MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

Onboard carbon capture - key considerations and challenges

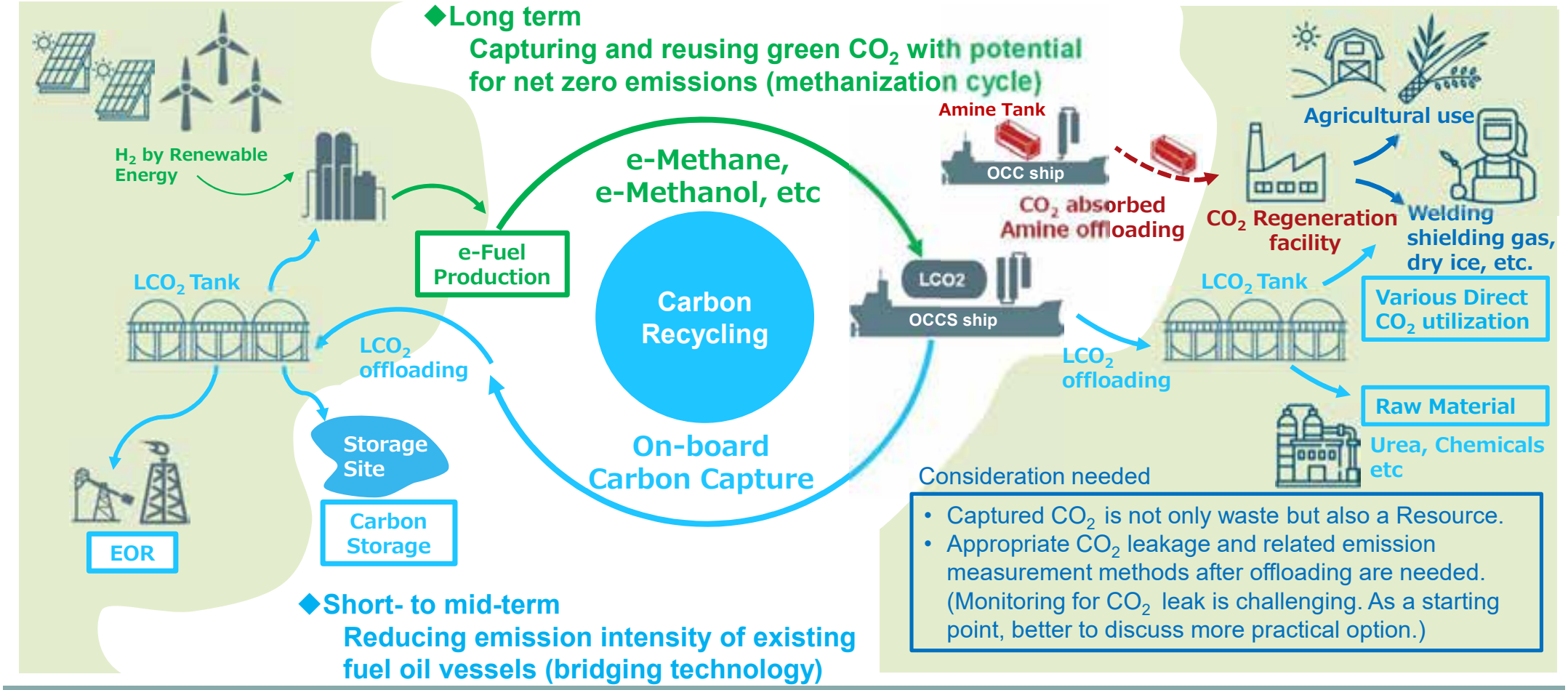
Technical Seminar on Onboard Carbon Capture and Storage (OCCS) Systems,
11 September 2025

Mitsubishi Shipbuilding Co., Ltd.

MITSUBISHI HEAVY INDUSTRIES

Why OCCS : OCCS has Short- and Long-term roles

- **Decarbonization through OCCS and CO_2 Value Chain has both short- and long-term roles .**



Why OCCS : Practical implementation is getting closer.

Generally, related technologies are reaching high TRL.

Technology Readiness[1] (from the perspective of marine applications)

		2020	2022	2024	2026	2028	2030	2032
CO_2 Capture (amine-based absorption)	• CC-Ocean project completed onboard verification testing in marine environment end of 2021, with LSFO/HFO • Application to HFO needs further development.	TRL7 (small-scale, LSFO)						
Exhaust gas treatment (depending on fuel type)	• Exhaust gas treatment method to be developed for application to HFO	TRL3		TRL7				
CO_2 Liquefaction (medium pressure)	• Already established onshore facilities and being developed for marine applications. • Small-scale unit was delivered in 2024-2025.	TRL6		TRL7				
LCO_2 Storage and BOG control (medium pressure)	• It is applied on a small-scale in OCCS, however technology of LCO_2 carriers has been established and is to be utilized for OCCS.	TRL6	TRL7		TRL9			
LCO_2 Shore connection (discharging)	• Ditto.	TRL6	TRL7		TRL9			
Integrated OCCS (amine-based absorption)	• Small-scale fully integrated OCCS was delivered in 2024 – 2025. • Large-scall system is to be ready in 2030	TRL6		TRL7 (small-scale)			TRL9	

https://www.mhi.com/news/211020.html

1 Technology readiness levels (TRL) as defined by EU Horizon 2020 Program

Why OCCS : Some advantages of OCCS.

- **OCCS has advantages in ship's perspective.**

Use of Conventional Fuel	General Crew Operation	Future potential
Utilization of conventional fuel supply chains and infrastructure. Utilization of conventional engine plants.	Operation can be carried out by general crew, no special technician to be assigned.	Utilizing with any carbon-containing fuel with lower carbon intensity, such as methane, methanol, biofuels or e-fuels.

Onboard carbon capture plant was operated by general crew members, at the 1st onboard carbon capture demonstration of "CC-Ocean" project (2021)

OCCS Technologies : CO_2 Capturing Methods

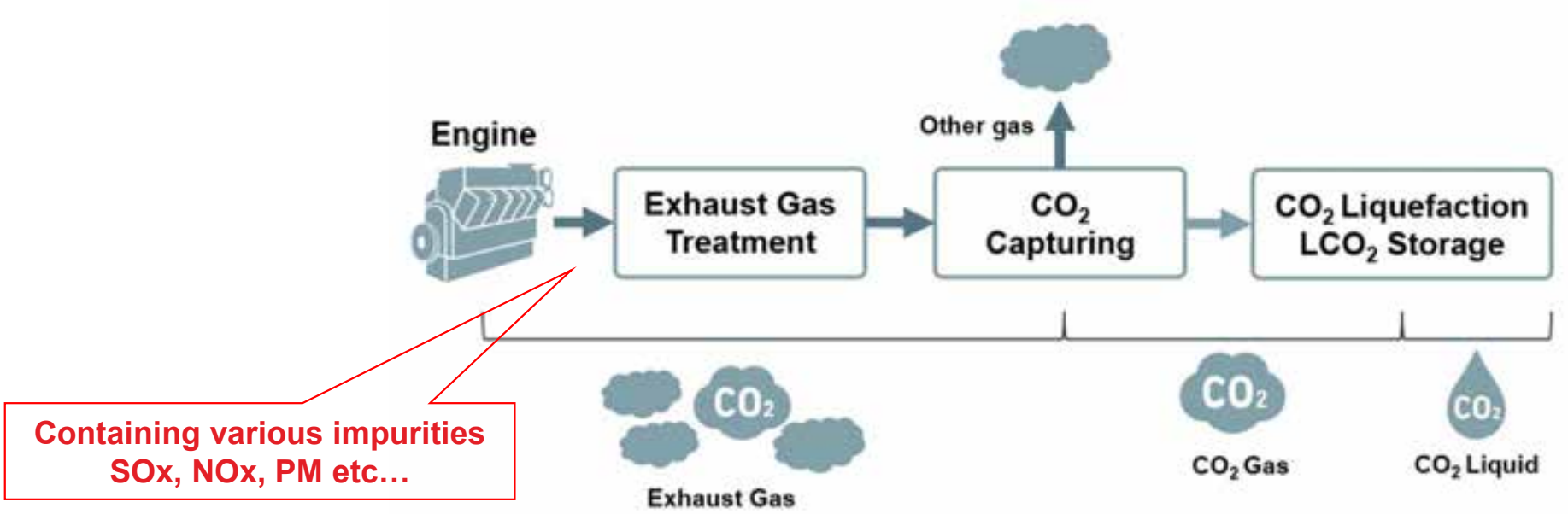
The chemical absorption method is suitable for OCCS relatively.

High TRL	Selective capturing of CO_2	Space and Energy Requirement
Reliable technology that has already been used in many onshore commercial CO_2 production plants for a considerable duration.	Capturing from low-pressure and low CO_2 concentration exhaust gas that contains various impurities and has a low concentration of CO_2.	Relatively suitable for onboard limitation regarding both space and energy.

Method	Explanation	Evaluation
Chemical Absorption	• Using an amine-based solvent, CO_2 is chemically absorbed into the liquid phase and separated from the flue gas.	• Well-suited for exhaust gas which is characterized by low pressure and low CO_2 concentration • Already been commercialized and is currently used in onshore plants to recover CO_2 from large volumes of exhaust gas.
Solid Absorption	• CO_2 is adsorbed onto the surface and micropores of a solid adsorbent, and subsequently released through thermal or pressure swing desorption.	• CO_2 desorption requires energy input for pressure reduction. • For large-scale applications, a significant number of adsorption columns are needed.
Membrane Separation	• Membrane separation is achieved by establishing a pressure differential across a CO_2 selective membrane, enabling preferential permeation of carbon dioxide.	• Significant energy is required to create a vacuum or reduced pressure on the permeate side of the membrane to allow CO_2 to pass through. • Scaling up the system is challenging, since the gas permeation rate per unit membrane area is limited.

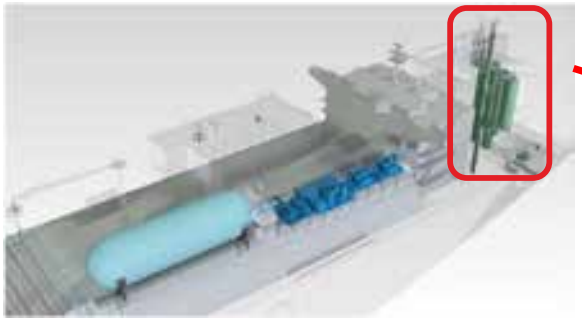
OCCS Technologies : Exhaust Gas Treatment

- **Treatment of exhaust gas is essential before CO_2 capturing.**
  - Exhaust gas from engine contains various impurities such as NOx, SOx, PM etc. (Especially, heavy fuel oil contains many unknown impurities, as it is a residual oil.)
  - Such impurities affect failure of the CO_2 capturing system, reduction of CO_2 capturing system efficiency, and carrying over the impurities to the CO_2 (or LCO_2). Primary treatment before CO_2 capture is necessary.



OCCS Technologies : CO_2 Capture

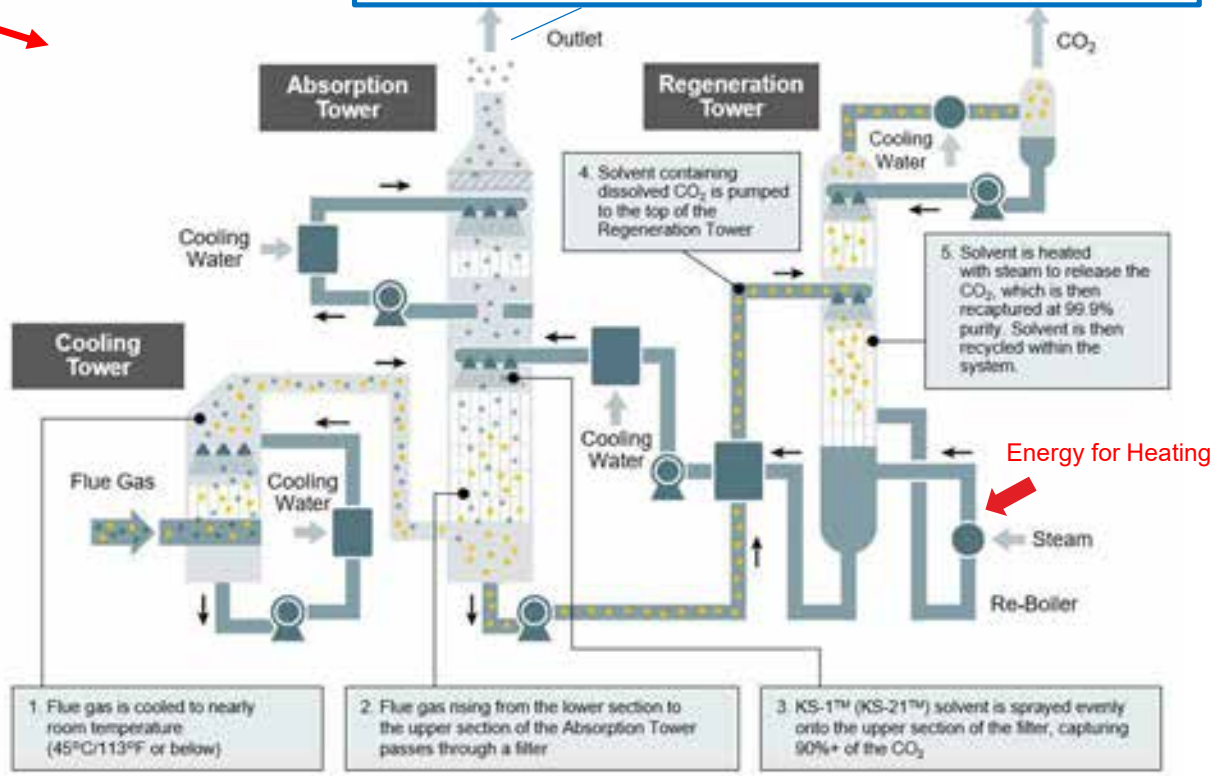
- **Chemical absorption process is driven by a special amine solution.**



- **Key features of Amine (KS-1™)**
  - Better CO_2 loading.
  - Lower energy for regeneration.
  - Reduced deterioration.
  - Less corrosiveness.
  - Long term commercial operation of onshore plants.

Consideration needed

Guidelines are needed to limit the release of chemicals (e.g. Amine slip) to the atmosphere.

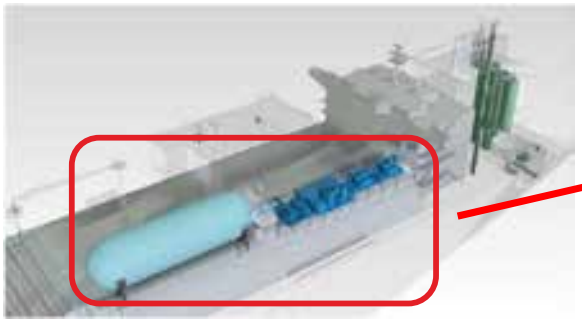


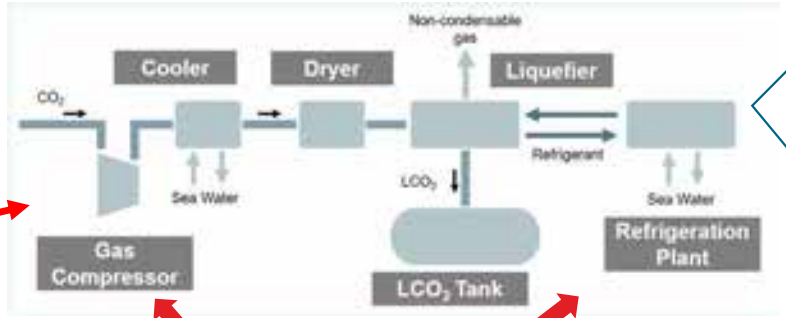
KM-CDR Process ™

https://www.mhi.com

OCCS Technologies : CO_2 Liquefaction and LCO_2 Storage

- **For onboard storage, CO_2 volume is reduced through liquefaction.** **(abt.1/500 of gas volume)**



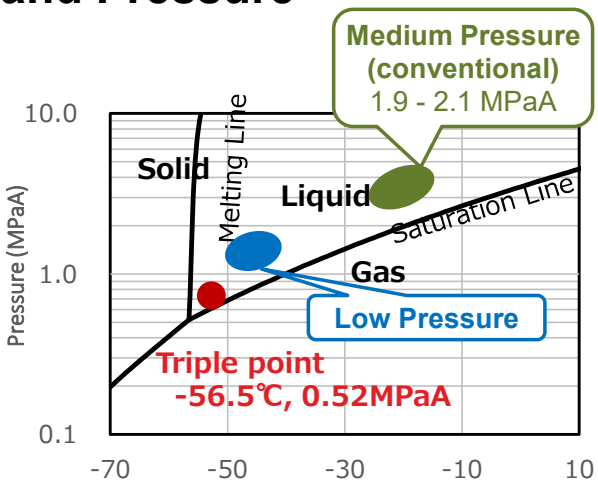


Energy for Refrigeration and Pressurizing.

Mitsubishi shipbuilding is developing a LCO2 handling system and utilizing its expertise in this process.

LCO_2 Temperature and Pressure

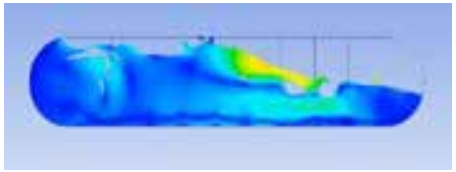
- Maintaining the liquid state requires appropriate control of both temperature and pressure.
- Low pressure is challenge because less margin from triple point.



CO2 Phase diagram

LCO_2 Tank

- Consideration of the weight of LCO_2, holding pressure, holding temperature, and forces due to sloshing are required



Consideration needed

Technical guidelines for safety may be needed regarding the release of CO_2 in emergencies or from the safety valves and etc.

OCCS Benefit : Case Study for VLCC (1 / 2)

Typical case studies ; New Building and Retrofitting application.

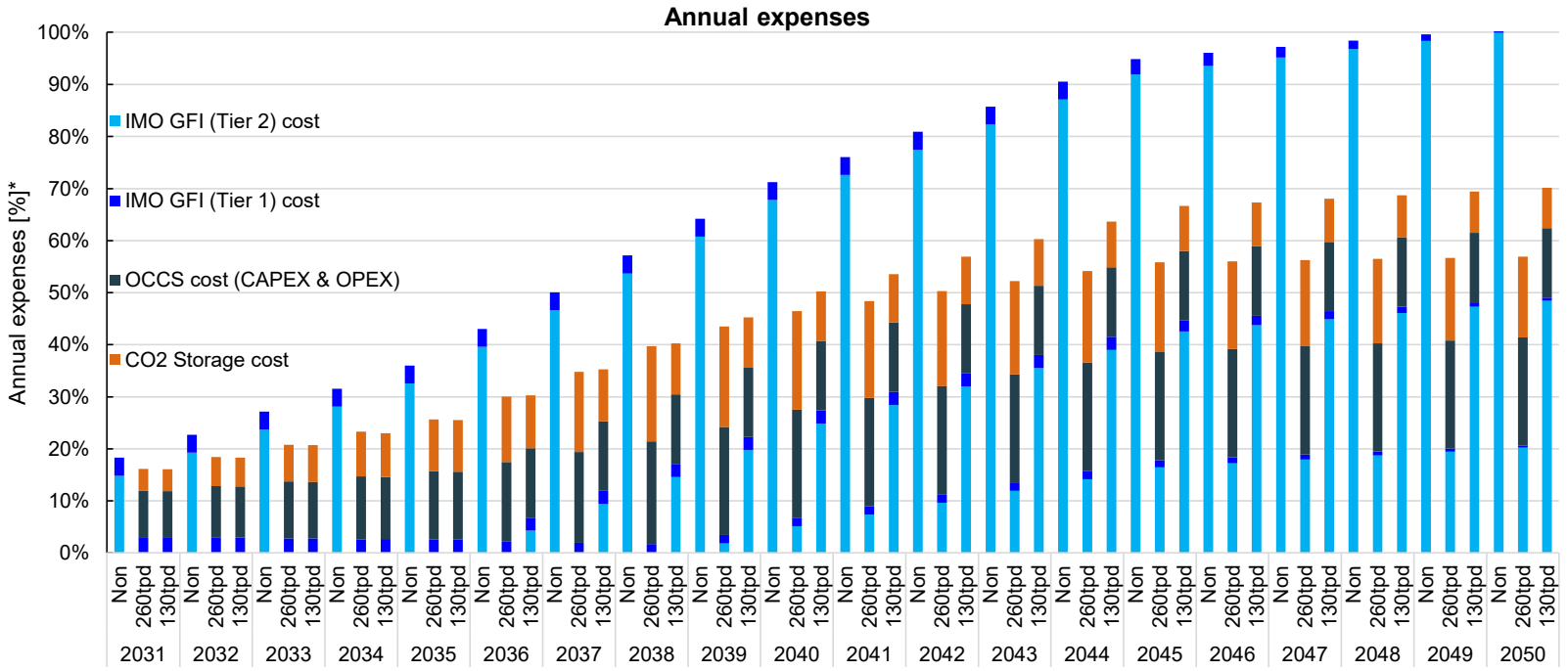
	Case	New Building	Retrofitting
Ship and OCCS cond.	Arrange		
	Engine Outputs	17,120 kW	17,120 kW
	OCCS size	260 ton/day (Tank 2,700 m3 x 4)	130 ton/day (Tank 2,700 m3 x 2)
Simulated one round trip*	CO_2 Capture Ratio**	abt. 66%	abt. 39%
	CO_2 Emission Reduction Ratio**	abt. 53%	abt. 27%
	Extra Energy (compared with non OCCS)	abt. +40%	abt. +20%

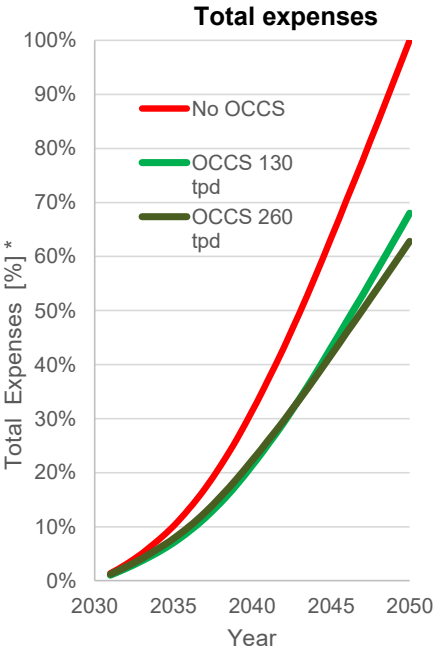
* OCCS is used only while at sea, but it is stopped during unloading, loading, and bunkering.
** Increase of the CO_2 emission due to the use of OCCS is included.

OCCS Benefit : Case Study for VLCC (2 / 2)

OCCS cases have advantages over the non OCCS case.

- The benefit of using OCCS becomes clear, due to the cost differences associated with IMO GFI cost.





Note) OCCS cost includes OPEX and CAPEX. (CAPEX distributed equally)

* : The costs for each case are expressed relatively, with the final cost of the 'non-OCCS' case set at 100%.

OCCS Challenges : CO_2 quality

- **Conformity of captured CO_2 components to CO_2 specifications is essential.**

  - **The CO_2 specifications are set (or will be set) by the CCUS industries.**
  - **In order to handover the captured CO_2 to the CCUS industries, OCCS is requested to process the captured CO_2 to meet the specifications.**
  - **Even though exhaust gas from engine contains unknown impurities, it is necessary to identify possible impurities and prepare provisions for their treatment.**

The CO2 specifications published in Northern Lights project and Wood's Joint Industry Project

https://norlights.com

https://www.woodplc.com

The CO2 specifications for welding is in ISO 14175.

https://www.iso.org

OCCS Challenges : Improvement and suitable application

- **Ship system**
  - **Optimum design ;**

    Evaluate its decarbonization benefits and various impacts (such as cargo capacity, weight and stability, structural strength, visibility, etc) to achieve a balanced design of the ship.

    To mitigate the impacts of OCCS installation, it is also important to reduce the amount of CO_2 emitted from the ship to minimize the size of the OCCS. For this purpose, the utilization of energy-saving devices and improvements in operational efficiency should also be considered.
  - **Find energy for OCCS ;**

    Find and utilize efficient methods to supply the energy required for the OCCS. (Waste heat recovery etc)
- **OCCS**
  - **Energy efficiency ;**

    Improve the efficiency of amine solutions and related devices. Additionally, search for refrigeration gases and refrigeration devices suitable for CO_2 liquiefaction pressure and temperature.
  - **Physical constraints ;**

    Improve space efficiency of the equipment in the OCCS.

Summary

- OCCS has Short- and Long-term roles towards GHG net-zero emissions.
- OCCS technologies are almost ready for practical implementation.
- Economically, the significance of utilizing OCCS is also recognized due to the IMO GFI reduction requirement.
- OCCS is viable option for the decarbonization, however still faces challenges regarding compliance with CO_2 specifications and achieving more efficient utilization.

Mitsubishi Shipbuilding will be working on the development and realization of OCCS, as well as energy transitions, contributing to the further development of shipping and the reduction of environmental impact on a global scale.

THANK YOU

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