Carbon Capture & Storage Onboard – Current State, Prospect & Risks

November 2022

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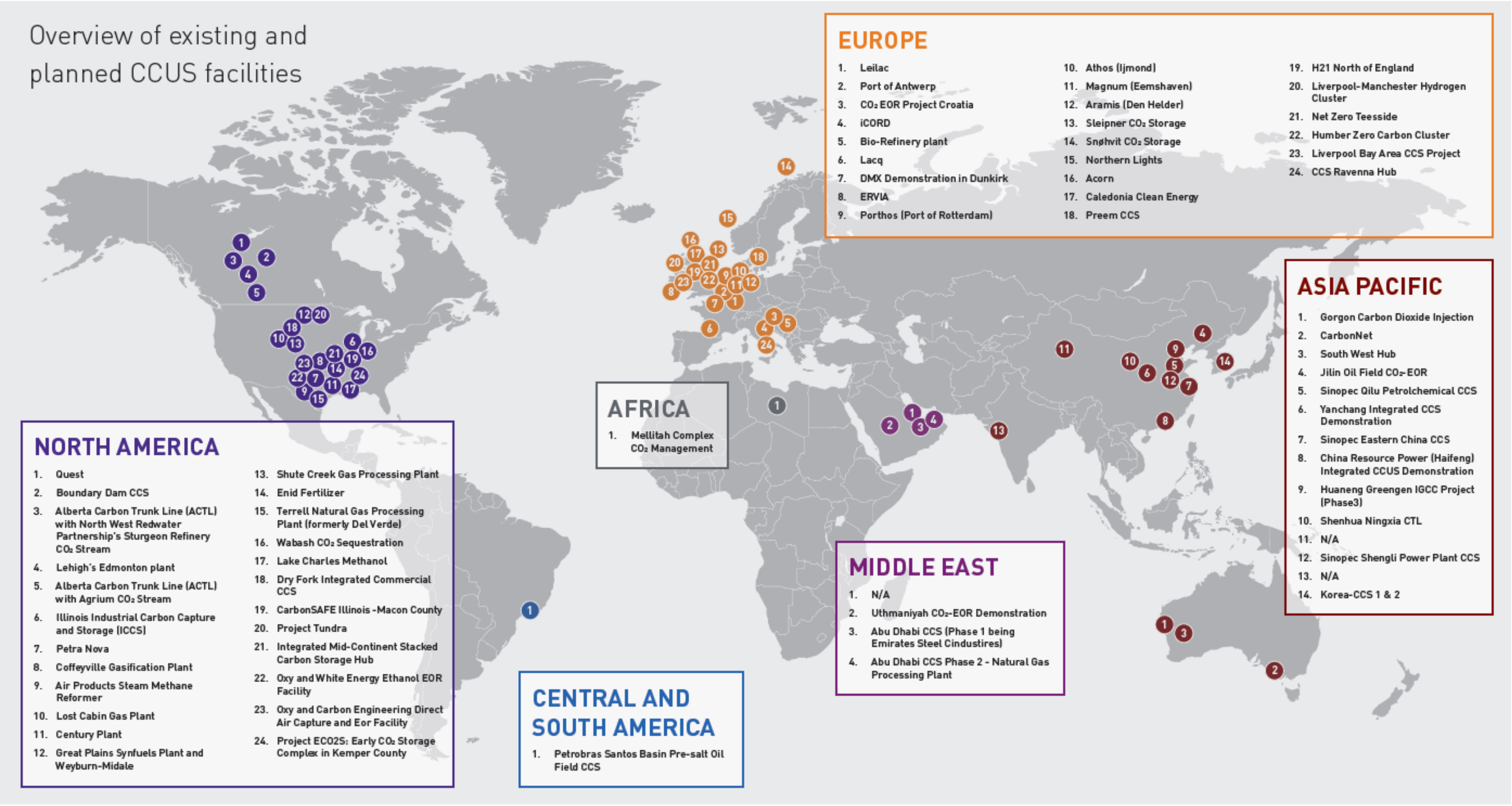
Mega Trends – Closing the Carbon Cycle

- CCSU at source combined with the new Hydrogen Supply Chains, LH2, Ammonia, LOHC
- CCSU post combustion use, combined with a new CO_2 supply chain
- Approximately 50% of CH_4 Calorific Value, ie Market Value, is linked to the Carbon Atom



Source: Global CCS Institute and IOGP data

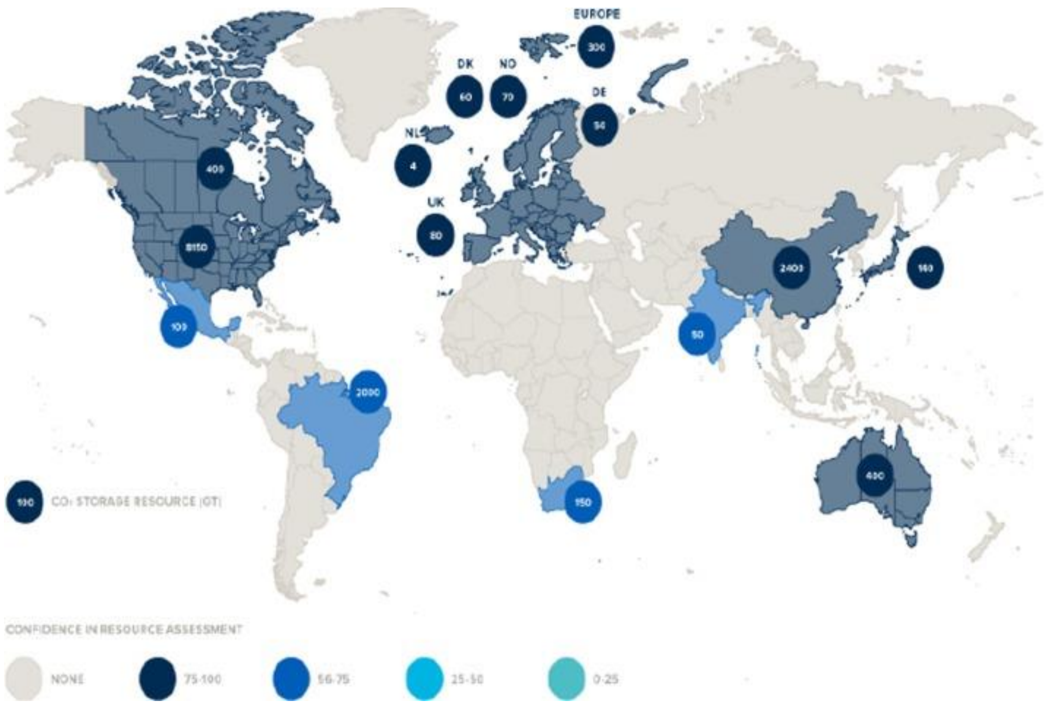
Current estimates show that there is adequate CO_2 storage capacity in the world's saline aquifers and oil and gas reservoirs to store 2 centuries of

The Role of Carbon Capture and Storage in the Energy Transition Hon Chung Lau,* Seeram Ramakrishna, Kai Zhang, and Adiyodi Veettil Radhamani Cite This: Energy Fuels 2021, 35, 7364−7386

Captured Carbon Storage Facilities

Under Development

CCS Facility	Northern Lights	Neptune	DeepC	Northern Endurance Partnership (NEP)	Exxon Mobil
Country	Norway	The Netherlands	Australia	UK	USA
Storage Location	North Sea	Dutch North Sea	Evan Shoals aquifer (Sea North Australia)	North Sea	Brunei Sea
Injection Capacity [m.t/y]	5	5–8	1.5–7.5	–	–



Source: Global Carbon Capture Storage Institute, 2018

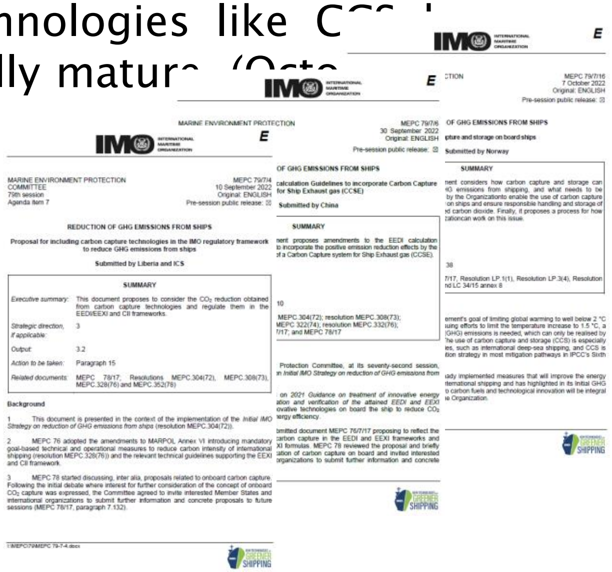
Regulatory Proposals

- **EU Emissions & Trading System (EU ETS)**

The EU Council recognizes that new innovative technologies allow GHG emissions reduction and aims at ensuring that reviewing of their effectiveness should be happening.

- **FuelEU Maritime**

The EU Parliament proposes that the Commission should present a review of the GHG abatement technologies by 1 January 2027 since new GHG abatement technologies like C[illegible] technically and economically matur[illegible] (Octo[illegible]



- **MEPC 79/7/4** (September 2022) submitted by Liberia and ICS proposes to consider CO2 reduction in the **EEDI/EEXI and CII** frameworks.
- **MEPC 79/7/6** (September 2022) submitted by China proposes amendments to **EEDI calculation guidelines** to reflect the contribution of Carbon Capture system for Ship Exhaust gas (CCSE)
- **MEPC 79/7/7** (September 2022) submitted by China proposes amendments to **EEDI survey and certification guidelines** to reflect the positive emissions reduction effects by the installation of CCS
- **MEPC 79/7/16** (October 2022) submitted by Norway considers
  - how CCS technologies can **reduce GHG emissions**,
  - the possible options for the accounting, verification and certification of **captured CO2**, and
  - the CCS incorporation in the **IMO regulatory framework.**
- **MEPC 79/7/22** (October 2022) submitted by Republic of Korea proposes to include the CO2 reduction from CCS in **EEDI, EEXI and CII** regulations.
- **MEPC 79/INF.27** (October 2022) submitted by Republic of Korea introduces a concept of CO2 capture system and recent developments.

Carbon Capture & Storage Onboard – Key points

- CO2 CCS will be **recognised by EU ETS**, the relevant **IMO regime** is not yet in place but **expected** to be established in due time
- The key challenge for CCS onboard lies with S , **Storage and onward Management** of CO2. Other challenges are
    - **Energy demand**
    - **Solvent or other process means availability, storage management**
    - **Purity of exhaust gas treated** – Sensitivity to some impurities may be very challenging e.g. Minimal concentration of SOx (even ULSFO) maybe a barrier.
    - **Purity of CO2 produced** – CO2 global value chain may have strict standards on CO2 quality, greater purity requirement may apply
- Based on the volume/mass of CO2 produced onboard but also cost and energy demand, **partial capture seems more feasible** (starting from a 25% rate of absorption)
- Based on volumes of CO2, a **global value chain of CO2 with many collection points** is a key prerequisite
- Other storage options include transformation of CO2 to a **solid by-product or even disposal at sea** (3rd option seems quite remote and immature)
- **LNG as fuel presents a 25% efficiency** in terms of volume/mass of CO2 produced

Type of Fuel	kg-CO_2/kg-Fuel (C_F)	Fuel Density (kg/m^3)	CO_2 Density (kg/m^3)	m^3-CO_2/m^3-Fuel
Diesel/Gas Oil	3.206	~ 900	~ 1116.4	~ 2.58
Light Fuel Oil	3.151	~ 855	~ 1116.4	~ 2.41
Heavy Fuel Oil	3.114	~ 1010	~ 1116.4	~ 2.82
Liquified Petroleum Gas	3	~ 537	~ 1116.4	~ 1.44
Liquified Natural Gas	2.75	~ 422	~ 1116.4	~ 1.04
Methanol	1.375	~ 791	~ 1116.4	~

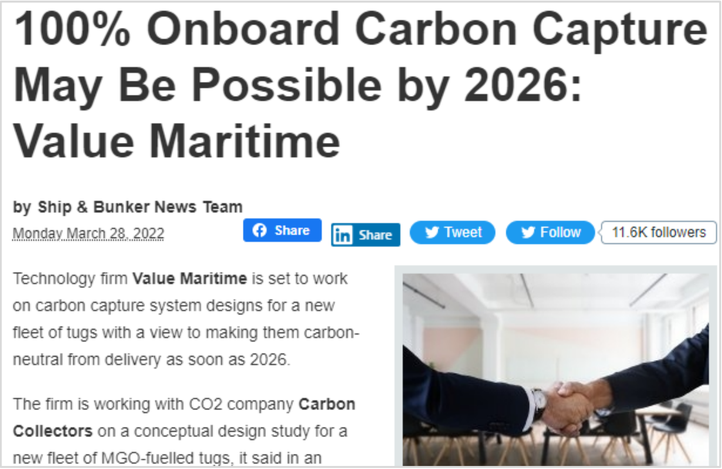
Fuel and CO2 mass and volume conversion Factors


Scorpio Tankers Joins Efforts to Develop Shipboard Carbon Capture

Scorpio Tankers is working with a U.S. start-up to develop and test carbon capture on one of its vessels (Scorpio Tankers)

PUBLISHED MAR 29, 2022 6:49 PM BY THE MARITIME EXECUTIVE

Scorpio Tankers, an operator of more than 120 product tankers, is the latest shipping company to announce that it is joining the efforts to develop shipboard carbon capture systems. Experts initially questioned the viability of the technology


100% Onboard Carbon Capture May Be Possible by 2026: Value Maritime

by Ship & Bunker News Team

Monday March 28, 2022

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Technology firm **Value Maritime** is set to work on carbon capture system designs for a new fleet of tugs with a view to making them carbon-neutral from delivery as soon as 2026.

The firm is working with CO2 company **Carbon Collectors** on a conceptual design study for a new fleet of MGO-fuelled tugs, it said in an

CCSU & Fuel Compatibility

CCSU can only work with a carbon atom in Fuel

Greater compatibility with cleaner fuels like LNG and LPG

- Almost 1/1 ratio of fuel to CO2 cubic capacity
- Cleaner flue gas to treat
- Cleaner CO2 produced
- An up to 24% lower GHG footprint which allows a more delayed application
- Synergy with cryogenic applications

Type of Fuel	15-days at 15MW			15-days at 40MW		
	Fuel volume	CO_2 Volume	Total Volume (Fuel + CO_2)	Fuel volume	CO_2 Volume	Total Volume (Fuel + CO_2)
Diesel/Gas Oil	~ 504 m^3	~ 1304 m^3	~ 1808 m^3	~ 1345 m^3	~ 3477 m^3	~ 4823 m^3
Light Fuel Oil	~ 559 m^3	~ 1351 m^3	~ 1911 m^3	~ 1493 m^3	~ 3603 m^3	~ 5096 m^3
Heavy Fuel Oil	~ 503 m^3	~ 1417 m^3	~ 1920 m^3	~ 1341 m^3	~ 3780 m^3	~ 5122 m^3
Liquified Petroleum Gas	~ 795 m^3	~ 1148 m^3	~ 1943 m^3	~ 2121 m^3	~ 3061 m^3	~ 5182 m^3
Liquified Natural Gas	~ 947 m^3	~ 985 m^3	~ 1933 m^3	~ 2527 m^3	~ 2627 m^3	~ 5155 m^3
Methanol	~ 1232 m^3	~ 1195 m^3	~ 2427 m^3	~ 3286 m^3	~ 3187 m^3	~ 6473 m^3

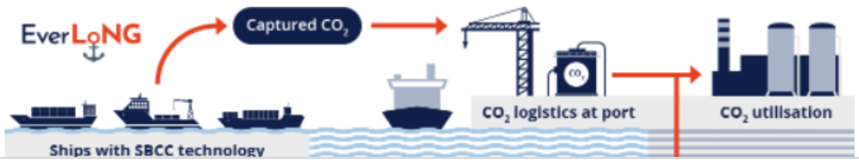
Fuel and CO2 volumes calculated per voyage leg

EverLoNG ship-based carbon capture project wins EU funding

CARBON CAPTURE USAGE & STORAGE

April 7, 2022, by Naida Hakirevic Prevljak

A cross-boundary project involving science and industry experts has landed €3.4 million ($3.7 million) from an EU climate action fund to accelerate the uptake of ship-based carbon capture (SBCC) by international shipping companies.



Carbon Capture Processes

Post-Combustion	Pre-Combustion	Oxyfuel Combustion
Capture of CO_2 from exhaust gas stream produced by fuel air combustion	Capture of CO_2 following the processing of fuel before combustion	Combustion of fuel with pure oxygen
Applied technologies • Chemical Absorption • Membrane Technology • Cryogenic Carbon Capture • Calcium Looping • Molten Carbonate Fuel Cell (MCFC)	• Synthetic gas produced from fossil fuels used as fuel • CO_2 separated during syngas production	• Oxygen separated from air in a separate process • Fossil fuel combustion takes place with oxygen/mixture of oxygen and re-circulated flue gas • Flue gas cooled and pure CO_2 further processed
Benefits		
• Applicable to retrofits • High operational flexibility • Lower technology risk	• High efficiency • Ability to widescale adoption & commercialization • Multiple fuels application • Low technology risk	• Very high capturing levels • Small physical size of the unit • Ability of retrofitting
Limitations		
• Low carbon capture efficiency • High energy generation costs • Large parasitic loads	• High CAPEX • Heat transfer challenges	• Inflexibility due to complex configuration • High combustion temperatures -> expensive materials • Reduced purity

Post-Combustion Capture Technologies

Chemical Adsorption

CO_2 in Exhaust absorbed by chemical solvent (e.g., Monoethanolamine)

[+] Highest technology maturity

[+] Lower energy demand in comparison with the cryogenic CO_2 capture system

[-] Large mass flow of solvent,

[-] Higher energy consumption

[-] Expensive solvent and high OPEX

[-] Safety hazards for specific solvents like Ammonia

Membrane Technology

Selective permeation of gases in exhaust through membrane

[+] Simpler system layout

[+] No need for solvent solutions, regeneration units etc.

[-] Membrane unit fouling

[-] Less effective when CO_2 content <10%

[-] Higher power requirements

[-] Pre-treatment of flue gas

Cryogenic Carbon Capture

CO_2 in exhaust cryogenically cooled with other components separated

[+] Able to remove several component gases in exhaust

[+] Lower OPEX in comparison with chemical absorption-based technologies

[+] Applicable to LNG fuel processing systems

[-] Higher onboard power consumption

[-] Low technology maturity

Calcium Looping

The process consists of two main cycles: an air contractor (CO_2 capture cycle) and a sorbent regeneration cycle

[+] CO_2 storage onboard not required

[+] Low CAPEX & OPEX

[-] Solvent losses

Molten Carbonate Fuel Cells

MCFC can operate as a CO_2 separator and concentrator while generating power

[+] Power production instead of consumption

[+] Low OPEX

[-] High CAPEX

[-] Technologically complex solution

[-] High separation efficiency (over 50%) but not comparable with the chemical absorption systems

Evaluating a system for shipboard installation

Key considerations

GHG reduction potential

Reduction of CO_2e emissions

CAPEX & OPEX

Equipment, components and Installation

Onboard fuel related costs, maintenance, solvent top-up

Handling of captured carbon

Technology maturity

Conceptual development

Pilot project

Proven technology with previous cases

Shipboard installation feasibility

Does installation requires major changes to established vessel design?

Space availability – CO_2 storage, CCS equipment

Safety

Safety risk from operations, exposure to solvents, captured CO_2

Ease of Operation

Training and operational manpower requirement onboard

Carbon Capture Makers with Technologies

Maker	Technology	Applications	Comments
Ecospray	Molten Carbonate Fuel Cell (MCFC)		Projected for development
Ecospray	Amine absorption		Derisking stage with pilot applications expected soon
Ecospray	Calcium Looping		Derisking stage with pilot applications expected soon
Aqualung Carbon Capture AS	Membrane technology	Cement plants and Natural Gas processing plant in Arkansas	Global Ship Lease (GSL) and Golar LNG invested in a carbon capture initiative led by Aqualung
Chart Industries + Svante	Rapid absorption technology (Svante) Cryogenic Carbon Capture Technology (Chart)		Cooler by Design MoU signed between Chart and Svante
Value Maritime	A capture module captures CO2 from the vessel's exhaust and uses the CO2 to charge a CO2 battery	EPS – 2 x tankers (within 2022) JR Shipping Group – 2 x container feeder vessels	CO2 Battery refers to a containerized tank that can be swapped at port
Daphne	Hybrid system combining solvent and membrane technology	Unit under development no application yet	Differentiating advantage it can be coupled with other Daphne abatement systems to purify the process
Wartsila	Under development probably solvent or membrane	Solvang Ethylene Carrier	Scrubber CCS System
PANASIA: PAN-CCUS	Wet absorption	target LNGC market	
VDL AEC Maritime B.V.	Solvent solution		Scrubber CCS System
Headway Technology Group (OceanGuard®			Autonomous calculation and adjustment of the CO2 collection ratio to meet IMO

Carbon Capture Projects & Platforms

Partners	Research Projects	Technology	Application / Demonstration
Conoship	EverLoNG	Demonstration and preparation project with many partners focusing at the framework and port reception infrastructure	Designed for LNG fueled ships, LR participates in the project
TNO, Conoship International BV, FME, Heerema Marine Contractors and Linde Gas Benelux	DerisCO2	Reactive absorption	LR HAZOP expected very soon pilot applications include 1. LNG Carrier 2. Heerema LNG fueled Crane Vessel (LR Classed)
Conoship with a consortium of German and Dutch companies	CO2ASTS	aqueous solution containing a chemically active amine (30wt% monoethanolamine)	Reference cases River boat, Dredger, Cruise ship
Mitsubishi Shipbuilding Co Ltd Kawasaki Kisen Kaisha Ltd (K Line) ClassNK	Carbon Capture for the Ocean (CC-Ocean)	Amine chemical absorption	"K" Line's bulk carrier "Corona Unity"
SINTEF Energy Research, SINTEF Ocean, NTNU, University of Oslo, Seoul National University, Wärtsilä Moss, Klaveness and Calix Limited	CCShip	Solvent and other novel CO2 solutions	Expected on Klaveness Combination Carriers
TECO and AVL	The relevant CCS technology will be integrated as part of the TECO 2030 Future Funnel	No info available yet	Decided to move from feasibility to system/process development
SINTEF, Wartsila, Aker Solutions, Cognite, Aize, AGR, OpenGoSim, Wintershall Dea, Vår Energi, Lundin, Equinor and TotalEnergies	LINCCS		The broader LINCCS project is focused on reducing costs for new carbon storage facilities by 70 percent

Currently ongoing projects – LR Involvement

A brand new CCSU onboard set of LR Rules to come live 1st January 2023

Project	Technology	Status
Ecospray	Chemical Absorption	Early stage design development/de-risking
TNO, Conoship International BV, FME, Heerema Marine Contractors and Linde Gas Benelux – DerisCO2	Chemical Absorption	HAZID workshop scheduled Project vessel – Heerema LNG fueled Crane Vessel (LR Classed)
Daphne technology	Hybrid system combining solvent and membrane technology	Unit under development no application yet
Fleet of Container ships – Japanese Yard 13.7K TEU project	Chemical Absorption/Others	Early stage design development
Value Maritime – MR tanker CCS installation/Container Feeder	Chemical Absorption	AiP Completed, HAZID/HAZOP sessions undertaken, Installation scheduled
Panasia CCS	Chemical Absorption	HAZID/HAZOP scheduled
Sinotech CCS – 58K Bulk	Chemical Absorption	AiP Completed, HAZID/HAZOP sessions

Concluding Remarks

- CCSU constitutes an intriguing solution for reducing CO_2 emissions
- It can deliver up to a Net Zero ambition
- Its infrastructure is going to constitute part of a wider Carbon value
- It remains the key technology to prolong the use of fossil fuels
- Its financials remain competitive to hydrogen based fuels
- It blends better with fuels already delivering carbon savings
- Much will depend on the integration of CCSU in Regulatory Framew
- Class Rules are around the corner
- Pluralism of technologies, makers and solutions creates a positive momentum
- Gradual and modular application is possible leading to more mature business roll out

Thank you

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