2016, 29. Nov.@Tokyo

# *On measures to burn low-sulfur fuels by engine side*

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1. *On general measures for low-sulfur fuels*
2. *On possible high-aromatic low-sulfur fuels after 2020*
3. *Alternative fuels like methanol and LPG*
4. *Development of natural gas fuelled marine engines*

# 1. On general measures for low-sulfur fuels

For example, according to the ClassNK technical seminar at spring 2010・・
http://www.classnk.or.jp/hp/pdf/reseach/seminar/2010_05.pdf
for the 0.1% sulfur fuel used in ECA, the following attentions were announced.

(1) Mismatching between low-sulfur fuel and high-BN cylinder lubricating oil

(2) Ignition and combustion quality

(3) Too low viscosity and lubricity

As results

(1) Some new low-BN cylinder lubricating oils for low-sulfur fuels have been developed by the lubricating oil companies side.

(2) At this moment, ECA fuels have rather good ignition and combustion quality. (However, for the 0.5% sulfur fuel after 2020, ignition and combustion quality would become a important theme. It is a today's topic.)

(3) It has become a problem in the case that MGO is unintentionally heated when it is switched from heated HFO to enter ECA.
(The possible problem after 2020 is not like this, but that distillate fuel is always used for the HFO designed engines.）

At this moment, good quality fuels are supplied for ECA as the quantity is not so large as the global case and the price can be set at much higher than HFO.

## ２. On possible high-aromatic low-sulfur fuels after 2020・・

According to the JPEC report No.17 (2015)：
http://www.pecj.or.jp/japanese/minireport/pdf/H27_2015/2015-017.pdf
the following four types of 0.5%S fuel would be supplied after the global cap.

(1) Marine Gas Oil (MGO/DMA)
(2) Marine Diesel Oil (MDO/DMB)
(3) IFO-380 (Intermediate Fuel Oil)
(4) Low sulfur residual fuel from low-sulfur crude

And referred that

As a base stock of (1) & (2), it is possible that high aromatic LCO* (Light Cycle Oil) would be used.

For case (3), it is possible that higher aromatic HCO*（CLO*）is blended.

It is referred on case (4) that the production of low-sulfur crude is too small.

- On the other hand, acc. to the list in next page, 'Hybrid ultra low sulfur fuel oil (ULSFO)' supplied for only ECA now is high paraffinic (CCAI = around 800). To supply such low-aromatic fuels for the global area is absolutely impossible.

＊LCO・HCO（CLO）・・Low-sulfur but high-aromatic rests from the FCC process referred afterwards in detail.

## 表 4 舶用として公表されている主な燃料（硫黄分 0.1%）の性状

（出所：各石油会社の HP より）

‘Hybrid ultra low sulfur fuel oil (ULSFO)’ supplied for only ECA : JPEC Report No.17（2015）

| 項目 | 単位 | 限界 | Premium HDME50 | Fuel Oil | ULSFO | ULSFO | Eco Marine | 参考 |
|---|---|---|---|---|---|---|---|---|
| 販売会社 | | | ExxonMobil | Chemoil | Shell | SK Energy | Lukoil | |
| ISO8217 相当 | | | RMD80 | | RMD80 | RME180 | | RMG380 |
| 動粘度 (50℃) | mm$^2$/sec | 上限 | 45 | 26.3 | 60 | 20～40 | 65 | 380.0 |
| | | 下限 | 30 | | 10 | | | |
| 密度 (15℃) | kg/m$^3$ | 上限 | 900～915 | 896 | 790～910 | 928 | 910 | 991 |
| CCAI | - | 上限 | 795～810 | 795 | 800 | 790～800 | 860 | 870 |
| 硫黄分 | mass% | 上限 | 0.10 | <0.1 | <0.1 | <0.1 | 0.095 | |
| 引火点 | ℃ | 下限 | 70 | 60 | 60 | 100 | 60 | 60 |
| 硫化水素 | mg/kg | 上限 | 1 | | <2 | | 2.00 | 2.00 |
| 酸価 | mgKOH/g | 上限 | 0.1 | 2.35 | <0.5 | | 2.5 | 2.5 |
| 全沈殿物 | mass% | 上限 | 0.01 | 0.01 | 0.01～0.05 | 0.02 | 0.1 | 0.10 |
| 残留炭素分 | mass% | 上限 | 0.3 | 3.8 | 2.0 | 2.7 | 14.0 | 18.0 |
| 流動点（冬用） | ℃ | 上限 | 6～12 | -6 | 18 | 20～25 | 20 | 30 |
| 流動点（冬用） | ℃ | 上限 | | | | | | |
| ｱﾙﾐﾅ＋ｼﾘｺﾝ | mg/kg | 上限 | 5 | <10 | 12～20 | | 17 | 60 |

Above ULSFOs for ECA are surprisingly low aromatic (CCAI = only around 800 except for EcoMarine).

However,

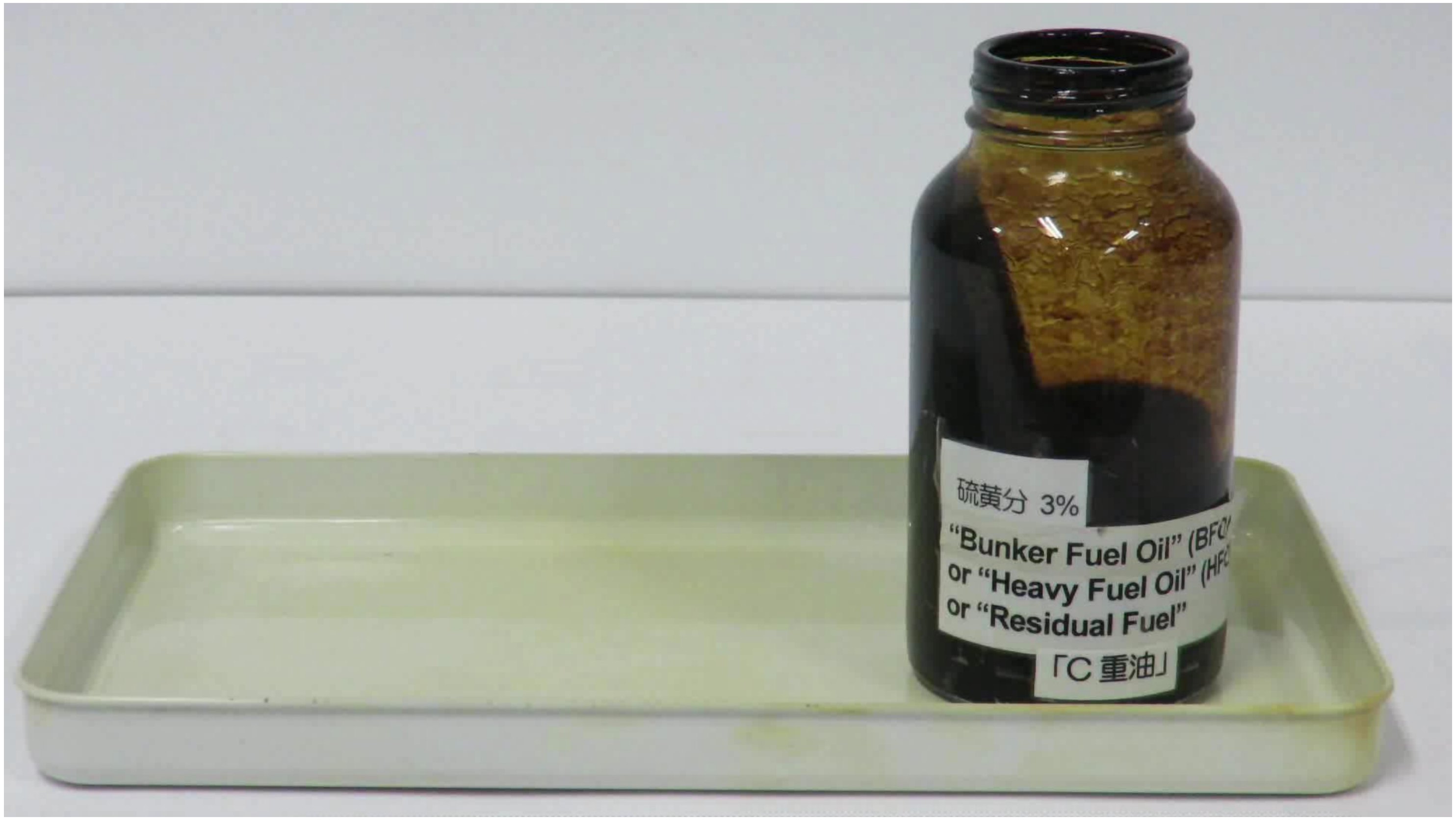
to supply such low-aromatic fuels for the global area after 2020 is absolutely impossible.

Preliminary information: Conventional high-sulfur (<3.5%) HFO

That has many different names like

HFO 'C' in Japan, Residual Fuel Oil (ISO 'RM' class), Heavy Fuel Oil (HFO), Bunker Fuel Oil (BFO) and Marine Fuel Oil (MFO)

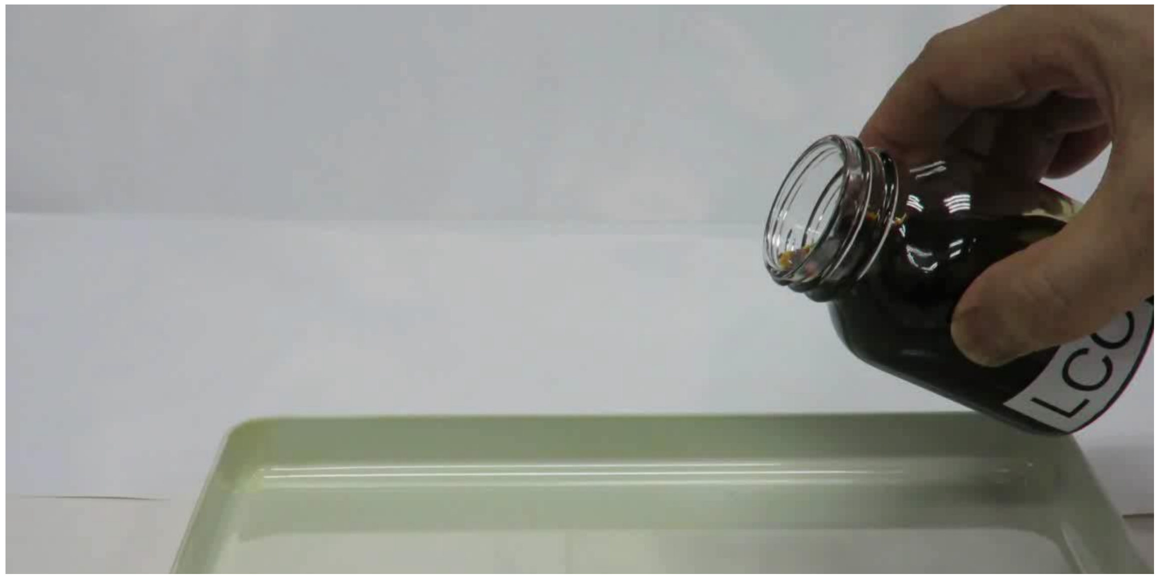
It's base-stock is the residue from oil refinery (almost solid) and some low-viscosity portion like LCO is blended as 'cutter-stocks' to reduce the viscosity.

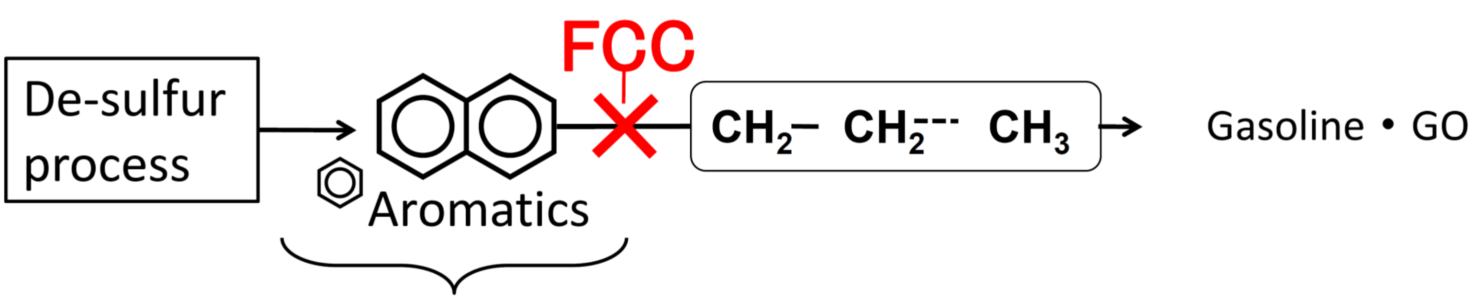


*What kind of marine fuel would appear after the Global Cap?*

*Low-sulfur but* ***high-aromatic LCO***

*(**L**ight **C**ycle **O**il, sometimes named as 'Cracked Gas Oil')*






***Light Cycle Oil（LCO）***

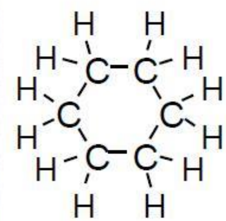
*(Low viscosity does not always mean good quality.)*

**PM** *(Soot) from MGO*

*(Marine Propulsion, April/May 2010)*

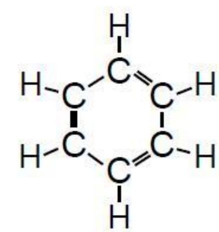
**Alicyclic hydrocarbons**

**Cyclohexane**
**($C_6H_{12}$)**

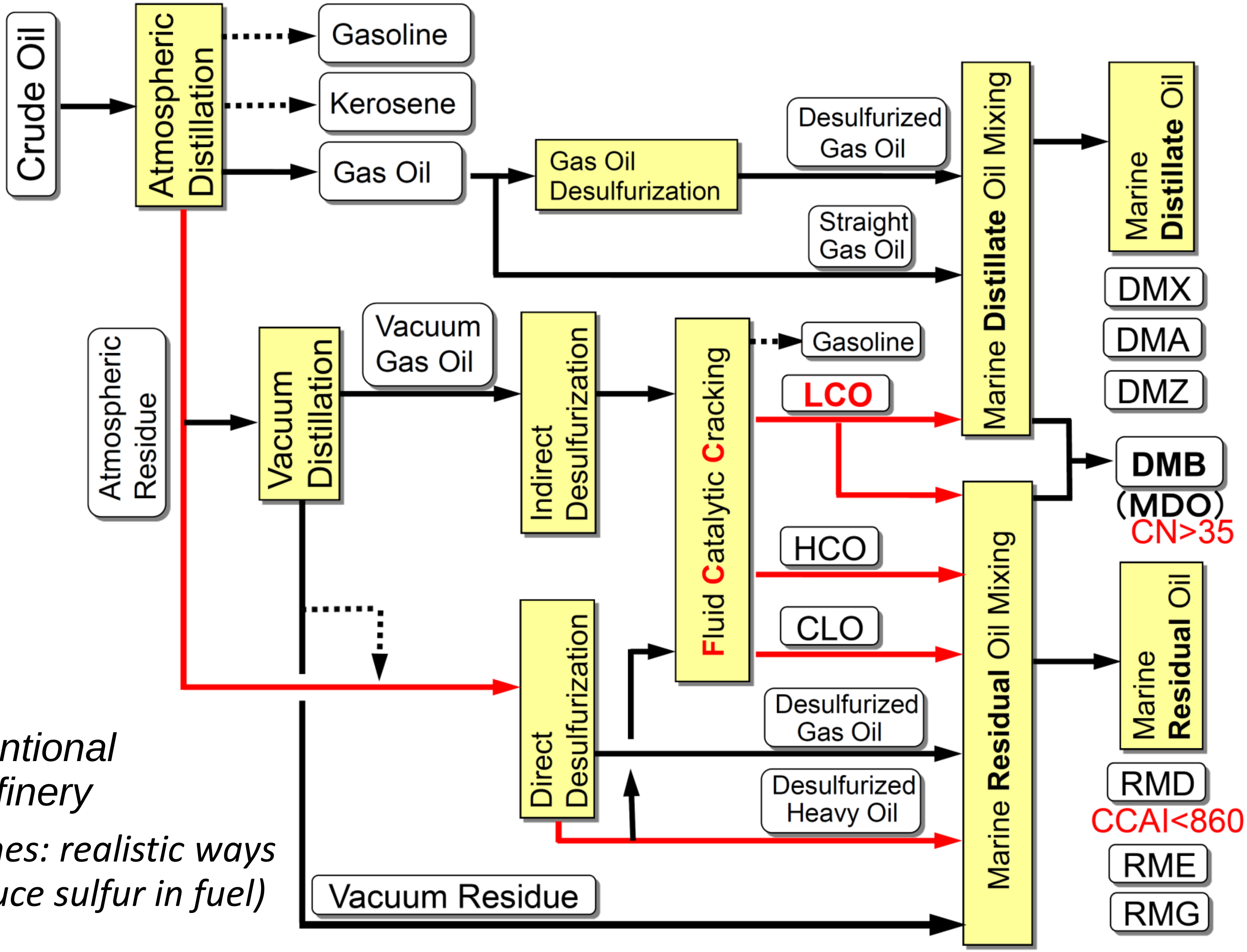


**Aromatic hydrocarbons**

**Benzene**
**($C_6H_6$)**



*Aromatic rings make the ignition and combustion poorer.*




*Conventional Oil Refinery*

*(Red lines: realistic ways to reduce sulfur in fuel)*

*Light Cycle Oil, a rest of FCC process, is now mixed to both the Distillate and Residual fuels. If less Residual fuel is produced after 2020, LCO as a cutter stocks for it would be diverted to the Distillate fuel. If the low sulfur Residual fuel will be produced, a great deal of low sulfur potion like LCO and HCO/CLO, all the rest of FCC process would be mixed. Then, the fuel becomes higher aromatic.*

Reference: Standard for the marine *distillate* fuel（ISO8217:2012）

| 項　目 | 単位 | 限界 | DMX | DMA | DMZ | DMB | 試験方法 |
|---|---|---|---|---|---|---|---|
| 動粘度(40℃) | $mm^2/sec$ | 上限 | 5.50 | 6.00 | 6.00 | 11.00 | ISO 3104 |
| | | 下限 | 1.40 | 1.50 | 3.00 | 2.00 | |
| 密度(15℃) | $kg/m^3$ | 上限 | － | 890.0 | 890.0 | 900.0 | ISO 3675<br>ISO 12185 |
| セタン指数 *Cetane Index* | | 下限 | 45 | 40 | 40 | 35 | ISO 4264 |
| 硫黄分 | mass % | 上限 | 1.00 | 1.50 | 1.50 | 2.00 | ISO 8754<br>ISO 14596 |
| 引火点 | ℃ | 下限 | 43.0 | 60.0 | 60.0 | 60.0 | ISO 2719 |
| 硫化水素 | mg/kg | 上限 | 2.00 | 2.00 | 2.00 | 2.00 | IP 570 |
| 酸価 | mgKOH/g | 上限 | 0.5 | 0.5 | 0.5 | 0.5 | ASTM D664 |
| 熱ろ過沈殿物 | mass% | 上限 | － | － | － | 0.10 | ISO 10307-1 |
| 酸化安定性 | $g/m^3$ | 上限 | 25 | 25 | 25 | 25 | ISO 12205 |
| 残留炭素分 | mass % | 上限 | － | － | － | 0.30 | ISO 10370 |
| 残炭(10%残) | mass % | 上限 | 0.30 | 0.30 | 0.30 | － | ISO 10370 |
| 曇り点 | ℃ | 上限 | －16 | － | － | － | ISO 3015 |
| 流動点（冬用） | ℃ | 上限 | － | －6 | －6 | 0 | ISO 3016 |
| 流動点（夏用） | ℃ | 上限 | － | 0 | 0 | 6 | ISO 3016 |
| 水分 | vol% | 上限 | － | － | － | 0.30 | ISO 3733 |
| 灰分 | mass% | 上限 | 0.010 | 0.010 | 0.010 | 0.010 | ISO 6245 |
| 潤滑性(60℃) | μm | 上限 | 520 | 520 | 520 | 520 | ISO 12156-1 |

Reference: Standard for the marine *residual* fuel（ISO8217:2012）

ご参考：船用残渣油の主要６グレードの規格（ISO8217:2012）

Conventional high-S HFO

| 項　目 | 単位 | 限界 | RMA 10 | RMB 30 | RMD 80 | RME 180 | RMG 380 | RMK 500 | 試験方法 |
|---|---|---|---|---|---|---|---|---|---|
| 動粘度（50℃） | $mm^2/sec$ | 上限 | 10.0 | 30.0 | 80.0 | 180.0 | 380.0 | 500.0 | ISO 3104 |
| 密度（15℃） | $kg/m^3$ | 上限 | 920 | 960 | 975 | 991 | 991 | 1,010 | ISO 3675<br>ISO 12185 |
| CCAI | ― | 上限 | 850 | 860 | 860 | 860 | 870 | 870 | 計算値 |
| 硫黄分 | mass% | 上限 | 法的要求値 | | | | | | ISO 8754他 |
| 引火点 | ℃ | 下限 | 60.0 | 60.0 | 60.0 | 60.0 | 60.0 | 60.0 | ISO 2719 |
| 硫化水素 | mg/kg | 上限 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | IP 570 |
| 酸価 | mgKOH/g | 上限 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | ASTM D664 |
| 全沈殿物 | mass % | 上限 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | ISO 10307-2 |
| 残留炭素分 | mass % | 上限 | 2.50 | 10.0 | 14.0 | 15.0 | 18.0 | 20.0 | ISO 10370 |
| 流動点（冬用） | ℃ | 上限 | 0 | 0 | 30 | 30 | 30 | 30 | ISO 3016 |
| 流動点（夏用） | ℃ | 上限 | 6 | 6 | 30 | 30 | 30 | 30 | ISO 3016 |
| 水分 | vol% | 上限 | 0.30 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | ISO 3733 |
| 灰分 | mass% | 上限 | 0.04 | 0.07 | 0.07 | 0.07 | 0.10 | 0.15 | ISO 6245 |
| バナジウム | mg/kg | 上限 | 50 | 150 | 150 | 150 | 350 | 450 | IP501,IP470 |
| ナトリウム | mg/kg | 上限 | 50 | 100 | 100 | 50 | 100 | 100 | IP501,IP470 |
| ｱﾙﾐﾅ ＋ ｼﾘｺﾝ | mg/kg | 上限 | 25 | 40 | 40 | 50 | 60 | 60 | IP501,IP470 |

分析時の注意事項等の詳細は、ISO 8217：2012を参照のこと。

*2020・・SOx + EEDI Regulation ・・*

*EEDI from 2020, -20％for newly built ships ・・*

*(further -30% from 2022 is proposed by USA）*

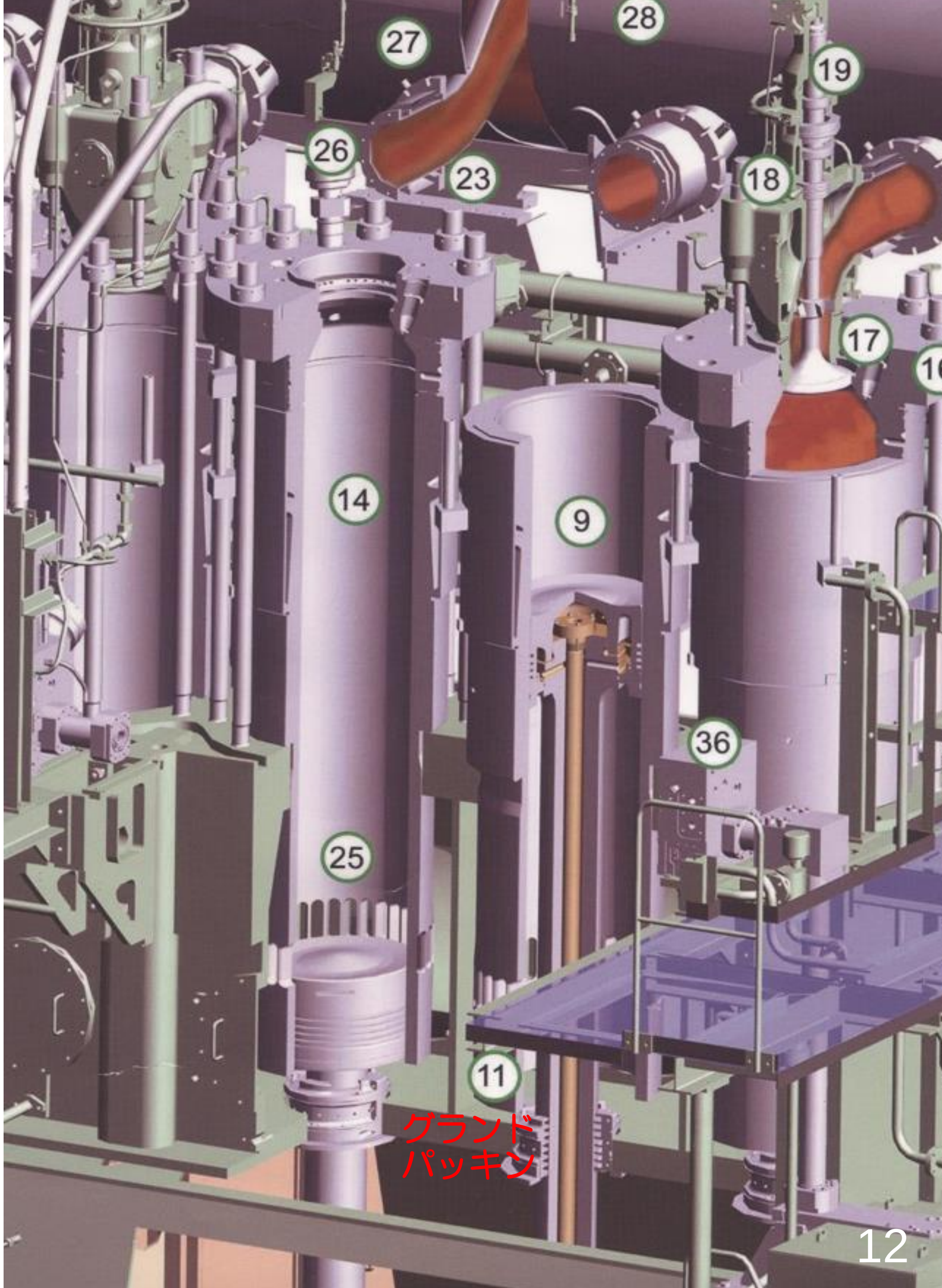
***EEDI*** ・・ *$CO_2$ g／ton ·mile*

$$\frac{\text{Engine power (kW) x SFC (g/kWh) x CO2 coefficient}}{\text{DWT (ton) x Ship speed (mile/h)}}$$

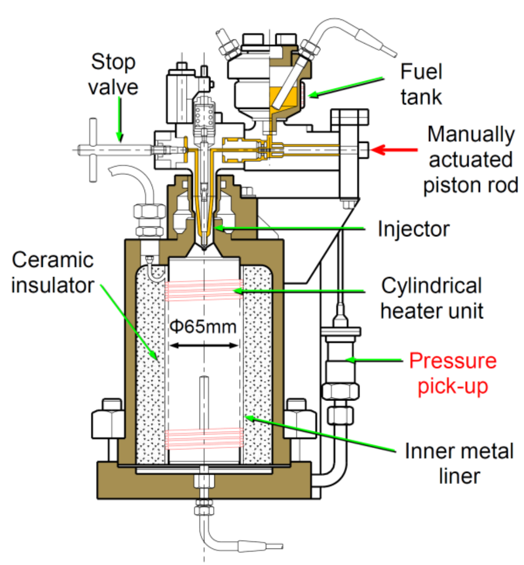
- *SFC (Specific Fuel Consumption) has only small room to be reduced.*
- *If a smaller engine than now is adopted to clear the EEDI, it must run always at high load.*

*・・Research work for the safe combustion is further important.*

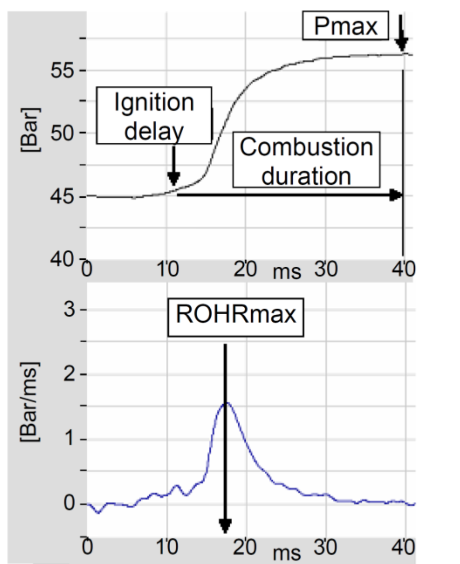
- *Lubricating conditions between piston ring and cylinder liner of two-stroke engine are severe.* *Deterioration of combustion leads to the lubricating problems.*



*To check the fuel ignition and combustion quality before use by some tools is a way to avoid the engine troubles.*

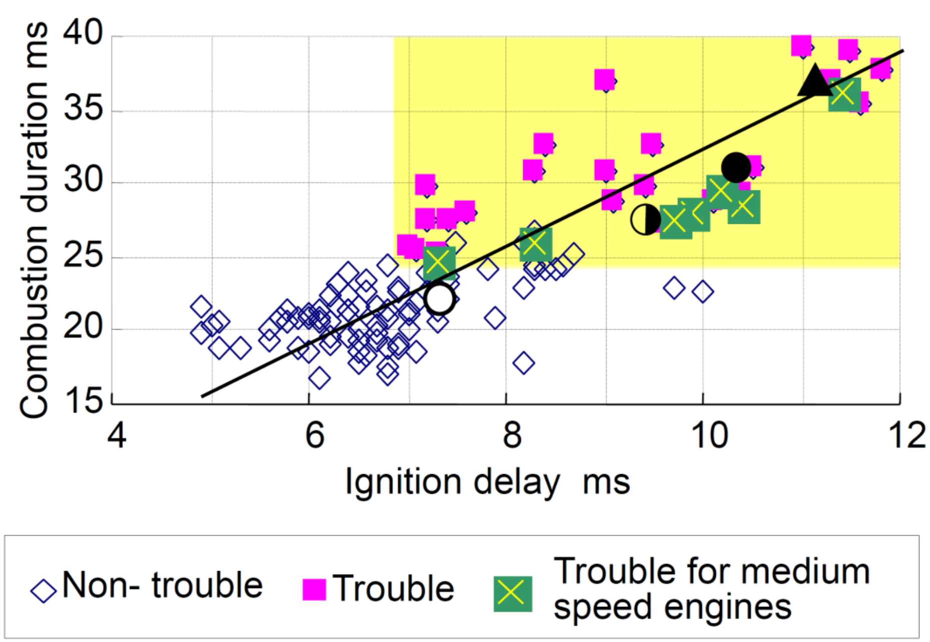


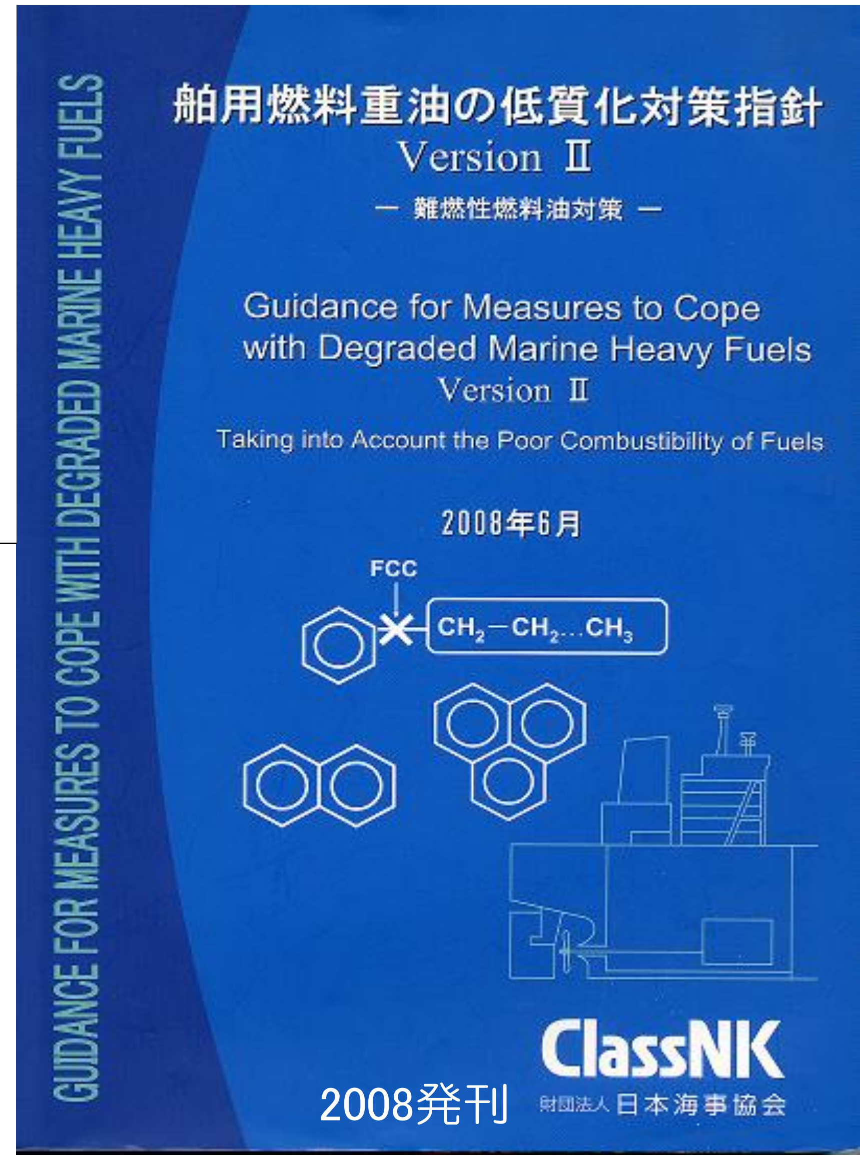

FIA (Fuel ignition analyzer)




Definitions of ignition and combustion factor

**FIA (Fuel Ignition Analyzer)**



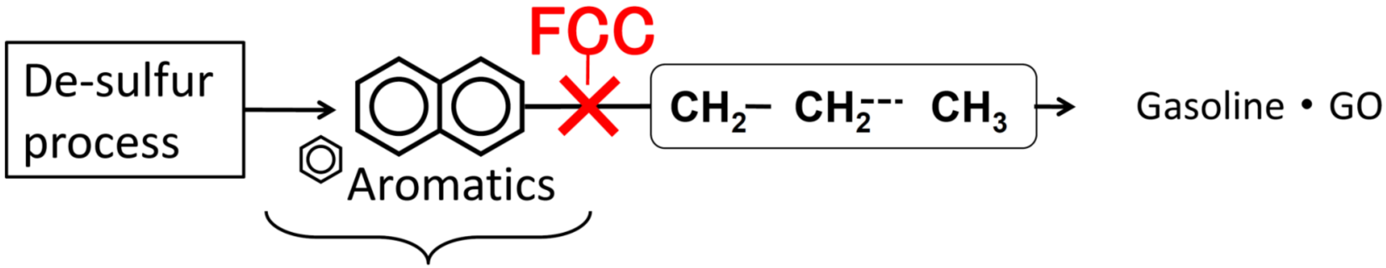
CIMAC 2016 No.91: Visual study on combustion for development of alternative liquid and gas fuels（by K. Takasaki）

(Combustion quality of the following low-sulfur fuels have been examined.)

*Methanol* Gas Oil <u>*Light Cycle Oil*</u> *CLO*

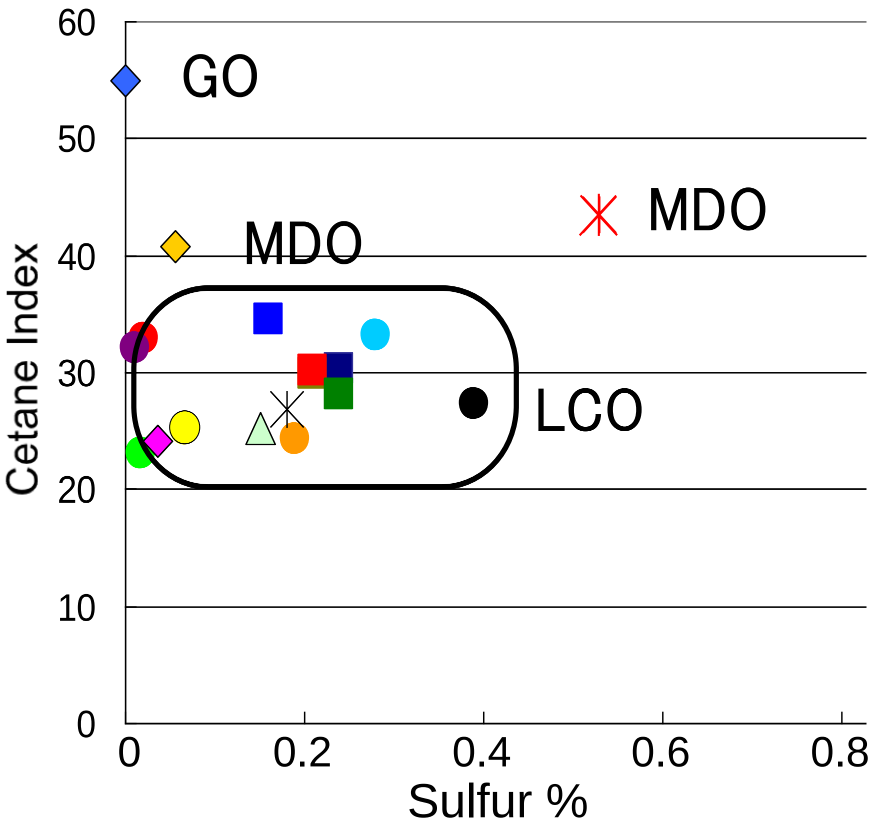
*(Zero sulfur)*
*(Zero aroma)*

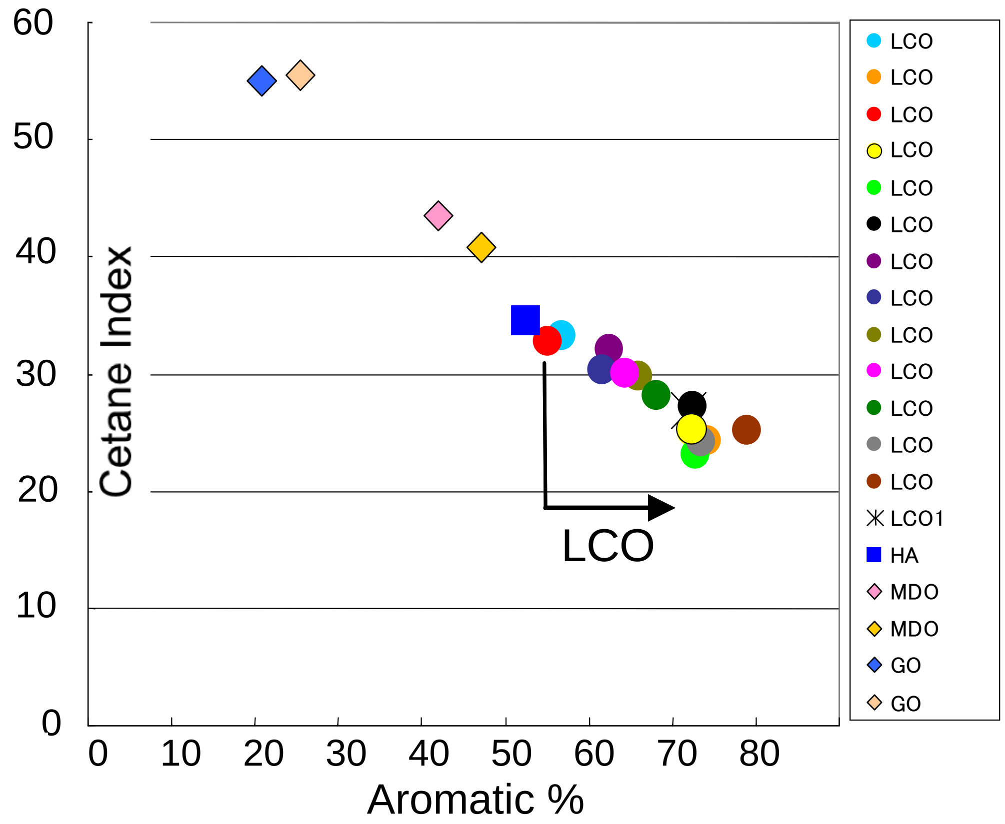
***(Low sulfur)***
***(High aroma)***

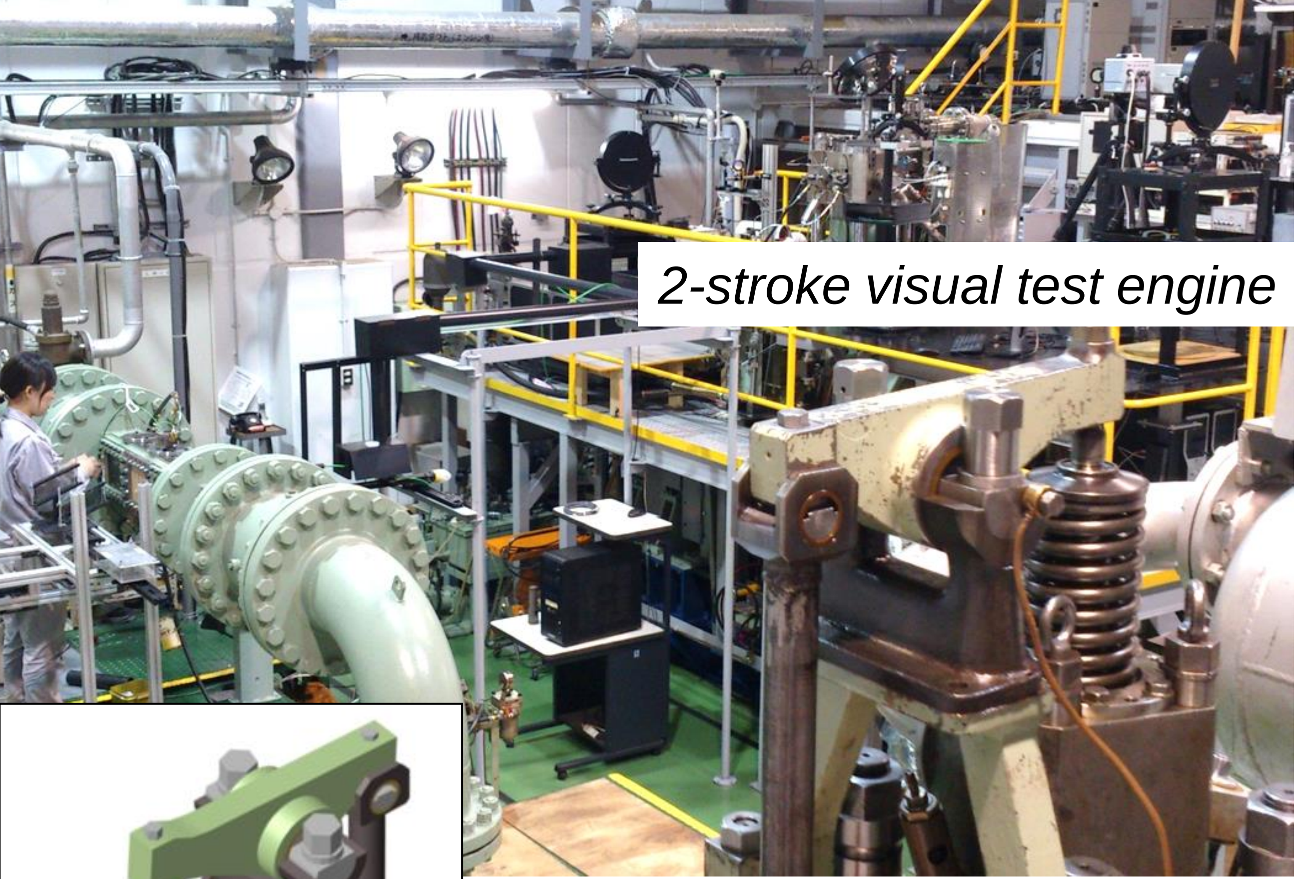



**LCO**(=**L**ight **C**ycle **O**il)

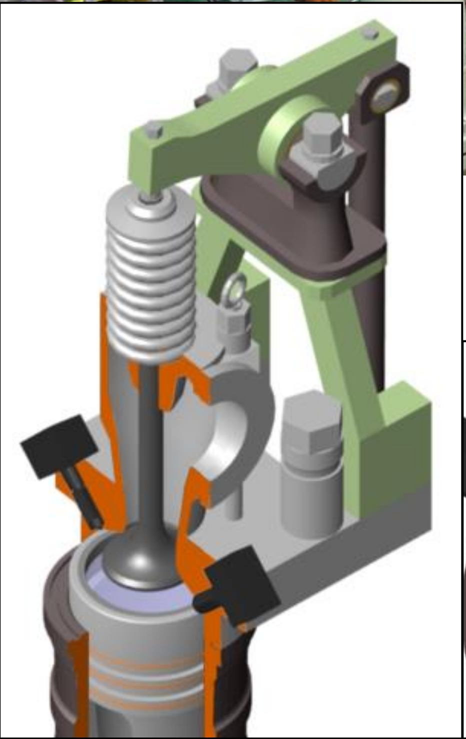
## *Sulfur %, Aromatic % and Ignition Quality (Cetane Index) of Japanese LCO Samples*

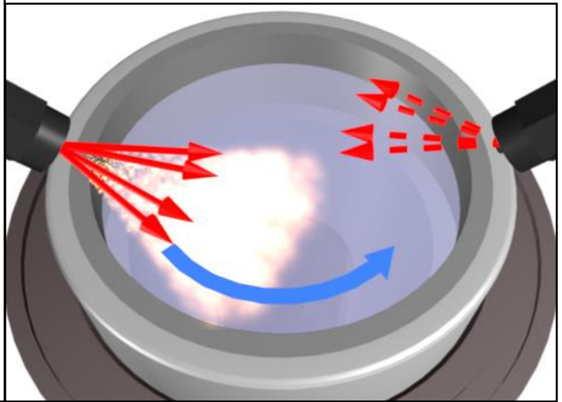




*2-stroke visual test engine*





*Bore/Stroke : 190 mm/350 mm*

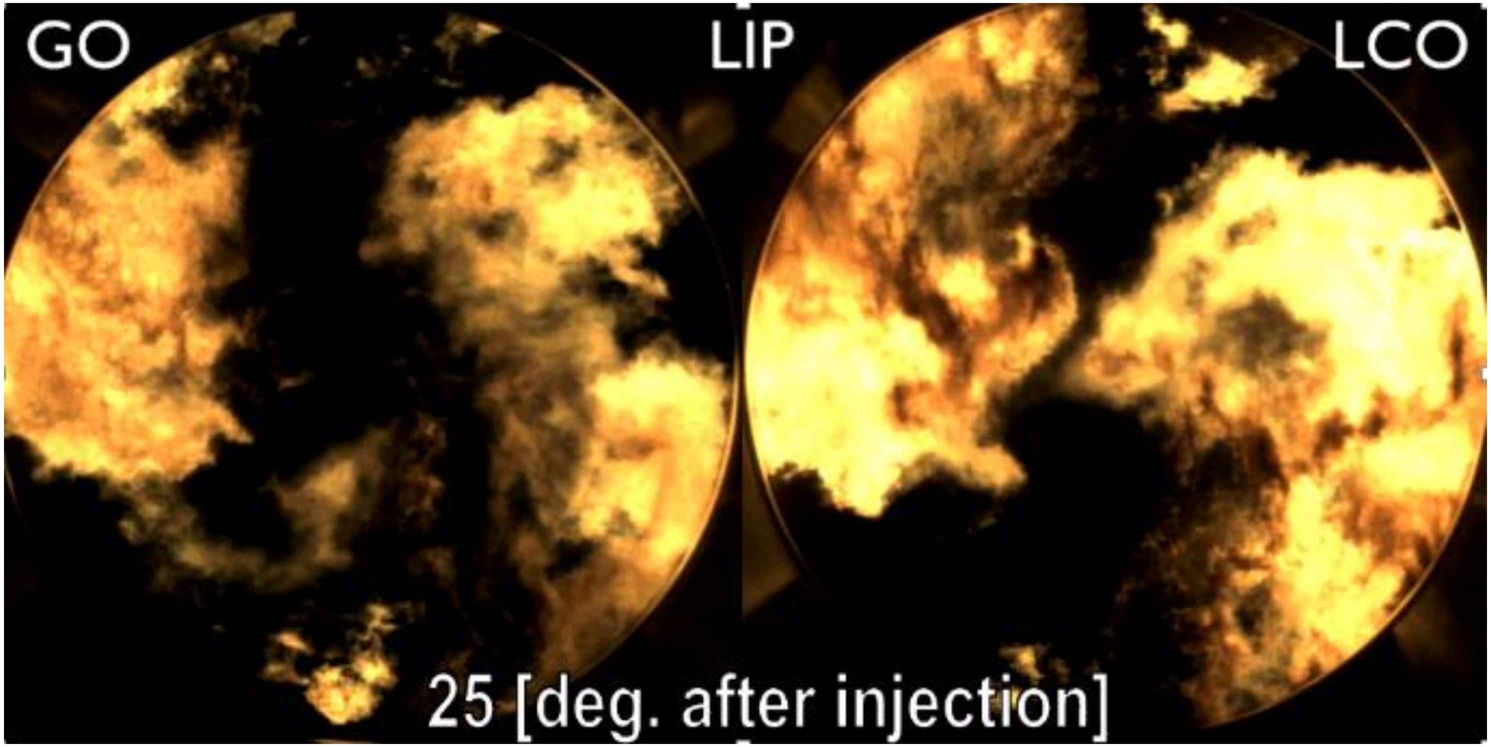
*2 -stroke, Super-charged*

*Engine speed：500 rpm*

# *Comparison of combustion image between normal Gas Oil and* ***LCO***
## *(Ignition delay, soot formation and after-burning)*

*Fuel injection conditions are just the same for both fuels*

*(・Inj. holes：0.23 mm x 4 holes x 2 sets・Inj. duration：−3 ～12°ATDC・Inj. Press.：**70** MPa)*



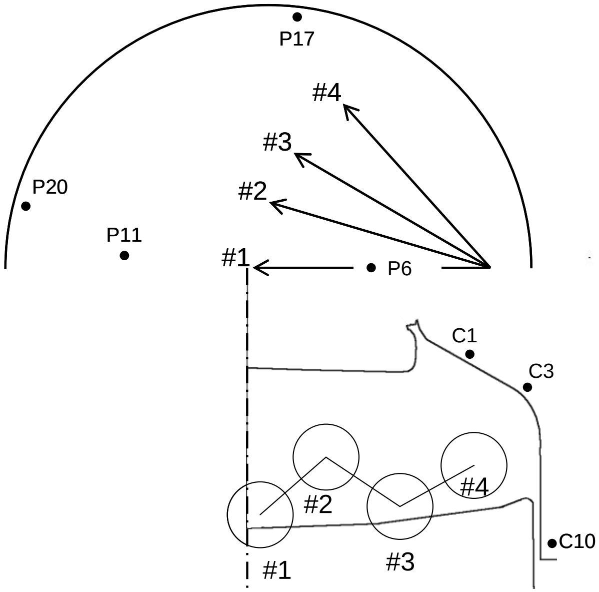

Normal GO **LCO**

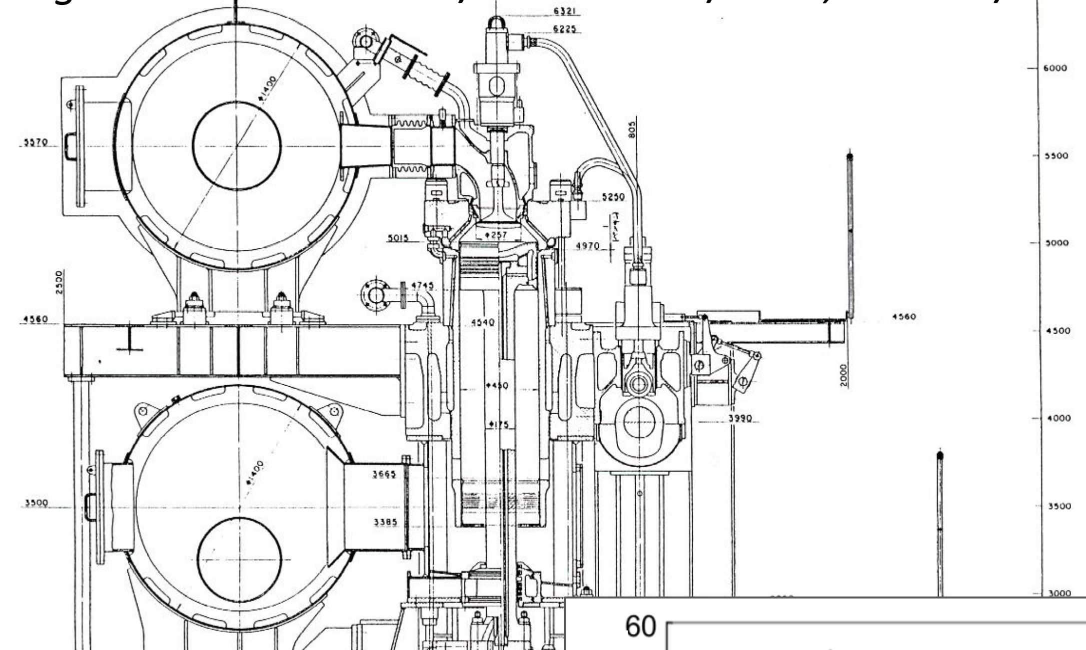
*Attention：Phenomena look emphasized than in the real low-speed 2-stroke diesel, as this visual test engine is smaller and runs at a higher speed.*

# *Running test by a low-speed 2-stroke test engine burning LCO*

*(CIMAC 2010 Bergen, Paper No.31)*

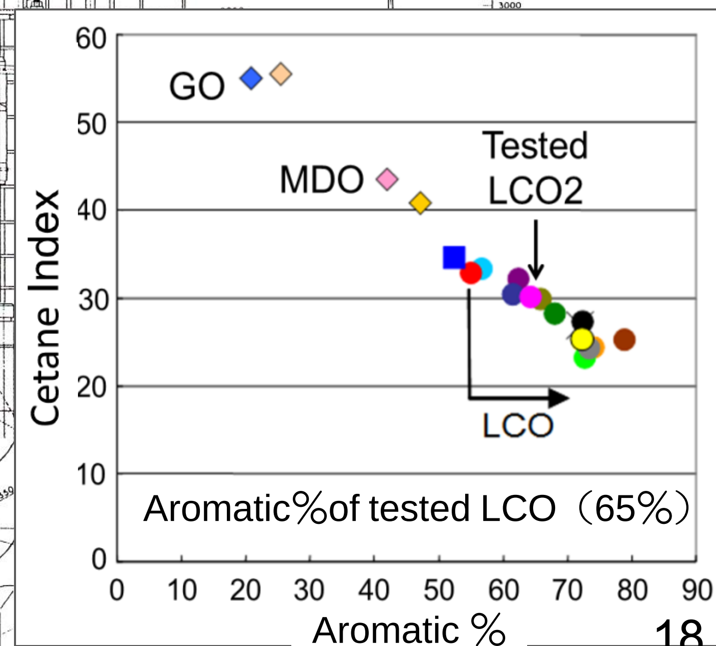
*Single cylinder test engine at Hitachi : Bore/Stroke : 400/1350, 985 kW/178 rpm*



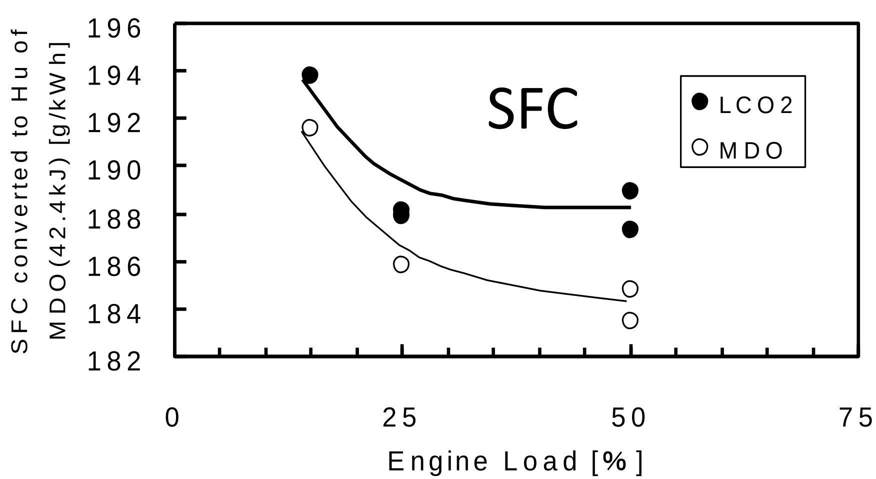



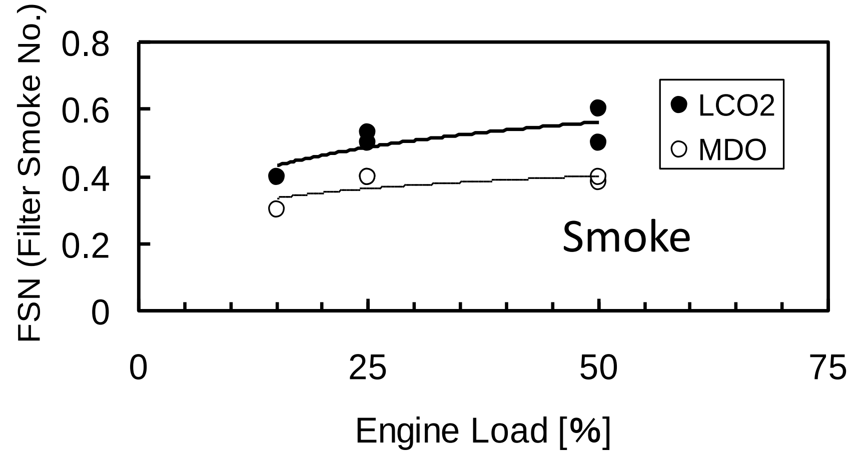
| Point | MDO | LCO |
|---|---|---|
| P6 | 351 | **365** **(+14)** |
| P11 | 334 | **351** **(+17)** |
| P17 | 230 | **249** **(+19)** |
| P20 | 171 | **184** **(+13)** |
| C1 | 219 | **230** **(+11)** |
| C3 | 209 | **220** **(+11)** |
| C10 | 225 | **239** **(+14)** |

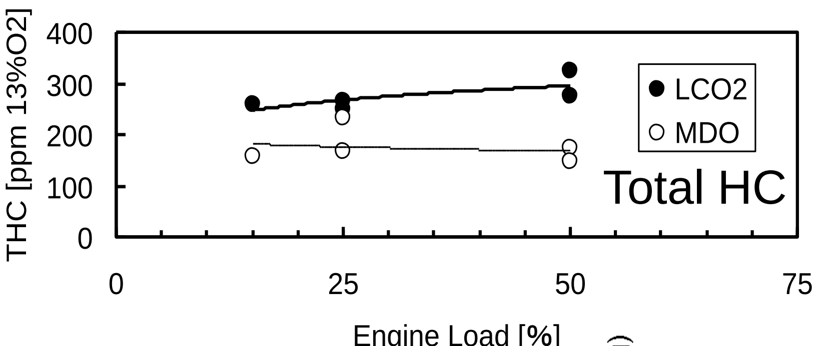
*Combustion chamber wall temperature at 50% Load*

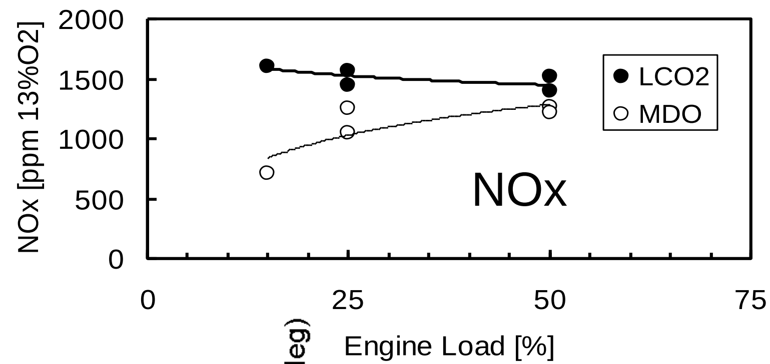


# *Running test results burning LCO compared to MDO at low load*



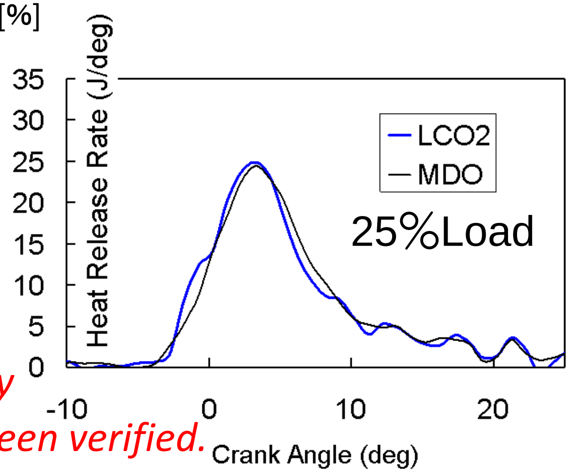



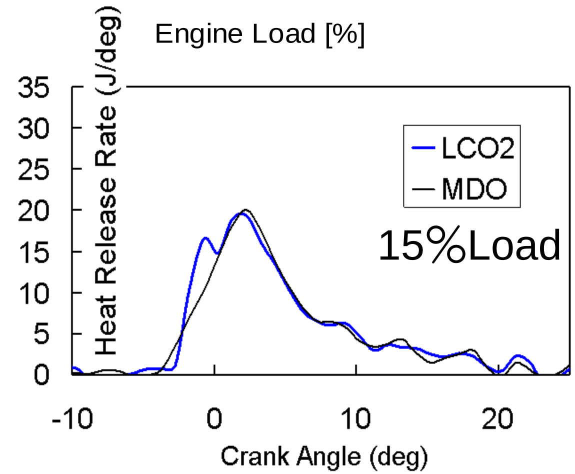




***LCO***

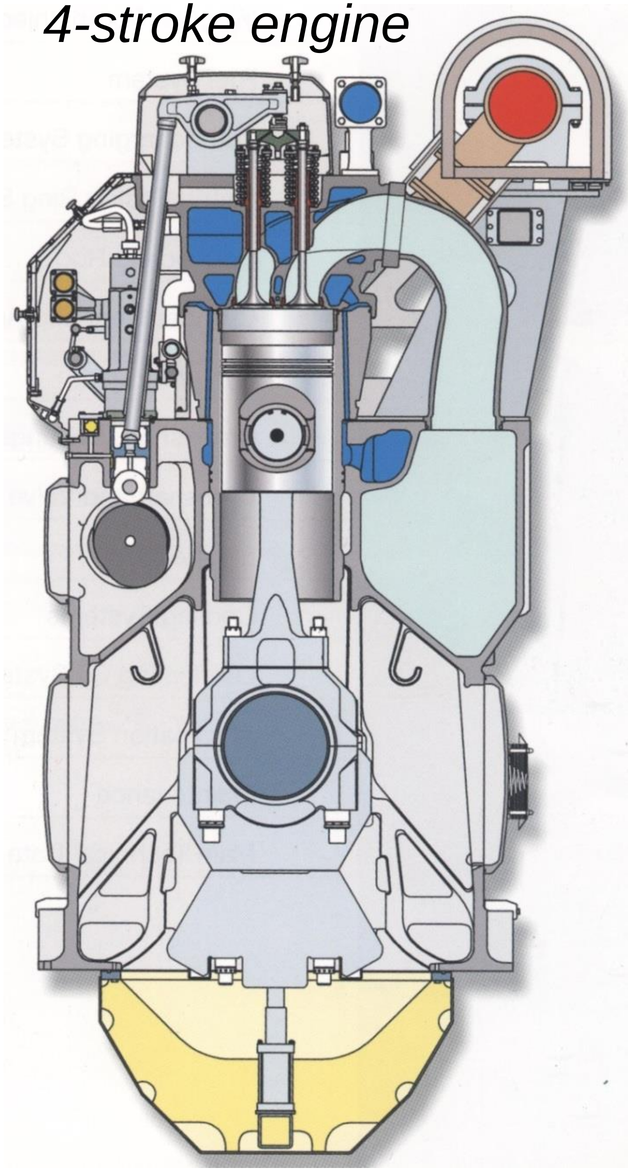
- *Influence by lower ignition quality is smaller for a low-speed engine.*
- *Increase in unburned portion and NOx is a problem to be solved.*

*·Negative effect for engine reliability after a long time running has not been verified.*

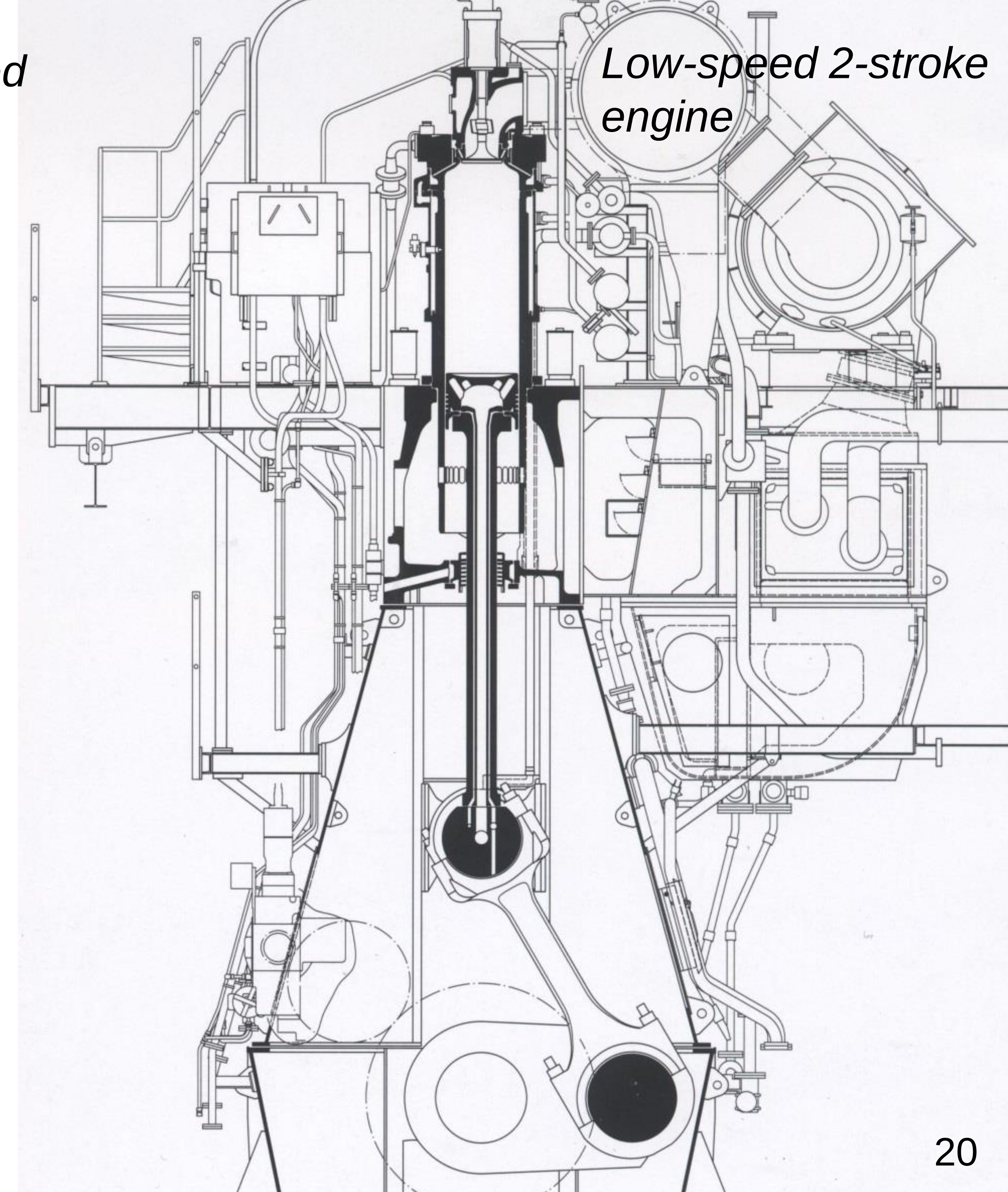


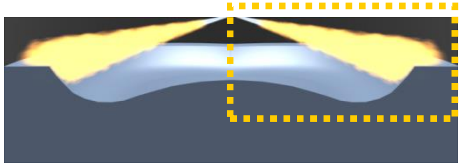



*Reference : Medium-speed 4-stroke engine*

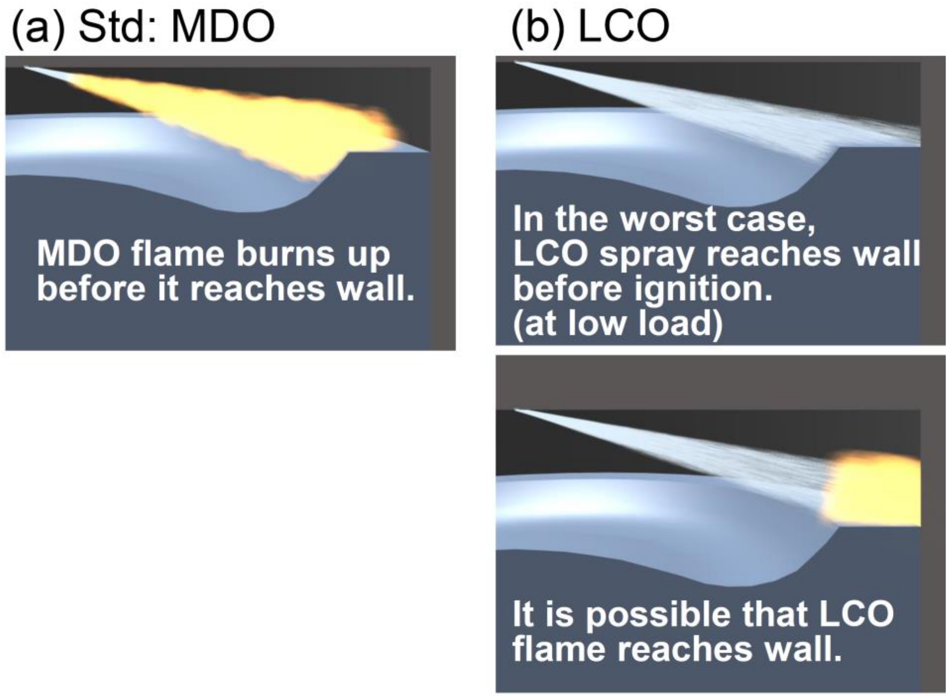


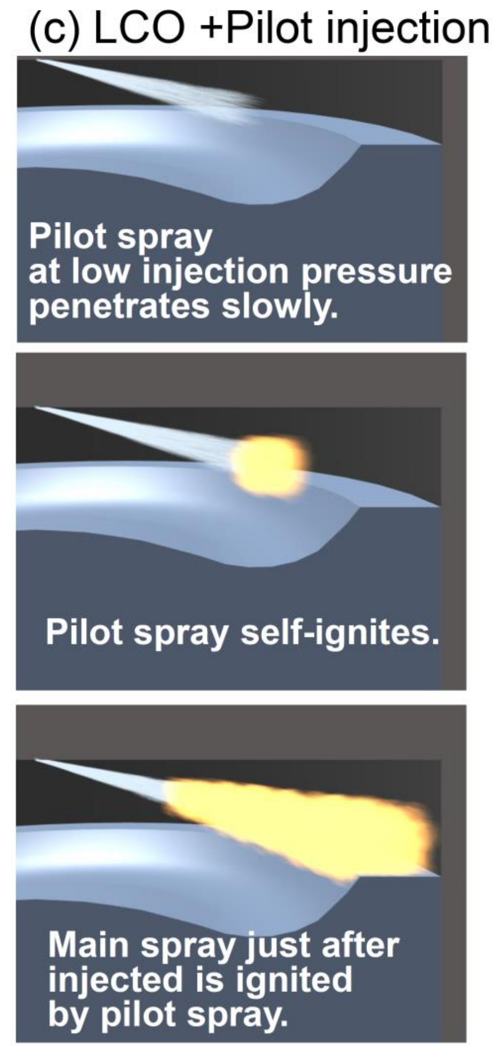
*Low-speed 2-stroke engine*





# *An possible problem by burning LCO for medium-speed 4-stroke engines*



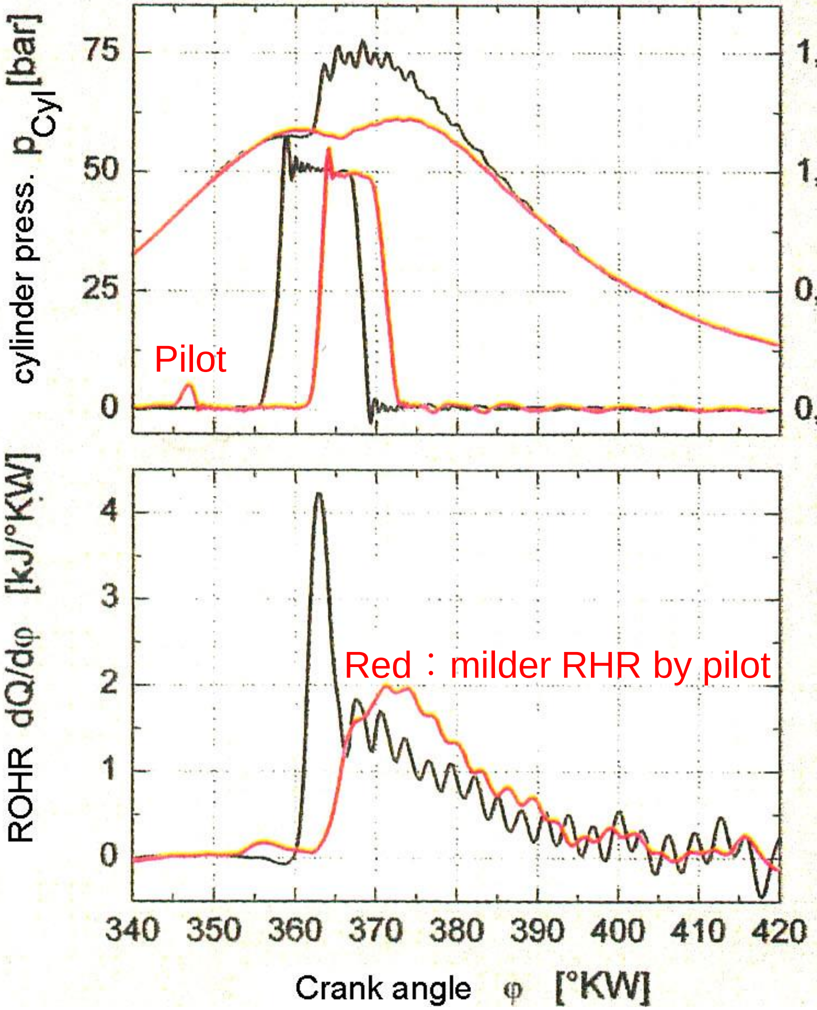

**+Diesel knock**
- **Rise of cylinder liner temp.**
- **Lub. oil dilution**

*As a measure to recover the prolonged ignition delay, a pilot injection could be applied (Figure right).*

*To improve the after-burning and reduce the soot formation, fuel injection pressure should be raised.*

*The both measures can be achieved, for example, by applying a Common Rail fuel injection system.*

# An example of pilot injection for HFO at low load running (red)




without pre-injection
IB = 4,5° BTDC,
NOx = 7,8 g/kWh, sfoc = 100,2%
FSN = 2,24, dp/dφ = 13,7 bar/°CA

with pre-injection
IB (pre) = 15° BTDC, IB (main) = 1°ATDC
pre ign. fuel mass = 2% of main ign.
NOx = 8,0 g/kWh, sfoc = 96,3 %
FSN = 0,82, dp/dφ = 1,6 bar/°CA

injection system:
MGV-pump + cam

Air and exhaust gas pressure:
like reference engine

sfoc reduction of 4%

(MTZ 2/2005) Prof. Dr.-Ing. H. Rulfs, Hamburg University of Technology

# 3. Alternative fuels like methanol and LPG

***Methanol*** Gas Oil LCO CLO

***(Zero sulfur)*** *(Low sulfur)*

***(Zero aroma)*** *(High aroma)*

*Photos ：Spray combustion of methanol （CH3OH）*

*Methanol and LPG have a low ignitability (must be ignited by a pilot diesel fuel) but have a good combustion quality. Unlike LCO, ignition quality does not represent the combustion quality.*

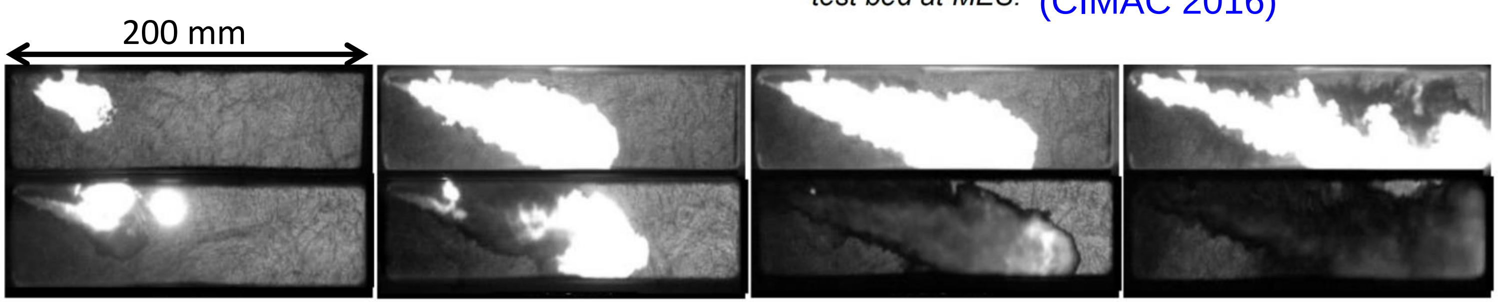
*Methanol is a low calorie fuel and more mass than GO must be injected from a larger injection hole to get the same combustion heat. This fact invites rather better combustion state.*

Methanol engine（Mitsui E & S)


*Figure 7 – Picture of the 7S50ME-B9.3-LGI engine on test bed at MES.* (CIMAC 2016)

**Gas Oil**
Inj. hole dia. 0.5 [mm]
Inj. press. 90 [MPa]

**Methanol**
Inj. hole dia. **0.8** [mm]
Inj. press. **57** [MPa]



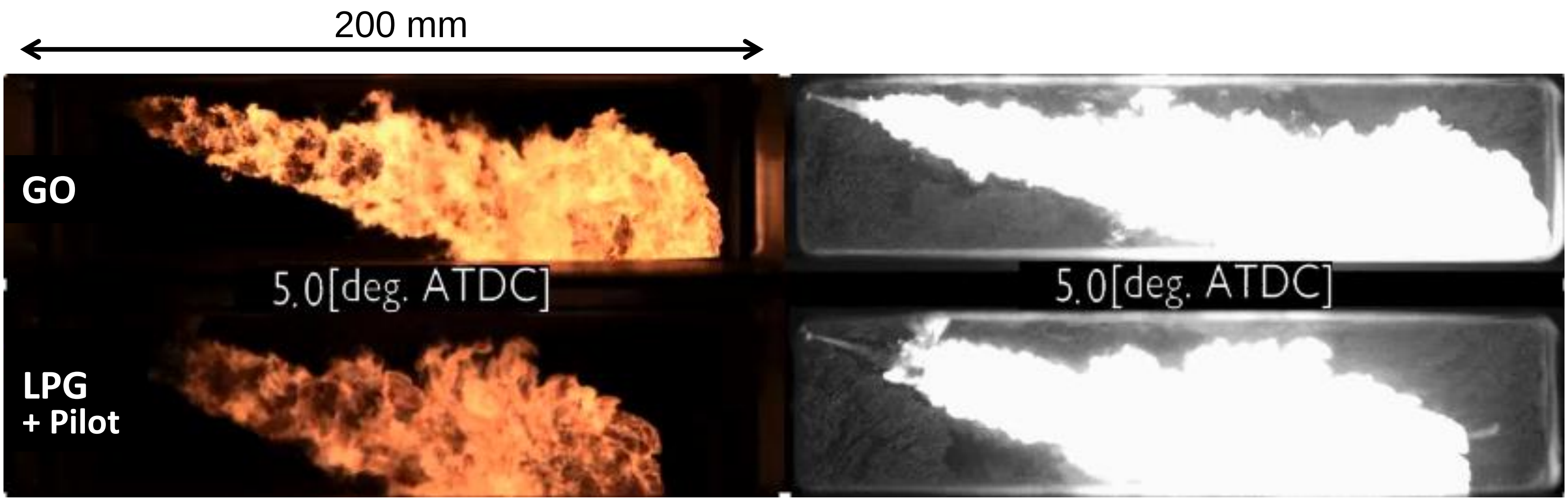

3.6 deg. 9 deg. 12 deg. 22 deg. (after inj. start)

# ***LPG** injection + pilot*

## *LPG (+ pilot) spray combustion compared to Gas Oil*

**GO (No.19)**
Inj. Hole Dia. 0.5 [mm]
Inj. Press. 110 [MPa]
Total Q 19.9 [kJ]

**LPG + Pilot (No.56)**
Inj. Hole Dia. 0.6 [mm]
Inj. Press. 100 [MPa]
Total Q 19.9 [kJ]




*Direct Photos* *Shadowgraph*

- *Different from the natural gas (methane) case, propane can be injected as liquid phase (LPG). In this experiment, LPG is pressurized to 3 MPa before injection pump to keep the liquid phase under the room temperature and injected using a normal diesel system at 100 MPa pressure. After injection, LPG evaporates faster than Gas Oil in a high temperature air and burns fast similarly to Gas Oil spray.*

*Possibility of the alternative fuels must be estimated by the following factors • •*

- *Combustion quality*
- *Practical cost*
- *Distributability in the market*

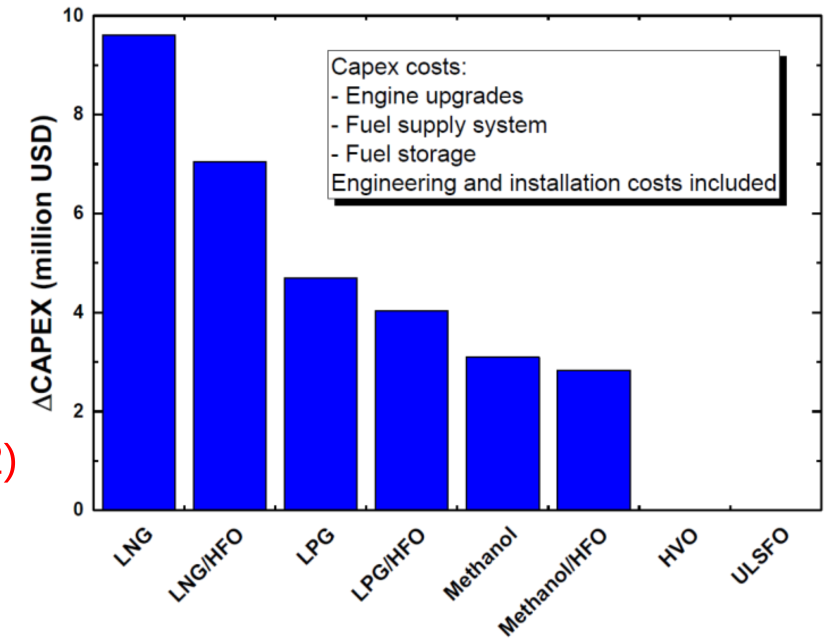



**Figure 4: Additional investment costs for the alternative fuel variants**

An example of feasibility study（CIMAC 2016, No.132)

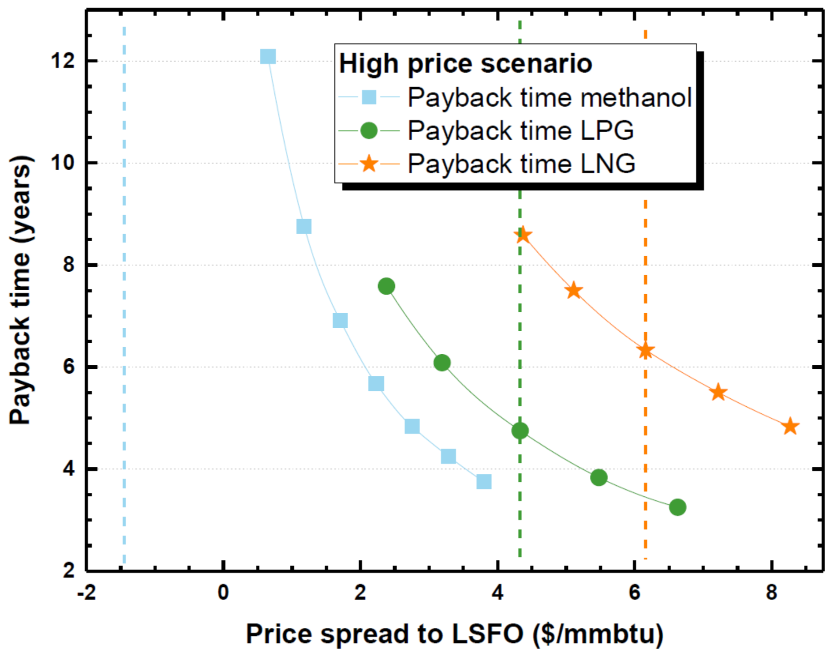
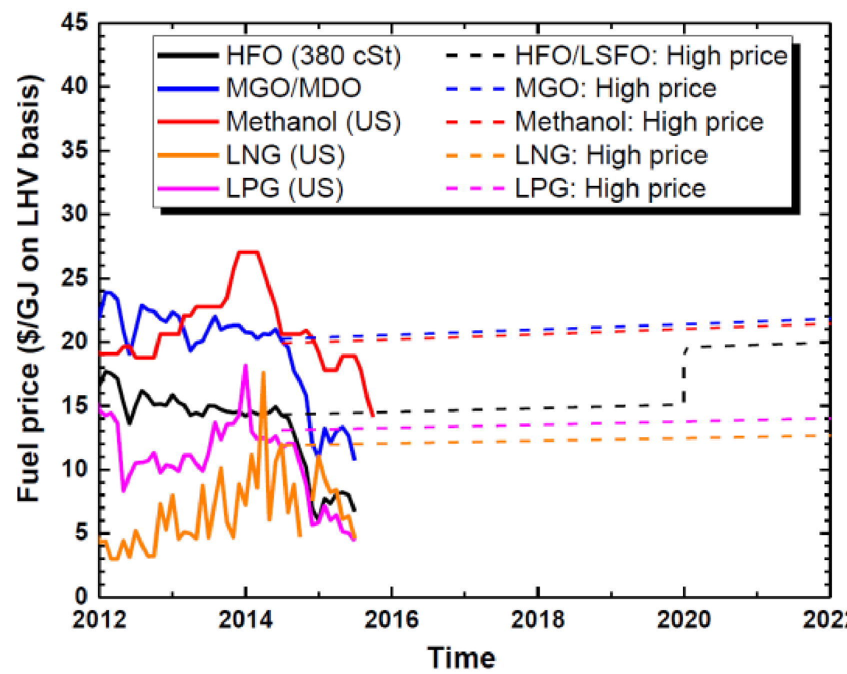
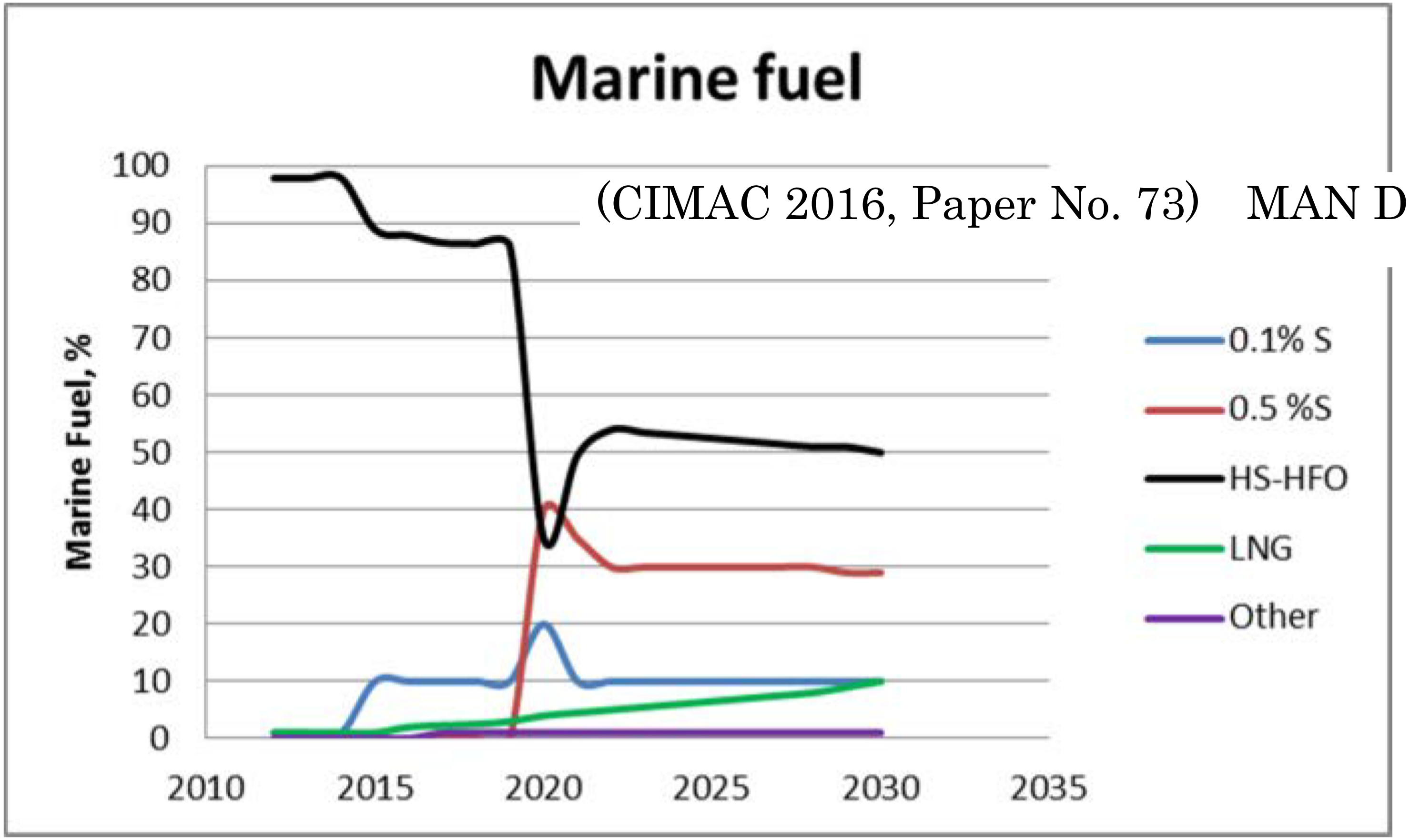



**Figure 12: Payback time as a function of price difference between LSFO (at 19.55 $/mmbtu) and the alternative fuel. Dashed lines represent the values used in the high price scenario for each fuel.**



# 4. Development of natural gas fuelled marine engines

Estimation that ***LNG would be 10％ of marine fuel at 2030*** • •




(CIMAC 2016, Paper No. 73)　MAN D&T

# *Natural gas fueled ships in service*

*About 70 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


Argonon/ Deen Shipping (110m x 16m, LR)
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）


Viking Grace/ Viking Line (218m x 32m, LR)
Seagas/ Sirius Shipping (50m x 11m, DNV)
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

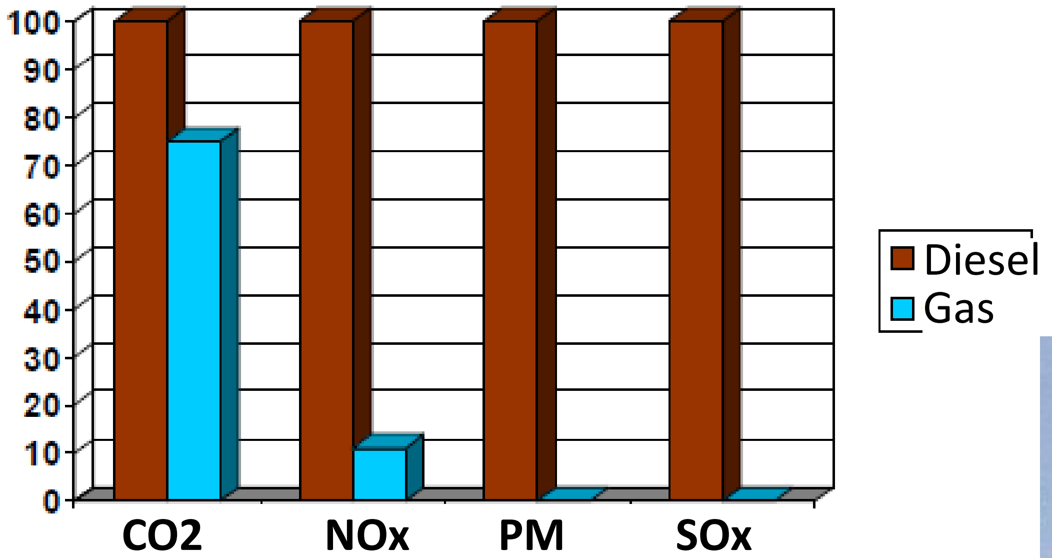

Barentshav/ Norwegian Coast Guard (93m x 17m, DNV)
沿岸警備船

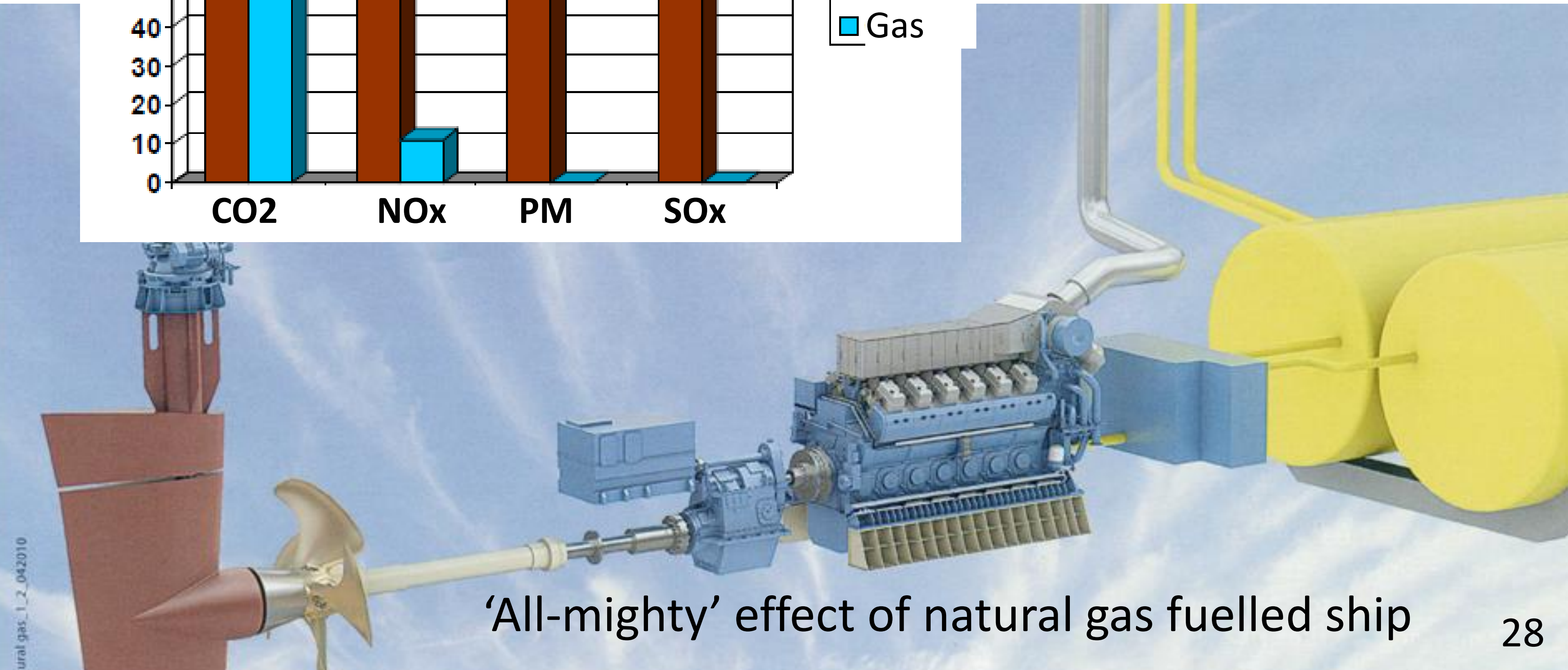

Francisco/ Buquebus (99m x 26m, DNV)
高速フェリー @豪州にて海上公試
（アルゼンチン⇔ウルグアイ航路）

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



‘All-mighty’ effect of natural gas fuelled ship

# *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)

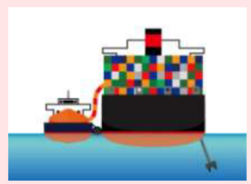
## 2) Safety requirements for navigation and port entry/departure of LNG fuelled ships that do not get fuel supply

- 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



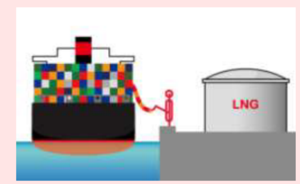
- Safety management system (e.g. collaboration with organizations (inc. private companies) for maritime disaster prevention etc.)
- Operating conditions (e.g. meteorological limitation, condition of oceanographic phenomenon etc.)
- Points to consider regarding operations to berthing/unberthing and mooring

Adoption

4) Measures for navigation safety regarding StS LNG fuel transfer

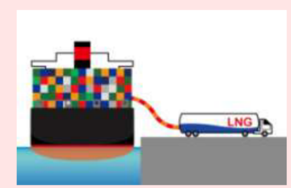
5) Measures for maritime disaster prevention on StS LNG fuel transfer

■ 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

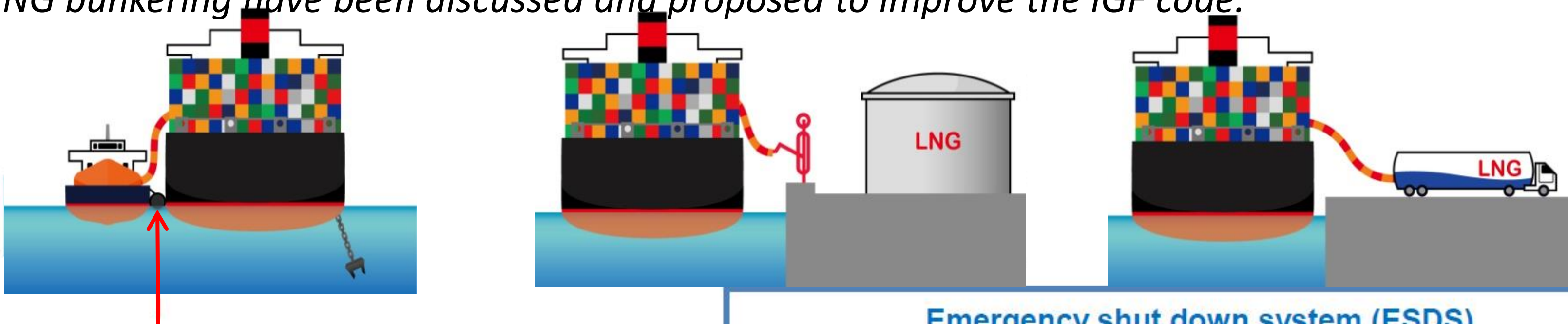
- Summarization of measures required for docking such as gas free operation etc.
- Handling of vacuum insulated Type C tanks

4


**LNG transfer arm**


**LNG transfer hose**


*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*

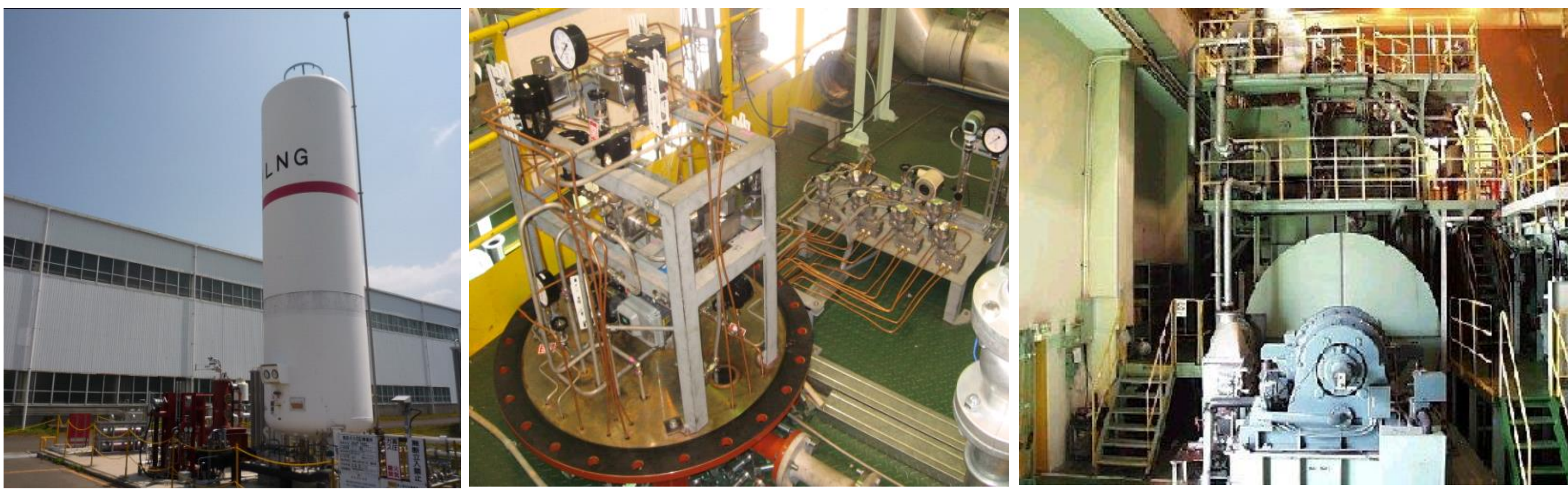
# *Safety requirements for high-pressure gas supply system*

*[ 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)*

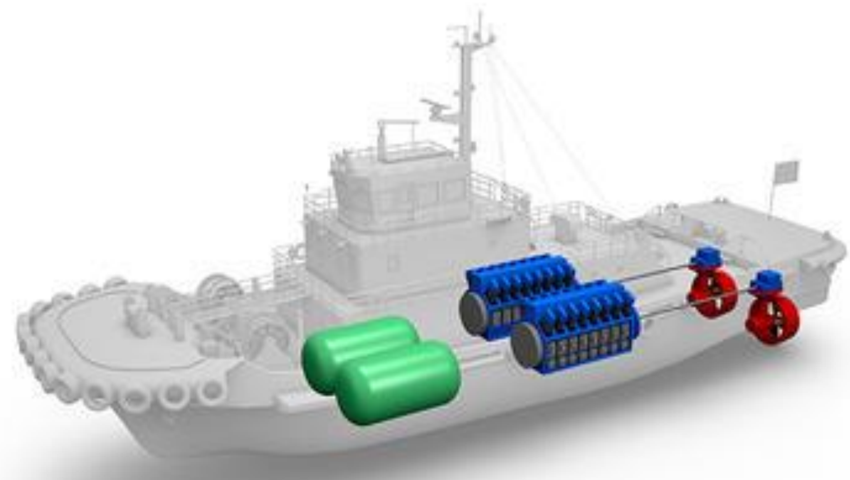
*This system is named FGSS（Fuel Gas Supply System）・・LNG is pumped to 300 bar and evaporated under 300 bar to be injected into GI engine. Pumping work is much smaller than high-press. compressor.*




Simulated plant used for the demonstration experiment

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

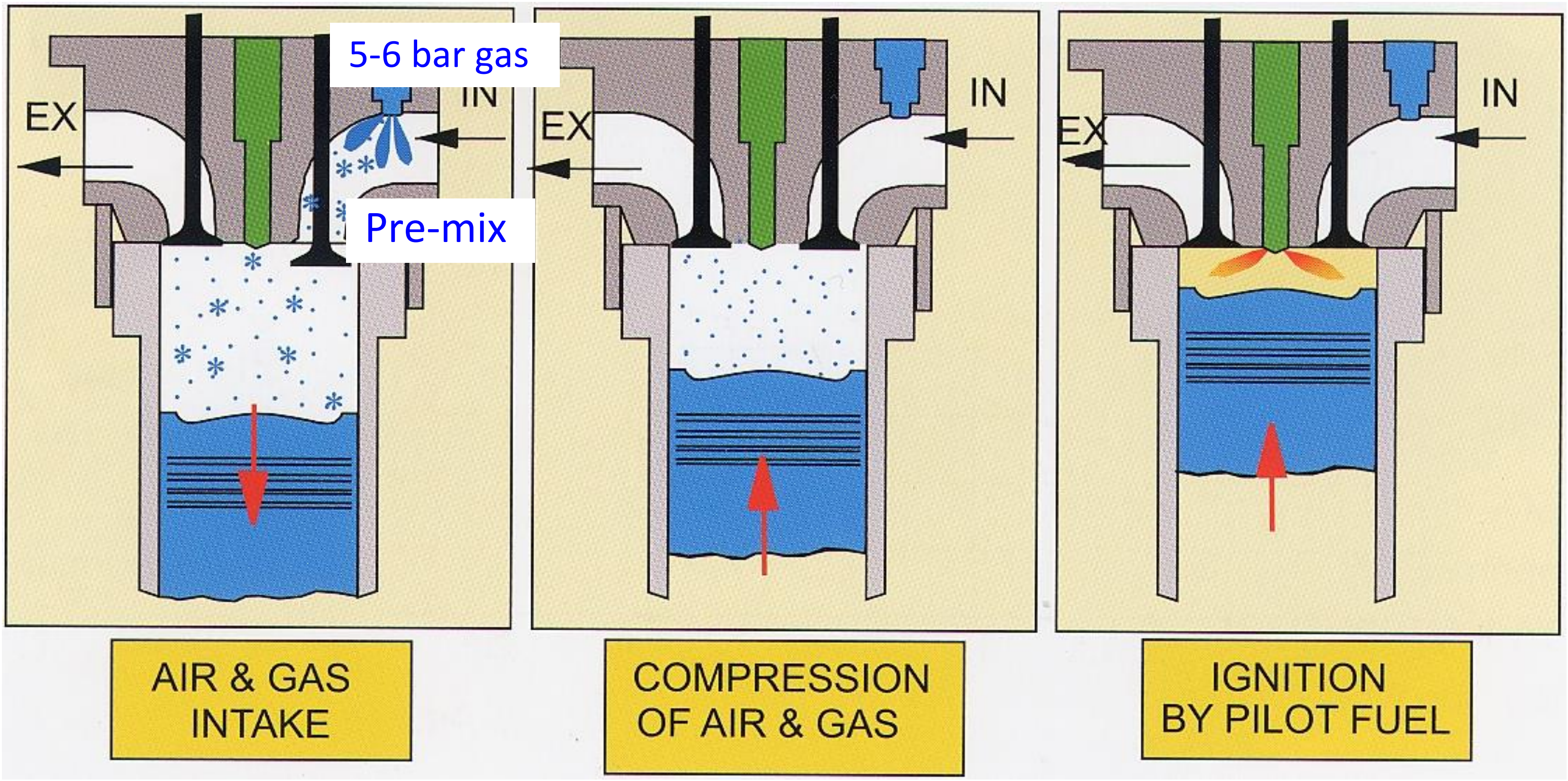
  *（ClassNK is supporting the development of not only the vessel itself but also the medium-speed DF engines）*

# *Natural gas **pre-mixed lean burn** combustion + pilot*

***Lean-burn type*** *(Otto-cycle type) gas engine has the same combustion style as a gasoline engine and it is possible to suffer **knocking** in some condition especially when a low 'Methane Number' gas is burned.*

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




*Function of medium-speed lean-burn gas engine*

*Merit of DF ('Dual Fuel') engine*

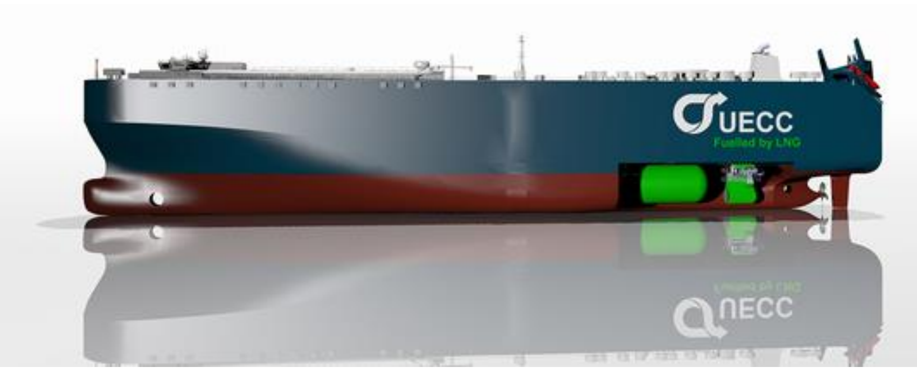
*(An example of platform supply vessel in rough sea condition in the North Sea)*

*・・Wartsila 32DF + Electric propulsion*

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

# *Natural gas fueled ships from now*

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



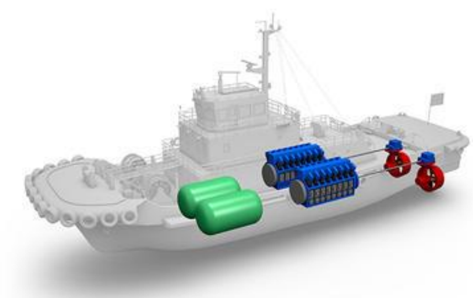


• United European Car Carriers (UECC) jointly owned by NYK and Wallenius Lines has ordered KHI two PCCs propelled by MAN low-speed ME-GI gas (DF) engine. (for voyage in European ECA)

・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）

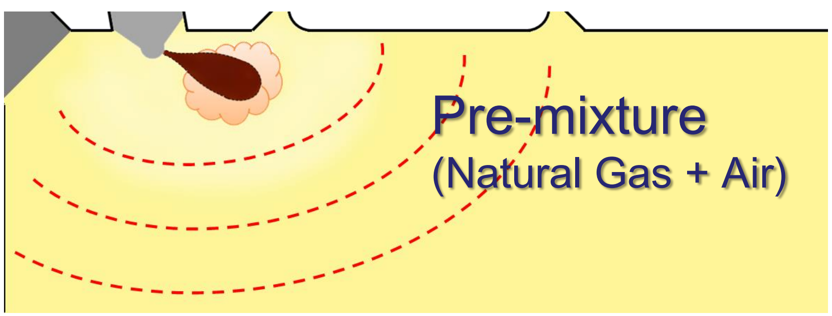
･Development of LNG-fuelled tug-boat by NYK Group･･ 2013～
（ClassNK is supporting development of not only vessel itself but also medium-speed DF engine）

・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）

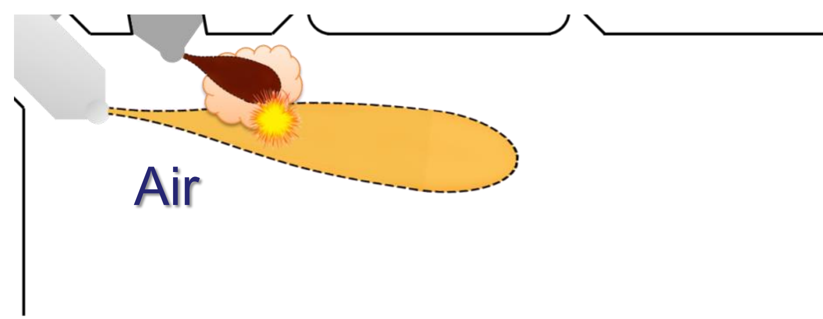
# *Category of natural gas engine combustion style*

| | **Lean-burn** *(pre-mixed)*<br>*(low-pressure gas supply)* | ***GI*** *(Gas Injection)*<br>*(high press. gas injection)* |
|---|---|---|
| *Medium-speed 4-st.* | *Currently **all*** | *Possible but not yet applied* |
| ***Low-speed 2-st.*** | ***X-DF type*** | ***ME-GI type*** |

**Otto-cycle** type gas engine




**Diesel-cycle** type gas engine

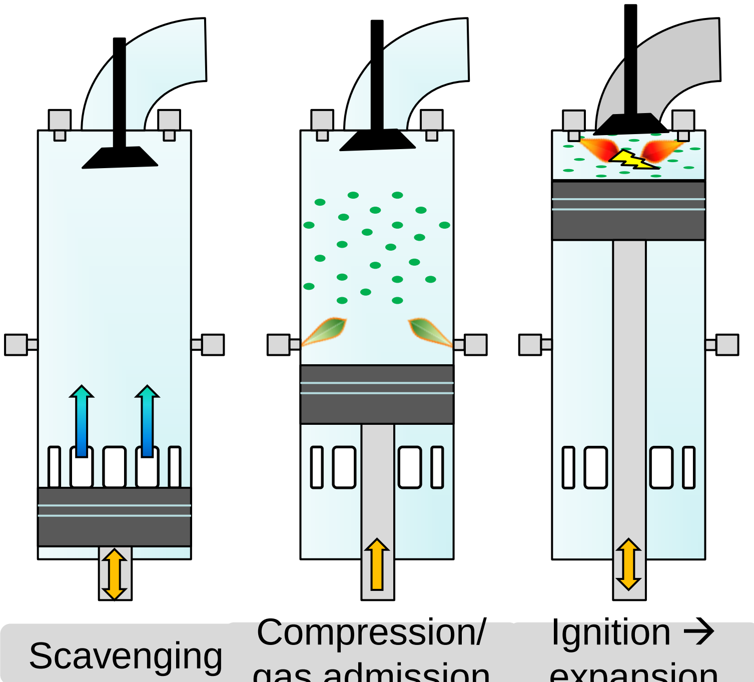


## *Introduction of low-speed two–stroke **lean-burn** type (DF) engine development*


*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

*On the gas-air mixing in X-DF type low-speed 2-stroke gas engine*



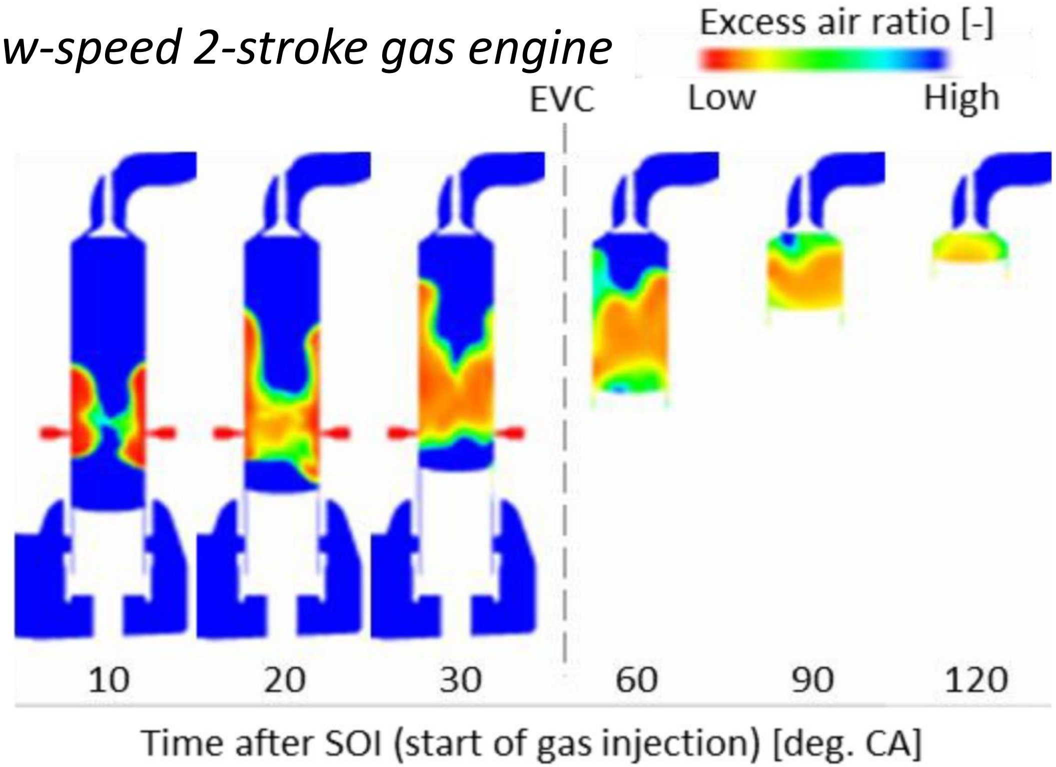




*Figure 11* λ distribution of fuel gas injected from the liner wall

*2-stroke gas concepts – Low pressure DF (16 bar)*

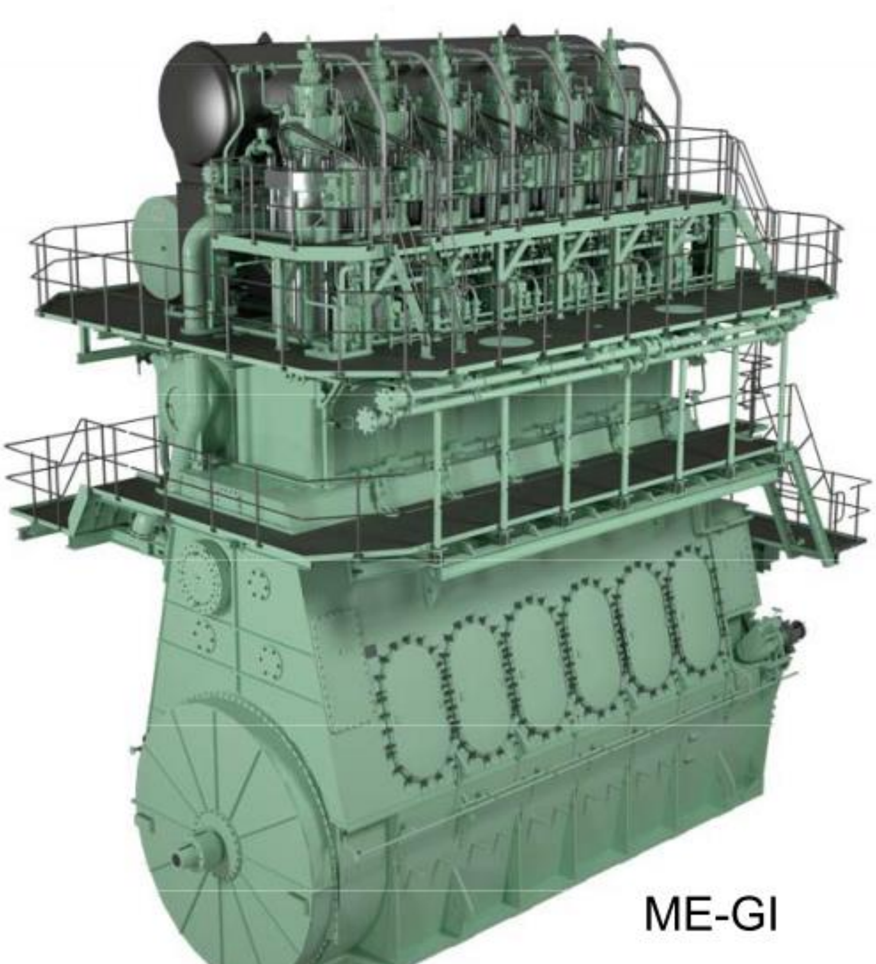
*Different from the figure in the left, actually like the figure in the right, two gas jets injected into the air before compression start penetrate and impinge on the cylinder wall and go up along the cylinder by their own momentum. It is a reason that gas distribute to the cylindrical direction.*

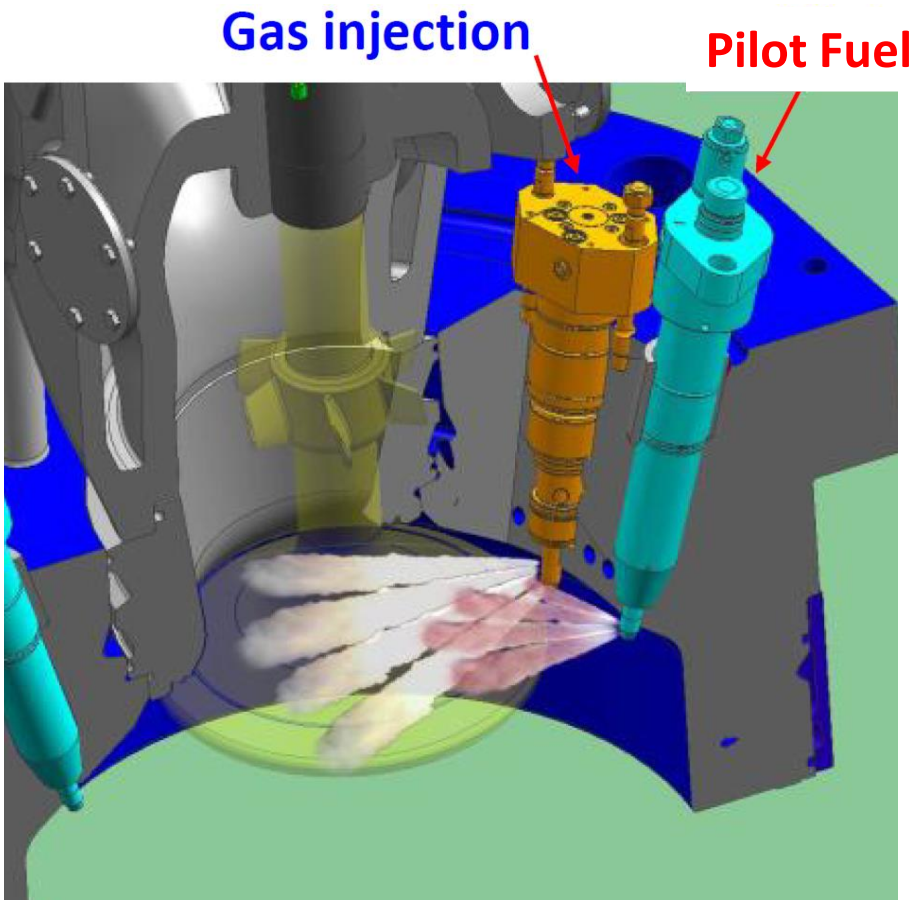
CIMAC 2016 • Paper No.207
"Study on Mixture Formation Process in Two Stroke Low Speed Premixed Gas Fueled Engine" by Takahiro Kuge (IHI Corporation, Japan)

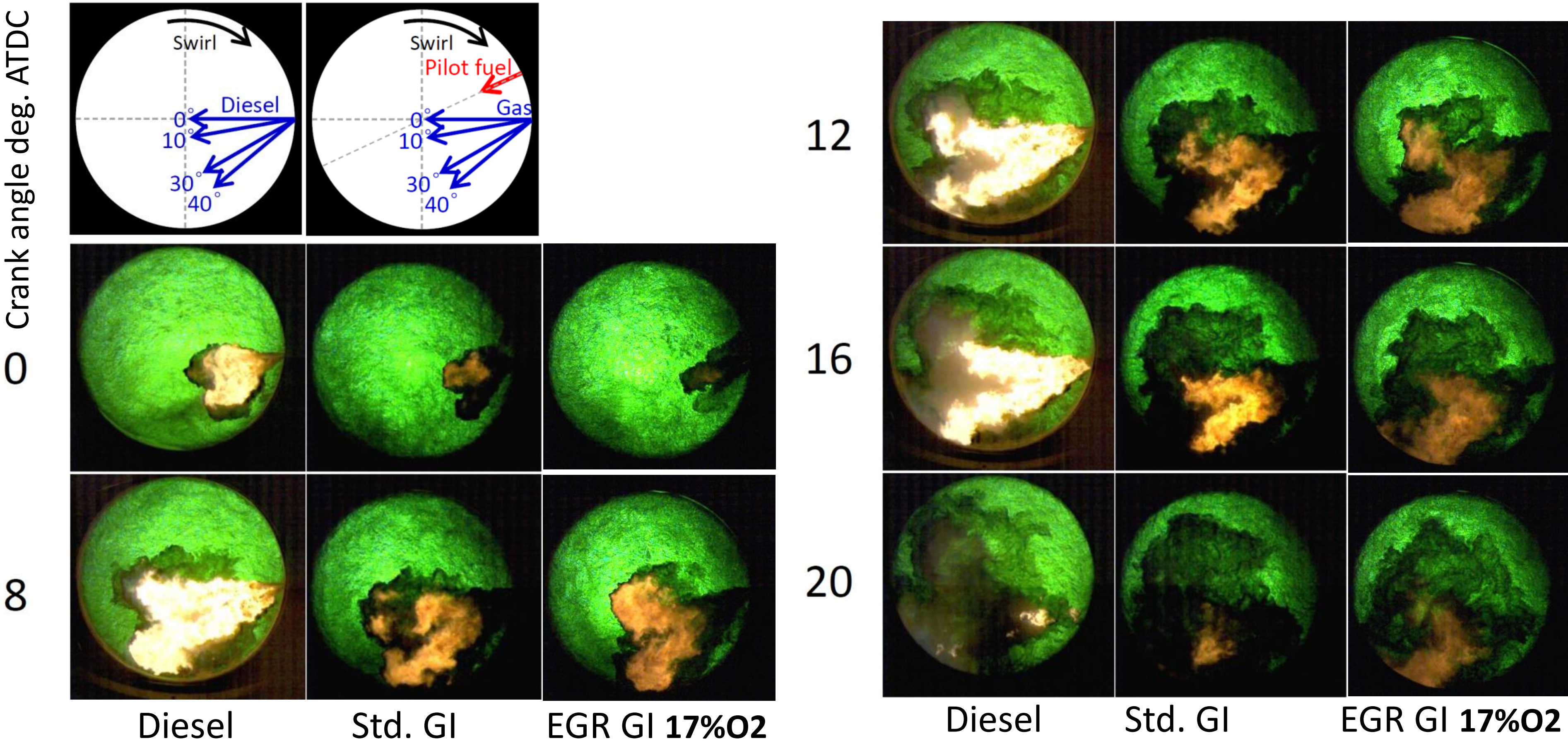
## ***Natural Gas*** *(Methane) high pressure injection + pilot*

*For **GI** (**G**as **I**njection) type engine・・named 'Diesel cycle gas engine'*

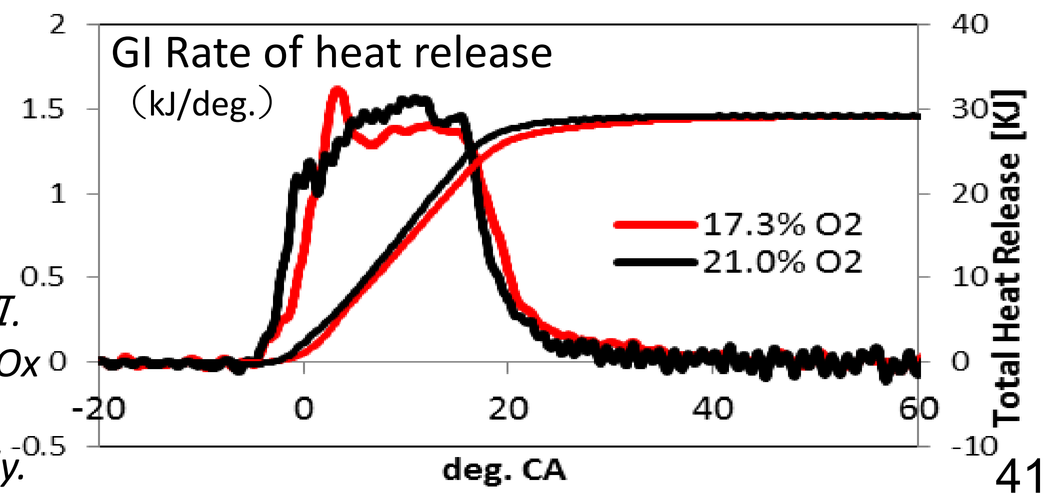
*Merits : Free from knocking & abnormal combustion (Any MN is allowable.)*
*Lower methane slip*






| 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 Tier Ⅲ. 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.*

# *Thank you for your kind attention. Research work is continued.*