Challenges of Onboard CO_2 Capture and Storage (OCCS)

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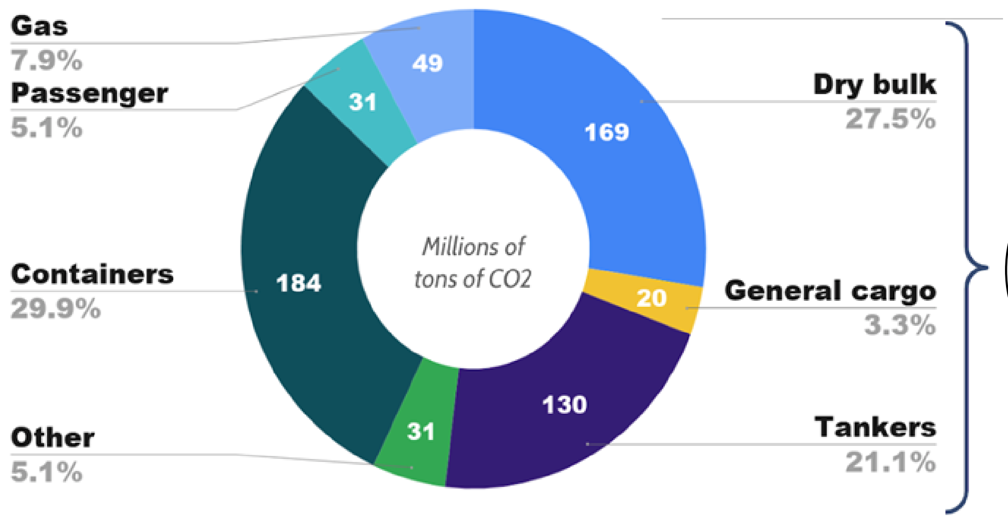
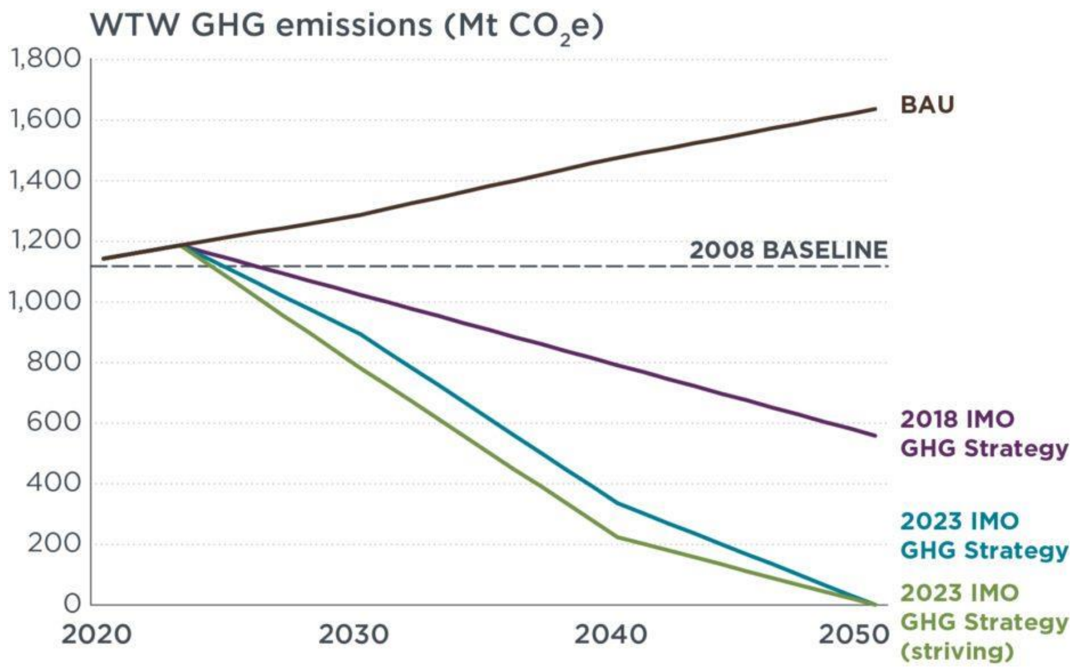
CO_2 Emission from Shipping Industry: Trends and Regulations

World fleet CO_2 emissions in 2023



>700 million tons of CO_2

GHG Emission Pathway Under Different Scenario



IMO Action to Reduce Greenhous Gas Emissions from International Shipping

2008	2018	2023	2023-2030	2030	2040	2050
2011 **Base Year**	2018 **Initial IMO strategy on reduction of GHG emissions from ships**	2023 **2023 IMO strategy on the reduction of GHG emissions from ships**	2023 – 2030 • **Low carbon fuels** • **Emission reduction mechanisms** • **Market-based measures (CO_2 tax)**	2030 - **20% Total reduction in CO_2** - **40% reduction in CO2 emission per transport work**	2030 - 2050 **70% reduction of total annual GHG**	2050 **Net-zero GHG Emission**

Source: IMO. 2019

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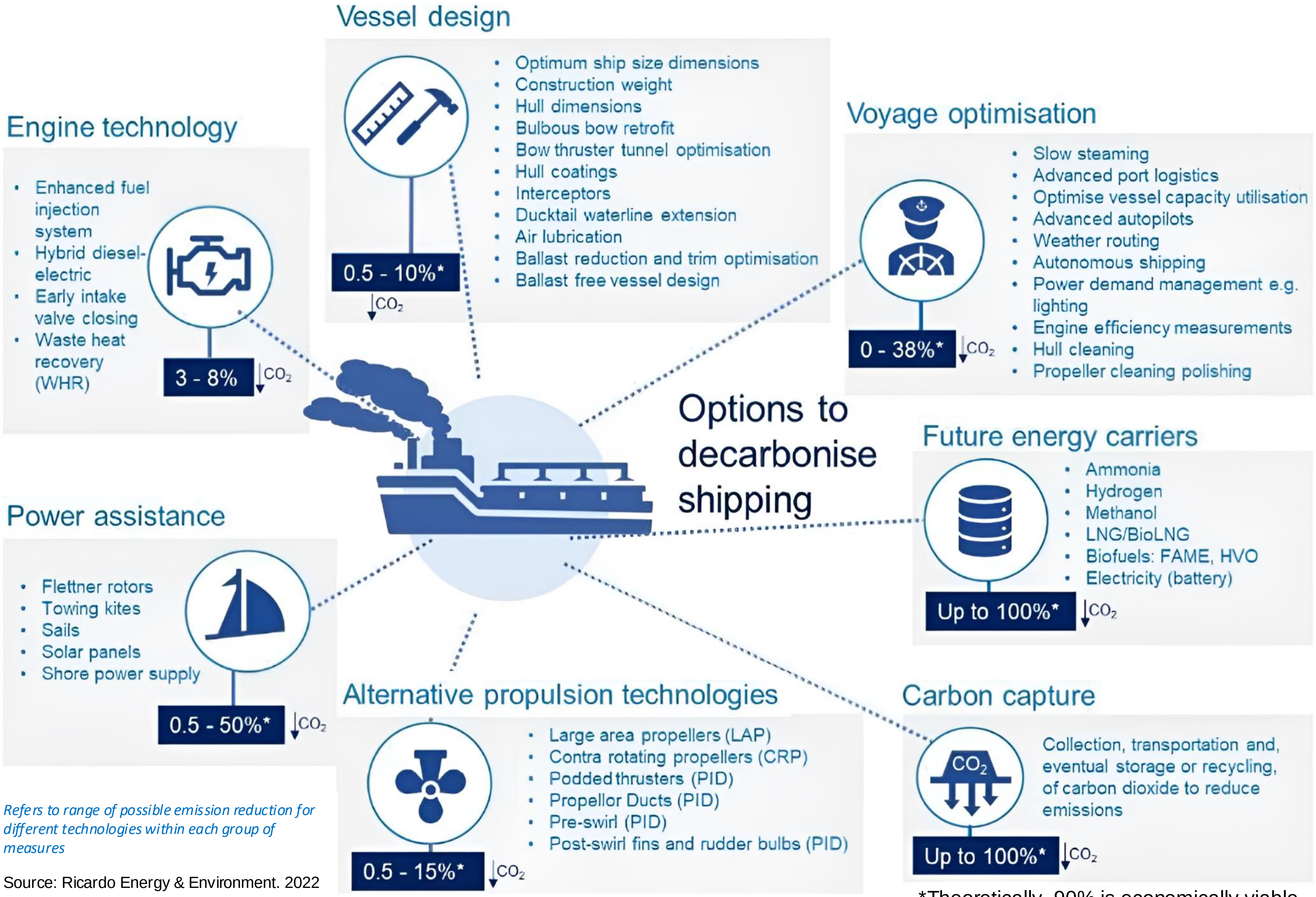
Pathway Towards Ship Decarbonisation



Refers to range of possible emission reduction for different technologies within each group of measures

Source: Ricardo Energy & Environment. 2022

*Theoretically, 90% is economically viable

A combination of multiple approaches is the way forward to achieve decarbonisation of the maritime industry.

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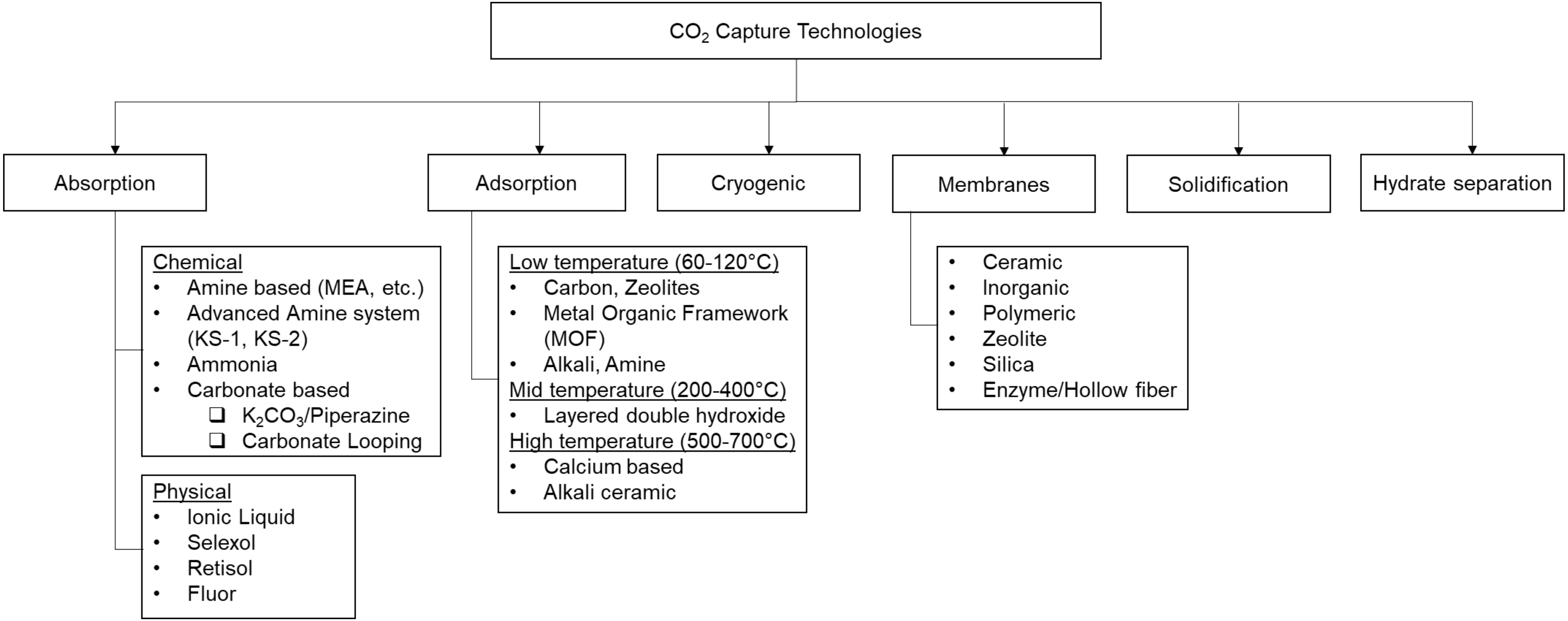
Post-combustion Capture Technologies: Overview



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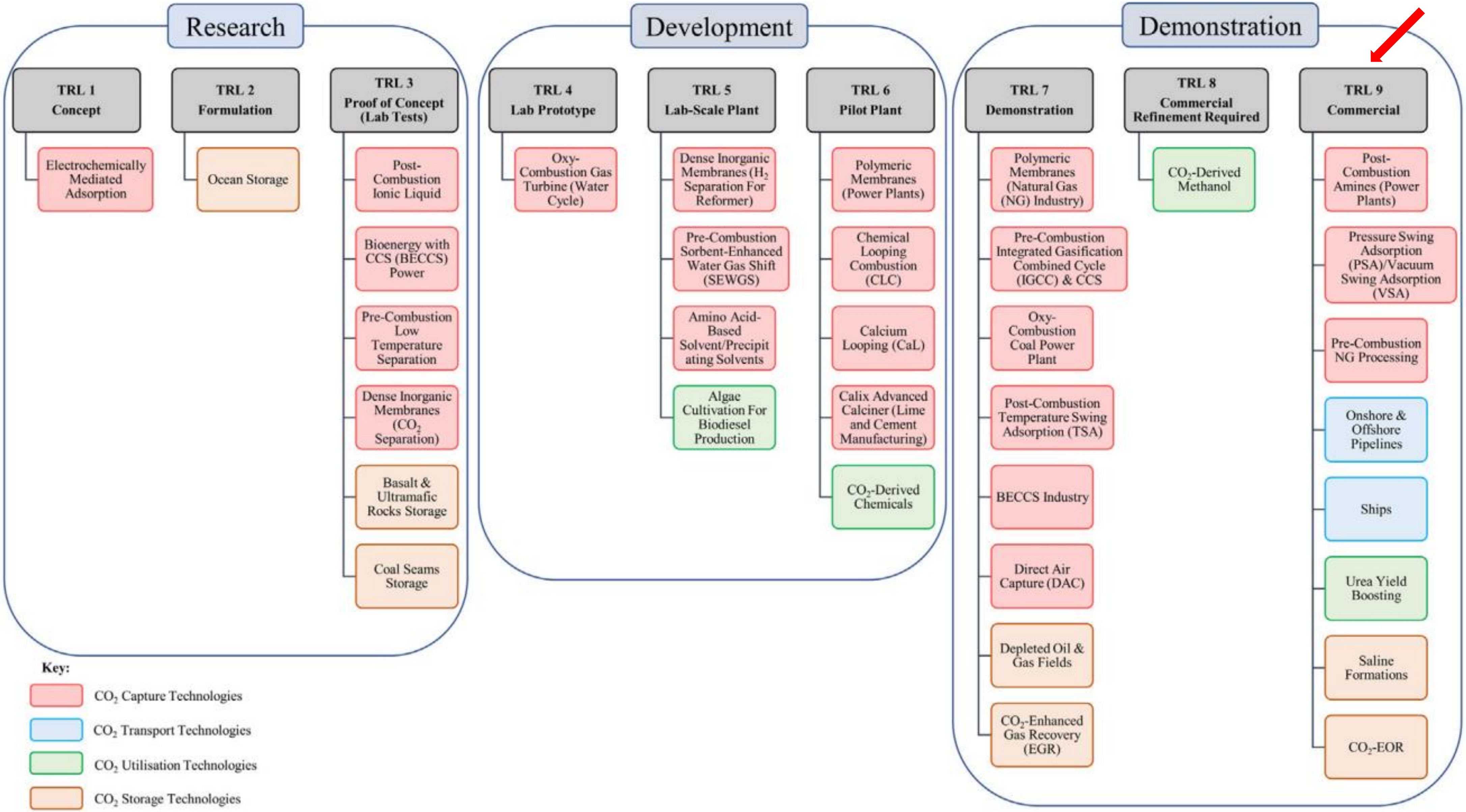
Technology Readiness Level for Different CCUS Technology

TRL for land-based CO_2 Capture. TRL for Onboard CO_2 Capture is expected to be lower.



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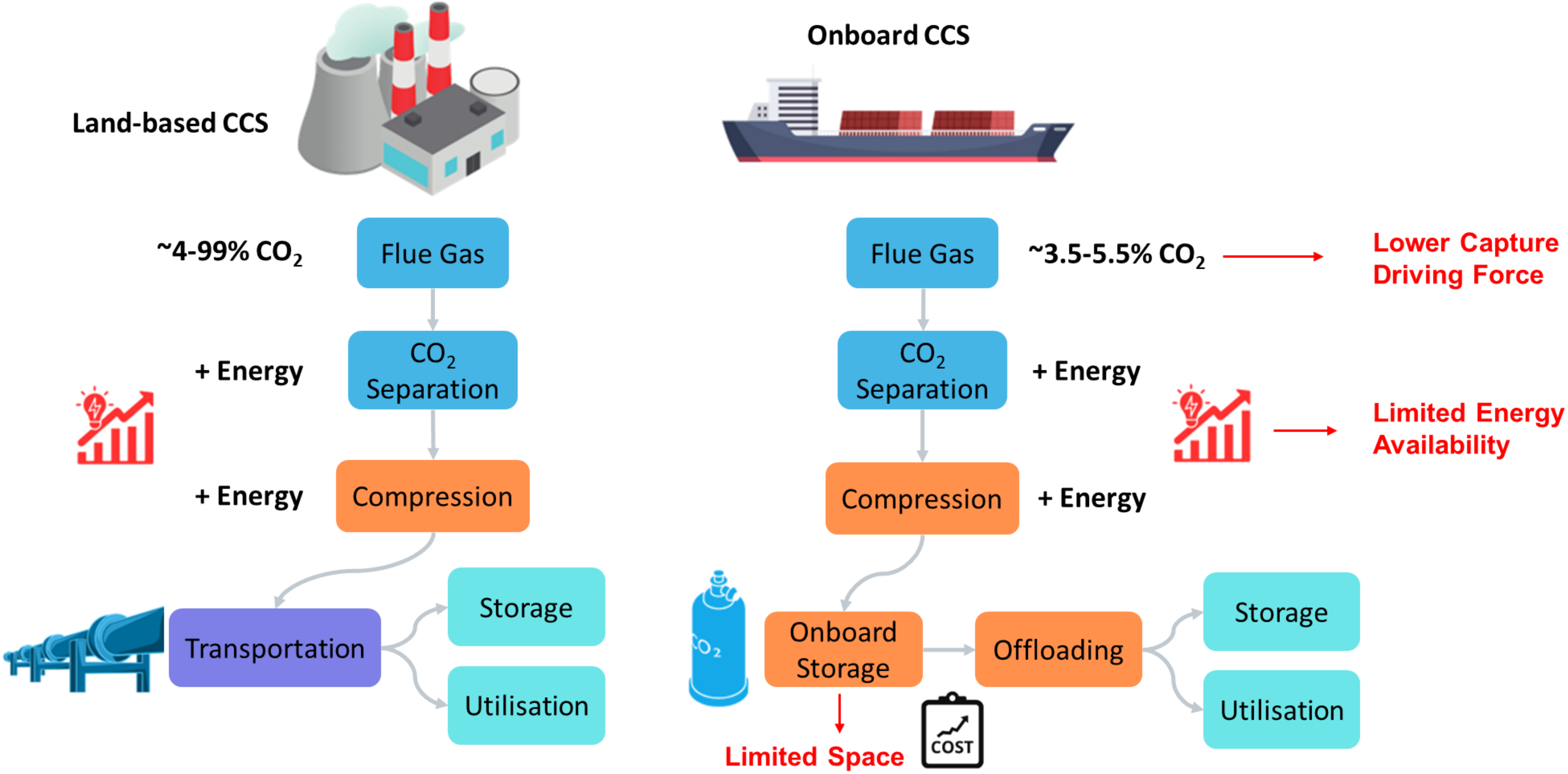
Differences Between OCCS and CCS



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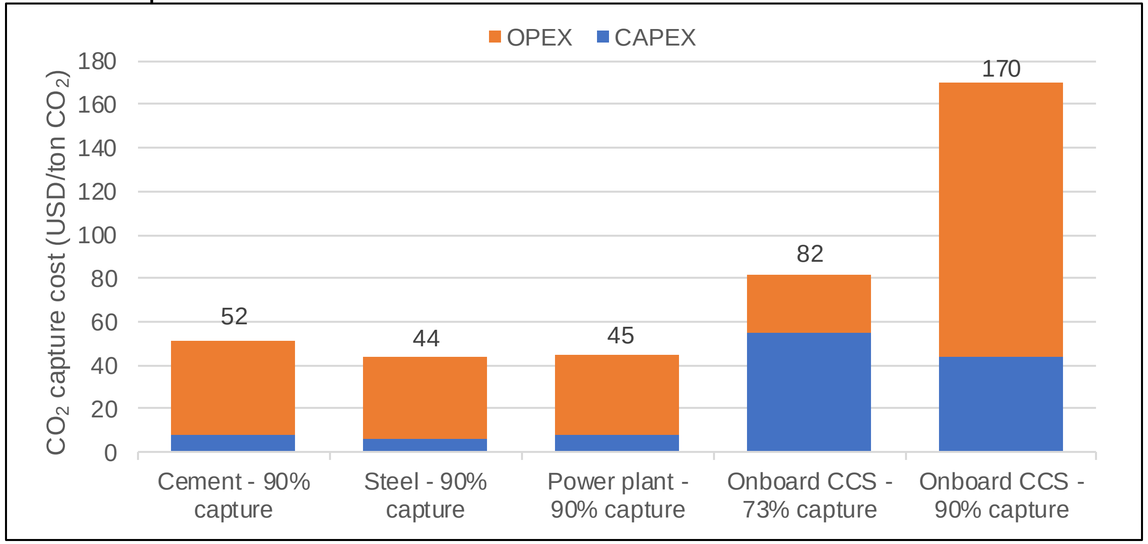
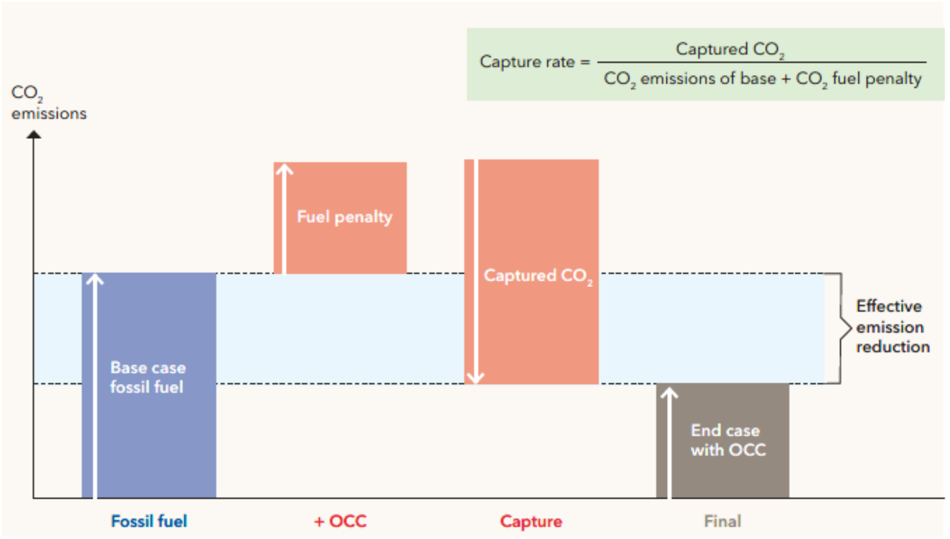
Case Study: The Simulation of Conventional Amine (MEA) for Onboard CCS

Cost comparison between land-based CCS and OCCS



Source: Roussanaly et al. 2018

Fuel penalty to be included to obtain effective CO_2 capture



Description	Case Study : Amine-based system for		
	No Capture	Onboard CCS-73% capture	Onboard CCS-90% capture
Main engine power, MW	17		
Auxiliary engine, MW	3		
CO_2 capture system	Without CO_2 capture	Amine-based	Amine-based
CO_2 removal		73%	90%
CCS power consumption (MW_e)		0.86	1.1
Regeneration duty (MW_{th})	-	7.8	12.2
Equipment size	-	A: ϕ4.2mxH12.5m S: ϕ1.6mxH6.5m Amine tank0.65m^3	A: ϕ4.9mxH12.5m S: ϕ2.1mxH6.5m Amine tank: 1.0m^3
CO_2 storage (m^3)	-	560 (liquefied CO_2)	940 (liquefied CO_2)
Cost of CCS (USD/ton CO_2)	-	82	170

Energy intensive

Huge footprint

Source: Luo and Wang, 2018

Although conventional amine system (MEA) is a proven technology for power plants, it may not be directly applicable for ships because of its huge footprint and high energy requirement, leading to a higher cost per ton of CO_2.

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Challenge of CCS to meet IMO – Ship Types

LNG Carrier	Tanker	Bulk Carrier	Container
+ Integration of cooling from LNG for liquefaction	+ More available space for CO2 storage on deck	+ / - Bigger ship may have space, but smaller vessels have more energy and space constraints	+ Frequent port calls enable less CO_2 to be stored onboard. However, this depends on the maturity of CCUS supply chain
+ Lesser CO_2 from LNG require lesser space and energy	- Energy and space constraints for higher CO_2 capture rate	- Energy and space constraints for higher CO_2 capture rate	- Cost loss may be more significant because of container loss.
- Space constraints	- Cargo loss	- Cargo loss	

Source: DNV

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Challenge of CCS to meet IMO – Space Requirement

Impact of voyage duration and capture rate to the space requirement of CO_2 storage

	Volume of Fuel Used	Volume of liquefied CO_2 captured in 1 trip of ~2700 hours (m^3)	
		30% Capture	90% Capture
Scenario 1	100% Fuel Tank	2,387	7,161
Scenario 2	75% Fuel Tank	1,791	5,373
Scenario 3	50% Fuel Tank	1,194	3,582
Scenario 4	25% Fuel Tank	597	1,791

The different scenario shows that lower CO_2 capture and lesser trip duration will reduce space requirement for CCS:

Scenario 1:

- there is no CO_2 offload throughout the entire trip (CO2 is captured and stored throughout voyage duration)

Scenarios 2 to 4:

- CO_2 needs to be offloaded at the nearest port when 75%, 50%, or 25% of fuel was consumed.
- This can reduce the space requirement to store CO_2 after CCS before interim offload

- Each scenario may not be applicable to all type of ships
- Container ship may be able to be in Scenario 1
- Other ship types may not have frequent port of call

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Economic Aspects – Ship Owners and Operator

Regulatory body

IMO

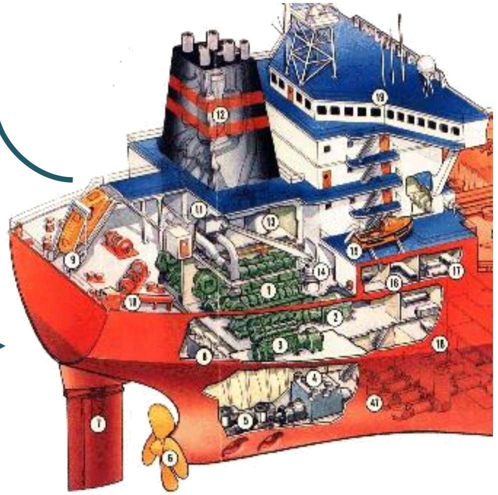
Market-based mechanism
(Carbon tax, bunker levy and carbon credit*)

Saving
due to CO_2 reduction
(application of
post-combustion and alternative fuels)

Reduction of CO_2 emission

1. CO_2 capture technology

+



Selling of CO_2

Revenue

Utilisation of CO_2

Limited uptake on CO_2 utilisation become the bottleneck for OCCS

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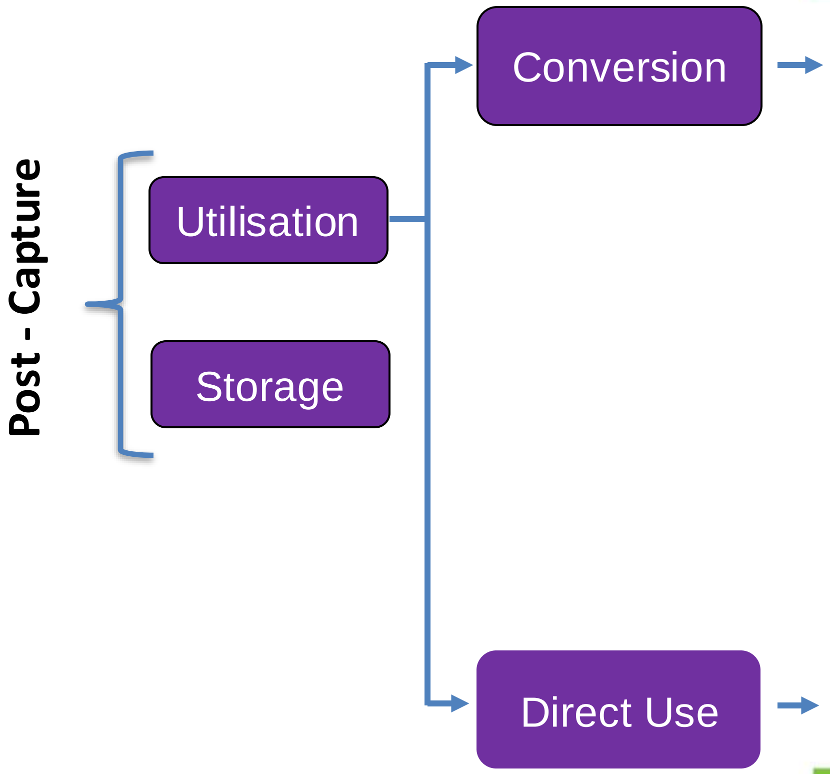
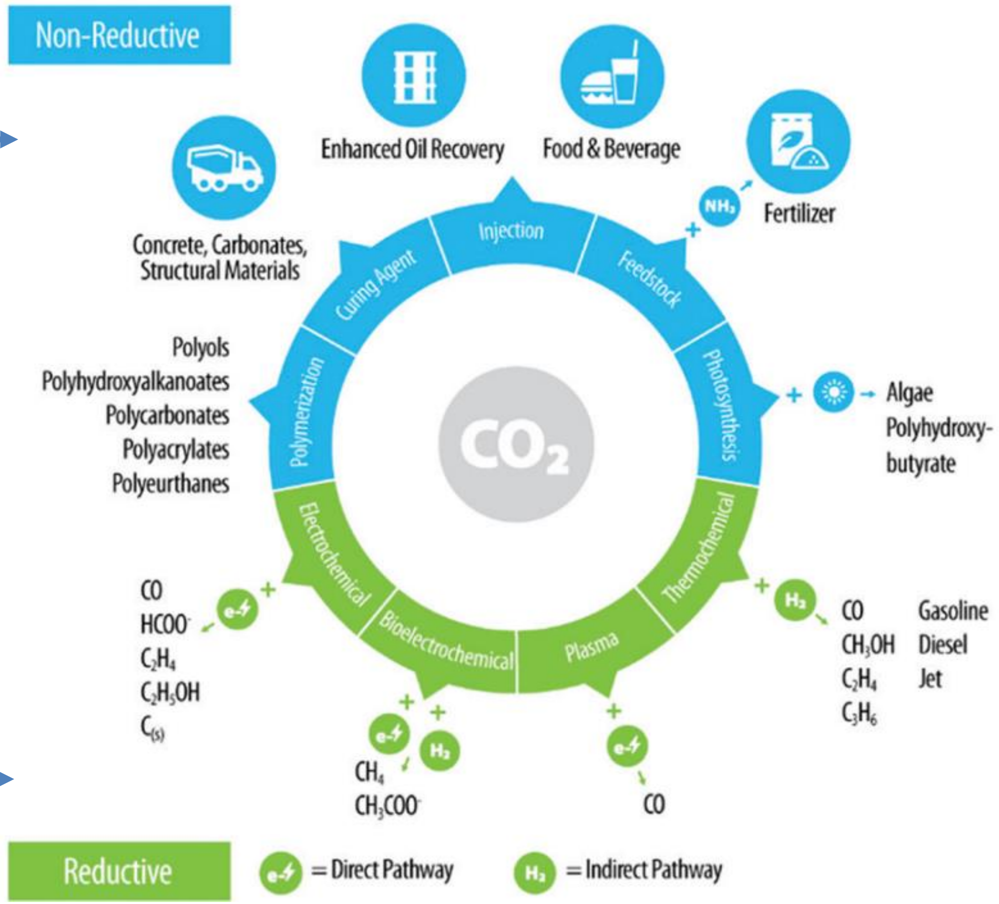
CO_2 Storage and Utilisation





Source: NREL

International Energy Agency (IEA) estimate CO_2 utilisation is around 230 million tons CO_2 in 2019:

- Fertiliser : 57%
- EOR: 34%
- Food and beverages: 6%
- Others: 3%

This is less than 30% of CO_2 emitted by the shipping industry

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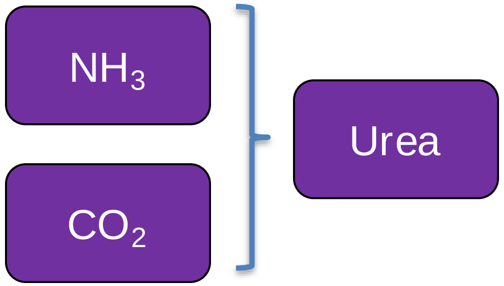
CO_2 Storage and Utilisation

Fertiliser production



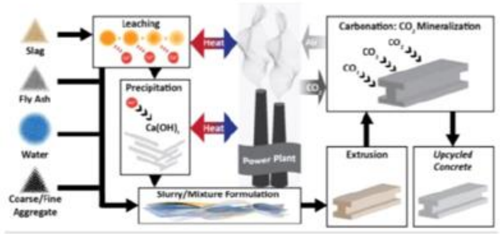
Algae cultivation for biodiesel production

Injection of flue gas into an open algae system (Orlando, Florida, USA)

US Dept of Energy, 2020

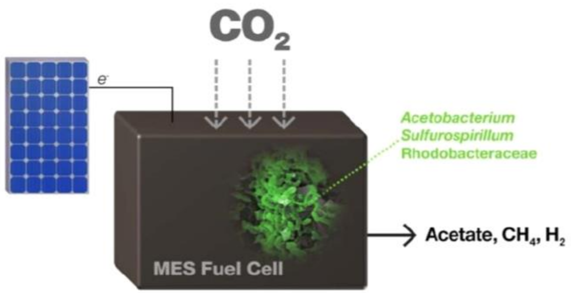
Additives for concrete production

DOE Office of Fossil Energy



Sant, 2019

Conversion to fuels/chemicals



Gulliver, 2019. US DOE/NETL Annual Meeting, Carbon Capture and Utilization, August 2019, Pittsburgh, PA

Pathways	Application/ Product	CO_2 Utilised (Mt CO_2/year)	Product Produced (Mt/year)	CO_2 Storage Period	TRL
Direct usage	Algae cultivation for biodiesel	2.0	1.0	Weeks/Months	4 to 7
	Beverage carbonation	2.9	2.9	Days/Months	9
	Enhanced oil and gas recovery (EOR/EGR)	25.0	7% to 23% of oil reserve; <5% of gas reserve	Millennia	9
	Food packaging	8.2	8.2	Days/Months	9
	Industrial gas	6.3	6.3	Days/Months	9
	Urea yield boosting	132.0	180.0	Days/Months	9
Conversion	Carbonates	0.5	>2.0	Decades/Centuries	7 to 8
	Methanol	10.0	60.0	Weeks/Months	7 to 8
	Chemicals (such as formaldehyde and acrylates)	6.5	28.0	Days/Decades	6 to 8
	Polymers (such as polycarbonates and polyurethanes)	1.5	15.0	Months/Decades	7

The majority of CO_2 uptake is fertiliser industry, followed by EOR. Other technologies are still in development and not yet at commercial level

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Summary

Topic	Challenges	Potential Solutions
Capture Rate	CCS will not be able to reach net zero by its own	CCS can be combined together with alternative fuel to improve capture rate
Energy Consumption	CCS requires energy. Proper configuration and additional energy may be required to achieve targeted CO_2 capture percentage	Better solvent and heat recovery management
Space Requirement	Cargo loss from CCS unit	Frequent port of call and/or lower CO_2 capture rate
Cost	It is more expensive than land-based CCS. How much more expensive depends on many factors, including the uptake on CCS	Better solvent/technology, design optimisation, combined with existing HFO+scrubber system
CO_2 Utilisation	Limited CO_2 handling infrastructure, slow development on CO_2 utilisation technology	Development of high TRL technology, hybrid solutions (storage and utilisation)

CCS faces challenges posed by the CO_2 offloading and logistic. The current economics of CCS offtake are not currently viable based on prevailing technological trends.

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Thank you

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