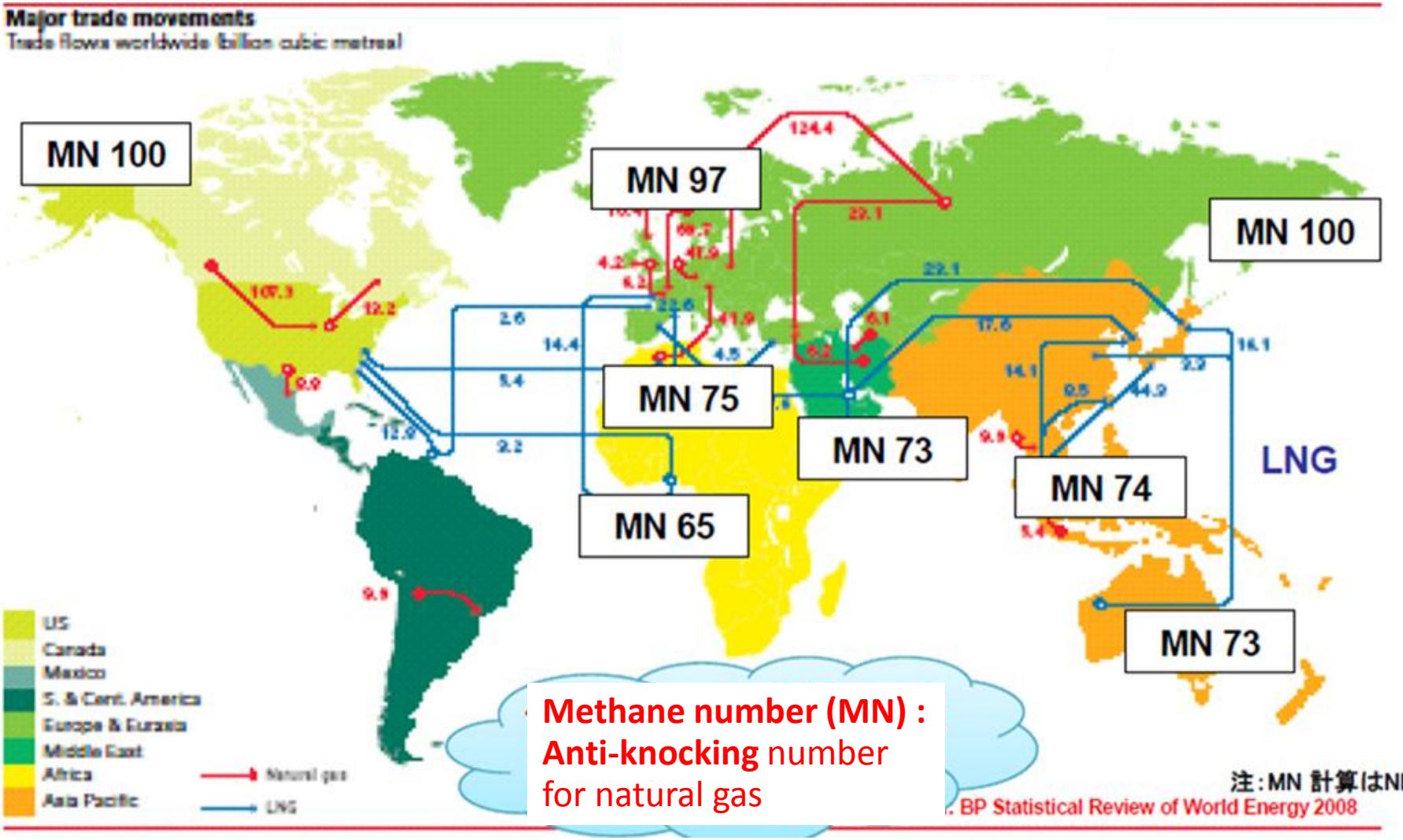
To keep safe operation at high load, MN higher than 80 is necessary.



Function of medium-speed lean-burn gas engine

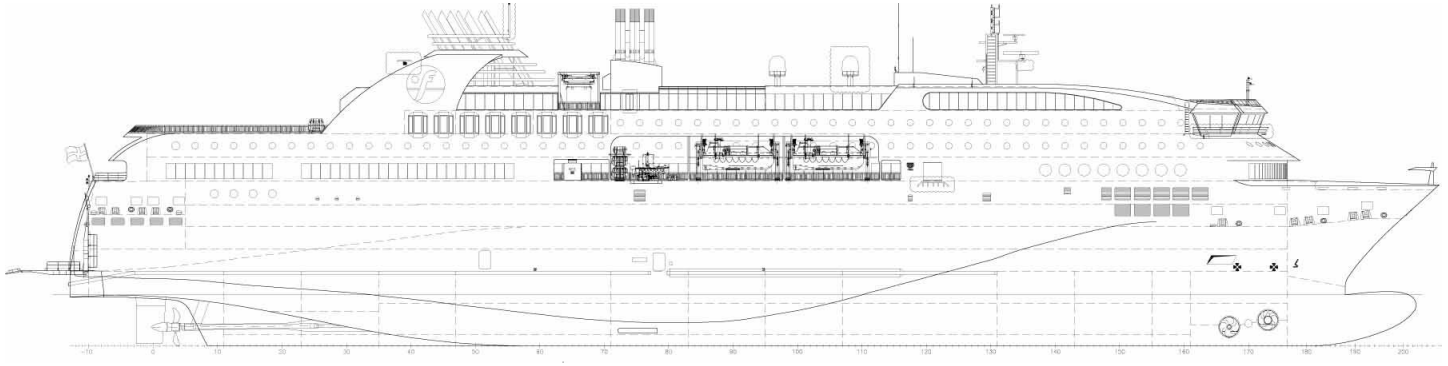
Movie・・ Well known flame propagation and knocking phenomena in automobile gasoline engine

Current Methane Number of natural gas in each area

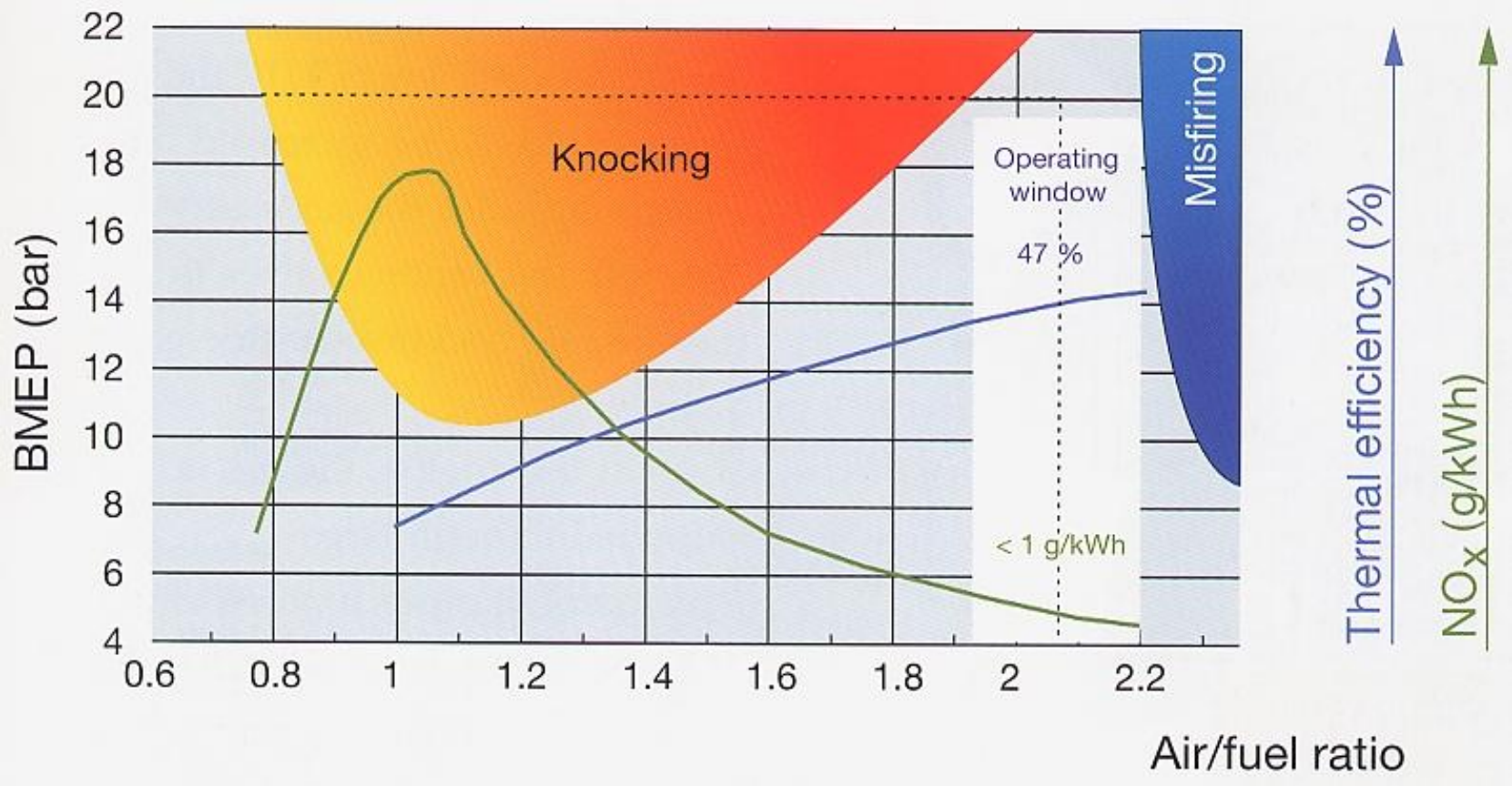


Real conditions of natural gas engines in marine use

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.



（Excess Air Ratio）

Possibility of abnormal combustion for lean burn gas engine

Wartsila company's data

(Of course, to reduce ship speed in rough sea is not convenient.)

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)

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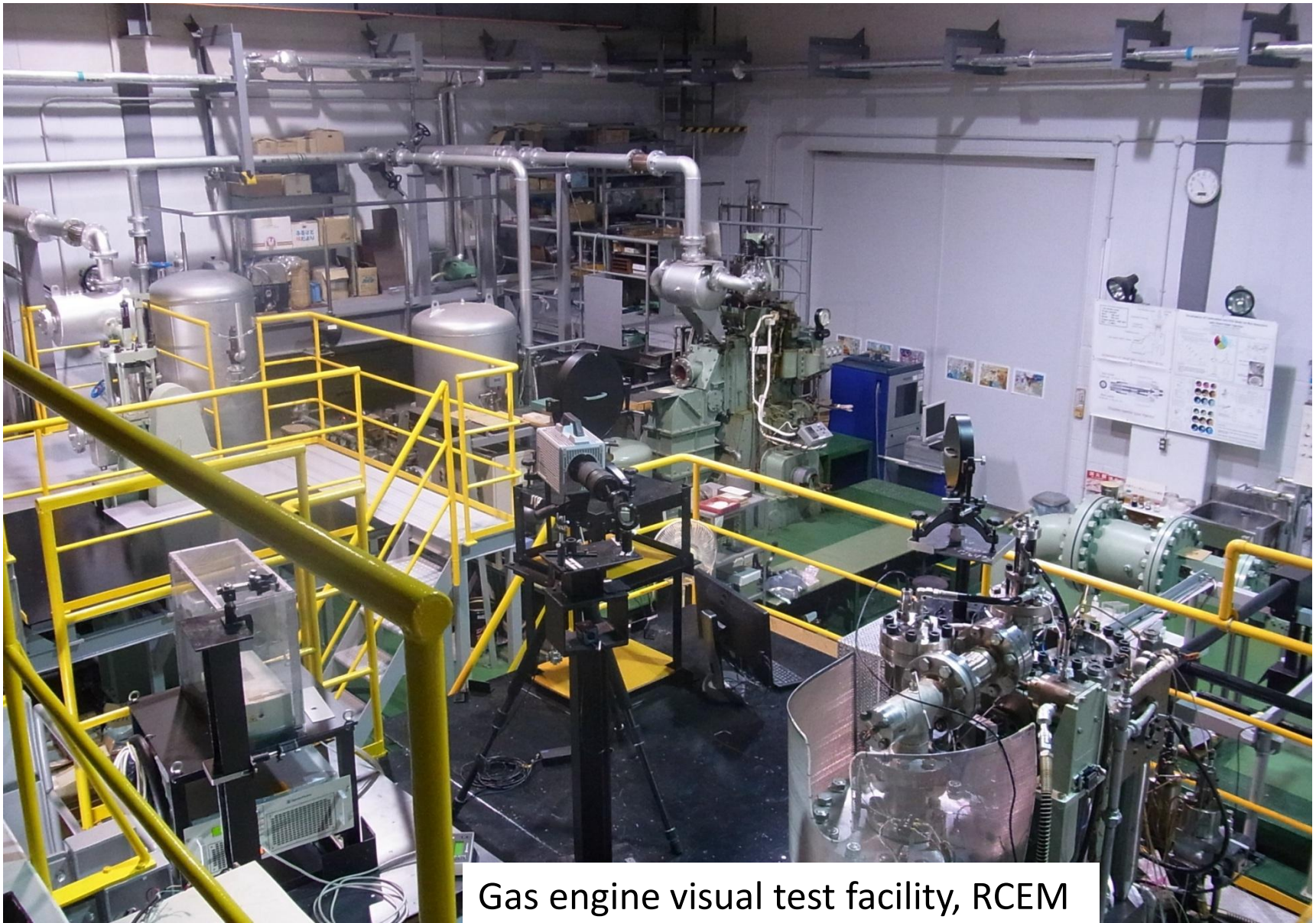
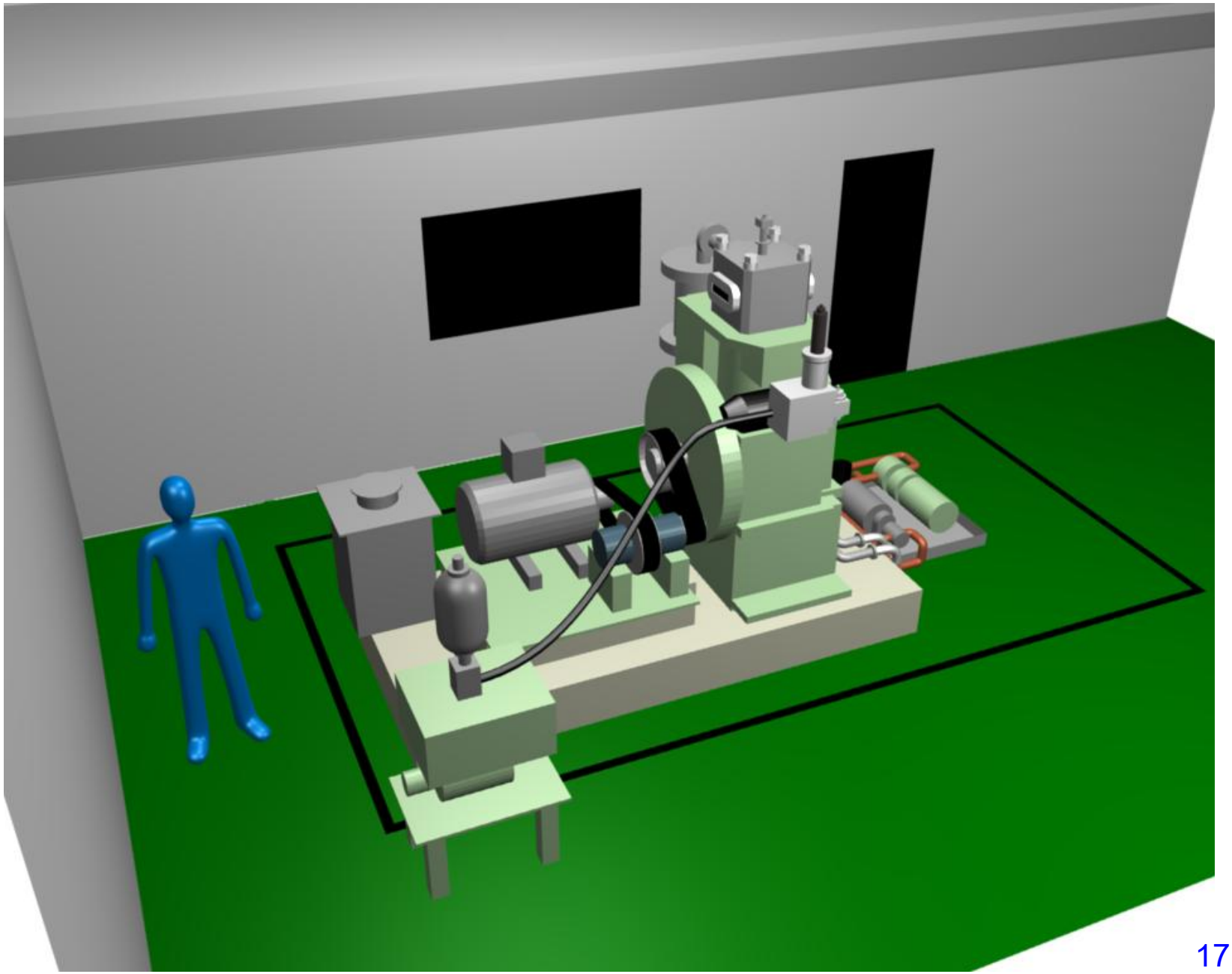
Introduction of fundamental study on natural gas engine combustion by Kyushu University,
for example, '**knocking**' phenomena・・**GI** combustion・・

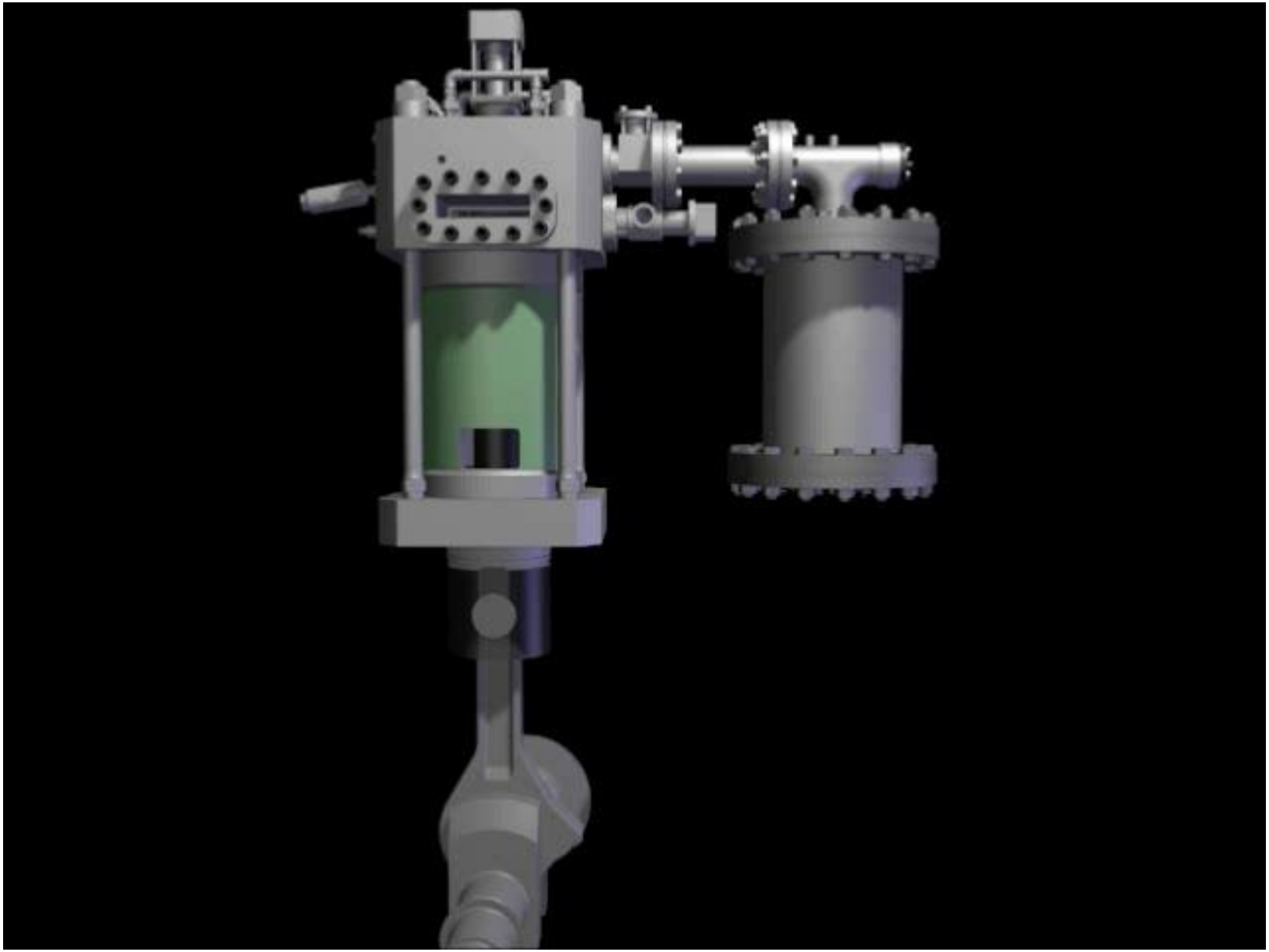


Gas engine visual test facility, RCEM

Construction and function of RCEM



RCEM: Highly-supercharged condition is realized by **double-stage compression**.
Frequent experiments in a short time are possible by **single-shot function**.



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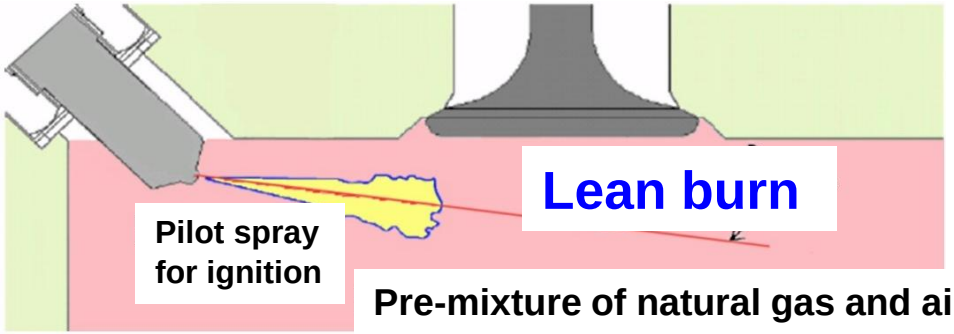
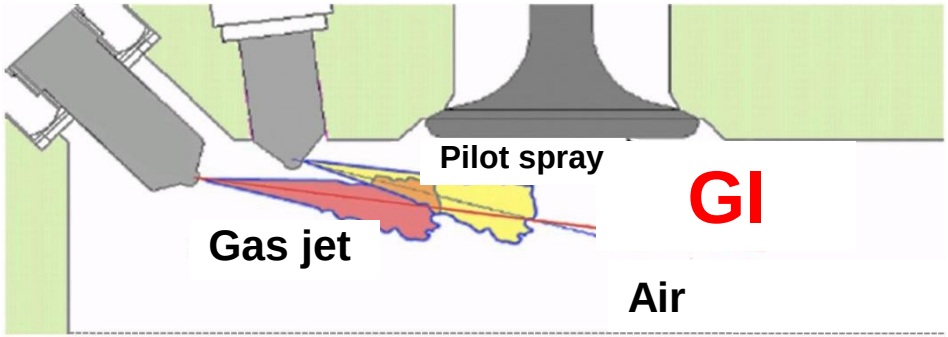
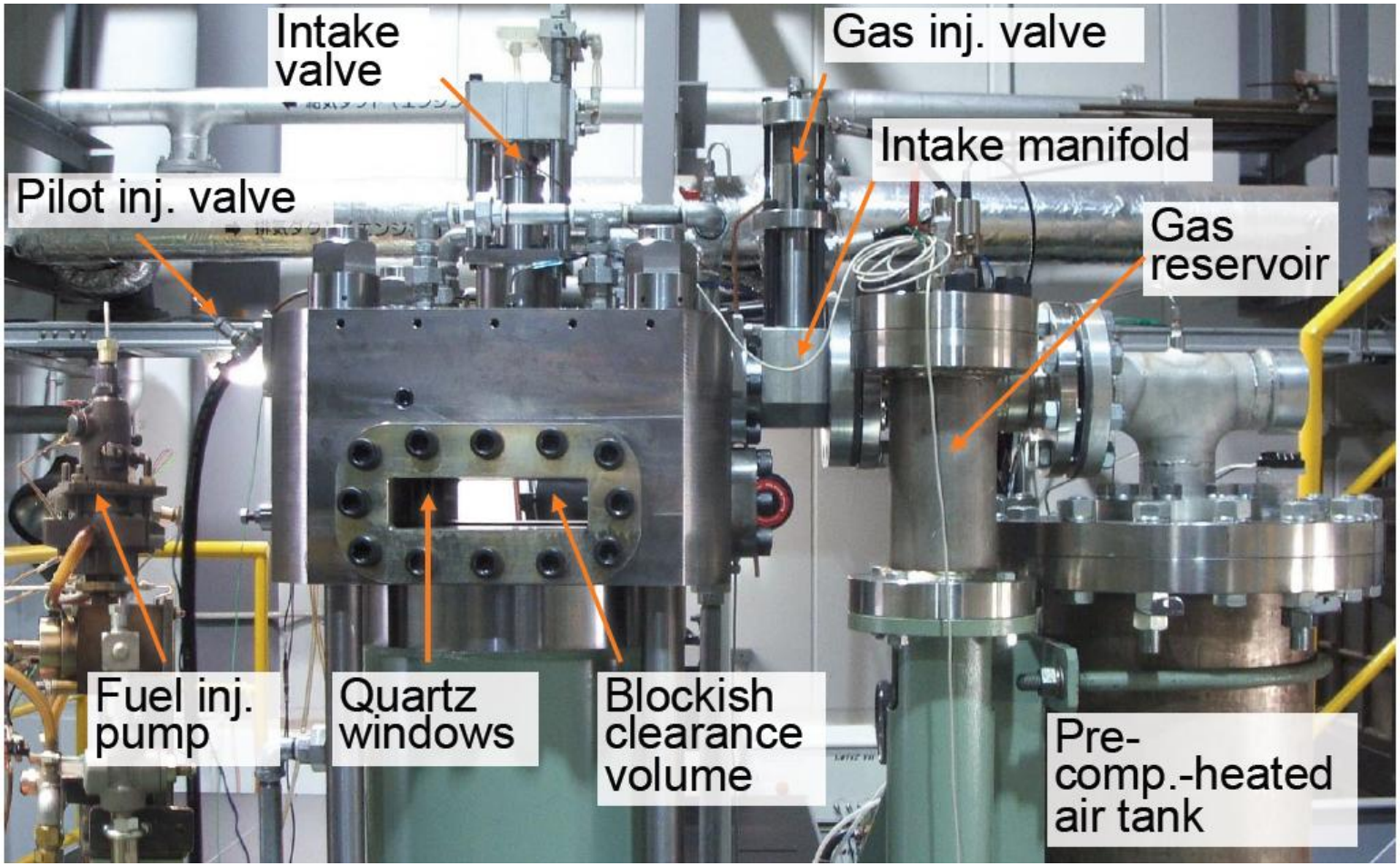
Lean-burn and GI combustion

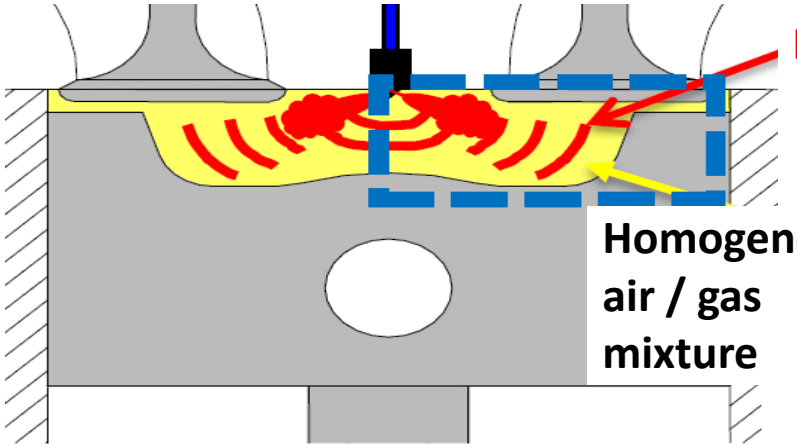


Lean burn type : Natural gas pre-mixed combustion named 'Otto cycle type gas engine'



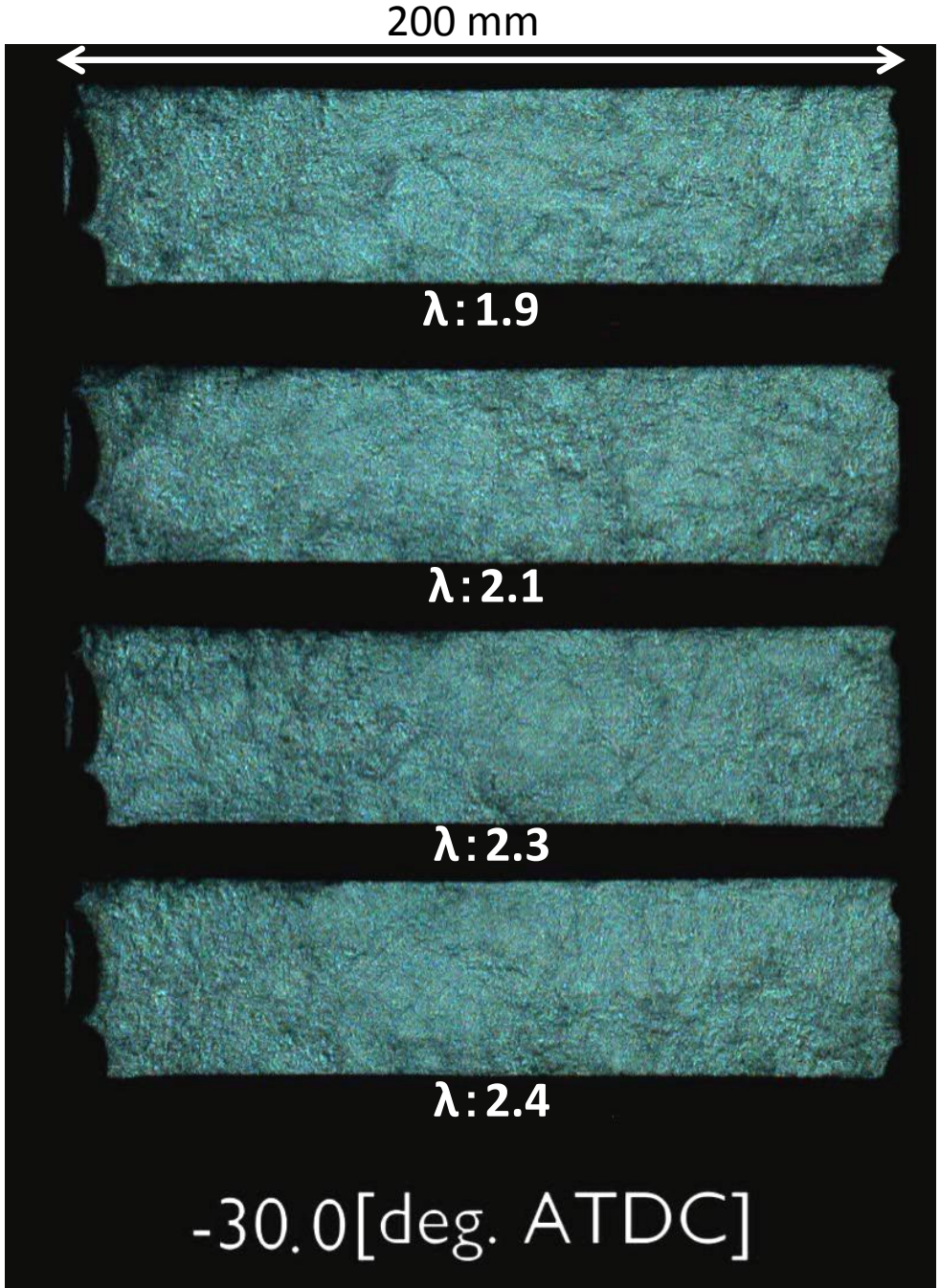
GI (Gas Injection) type : Natural gas diffusive combustion named 'Diesel cycle type gas engine'

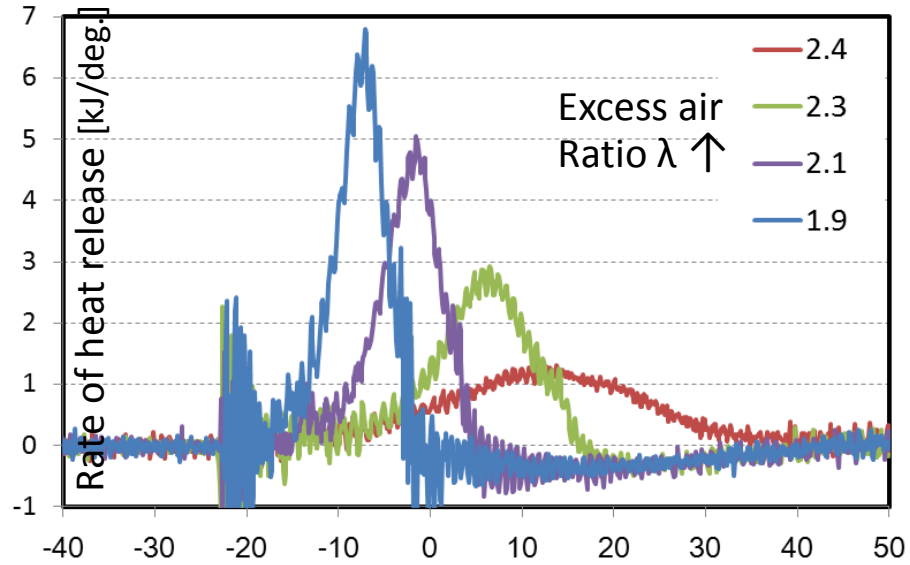


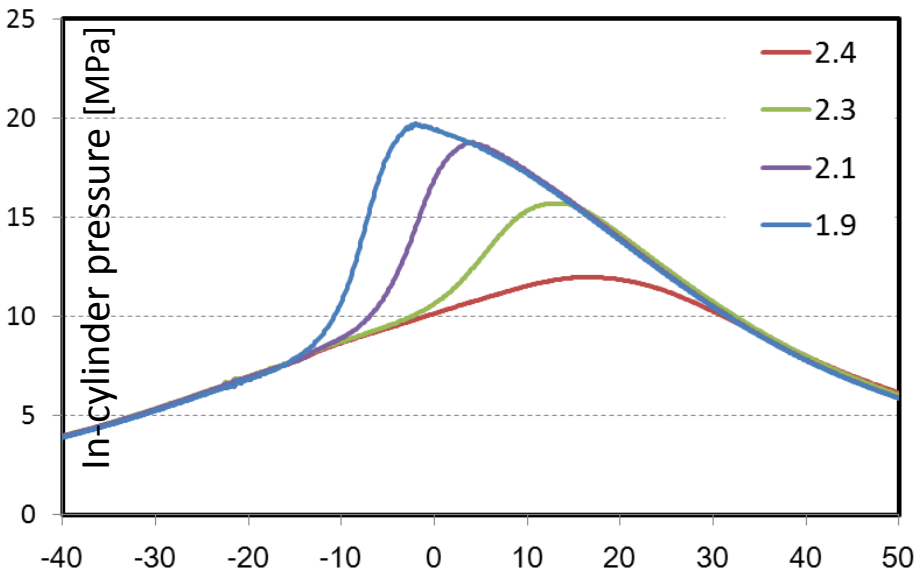


Visual study on
natural gas **lean-burn** combustion
in ‘open chamber’

Lean mixture burns with non-luminous flame. (Burning area looks black by applying Shadowgraph.)

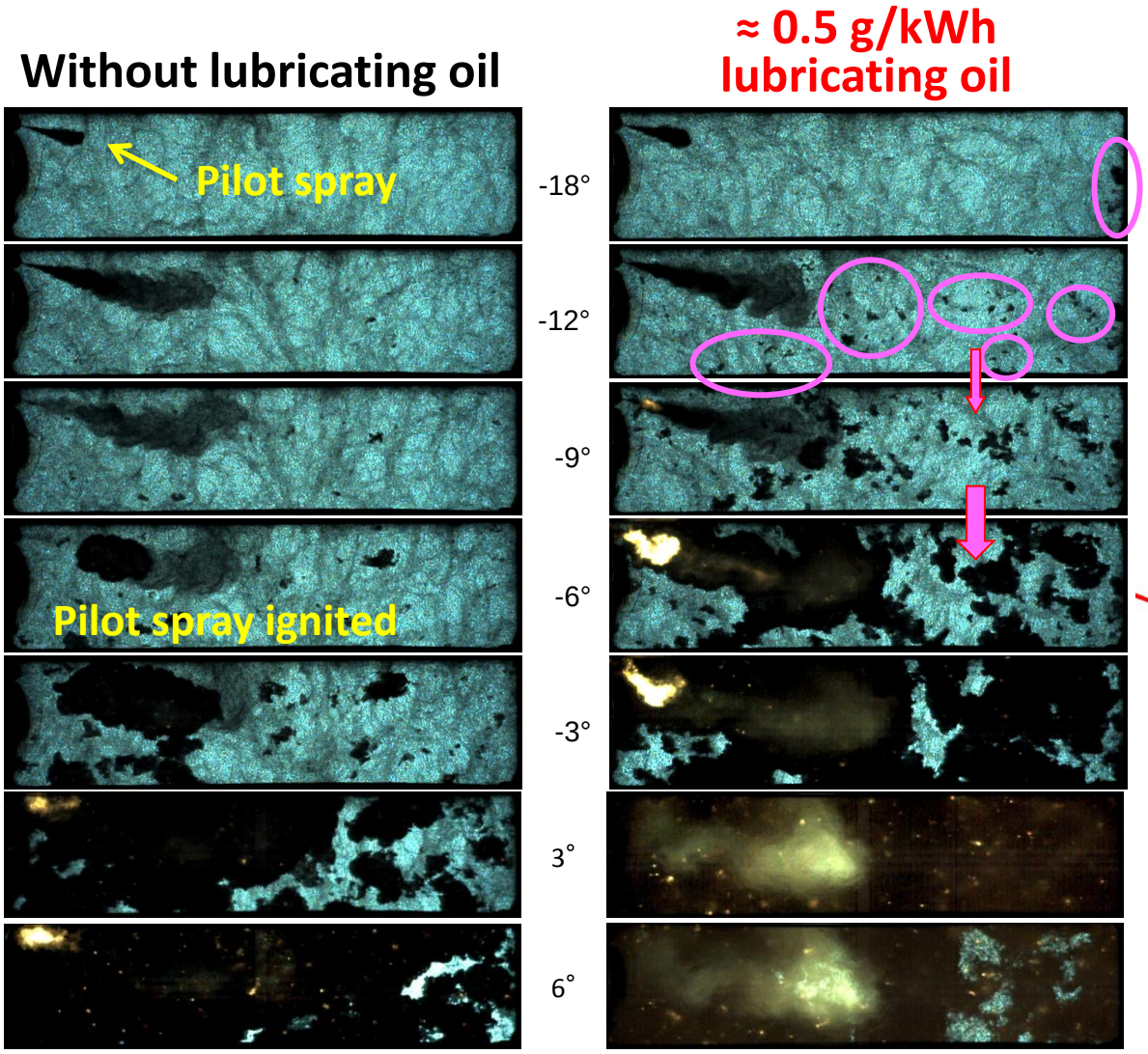


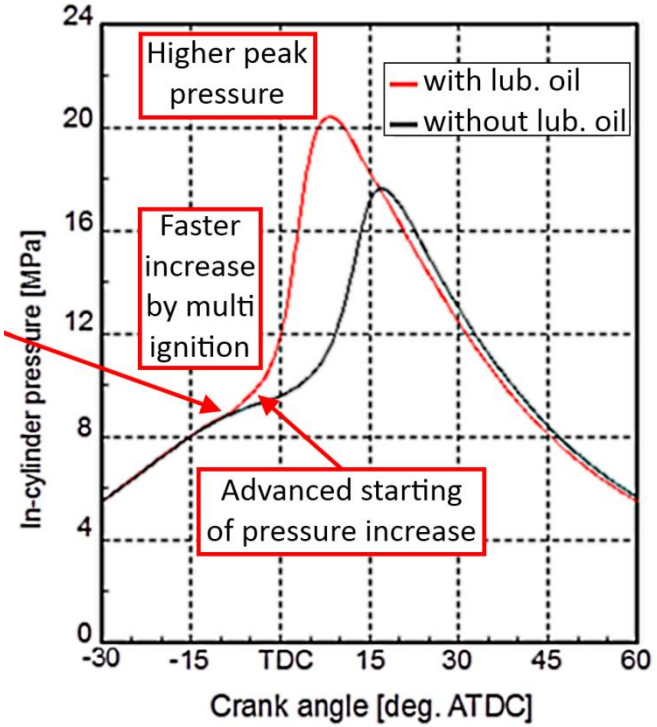


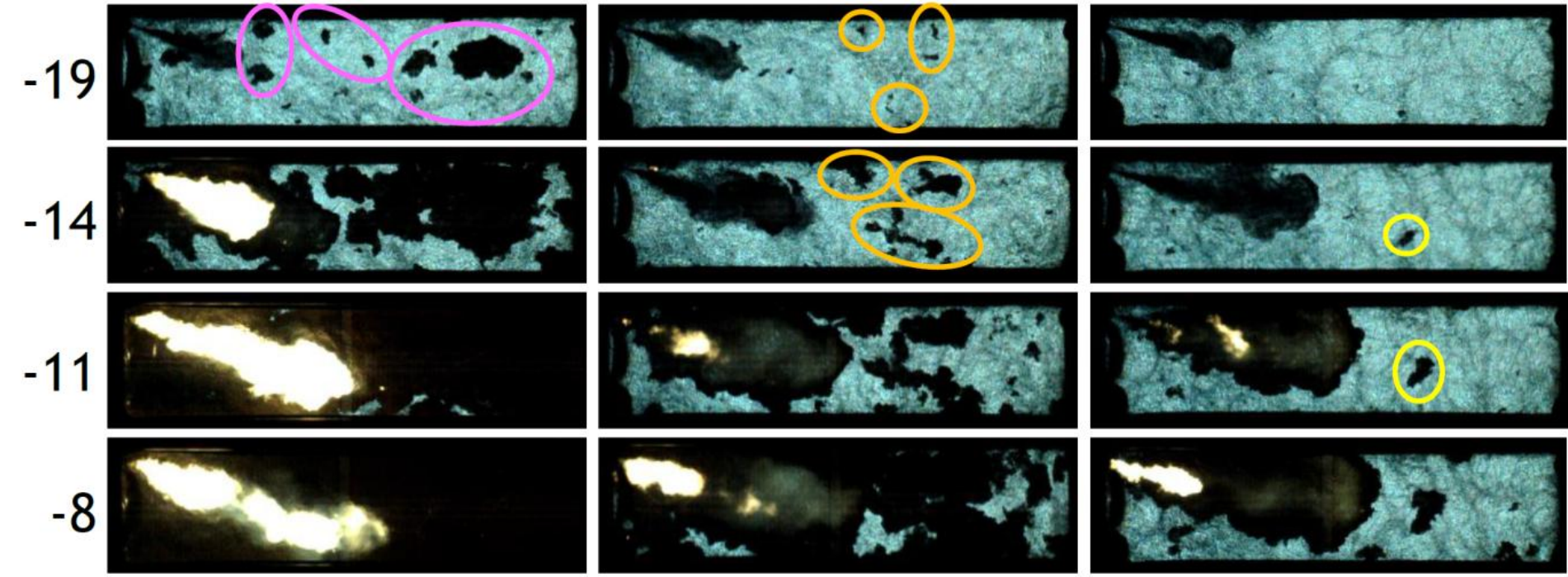


Fuel Gas : Japanese natural gas, Pilot: GO

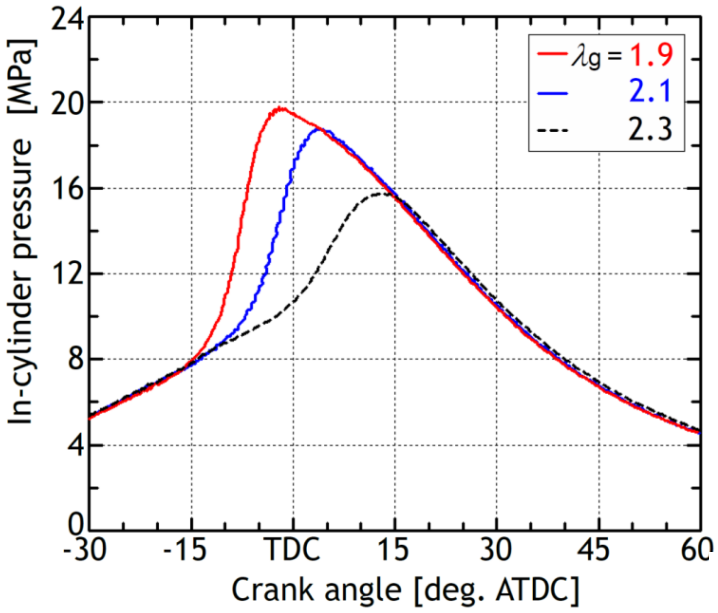
Abnormal combustion caused by lubricating oil







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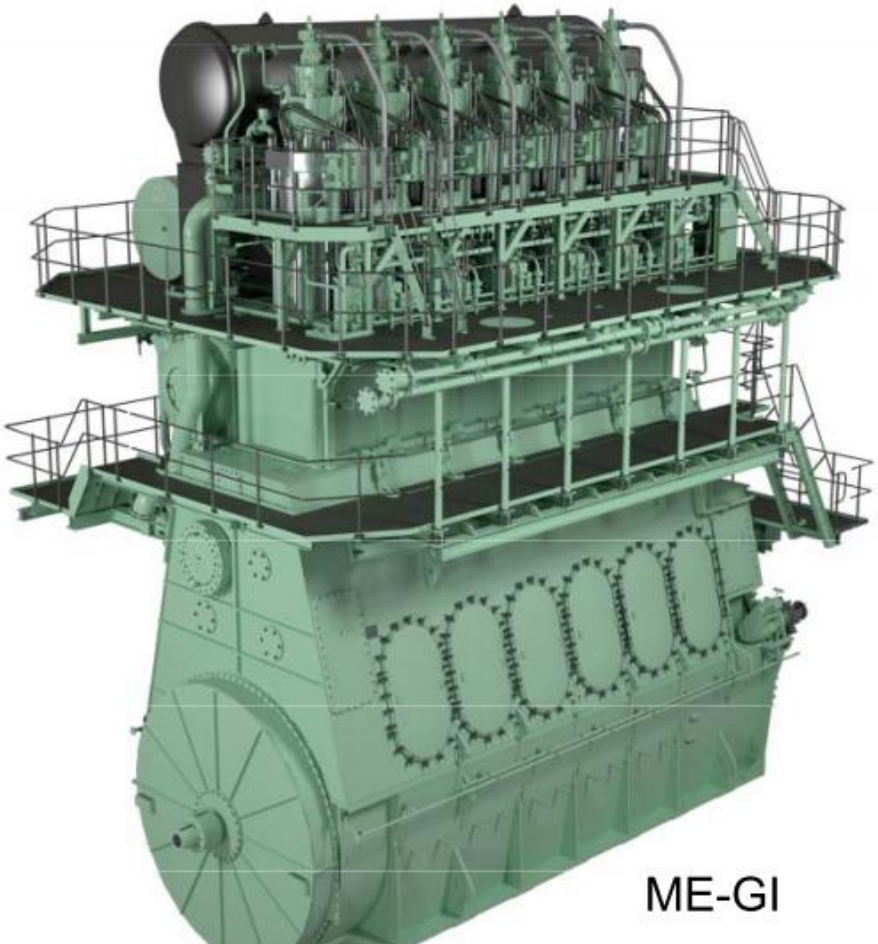
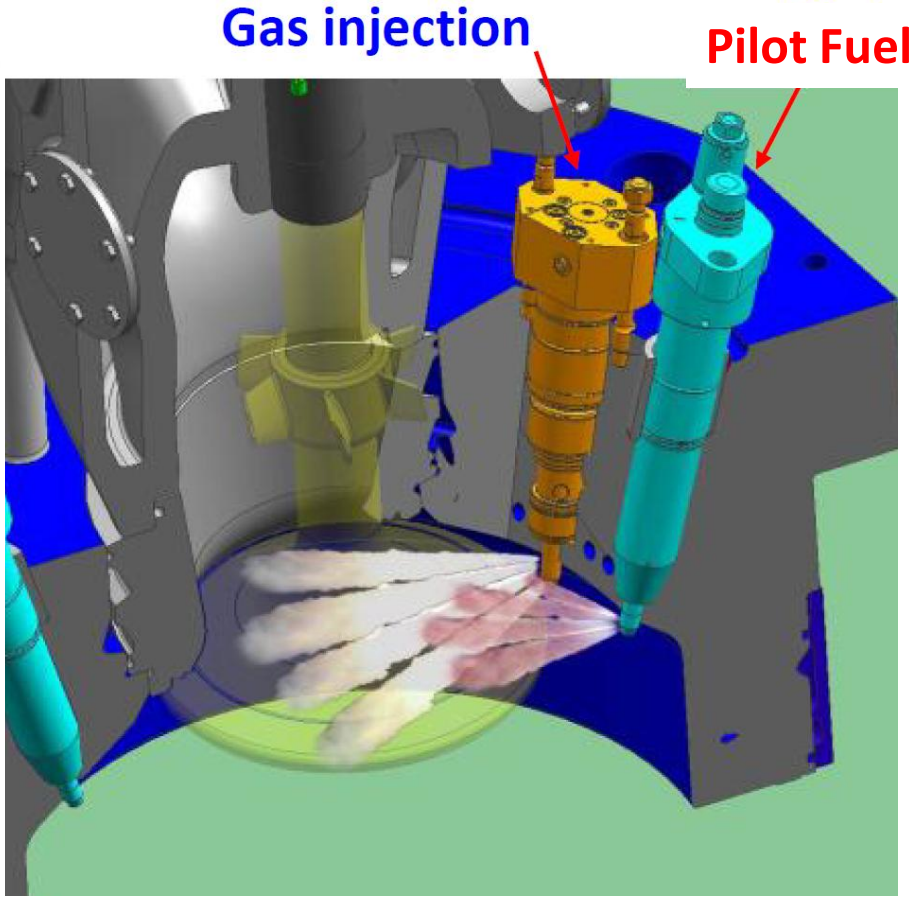
GI (**G**as **I**njection) type combustion • • named ‘Diesel cycle gas engine’

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

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

Lower methane slip

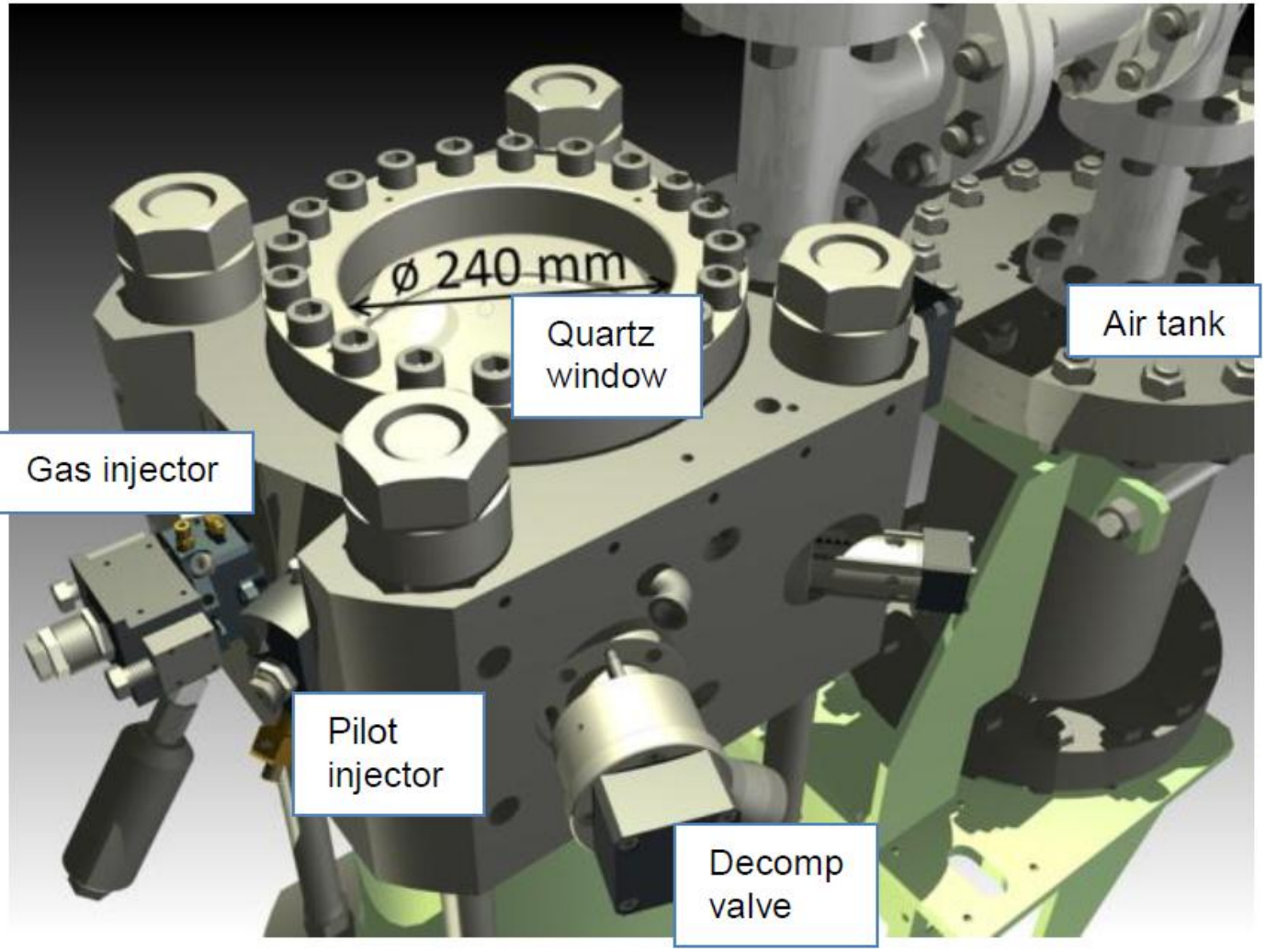


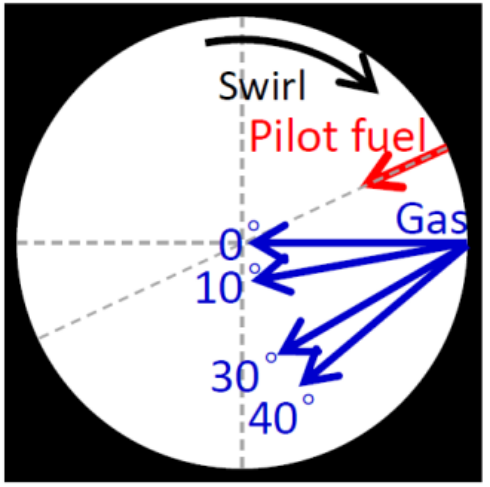


Let us go on to the next step.

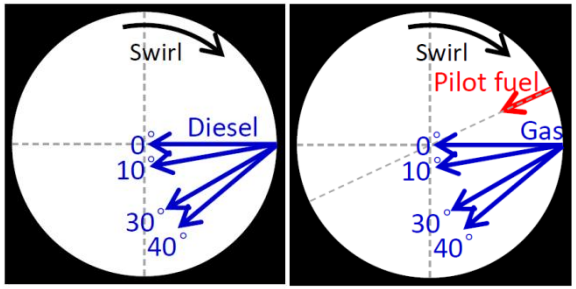
Observation of GI multi flames in air swirl

The new combustion chamber for top view





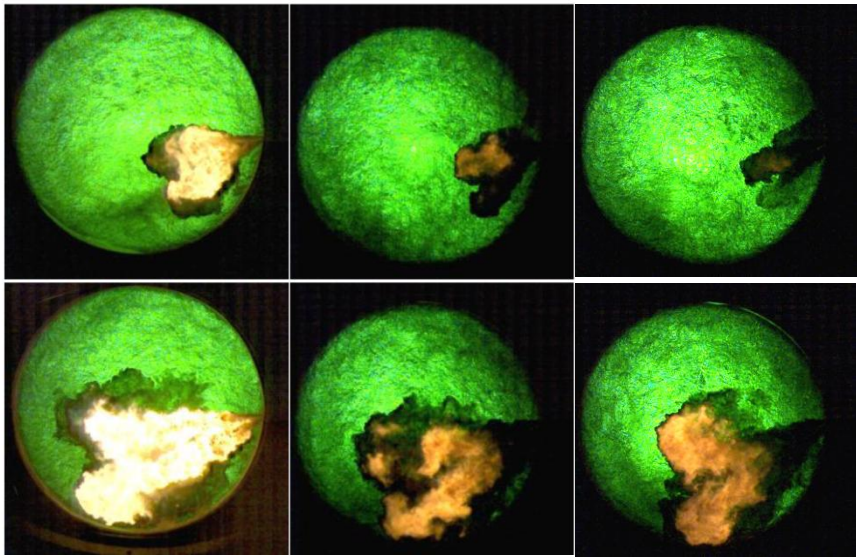
Mirror on top of piston for Schlieren technique



Crank angle deg. ATDC

0

8

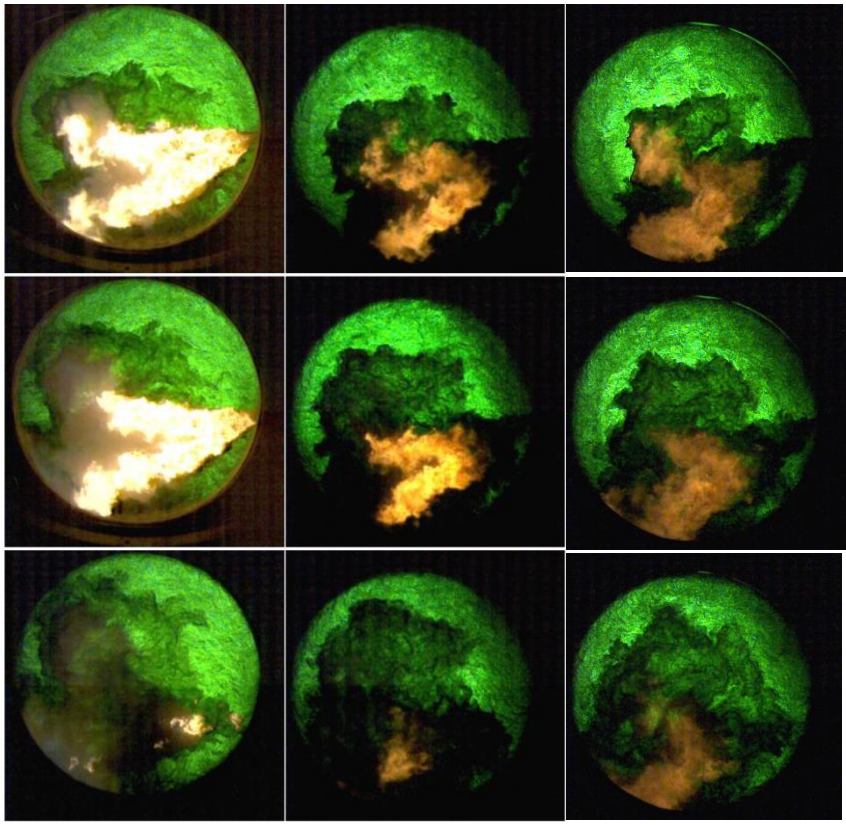


Diesel Std. GI EGR GI **17%O2**

12

16

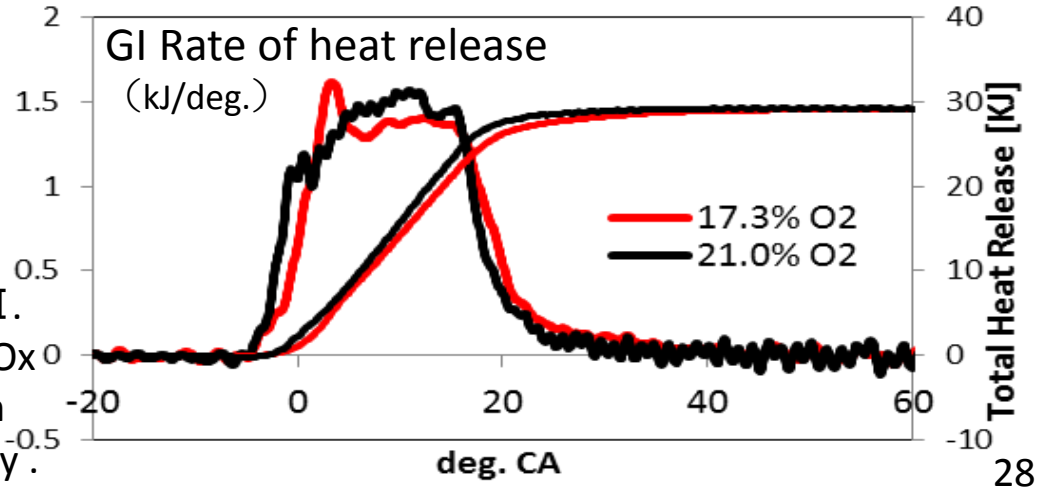
20



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

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

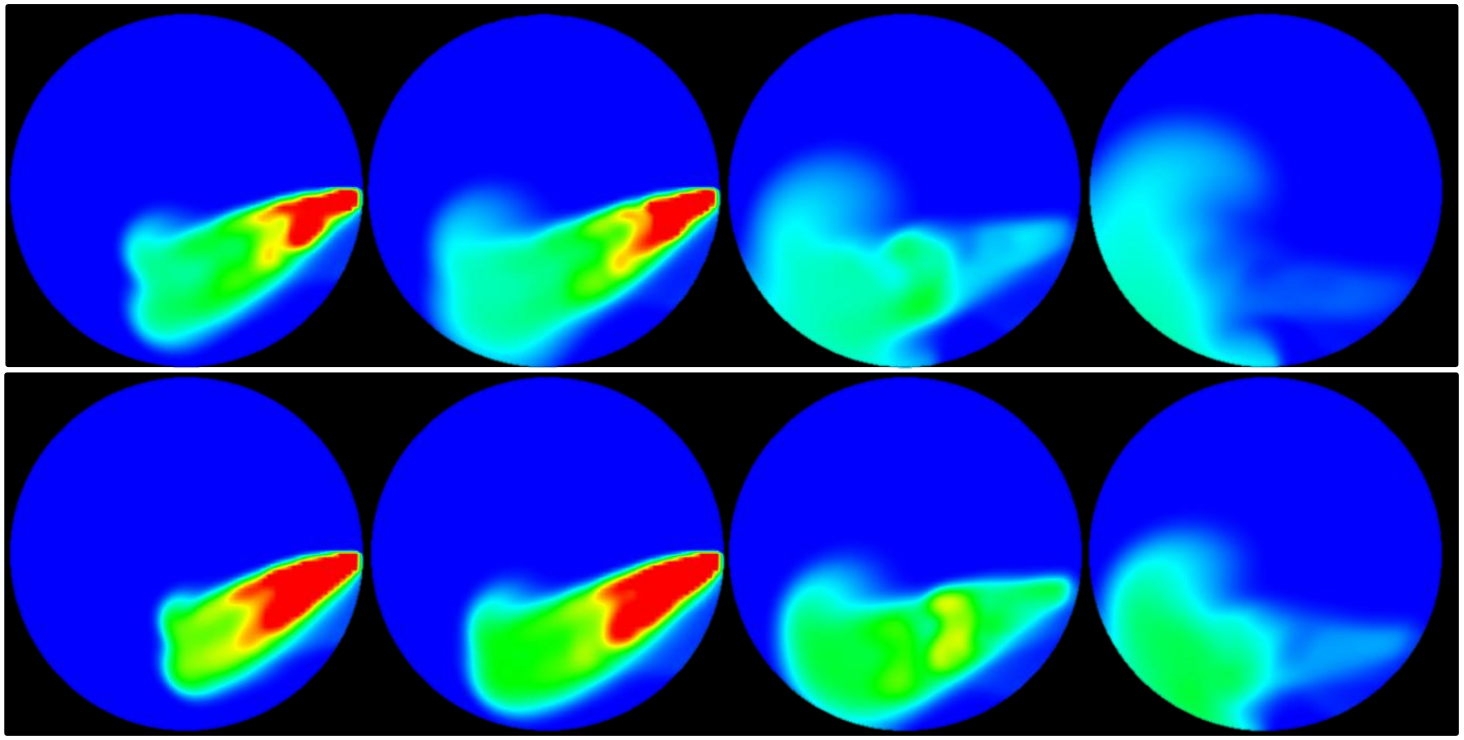
EGR（or SCR）is necessary for GI to clear TierⅢ.
EGR condition is simulated by 17% O2 air and NOx is reduced to 10% of diesel mode with minimum sacrifice of combustion in this fundamental study.

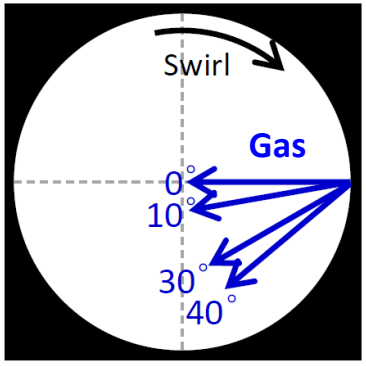


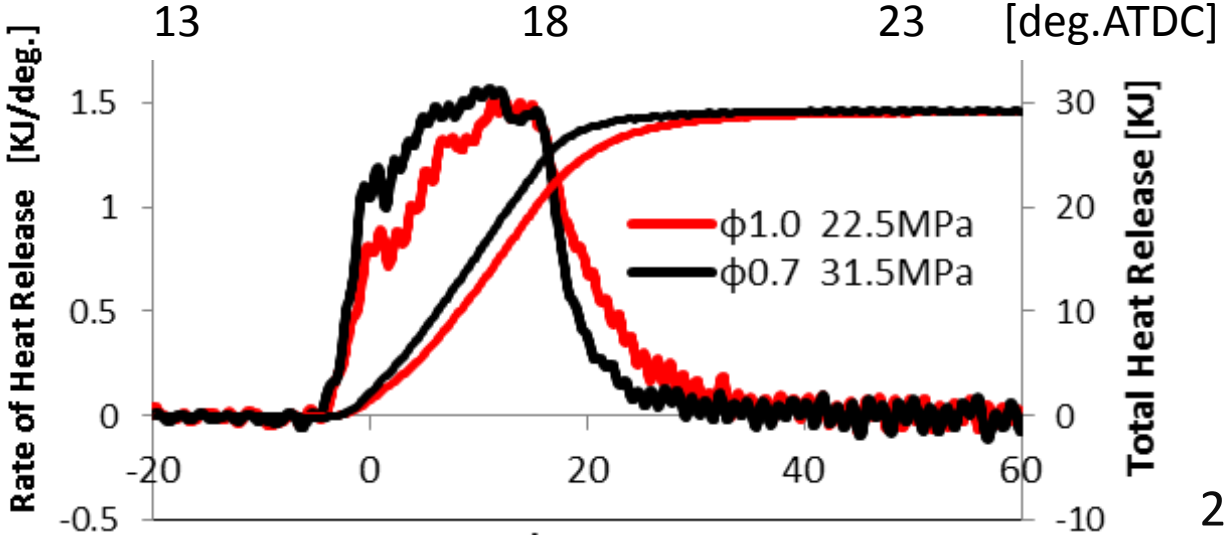
Visualization of fuel mass fraction in gas jet applying CFD

d: 4x **ϕ0.7**
31.5MPa

d: 4x **ϕ1.0**
22.5MPa



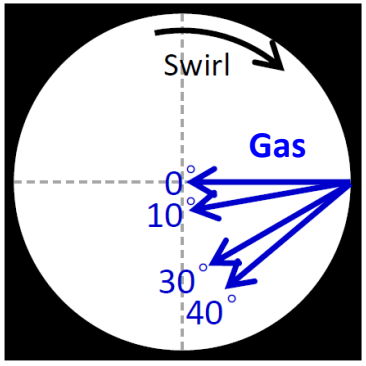




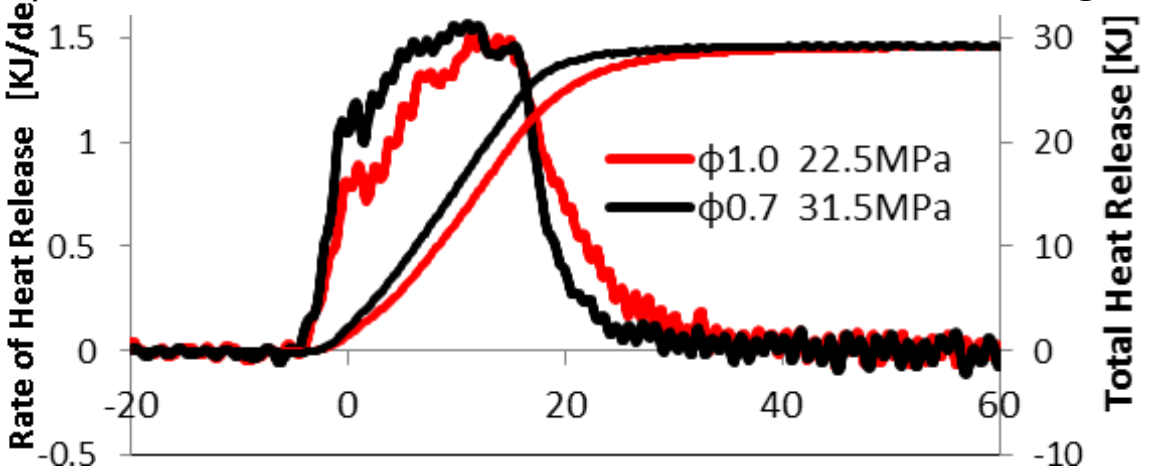
Lower gas pressure case shows longer burn-up length of flame.

d: 4x **ϕ0.7**
31.5MPa

d: 4x **ϕ1.0**
22.5MPa

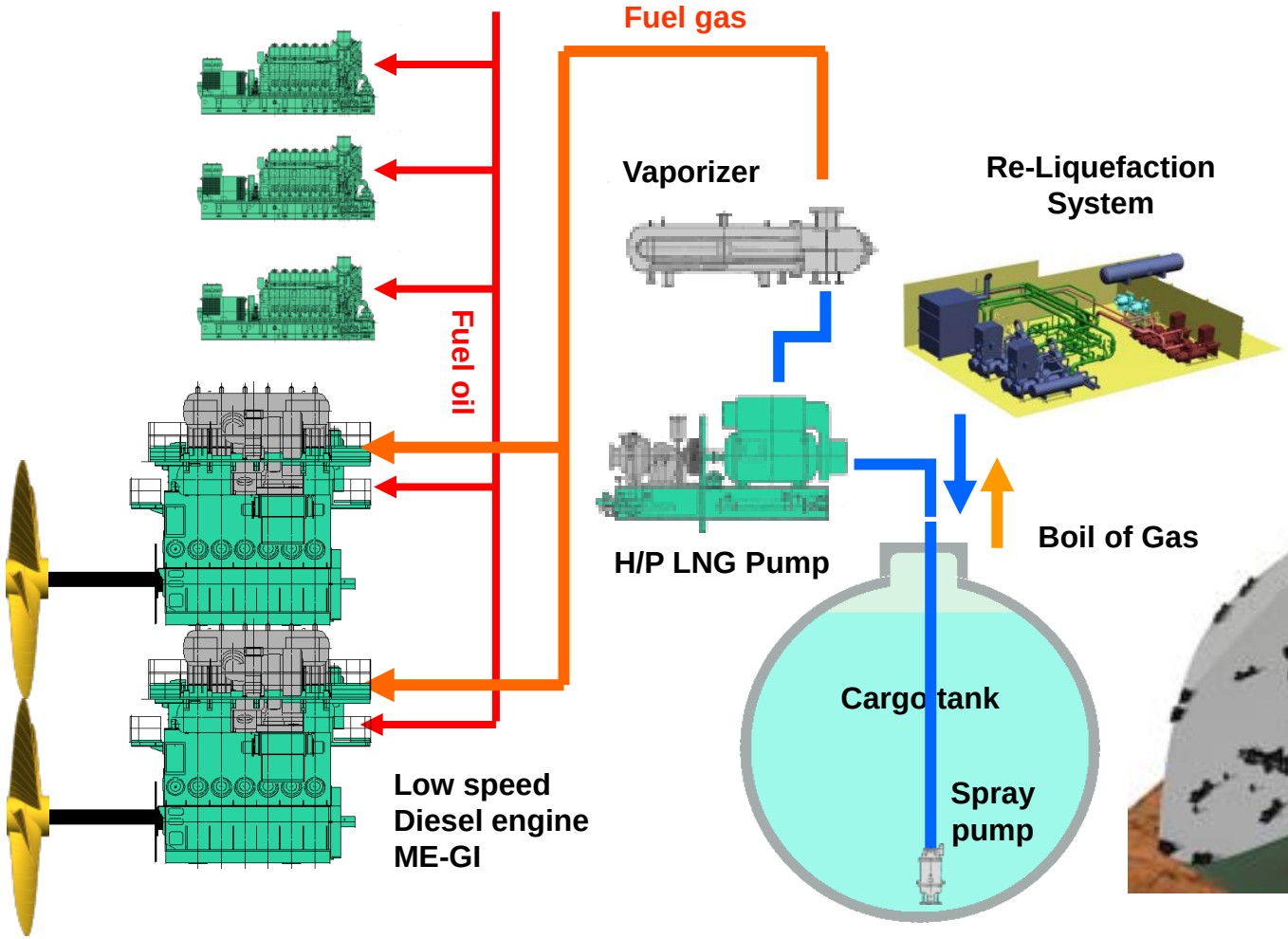


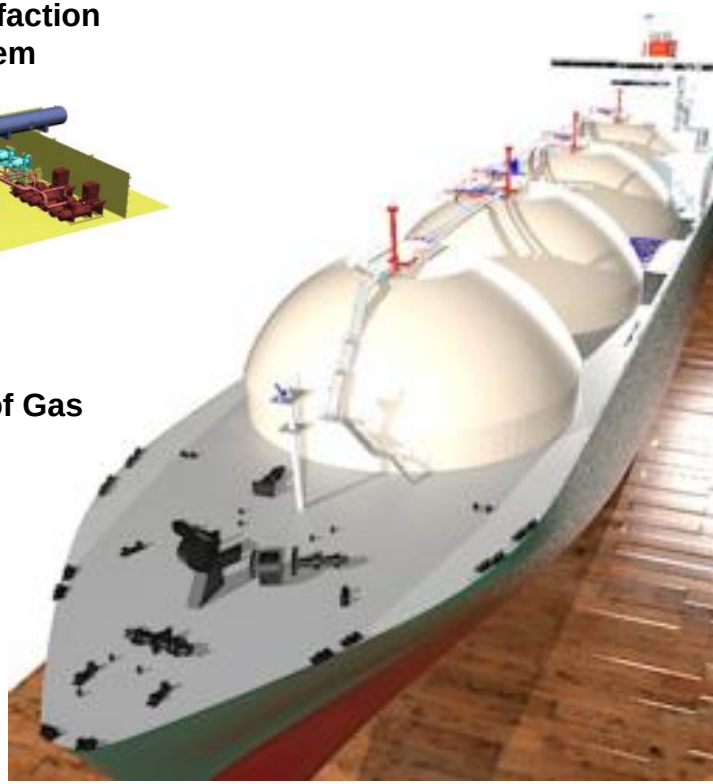
8 12 16 20 [deg.ATDC]



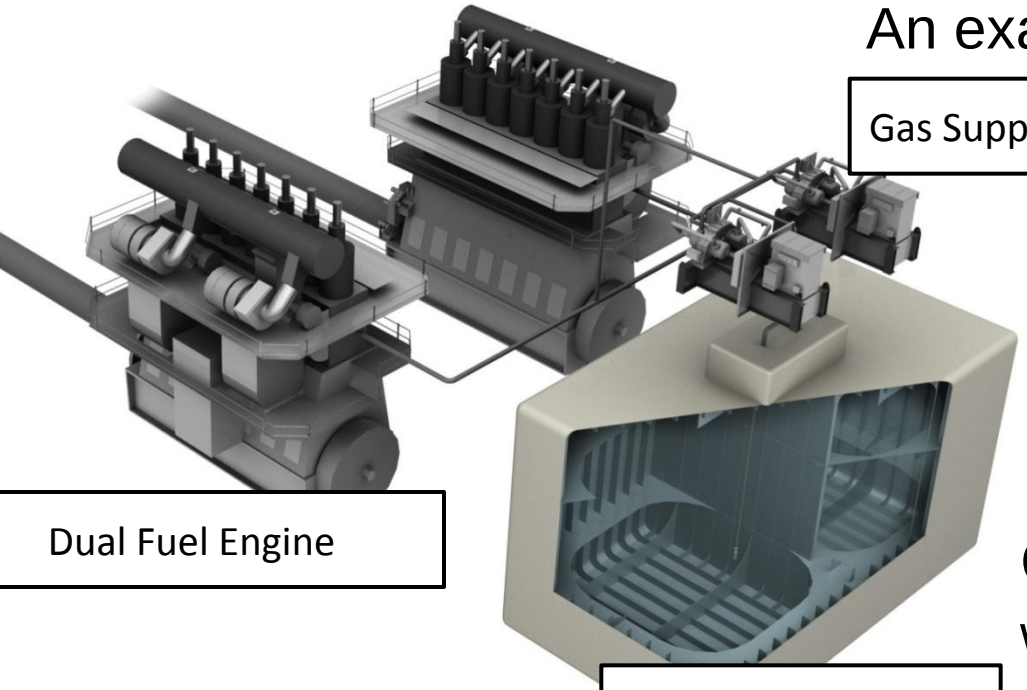
An example of installation of FGSS : Double Eco Max LNGC

- 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

References

Examples of operation and bunkering for LNG fuelled ferries in Europe.

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**

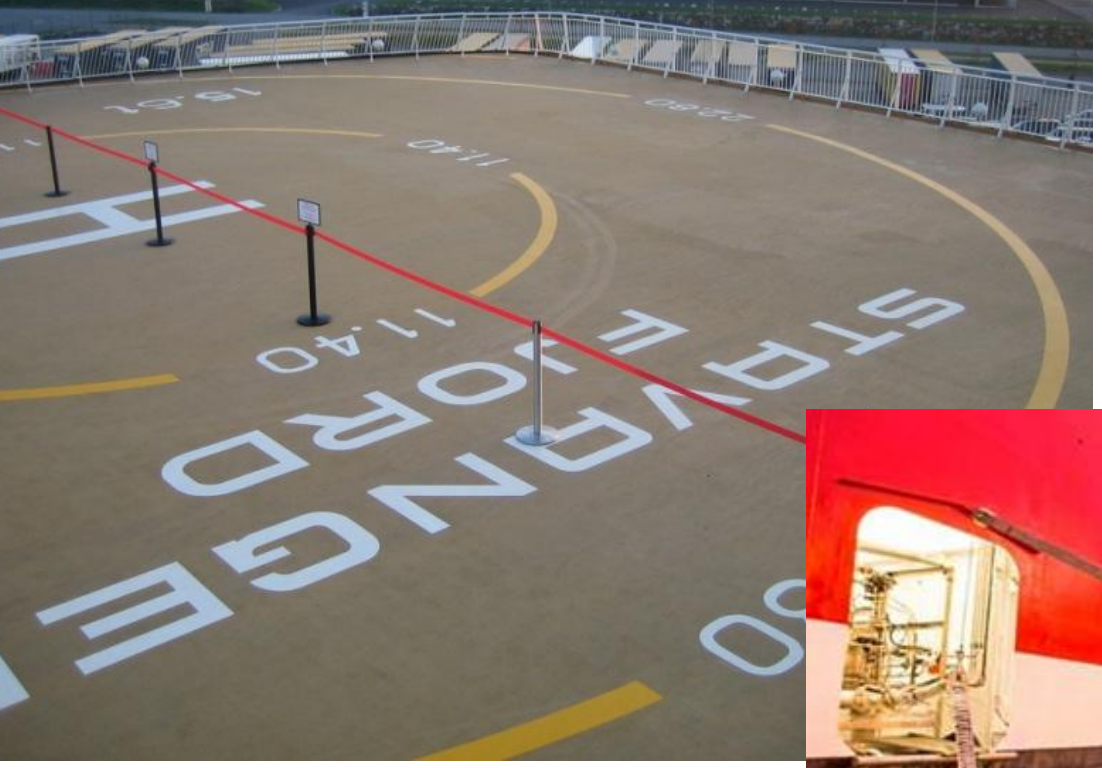
Operating between Turku and Stockholm

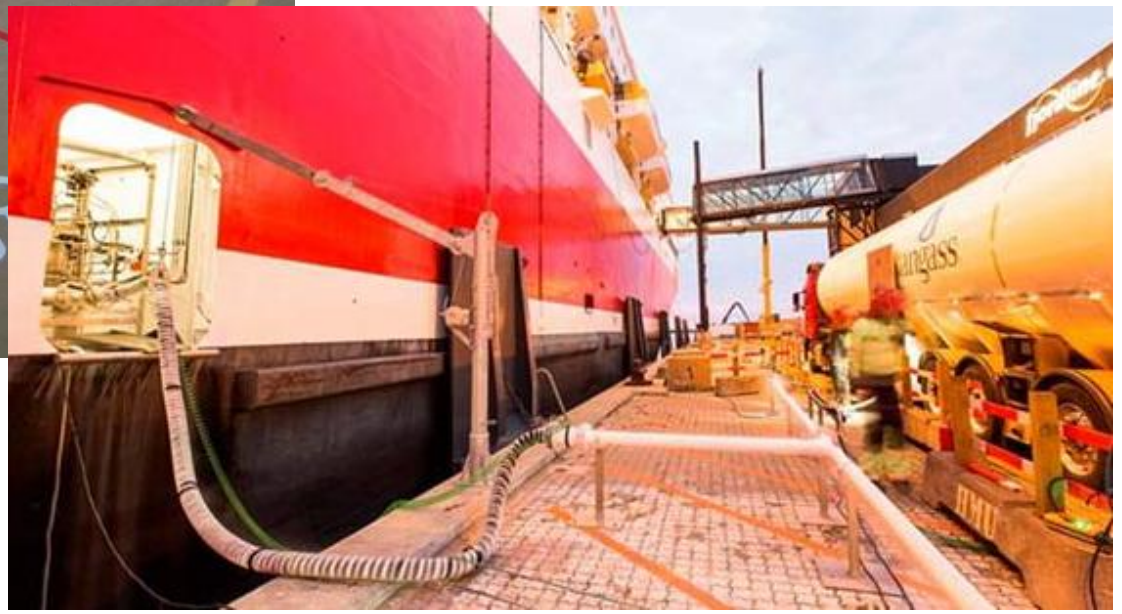
Length	50 m	Breadth	11.3 m
Service speed	abt. 12 knot	Bunker Capacity	200m3

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





Reference :

Truck to Ship bunkering for ferry ‘Stavanger Fjord’ in Denmark.

• Tank capacity is 600 m3 (two 300 m3 tanks) . However, one time bunkering is 100 m3 by two lorries for two hours. During bunkering, passengers are on board. Only access to bunkering side is prohibited.

34

LNG transfer arm

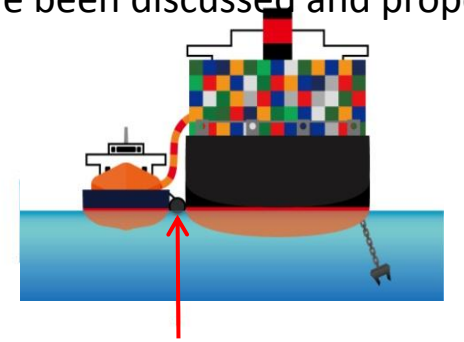
LNG transfer hose

Hose saddle

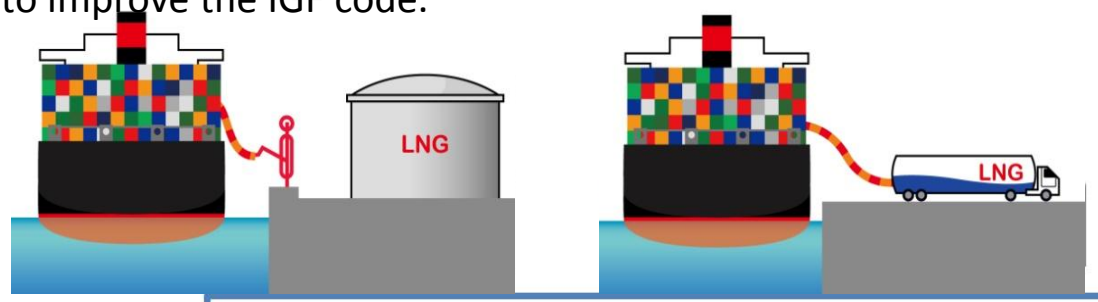
Drip tray

Water curtain

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.

Research work is being continued.

Thank you for your kind attention