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Onboard Carbon Capture Utilisation and Storage: A Promising Solution for Maritime Decarbonisation

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The maritime industry, responsible for approximately 3% of global CO2 emissions, is under increasing pressure to reduce its carbon footprint. The International Maritime Organization (IMO) has set ambitious targets to cut the carbon intensity of international shipping by at least 40% by 2030 and 70% by 2050 compared to 2008 levels. Achieving these goals necessitates a multi-faceted approach, including the adoption of alternative fuels, energy efficiency measures, and carbon capture technologies. Onboard Carbon Capture Utilisation and Storage (OCCUS) is emerging as a promising technology to mitigate CO2 emissions from ships, allowing the continued use of conventional marine fuels while reducing their environmental impact.

One of the main advantages of OCCUS is that it allows for the continued use of well-established maritime fuels while still reducing carbon emissions. This is particularly important as the competition for green energy carriers like ammonia, hydrogen, and methanol is expected to be fierce and expensive across various industries.

The Concept of OCCUS

The process of OCCUS involves capturing CO2 from a ship's exhaust gases, separating it, and storing it onboard for eventual offloading. The captured CO2 can then be transported away and stored deep underground or converted into value-added products.

The process of OCCUS can be broken down into several key steps:

1. Onboard capture

The ship requires a system to capture, remove and process the CO2 to a state suitable for onboard storage. The captured carbon can be in various states, depending on the capture method: compressed gas, liquid, or solid (bonded in a mineral). The different potential methods used are:

- *Chemical absorption* - The exhaust gas stream is scrubbed by a liquid solution, comprising of a chemical agent and water, such as amines. CO2 is selectively absorbed into the liquid, where it is bonded by the chemical compound and thus removed from the exhaust.

- *Membrane separation* - The exhaust gas stream passes through membrane modules that selectively allow CO2 to transport through their structure and become separated from the exhaust. The cleaned gas leaves the system, while the CO2 stream is led to the treatment system, to become either compressed gas, or liquid.

- *Cryogenic separation* - The exhaust stream is cooled down until CO2 is separated into liquid and solid forms. As a result, CO2 is separated from the gas constituents (e.g. nitrogen and oxygen) that require significantly lower temperatures to solidify. The system requires electric power for the cooling and compression unit.

- *Mineralisation (calcium looping*) - Depending on the concept design, the exhaust gas is passed through a reactor, where minerals are used to bond CO2 into their structures, removing it from the exhaust gas. The saturated mineral is gathered as deposited sludge, which is offloaded at the port. The concept involves storage areas for both the mineral and the saturated product.

Step 2 – Onboard storage

The liquefaction of CO2 on ships is the most suitable method for storing and handling captured carbon. The captured CO2 would need to be stored onboard as a liquid in pressurised and insulated tanks to maintain cryogenic conditions. The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) specifies Type C liquefied gas tanks as the standard for pressurised CO2 storage

Step 3 - Offloading and Transportation to reception facility

Periodically, the ship will need to get rid of the captured carbon, either at the end of a voyage, or by making additional port calls or offloading to CO2 carrying vessels. After offloading, the CO2 is transported to CO2 reception facilities. In general, the CO2 can be transported by ship and pipelines (but also trucks and trains). As of April 2024, 35 carbon storage projects were in operation worldwide with a total storage capacity of 37 million tonnes per annum (Mtpa). The forecasted global CCS capacity in net-zero policies' 2050 scenarios ranges from 4,000 to 8,400 MtCO2 stored annually, part of which could be made available for CO2 captured from shipping.

Step 4 - Permanent storage/Utilisation.

The final step includes permanent storage (sequestration) of CO2 as waste or utilisation. As waste, the captured CO2 is permanently stored deep underground geological formations.

Permanent storage of CO2 involves injecting it into geological formations, such as depleted oil and gas fields or deep saline aquifers. This process, known as geological sequestration, ensures that CO2 is stored safely and permanently underground.

Permanent geological storage of CO2 has been achieved since the 1996 at the Sleipner gas field in Norway with around 19 million tonnes stored up to 2022. The Snøhvit CCS project has operated since 2007 and stored around 7 million tonnes up to 2022. Both projects have had some issues with either injection or venting of CO2 but are generally considered to show that permanent CO2 storage is possible.

Utilisation of Stored CO2

Captured CO2 can be utilised in various industrial applications, including:

1. Enhanced Oil Recovery (EOR): Injecting CO2 into oil fields to increase oil recovery rates.

2. Chemical Production: Using CO2 as a feedstock for producing chemicals like methanol and urea.

3. Building Materials: Incorporating CO2 into concrete production to enhance its properties and reduce its carbon footprint.

Current Developments and Pilot Projects

Several companies and organisations are actively developing and testing OCC technologies for maritime applications:

1. Seabound: This startup has successfully piloted its innovative OCC system on a container ship, achieving approximately 80% carbon capture efficiency.

2. Global Centre for Maritime Decarbonisation (GCMD): GCMD has commissioned studies on offloading captured CO2 from vessels, addressing crucial logistical challenges.

3. EverLoNG project: launched in 2021, aims to demonstrate ship-based carbon capture on commercial vessels

4. VDL Carbon Capture: Dutch marine system integrator VDL Carbon Capture is working on compact carbon capture systems designed to fit within the space constraints of ships.

5. TECO 2030 and Chart Industries: TECO 2030 and American manufacturer Chart industries is involved in joint development of onboard carbon capture for ships using the Cryogenic Carbon Capture TM (CCC) technology.

6. MAN Energy Solutions: MAN Energy Solutions is developing an onboard CO2 capture and storage system as part of its strategy to support maritime decarbonisation.

7. Japan's CCR Study: A consortium of Japanese companies, including Mitsubishi Shipbuilding, has been conducting a Carbon Capture on the Ocean (CC-Ocean) project to test a compact CO2 capture system installed on a coal carrier.

Regulatory Landscape

Today, the EU ETS is the only adopted regulatory framework which provides incentives for the use of carbon capture on board ships. However, there are ongoing discussions at the International Maritime Organisation (IMO) and EU levels for updates on the matter:

- IMO: Currently, there are no regulations that include provision for onboard carbon capture in MARPOL or other instruments. At MEPC 81 in March 2024, the IMO agreed to develop a detailed work plan for establishing a framework to regulate onboard carbon capture technologies.

- EU ETS: EU ETS). In May 2023, the EU added a provision (Directive 2023/959) for GHG emission captured and utilised in such a way that they have become permanently chemically bound in a product so that they do not enter the atmosphere under normal use (EU, 2023).

Key Challenges and Considerations

Implementing onboard carbon capture faces several technical, economic challenges:

Technical Challenges

1. Space constraints: Ships have limited available space, requiring compact and efficient capture systems.

2. Energy requirements: Carbon capture processes consume significant energy, potentially reducing overall vessel efficiency.

3. System integration: Capture systems must be seamlessly integrated with existing ship systems and operations.

4. CO2 storage and handling: Safe storage and transfer of large volumes of liquefied CO2 present operational challenges.

5. Capture efficiency: Achieving high CO2 capture rates (>90%) while maintaining system compactness is technically challenging.

Economic Considerations

1. Capital costs: Installing capture systems represents a significant upfront investment for ship owners.

2. Operational costs: Energy consumption and maintenance of capture systems add to vessel operating expenses.

3. CO2 offloading infrastructure: Ports will need to invest in facilities to receive and process captured CO2.

Conclusion

Onboard Carbon Capture Utilisation and Storage (OCCUS) offers a promising solution for reducing greenhouse gas emissions in the maritime sector. Despite technical, economic, and regulatory challenges, research and development are advancing towards commercially viable solutions.

Continued investment in research, pilot projects, and technology scaling, along with collaboration among ship owners, technology providers, ports, and regulators, is essential for overcoming barriers and enabling widespread adoption of OCCUS.

As the maritime industry transitions to a low-carbon future, OCCUS could significantly reduce emissions while allowing the continued use of existing vessel designs and fuel infrastructure. With further development and supportive policies, this technology could become a key component in the global shipping industry's decarbonisation efforts.