ASEF Nov.7, 2013

Latest technologies for environmental measure in 2 stroke diesel engine

11 07 2013

MITSUBISHI HEAVY INDUSTRIES MARINE MACHINERY & ENGINE CO., LTD.
Designing Section, Designing and Service Engineering Department, Marine Engine Division

MITSUBISHI HEAVY INDUSTRIES MHI GROUP

Contents

1. Background

- Marine 2 stroke diesel engine can use Heavy Oil as a fuel that is a residue by petroleum refinery process, then it is very economical for users and has high heat efficiency of approximately 50%.

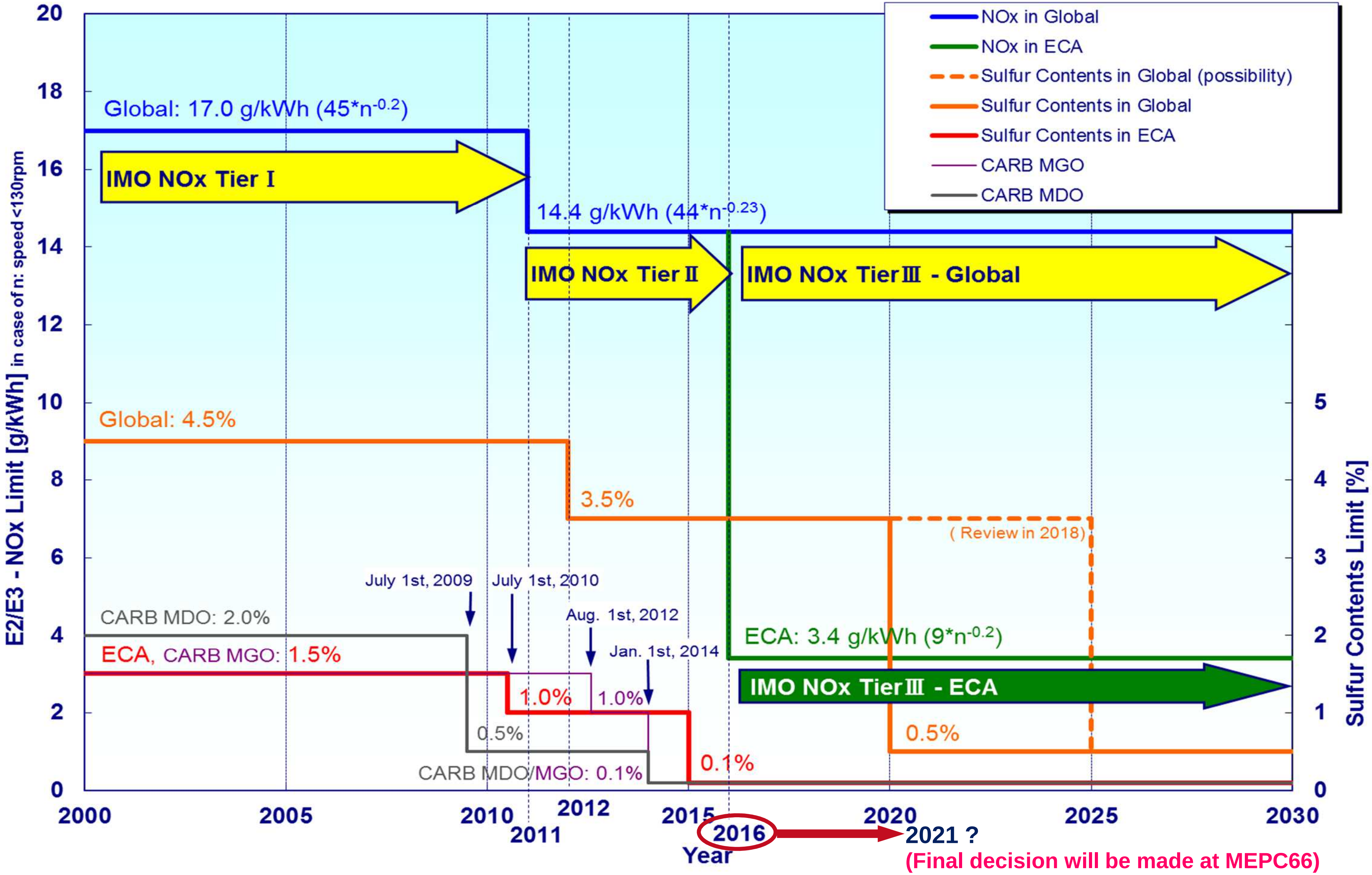
  So, it is “eco-” prime mover originally.

- However, because of diffusion combustion in high temperature and high pressure, NOx production is in large amounts. Also, since combustion using HFO, SOx and PM are produced in large amounts, too.

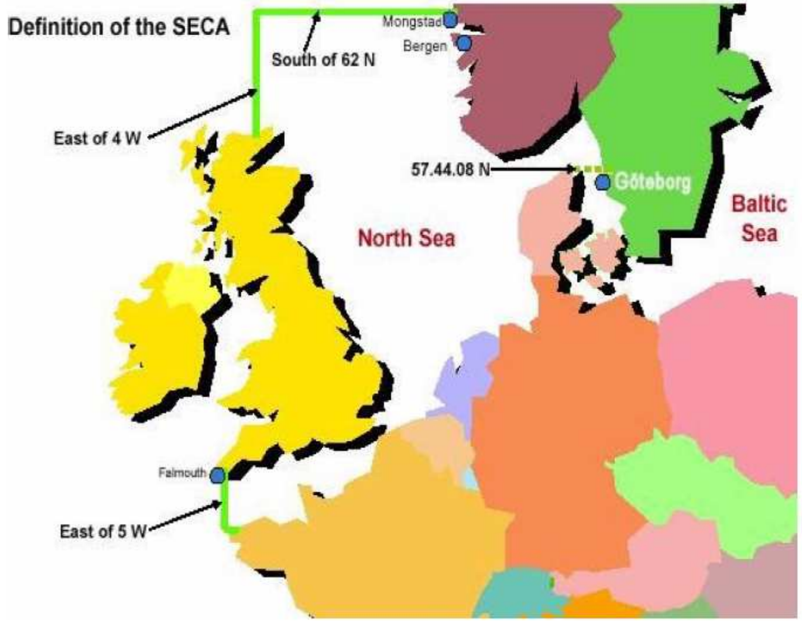
  Therefore, emission regulation is getting harder by IMO.

- And, CO_2 emission is also needed to reduce further.

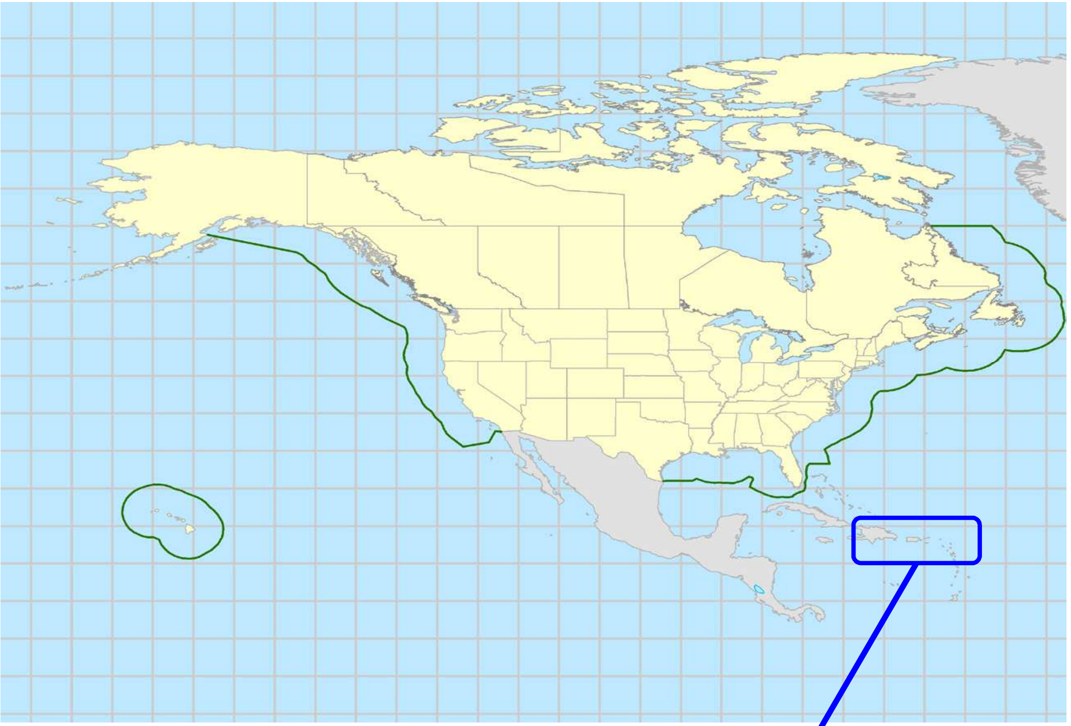
1. Emission Regulation of IMO & CARB



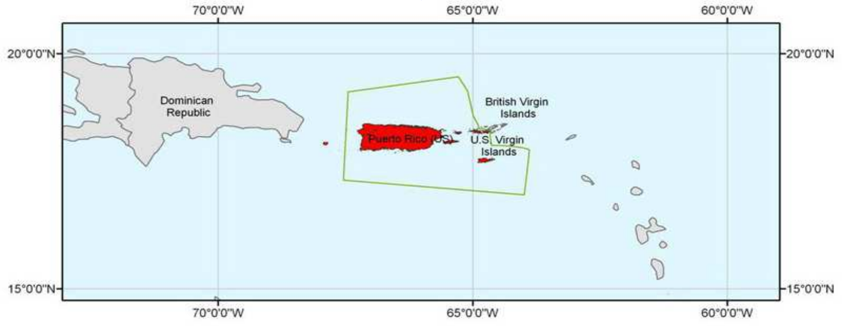
1. ECA（Emission Control Areas）



＜ECA＞
（SOx）

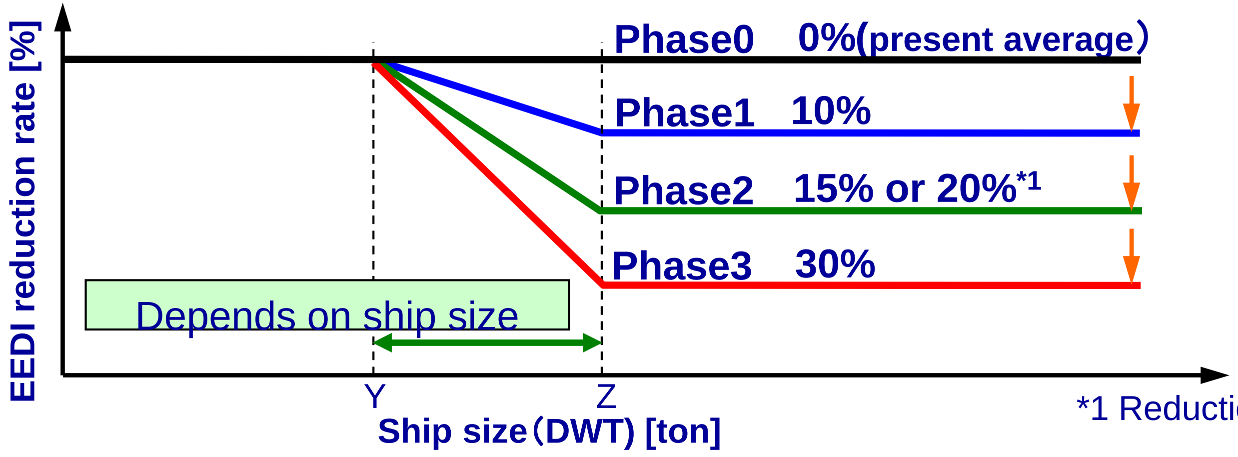


＜ECA＞
（NOx＆SOx）



EEDI (Energy Efficiency Design Index): Theoretical transport efficiency

$$\text{EEDI [g/(ton x mile)]} = \frac{\overbrace{\text{Specific CO2 content of relevant fuel x SFC [g/kWh] x power [kW]}}^{CO_2 \text{ emission [g/h]}}}{\underbrace{\text{DWT [ton] x speed [mile/h]}}_{\text{Capacity [ton x mile/h]}}}$$



EEDI limitation will go up gradually after 1/1/2015

*1 Reduction rate depends on vessel type

Ship type	Ship size (DWT)	EEDI reduction rate Phase0 → 2013/1/1 ~	Phase1 → 2015/1/1 ~	Phase2 → 2020/1/1 ~	Phase3 2025/1/1 ~
Bulk Carrier	20,000(Z) ~	0	10	20	30
Container ship	15,000(Z) ~	0	10	20	30
General Cargo ships	15,000(Z) ~	0	10	15	30

2. Comparison of NOx reduction technology

Item	NOx Reduction Rate (vs Tier1)	FOC variation	Technology progress	CAPEX	OPEX
Engine Spec Optimization (Mechanical-type engine)	Δ20%	+2～+3%	Traditional technology	Small	Small
Eco-Engine	Δ20%	0～+1%	Developed	Middle	Small
Water Injection	WEF（※1）：Δ50%	+2～+5%	Developed	Middle	Middle
	IWI（※2）：Δ80%	+7～+10%	Developed	Middle	Middle
	SFWI（※3）：Δ80% (For restriction of FOP capacity etc., actual reduction rate will be Δ40% level)	Approx. +10%	Developed	Middle	Middle
EGR with Scrubber	Δ80%	+1～+3%	Developing (New test engine)	Large	Small
SCR	Δ80～90%	0～+1%	Developing (Onboard test carried out)	Large	Large

※1 WEF：Water Emulsified Fuel ※2 IWI：Independent Water Injection ※3 SFWI: Stratified Fuel Water Injection

- **Now under developing EGR (also with WEF) and SCR.**

2. Compliance with IMO-NOx Tier III;

How to operate the ENGINE

Outside of ECA => Basically same as Tier II specification.

Inside of ECA => NOx reduction technology (80% less than Tier I)

AFTER TREATMENT

- SCR (**S**elective **C**atalytic **R**eduction) after Turbocharger*
- SCR before Turbochaeger

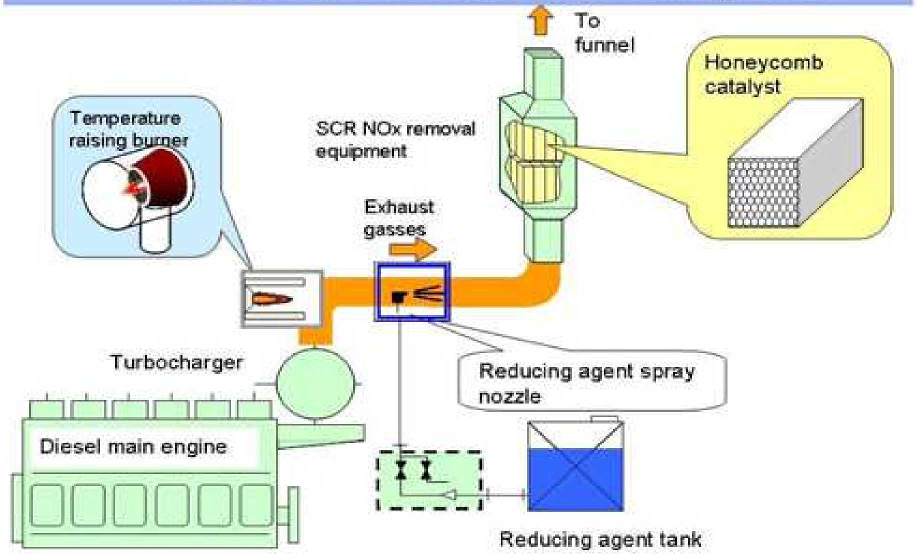
METHODS IN-ENGINE

- EGR (**E**xhaust **G**as **R**ecirculation) with low press. loop
- EGR with high press. loop
- EGR with WEF

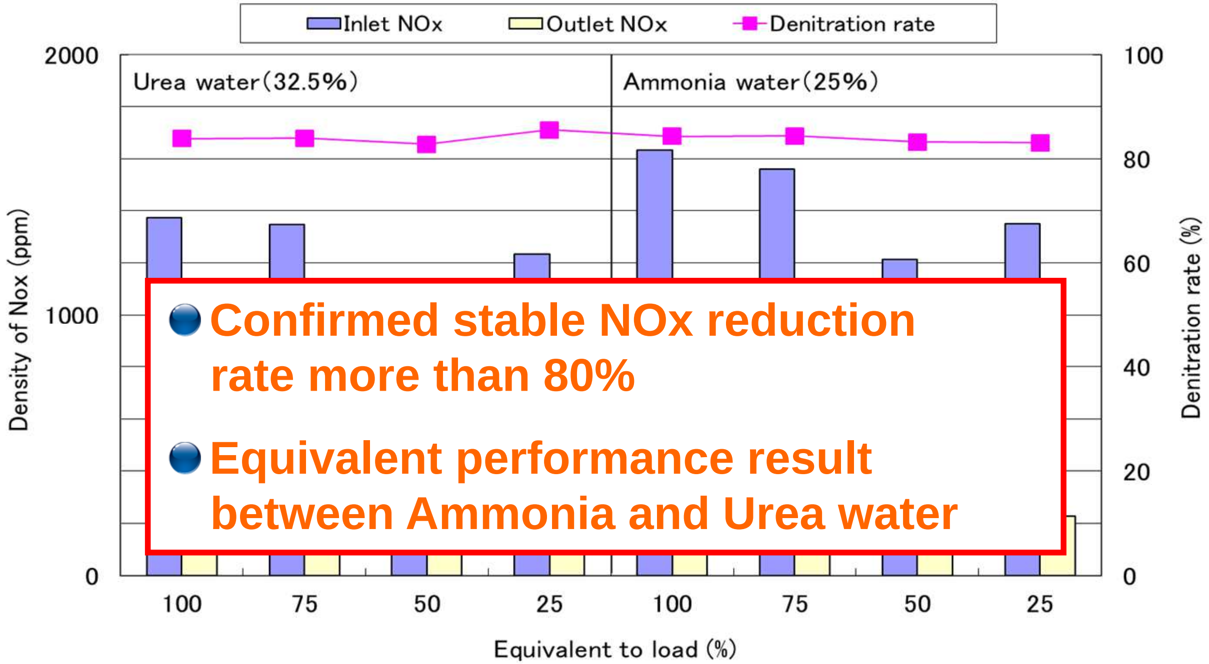
* The national project called "Super Clean Marine Diesel" was carried out by the Japan Ship Machinery & Equipment Association (JSMEA) financially supported by the Nippon Foundation, led by the Ministry of Land, Infrastructure, Transportation and Tourism (MLIT).
The research and development contract for the large slow speed diesel engines' application was carried out by JSMEA, Akasaka Diesels Limited, Oshima Shipbuilding Co., Ltd., Sakai Chemical Industry Co., Ltd. and Mitsubishi Heavy Industries, Ltd.

2. SCR Development (Result of SCMD project)

Image of SCR NOx removal system



<Onboard test result>



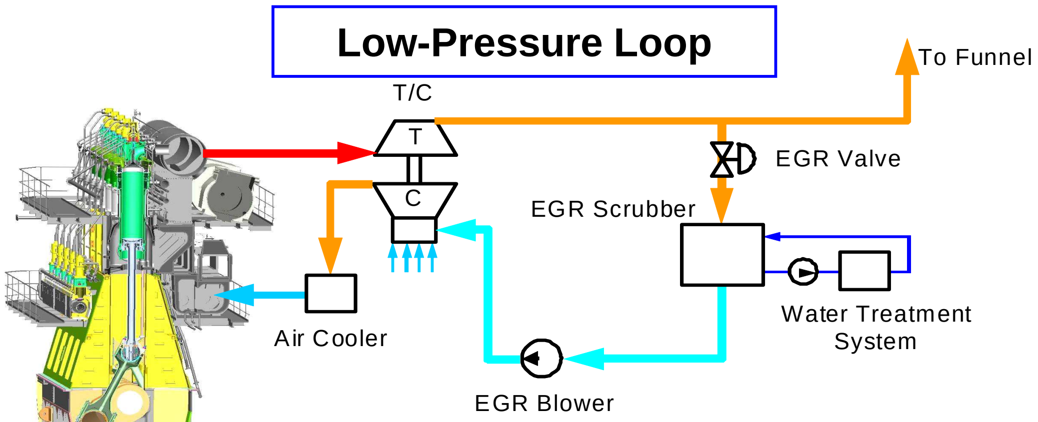
- Confirmed stable NOx reduction rate more than 80%
- Equivalent performance result between Ammonia and Urea water

<Summary and future schedule>

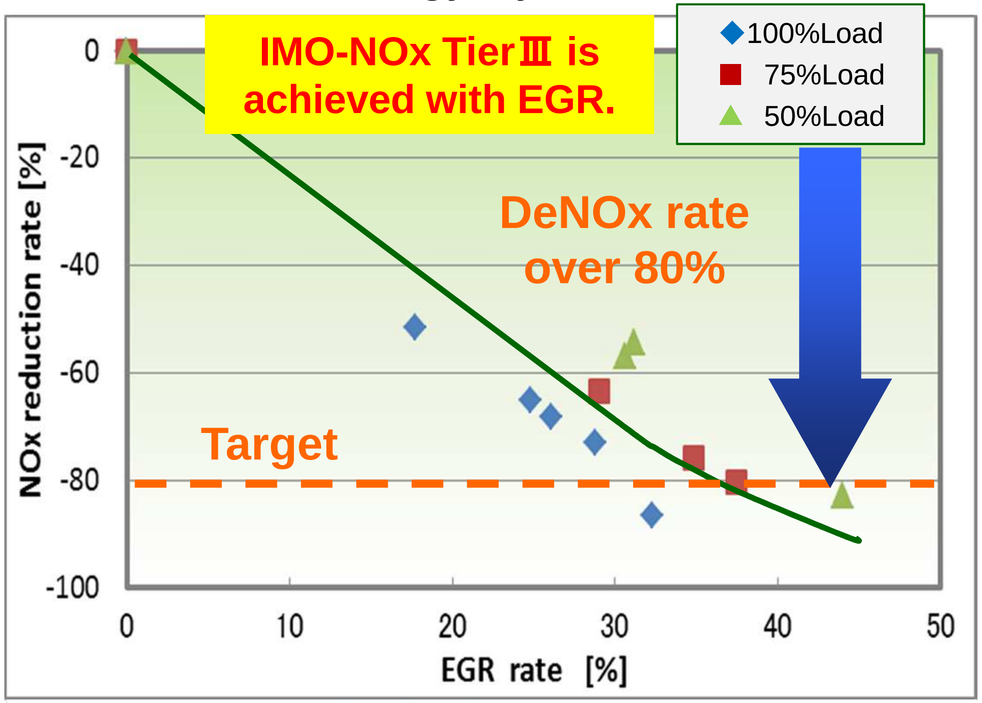
- Confirmed DeNOx rate more than 80% by onboard test in Super Clean Marine Diesel Proj.
  ⇒ Results already submitted to IMO / MEPC
- Implementation of long-term durability test
  ⇒ Quantification of performance changing rate
- Optimization of commercial SCR system
  ⇒ Improving the prediction accuracy of SCR lifetime and minimizing life cycle cost

2. EGR (System outline and Test Result)

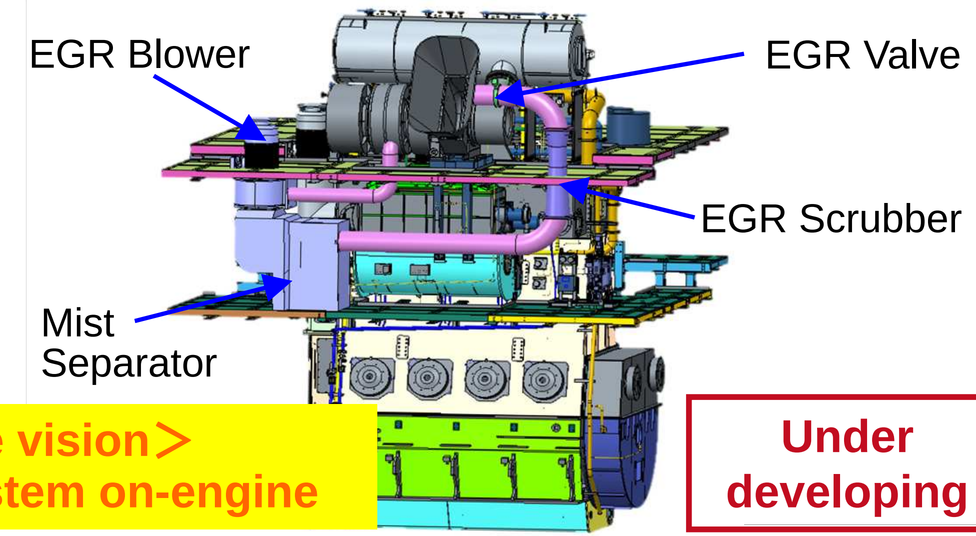
- EGR (Exhaust Gas Recirculation) is a NOx reduction technology by recirculating a part of exhaust gas to scavenging air.



Outline of EGR system



Overview of EGR system in 4UE-X3



＜Future vision＞
EGR system on-engine

Under developing

2. Summary

- **SCR is one of the most effective NOx reduction technologies, confirmed DeNOx rate more than 80% by onboard test in Super Clean Marine Diesel Project. High pressure SCR system is also under operating in actual vessel.**
  - **⇒ Results already submitted to IMO / MEPC**
  - **⇒ Now under optimization of commercial SCR system**

- **EGR is another TierⅢ technology confirmed drastic emission decreased adapting TierⅢ, both Low pressure loop EGR system and High pressure loop EGR system confirmed sufficient DeNOx performance.**

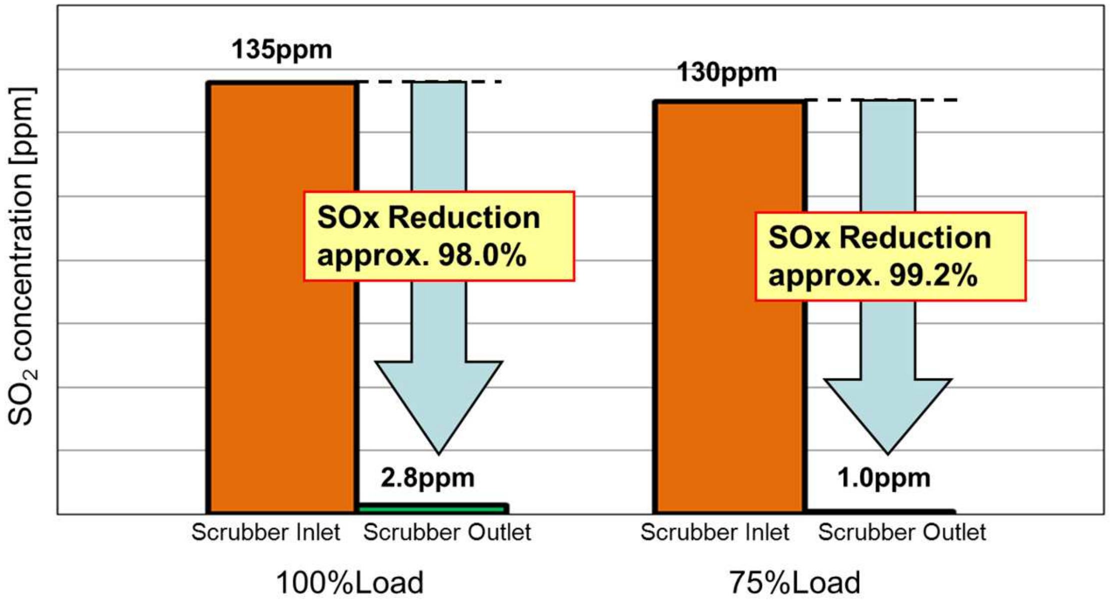
  Furthermore, a system of EGR combined with WEF is also under developing, confirmed adapting TierⅢ.
  - **⇒ For commercial design, now under developing optimized EGR equipment**

SCR and EGR will be explained in detail by Hitachi Zosen Corp. soon after.

3. SOx Scrubber

- Confirmed stable SOx reduction rate more than 98%

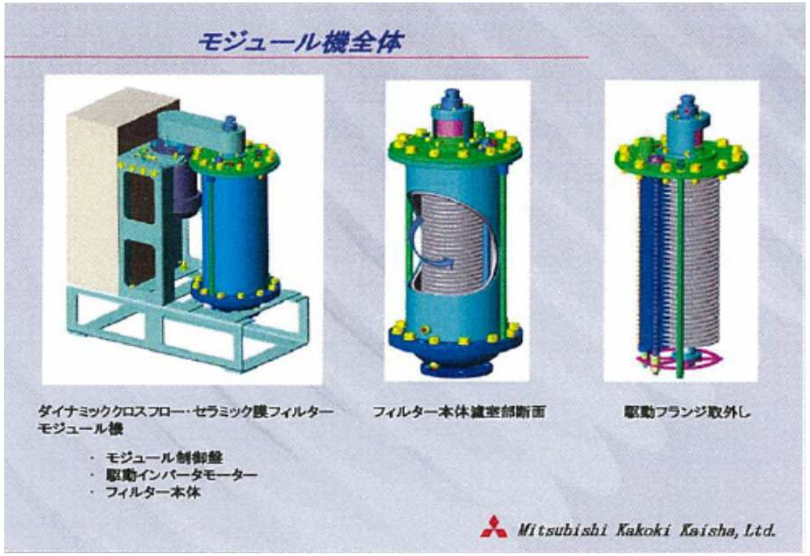
  ⇒Applying entire exhaust gas SOx scrubber, enables to use C-oil not only at Global area but also in ECA



<SOx reduction performance>

3. Water Treatment System

＜SJ（centrifuge）＞



＜DyF（rotor disc filter）＞

Wet scrubber system uses scrubbing water, it is necessary for Water Treatment System.

(before treatment)

(after treatment)

(sludge)

＜Comparison of before/after treatment and sludge＞

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EEDI (Energy Efficiency Design Index): Theoretical transport efficiency

$$\text{EEDI [g/(ton x mile)]} = \frac{\overbrace{\text{Specific CO2 content of relevant fuel x SFC [g/kWh] x power [kW]}}^{CO_2\text{ emission [g/h]}}}{\underbrace{\text{DWT [ton] x speed [mile/h]}}_{\text{Capacity [ton x mile/h]}}}$$

Energy saving technology

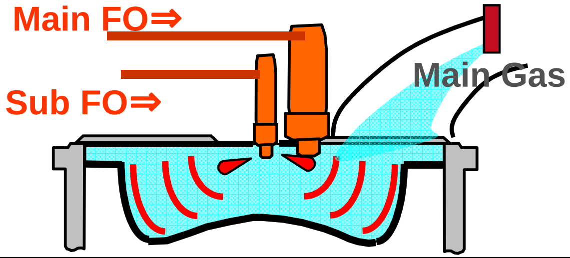
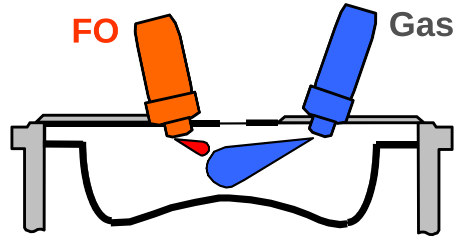
$$= \frac{\overbrace{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right)}^{\text{M/E}} + \overbrace{\left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right)}^{\text{D/G}} + \left(\left(\prod_{j=1}^{n} f_j \cdot \overbrace{\sum_{i=1}^{nPTI} P_{PTI(i)}}^{\text{Shaft motor}} - \overbrace{\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}}^{\text{Electric}}\right) C_{FAE} \cdot SFC_{AE}\right) - \overbrace{\left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}**\right)}^{\text{Machinery}}}{\underbrace{f_i}_{\substack{\text{Capacity factor} \\ \text{(Ice-class etc.)}}} \cdot \underbrace{f_c}_{\substack{\text{Cubic capacity correction factor} \\ \text{(Chemical tanker etc.)}}} \cdot Capacity \cdot \underbrace{f_w}_{\text{Weather factor}} \cdot \underbrace{V_{ref}}_{\text{Ship speed}}}$$

⇒ EEDI reduction possibilities;

- Speed reduction
- Optimizing vessel & propeller
- Air lubricating system

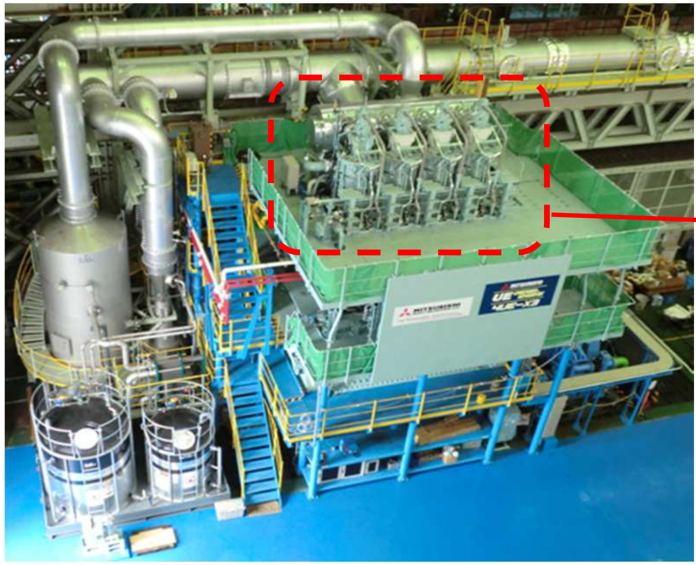
- De-rated engine
- Waste heat recovery
- Gas fueled engine
- Renewable energy etc.

4. Comparison of DF System

	Premixed DF	Gas Injection DF
		
Merit	▪ Low gas supply pressure (5-10bar) ▪ Lower NOx	▪ Robust combustion to fuel gas composition ambient condition etc. ▪ No methane slips ▪ Same performance as Oil mode (efficiency, gas temp. etc.)
Demerit	▪ Sensitive combustion to fuel gas composition ambient condition etc. ⇒ Load restriction (2 cycle) ▪ Lower efficiency in Oil mode ▪ Methane slip (1-2% of fuel gas) ▪ More time to switch from Oil to Gas	▪ High gas supply pressure (250 ~ 300bar) ▪ Higher NOx than premixed DF but lower than Oil mode

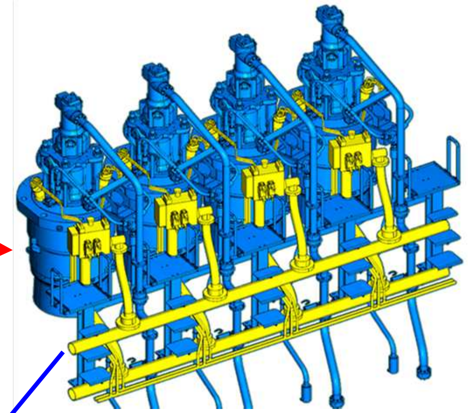
4. UEC-LSGi (Dual Fuel Engine)

- Dual Fuel Engine can use both heavy oil and LNG as fuel.



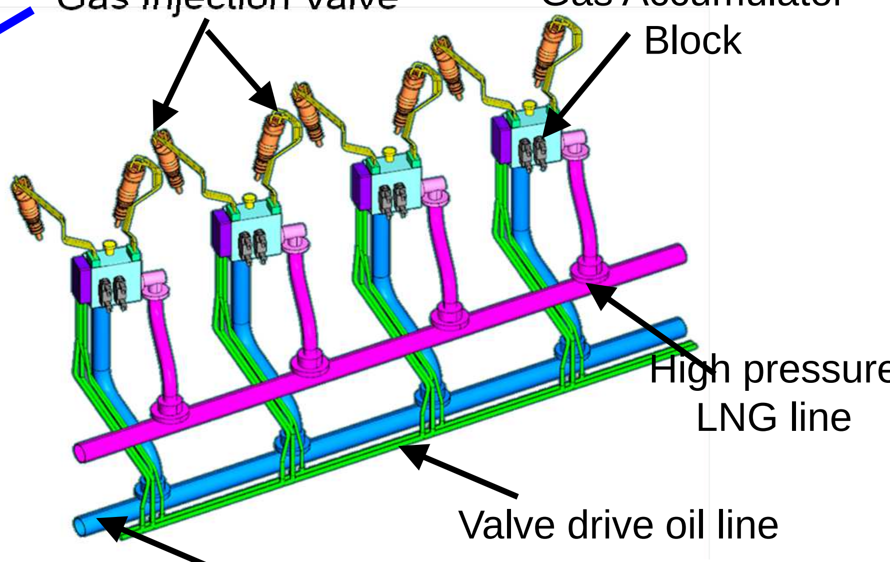
Plan for 4UE-X3

Blue parts: Diesel origin
Yellow parts: Gas addition

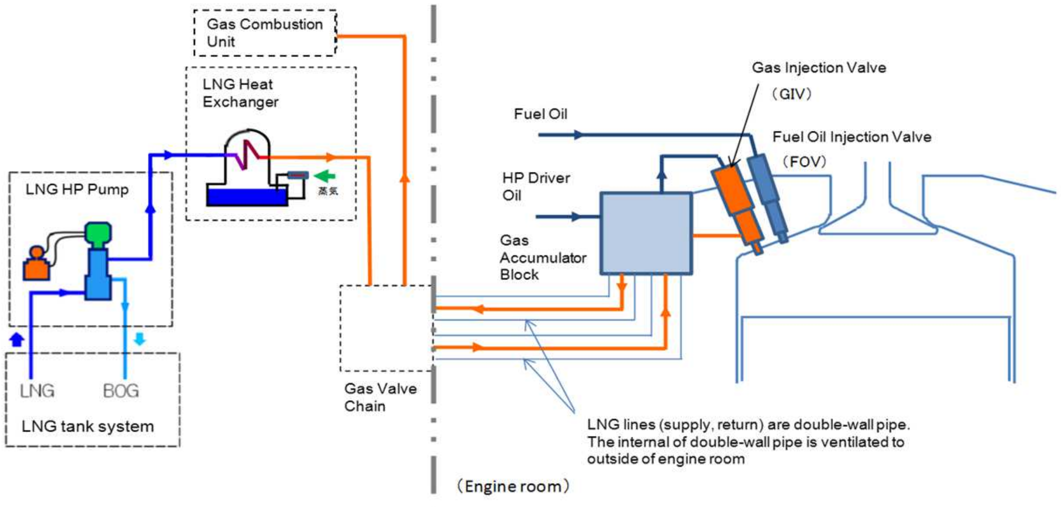


GIV overview

Gas parts overview



<System outline of UEC-LSGi>



- Consist of LNG HP supply, HP driver oil line and Ventilation/Safety system

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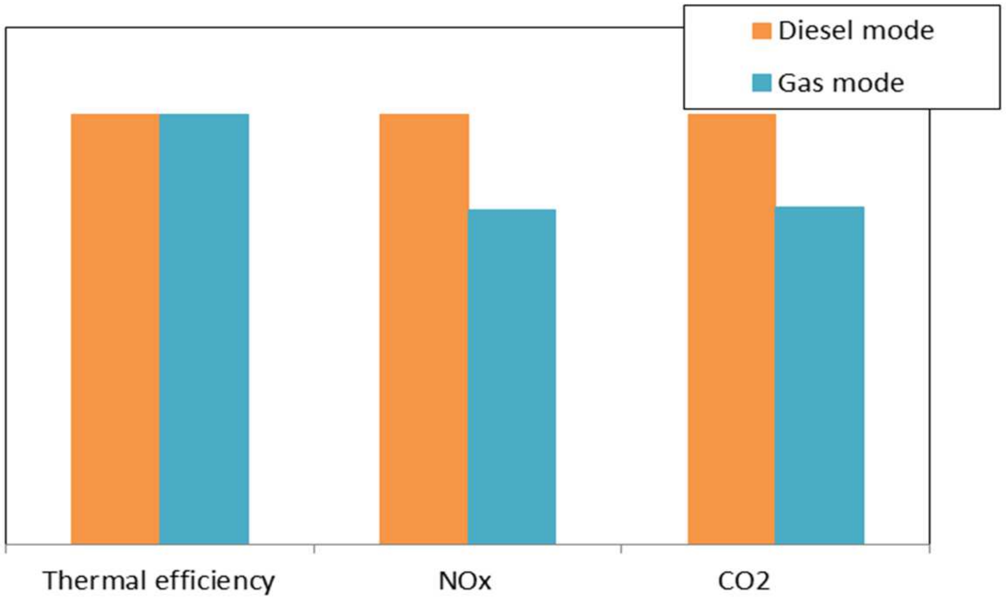
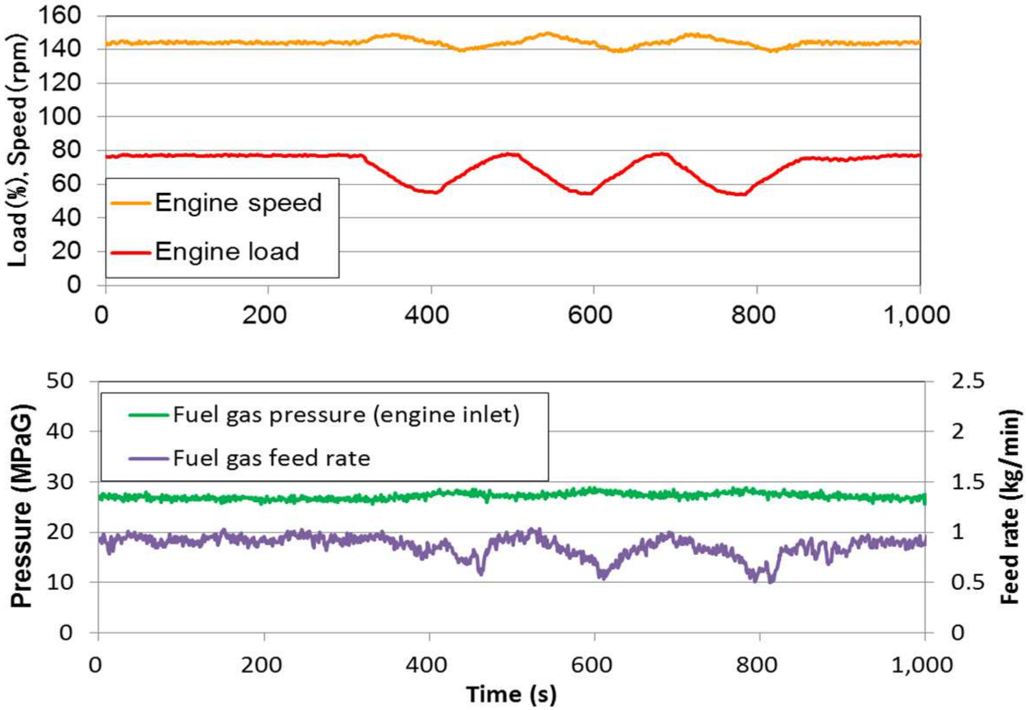
4. UEC-LSGi Test result

<Static performance>



<Dynamic performance>

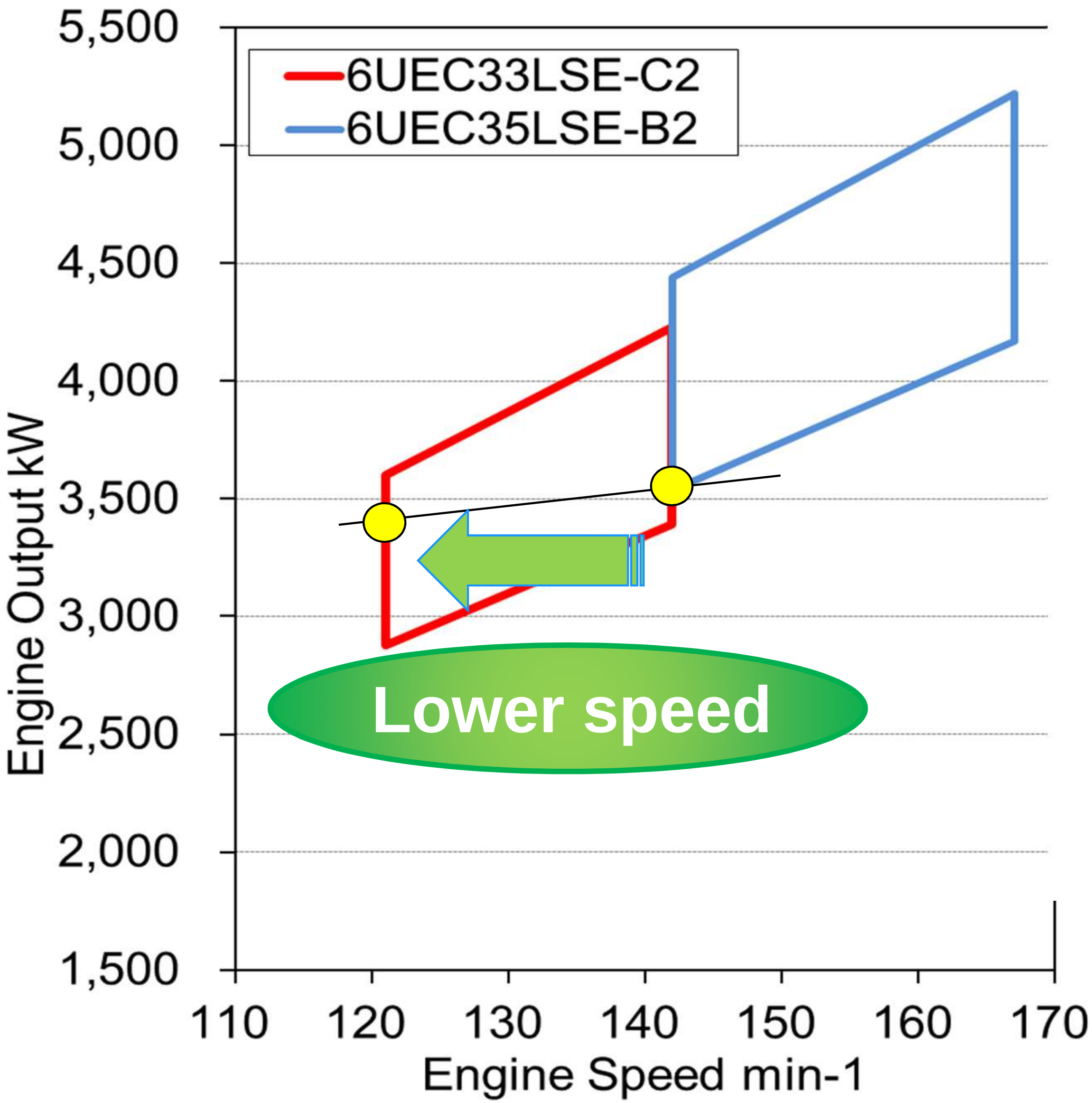


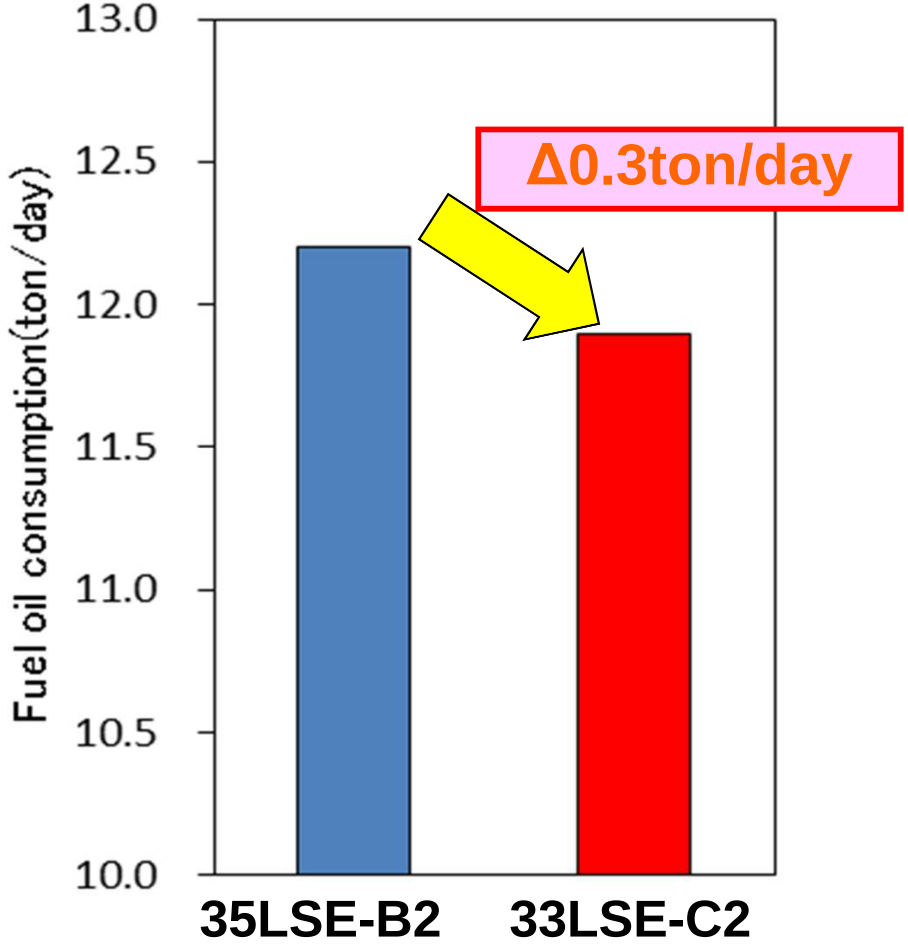
＜Summary＞

- At 75% load, thermal efficiency is almost same, NOx and CO_2 are slightly reduced. (between Diesel mode and Gas mode)
- Adequate response for load variation (60% ~ 80%) considering the rough weather condition

4. CO_2 reduction (Super Long Stroke Engine)

Super long stroke engine for various kind of small vessels





Comparison point:

3540kW X142min^{-1} 3400kW X121min^{-1}

※Calculation condition of FOC is 85%MR, LHV=10,200kcal/kg.

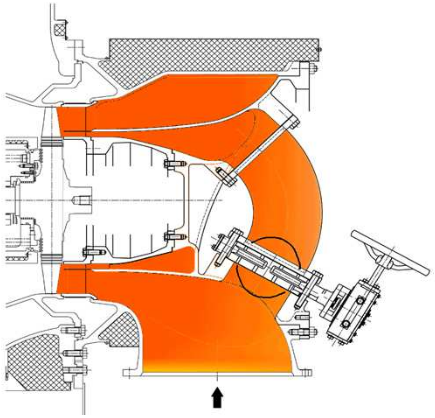
4. MET-VTI Turbocharger

VTI (Variable Turbine Inlet) System

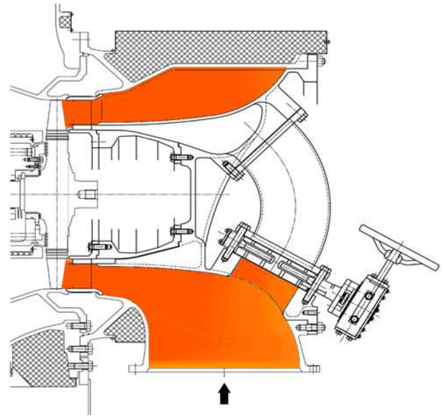
Improve engine performance owing to high scavenging pressure due to change the nozzle passage area at **low load operation**

MET-VTI Features

1. Simple construction ········ Low cost
   ········ Easy maintenance
   ········ High reliability
2. Easy application ········ Retrofit ready



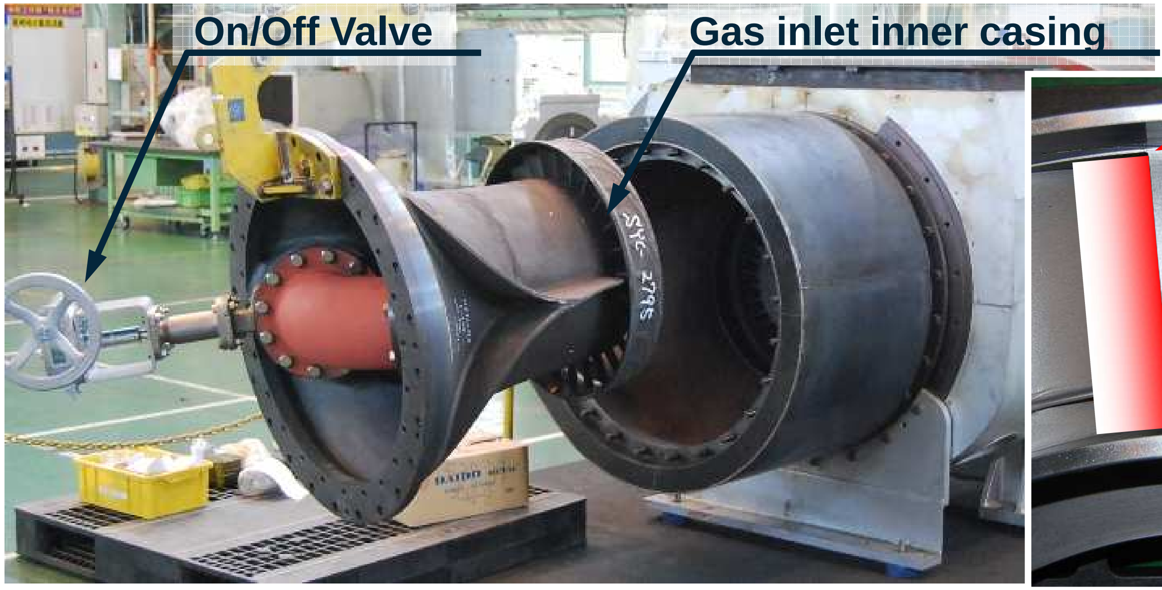
Valve open



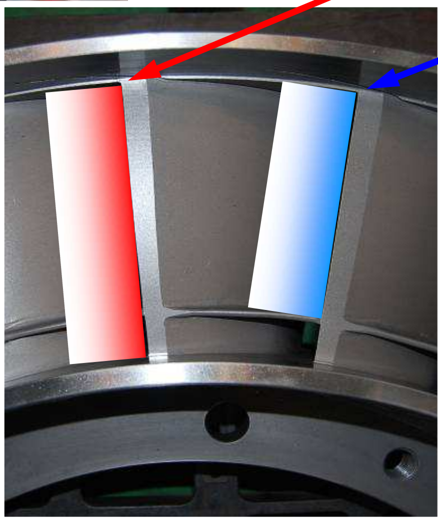
Valve close

Nozzle area : Large (Valve open)

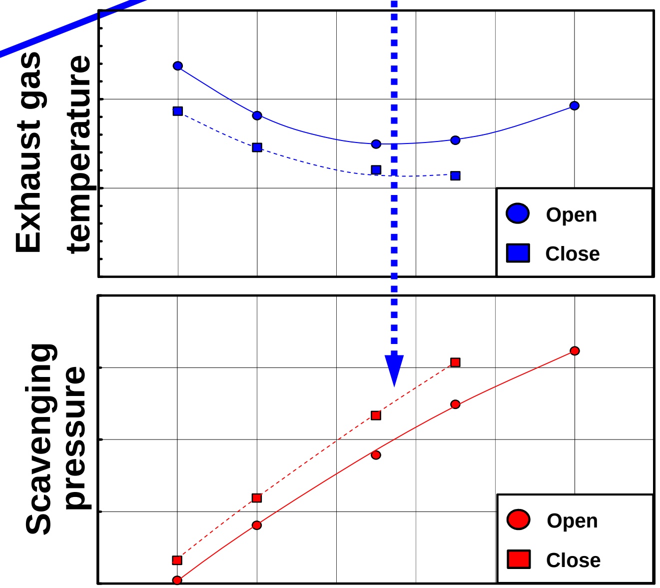
Nozzle area : Small (Valve close)



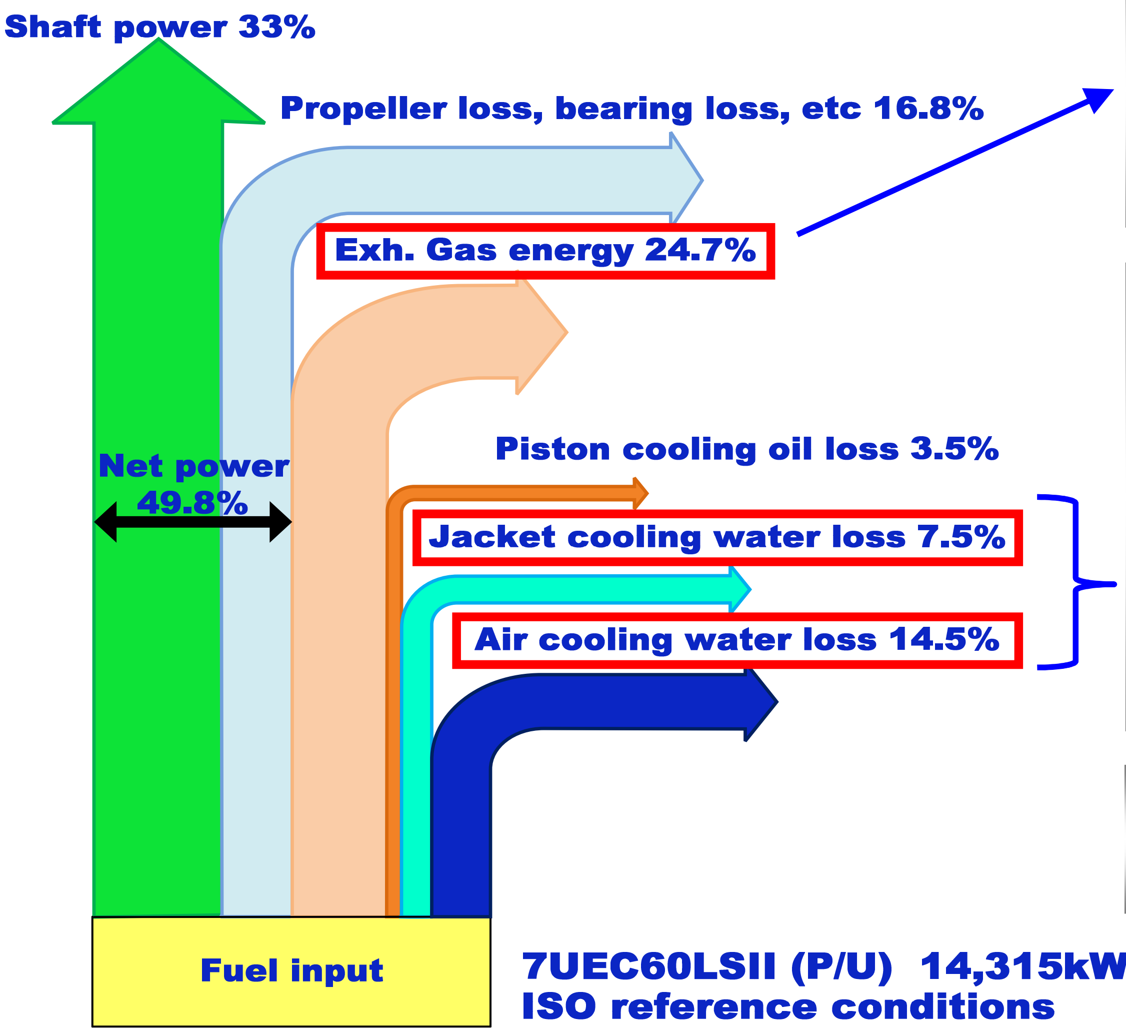
- **MET-VTI appearance**



- **MET-VTI nozzle**



➢ Solution of Further Energy Saving
⇒ Effective utilization of unused energy



7UEC60LSII (P/U) 14,315kW x 105rpm
ISO reference conditions

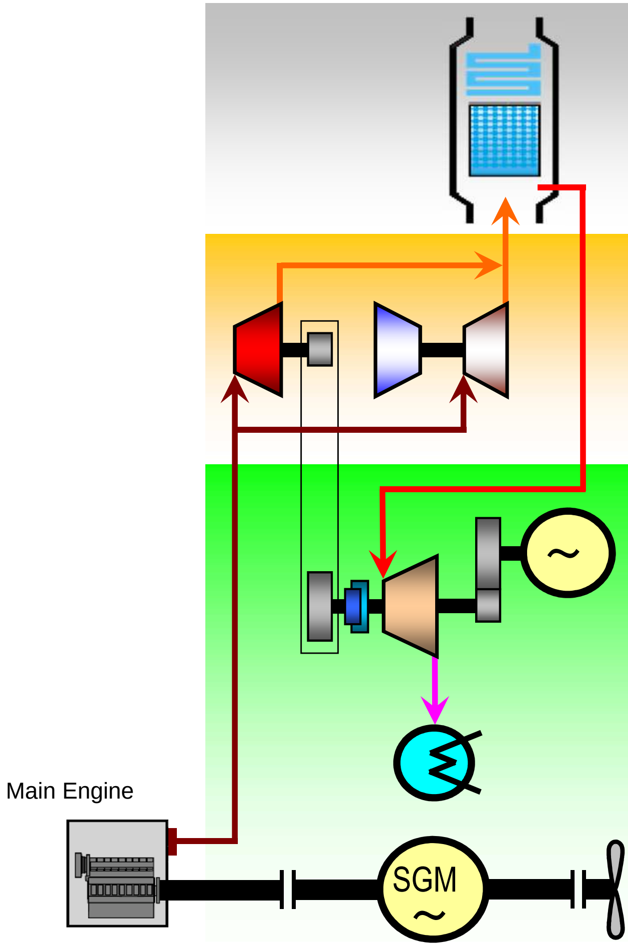
1. High temperature waste energy is recovered in forms of electricity by turbine generator directly or indirectly.

2. ORC(※) system, operating with organic refrigerant (e.g. freon such as R245Fa, pentane, and butane), has a possibility to recover the low temperature waste heat from Main Engine.
(※Organic Rankine Cycle)

3. Battery system is usable as energy storage buffer.

4. WHR system

WHR utilizing engine exhaust gas energy consists of Power-Turbine, Steam-Turbine using steam from Economizer and Hybrid-Turbocharger, etc.



Marine Boiler Designing Section

- Exhaust Gas Economizer
- Auxiliary Boiler

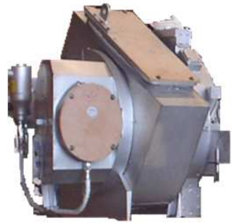
Turbo Charger Designing Section

- Exhaust Gas Turbocharger (MET)
- Exhaust Gas Power Turbine

Marine Turbine Designing Section

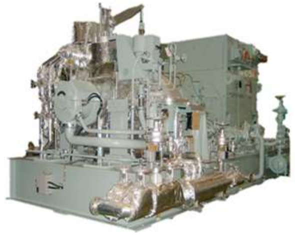
- Steam Turbine
- Reduction Gear & SSS Clutch
- Generator
- Condensing System
- Shaft Generator / Motor
- Power Management System

Exhaust Gas Economizer



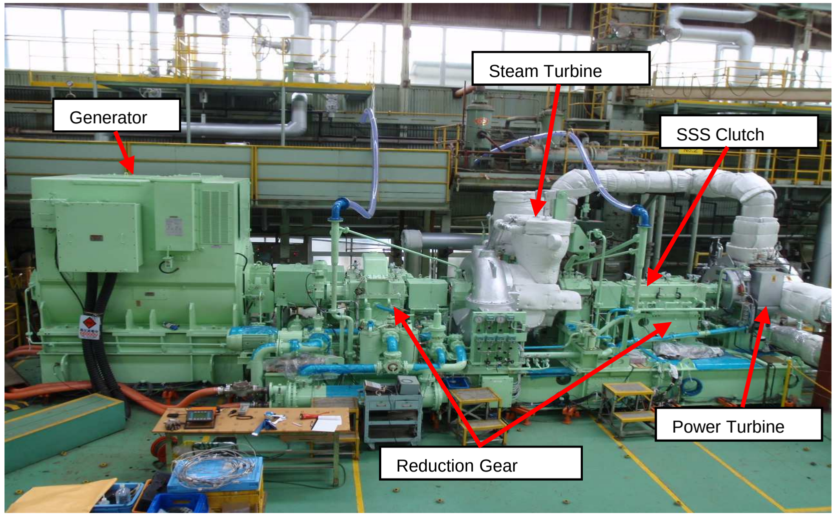
Exhaust Gas Power Turbine

Turbocharger (MET)



Steam Turbine

Shaft Generator / Motor



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Introduction of 100kW ORC

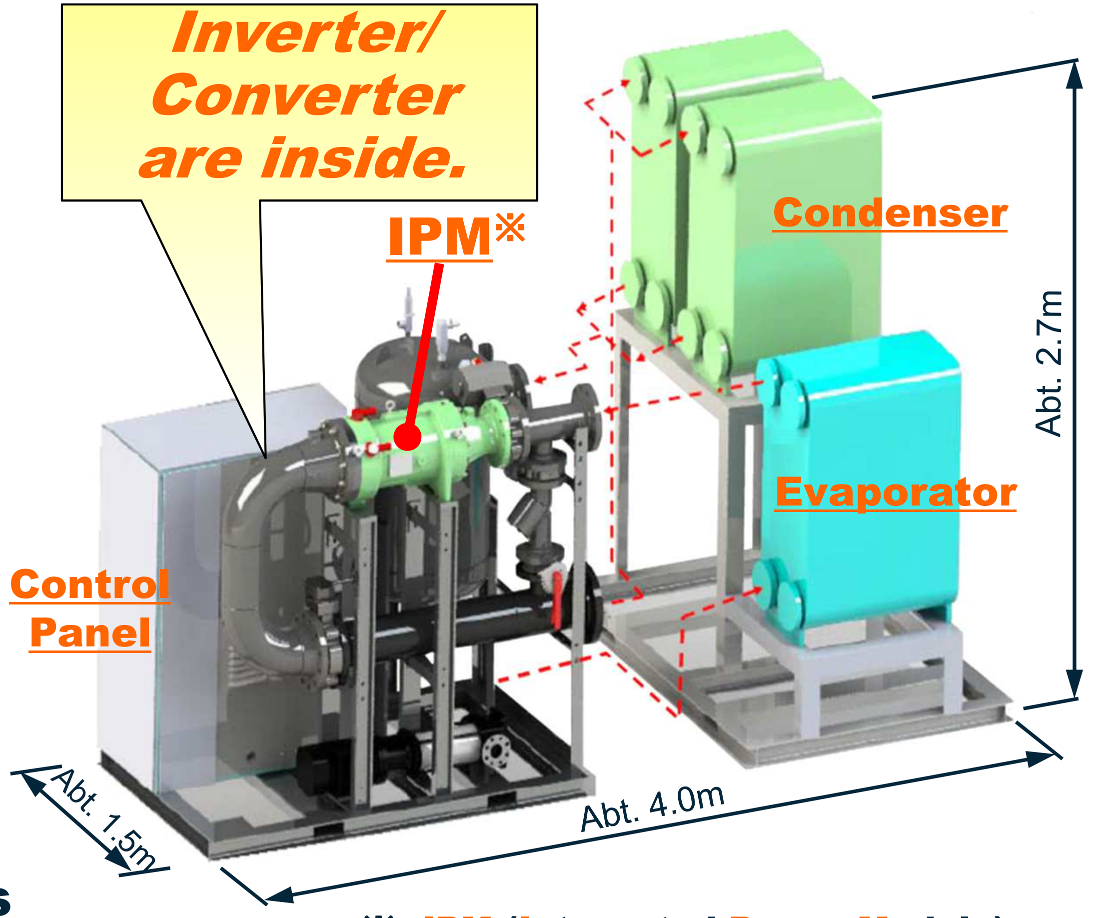
- **Output : 100kW(NET)**

Heat source : Jacket Cooling Water(85°C)
Media :R245fa
Main Engine : more than 10,000kW
(depending on the amount of jacket water heating source)

- **Feature :**

(1) Compact Space/Skid Mounted(Fig.)
⇒ Easy retrofiring
(2) High speed generator with Magnetic Bearing
⇒ No oil lubrication required

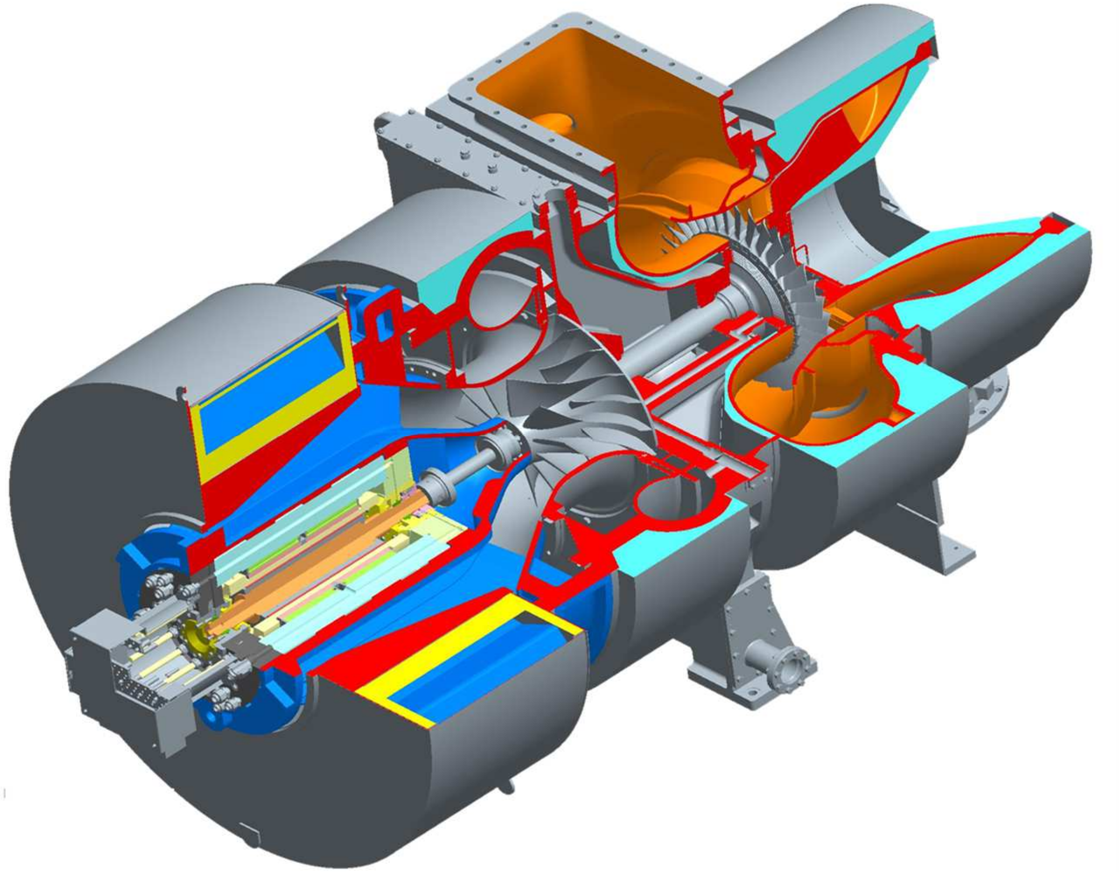
- **Payout time (Expected) : 4 ~ 5 years**
- **Delivery : 2014(Scheduled)**
- **No maintenance with the Magnetic Bearing**



※ **IPM (Integrated Power Module)**
⇒ Expander/Generator

Outline View of 100kW

4. Hybrid Turbocharger



- **The world's first vessel with hybrid turbo**
- **No need for diesel generator running**
  - Less fuel oil consumption
  - Less noise
  - Less maintenance work on diesel generator

- **Hybrid turbocharger series featuring**
  - **High efficiency high speed permanent magnet synchronous generator coupled with T/C rotor**

  - **State of the art power electronics supplying stable electric power to the ship's grid**

5. Summary

- Marine 2 stroke diesel engine has high heat efficiency of approximately 50%, so it is “eco-” prime mover originally. However, because of using HFO and diffusion combustion in high temperature and high pressure, NOx, SOx and PM are produced in large amounts.

  Therefore, emission regulation is getting harder by IMO.

  And, CO_2 emission is also needed to reduce further.

- Regarding to NOx, drastic reduction technologies such as SCR and EGR are now under developing. As for SOx, in addition to changing fuel oil, scrubber can adapt the regulation.

- Aiming for CO_2 reduction, there are several technologies under developing or in commercial such as Dual Fuel engine (gas fueled), WHR system, new Turbocharger application, etc.