Unlocking the carbon value chain: Operationalising offloading, transport and offtake of onboard captured CO_2

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Technical Seminar on Onboard Carbon Capture and Storage (OCCS) Systems
IMO Headquarters

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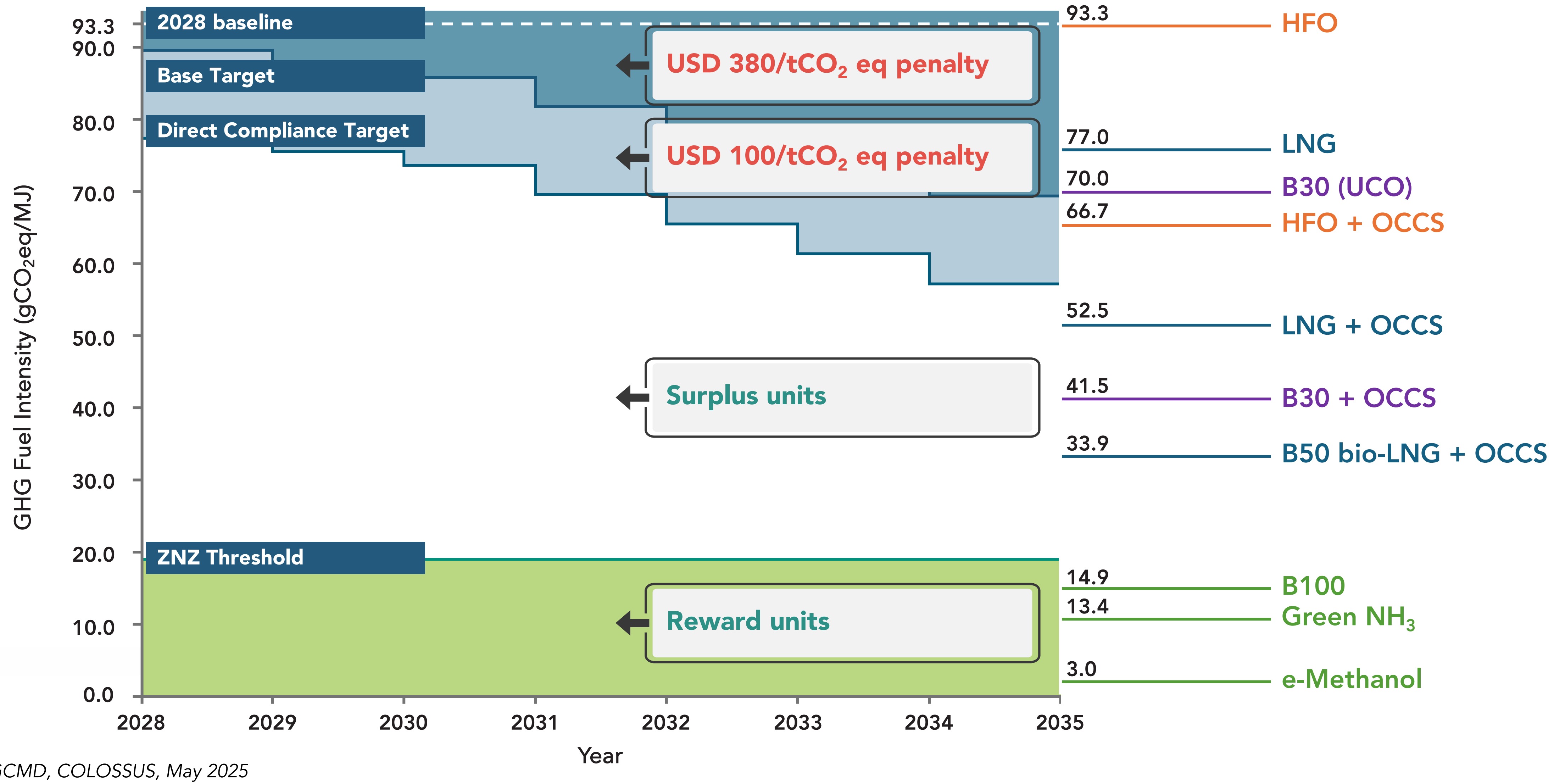
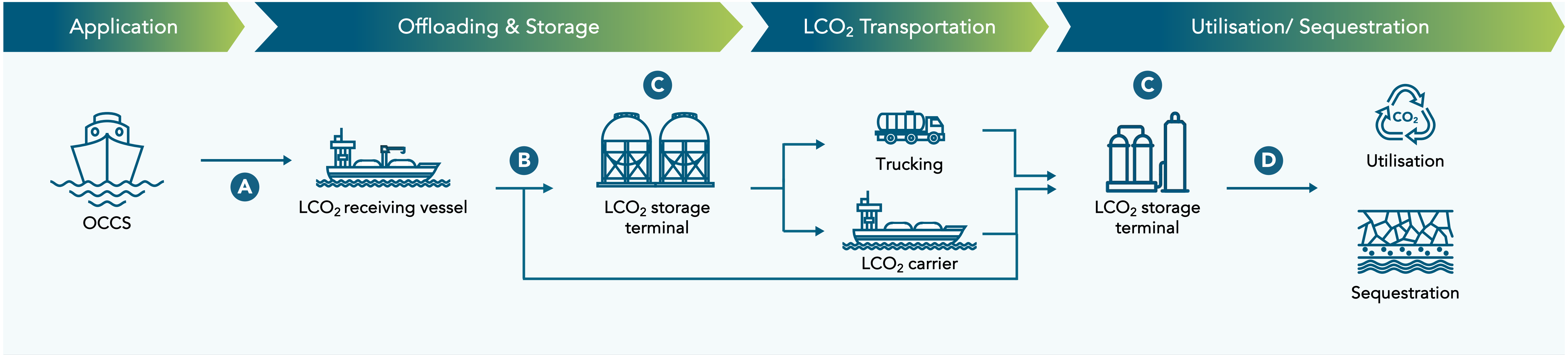
OCCS: a potential compliance pathway

Assumes 40% capture with MEA, CO_2 liquefied and stored onboard; on a well-to-wake basis



Source: GCMD, COLOSSUS, May 2025

An ecosystem needed to operationalise OCCS



Key challenges identified

A — Lack of established LCO_2 STS transfer guidelines

B — Lack of regulatory clarity on CO_2 offloading

C — Infrastructure readiness

D — Limited end-use options for captured CO_2

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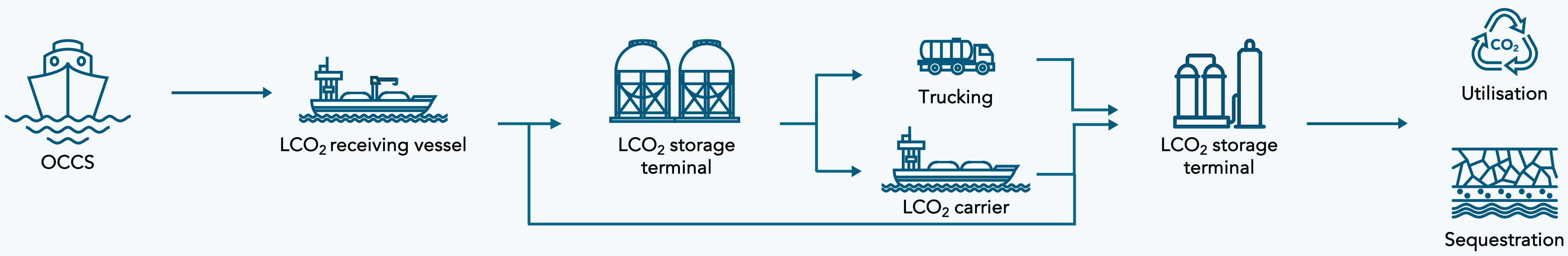
Addressing gaps in the carbon value chain

From capture to its end use, whether that be utilisation or sequestration

Application | Offloading & Storage | LCO_2 Transportation | Utilisation/ Sequestration



- **Project REMARCCABLE:** Engineering study to demonstrate onboard carbon capture at scale
- Concept study to address the safe offloading of captured CO_2 onboard ships
- Study to explore the role of shipping in enabling CCUS initiatives
- **Project COLOSSUS:** Life cycle assessments of GHG emissions and cost analysis of OCCS across the carbon value chain
- **Project CAPTURED:** Pilots to demonstrate the offloading, utilisation and/or sequestration of onboard captured CO_2

Operationalising StS offloading of onboard captured CO_2

Four concepts to offload LCO_2 identified

Key findings

- Offloading ISO containers uses existing quay cranes; **most operable today**
- The *Ever Top* offloaded a 20-foot tank container of LCO_2 (est. 20 MT if full tank) in January 2025 at the Port of Rotterdam.
- With increasing transfer capacities anticipated, container offloading logistically **not scalable**
- StS transfer via an intermediate LCO_2 receiving vessel offers **flexibility and versatility** for handling large volumes of LCO_2 while adapting to operational constraints of ports and terminals.

Source: GCMD, Concept study to offload onboard captured CO_2, March 2024

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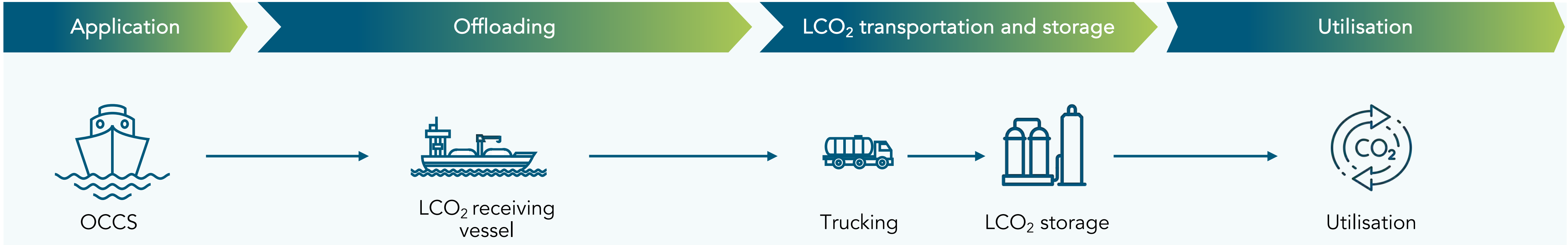
Project CAPTURED: Learning through a real-world pilot



Completed: 25 June 2025

Objectives

01 Understand operational and safety challenges of StS LCO_2 offloading

02 Identify and address regulatory barriers that hinder the transfer and transport of captured CO_2

03 Showcase how onboard captured LCO_2 can integrate into an industrial CO_2 utilisation pathway

04 Conduct LCA to quantify GHG emissions abatement

Project partners

Vessel owners	Evergreen Marine Corp, Zhoushan Dejin Shipping
OCCS provider	Shanghai Qiyao Environmental Technology (SMDERI-QET)
LCO_2 offtaker	Baorong Environmental, Greenore
LCA advisor and independent verifier	DNV China DNV Business Assurance China
Port authorities and regulators	Shanghai Municipal Transportation Commission Shanghai Maritime Safety Administration Shanghai International Port Group (SIPG) Shanghai Customs Shanghai Border Inspection

World’s first onboard-captured CO_2 value chain demonstrated

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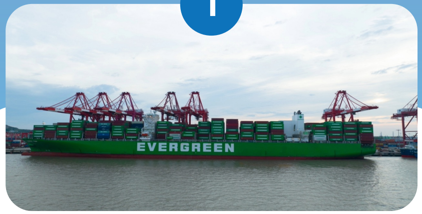
The sequence of events

1



Port of Rotterdam, The Netherlands

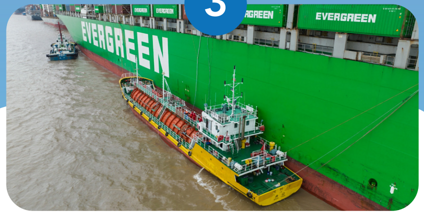
The *Ever Top* began its voyage

2

Port Klang, Malaysia to Yangshan Deepwater Port

SMDERI-QET’s OCCS system activated; CO_2 captured and stored enroute

3



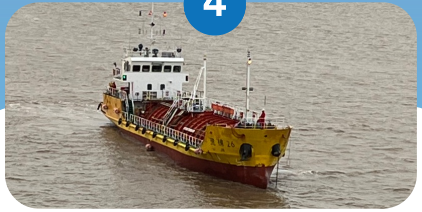
Yangshan Deepwater Port

Vessels moored at berth

25.44 MT LCO_2 transferred @ 4-6 m^3/hr

LCO_2 sample collected for quality testing before transfer

4

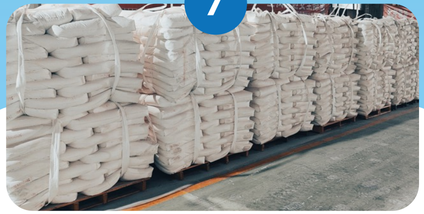


Yangshan Deepwater Port to Zhoushan

The *Dejin 26* in transit

The journey

7



Baotou

Captured CO_2 used as feedstock

LCO_2 sample collected from Baorong’s regular vendor for quality benchmarking

6

Zhoushan to Baotou

LCO_2 transported 2,200 km overland

LCO_2 sample collected for quality testing before transfer

5

Huihao jetty, Zhoushan

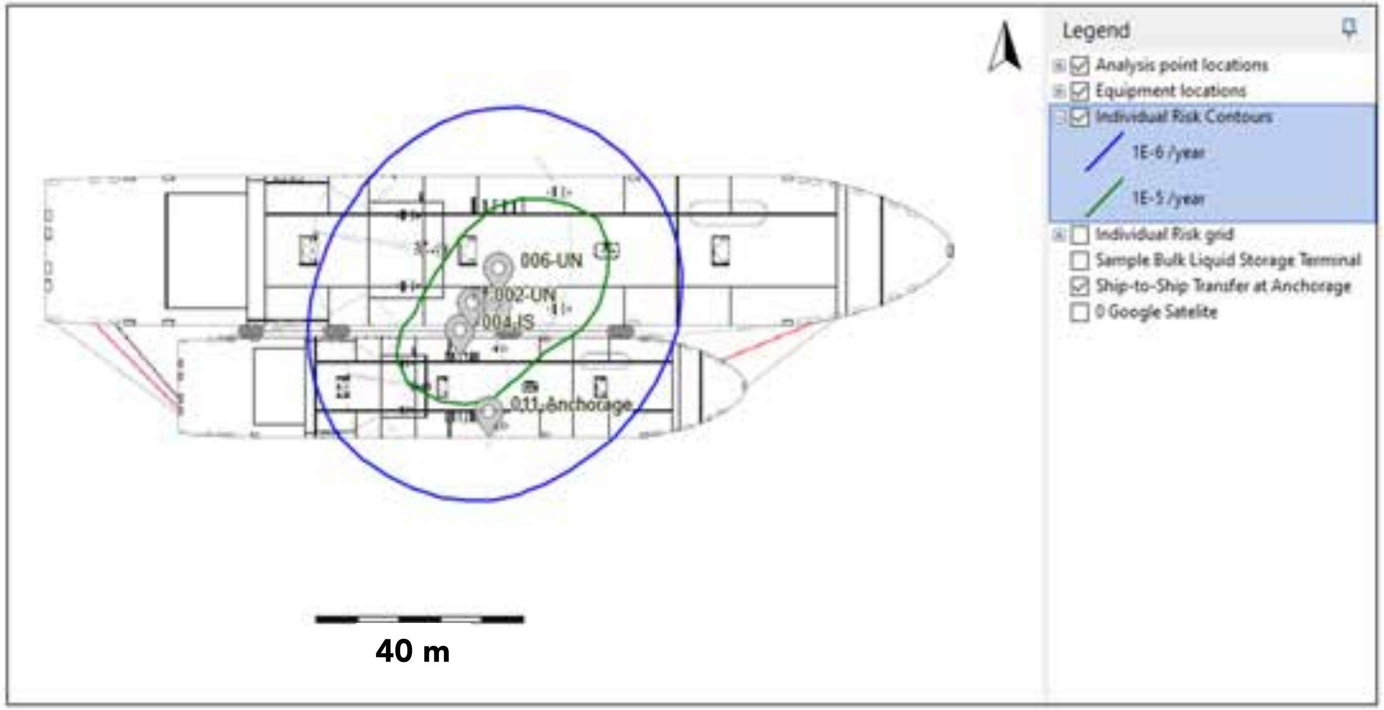
LCO_2 offloaded; CO_2 reclassified from “hazardous waste” to “hazardous cargo”

LCO_2 sample collected for quality testing before offloading

StS LCO_2 offloading at a hypothetical anchorage location

CO_2 is denser than air and can be an asphyxiant; can form acid when it reacts with water

Location Specific Individual Risk (LSIR) Contours



Assumptions

Modelling assumptions:

- 250 m^3/hr, or 272 MT/hr transfer rate
- 1,200 mm release diameter
- 20 m liquid head
- 10,000 m^3 of LCO_2 released, of which 70% vapourised

Offloading frequency:

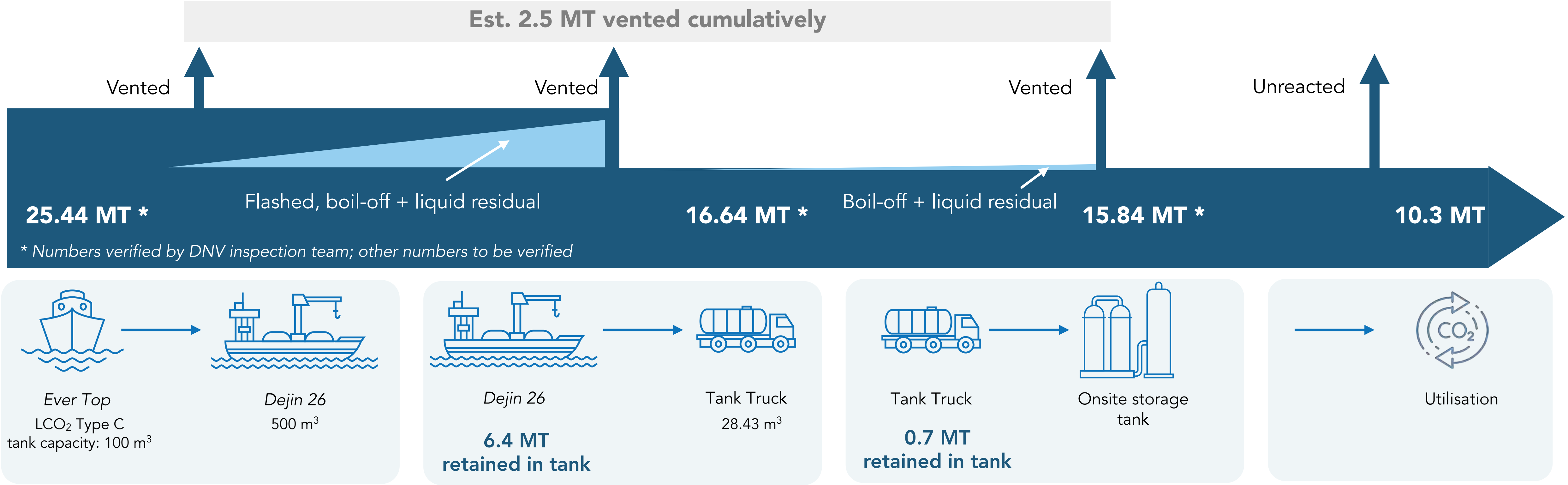
- 8 hours of offloading, 4 times a week, 208 times a year

- **No** intolerable risk (individual risk << $1x10^{-4}$/yr)
- Tolerable risk **< 50 m** (inside **blue** contour; as low as reasonably practicable)
- Broadly acceptable **> 50 m** (outside **blue** contour; $<1x10^{-6}$/yr)

Source: *GCMD, Concept study to offload onboard captured CO_2, March 2024*

Quantifying captured CO_2 along the value chain

Almost two-thirds of offloaded CO_2 was delivered to end user



Tracking captured CO_2

(preliminary findings)

28% vaporised in tank/ liquid residual

10% vented during transfers

62% reached end user

65% fixed; of CO_2 delivered

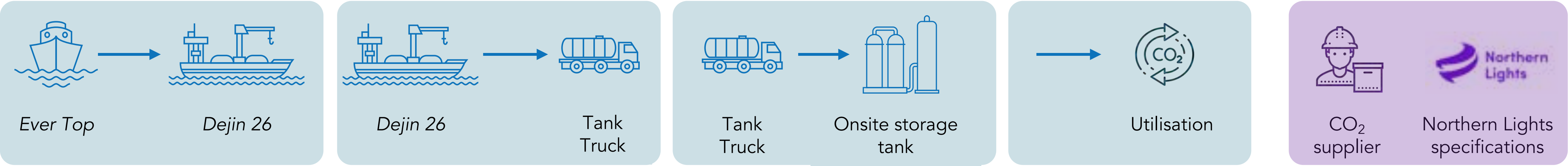
To optimise CO_2 transfer:

- Align transfer volume with receiving tank capacity
- Precondition LCO_2 tanks to minimise vaporisation and residual CO_2
- Use custody transfer-grade flow meters to quantify and monitor CO_2 movement

Quality of captured CO_2 along the value chain

Captured and transported CO_2 met end-user specification

Reference



	Concentration (v/v)					
	Ever Top → Dejin 26	Dejin 26 → Tank Truck	Tank Truck → Onsite storage tank	Utilisation	CO_2 supplier	Northern Lights specifications
CO_2 (%)	99.96	99.97	99.97		99.99	≥99.81
H_2O (ppm)	40.1	141	13.3		8.4	≤30
NO_x (ppm)	70	105	55		0.2	≤1.5
CH_3CHO (ppm)	594	219	78.7		0.1	≤20
C_2H_4 (ppm)	<0.1	1.5	15.5		<0.1	≤0.5

Observations

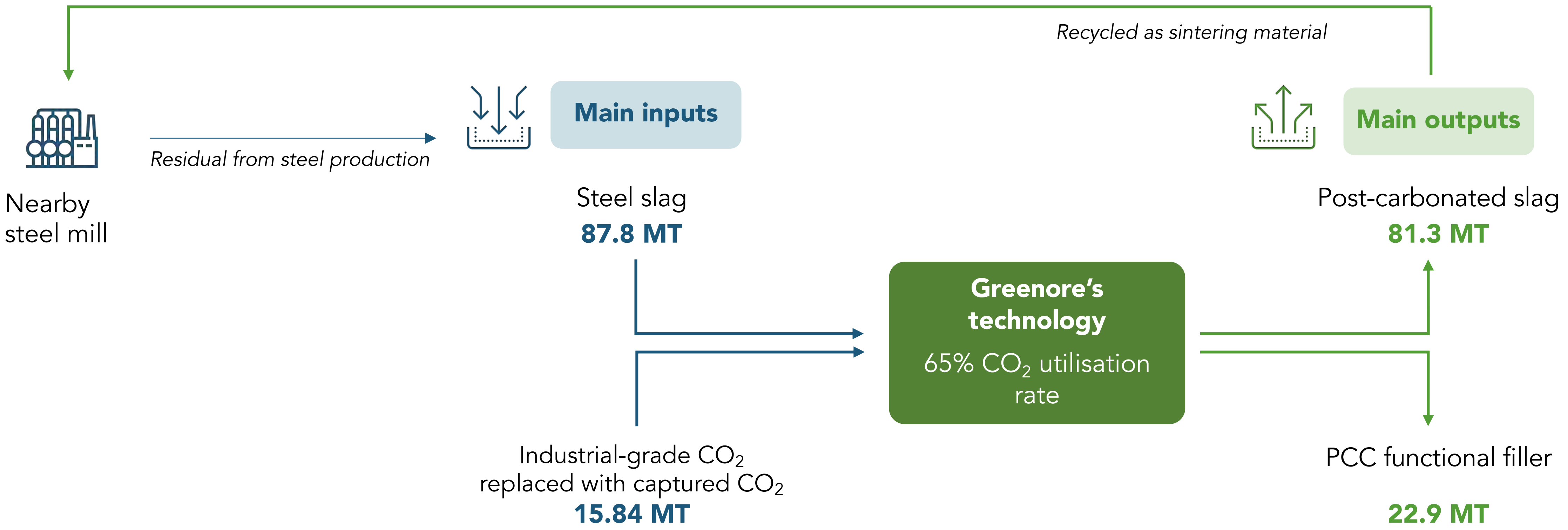
- Among 27 parameters tested
- Met Chinese industrial CO_2 specifications GB/T6052-2011, except for odour
- Acetaldehyde (CH_3CHO) is a by-product of amine degradation

Learnings

- Thresholds for impurities ultimately specified by end user or reception facility
- Contamination risk cumulative across transport and storage receptacles
- Custody transfer-meter with chemical analysers enable independent and efficient confirmation of CO_2 composition

Steel slag valorisation + carbon mineralisation

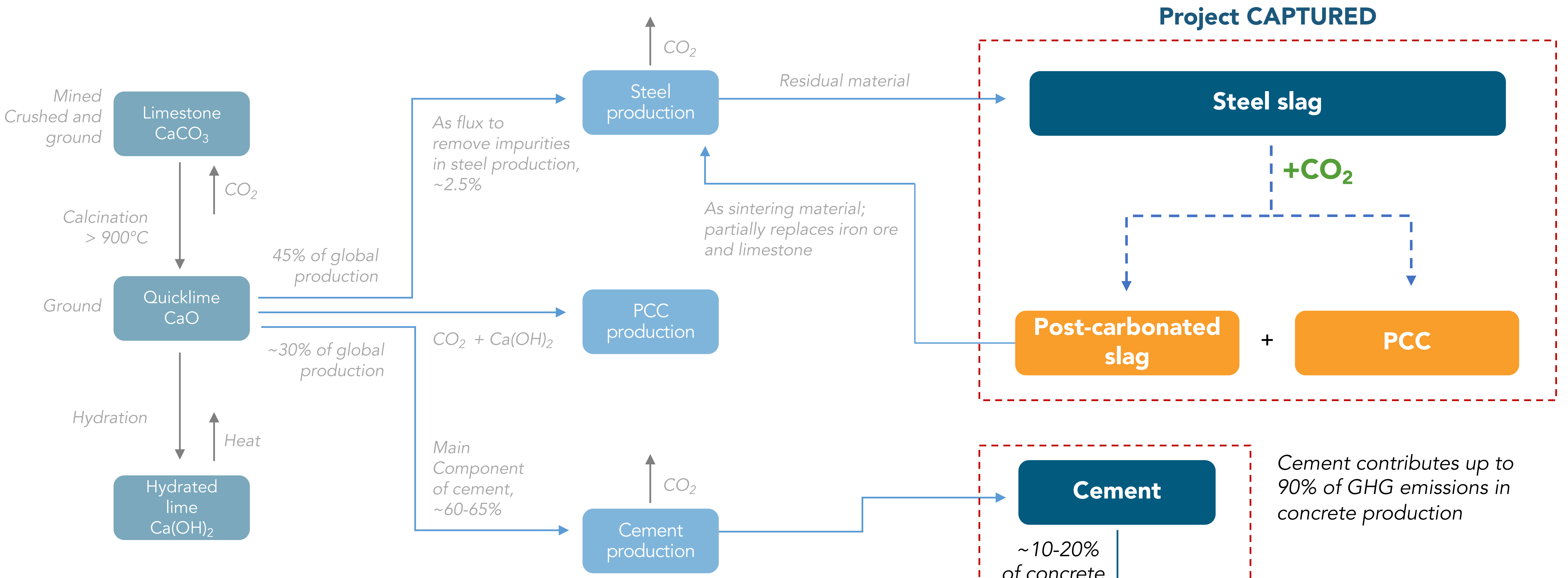
Baorong's production line annual processing capacity: 100,000 MTPA of steel slag + 15,000 MTPA of CO_2

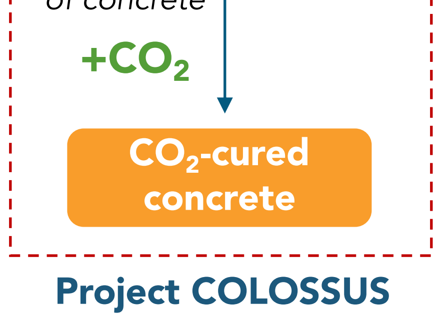


PCC market size and regulatory constraints under EU ETS

- PCC market size est. USD 2-12 billion in 2024 (paper, plastic, building materials industries)
- Current EU ETS regulations do not recognise PCC applications as permanent fixation unless it is used for construction material

Carbon mineralisation to reduce GHG emissions





Advantages of carbon mineralisation

Multiple pathways for CO_2 mineralisation

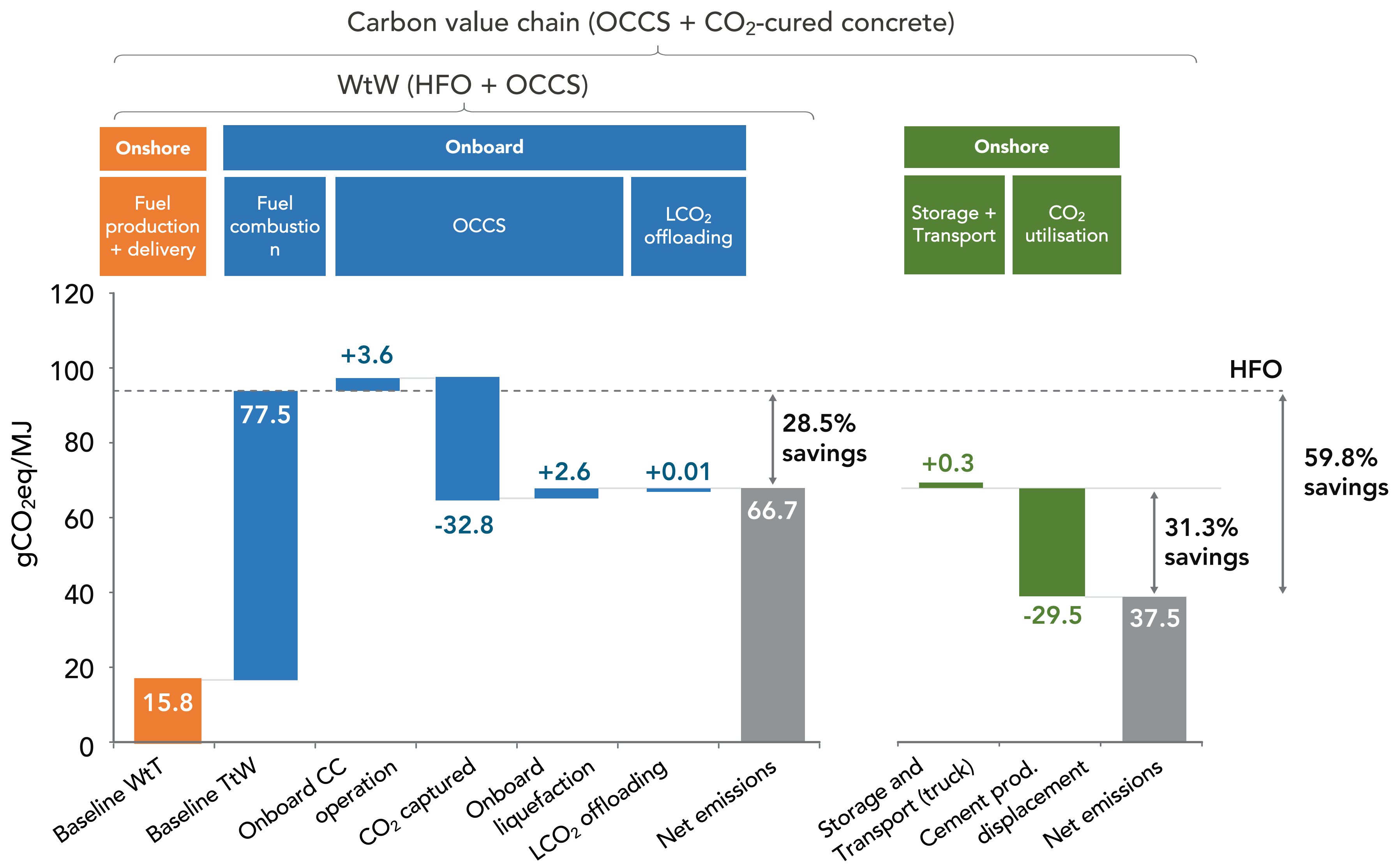
Reduced reliance on virgin $CaCO_3$ and other raw materials (e.g., cement, steel)

Permanent fixation of captured CO_2 in products, such as PCC and CO_2-cured concrete

GHG emissions reduction for both emitters (e.g., shipowners) and end-users

GHG emissions accounting across value chain

Example from COLOSSUS; LCA on Project CAPTURED to come



Fixing CO_2

60% GHG emissions savings across the carbon value chain

Based on HFO and OCCS (MEA) with 40% capture, onboard liquefaction and storage of CO_2

Source: GCMD, COLOSSUS, May 2025

Showing what's possible through incremental progress

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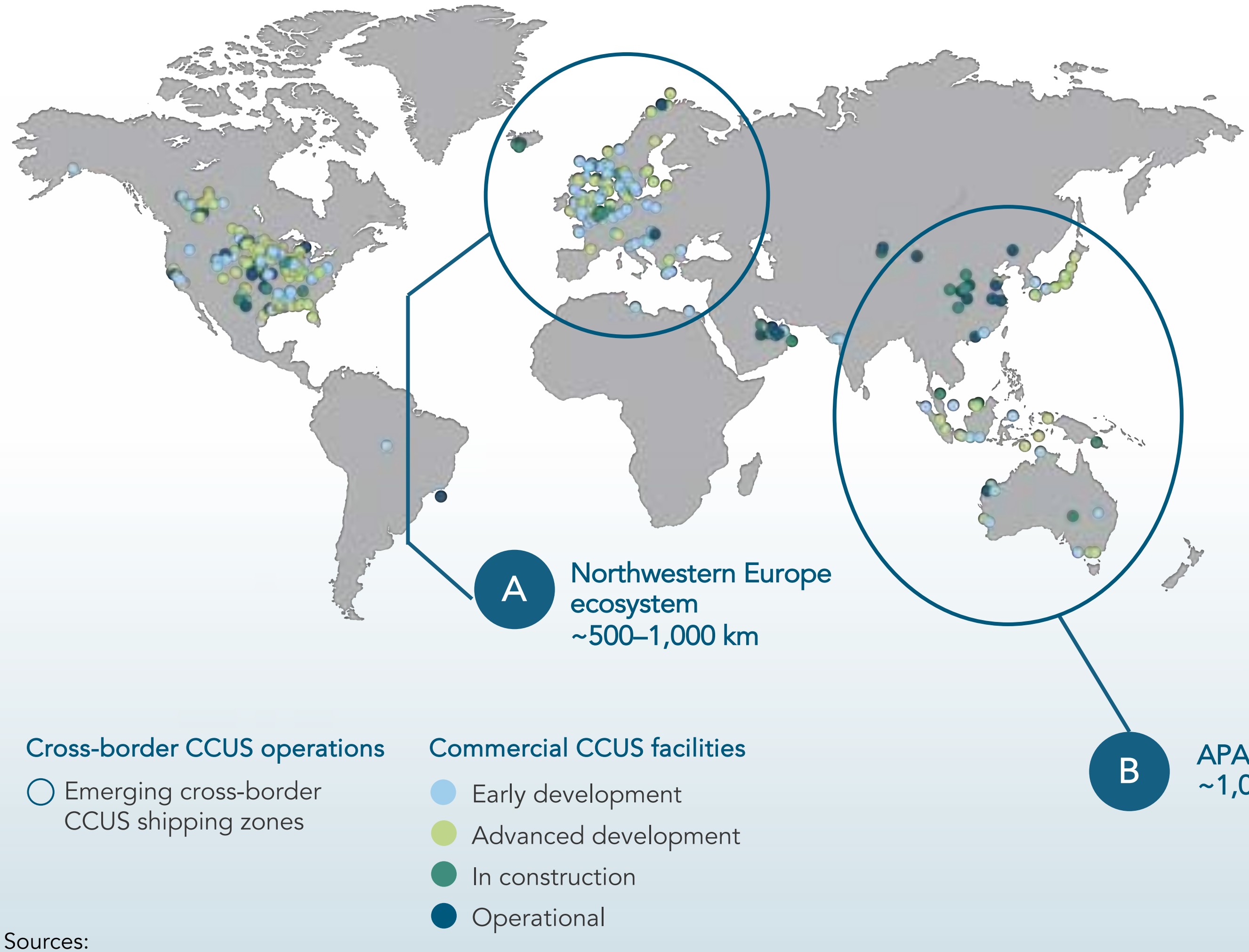
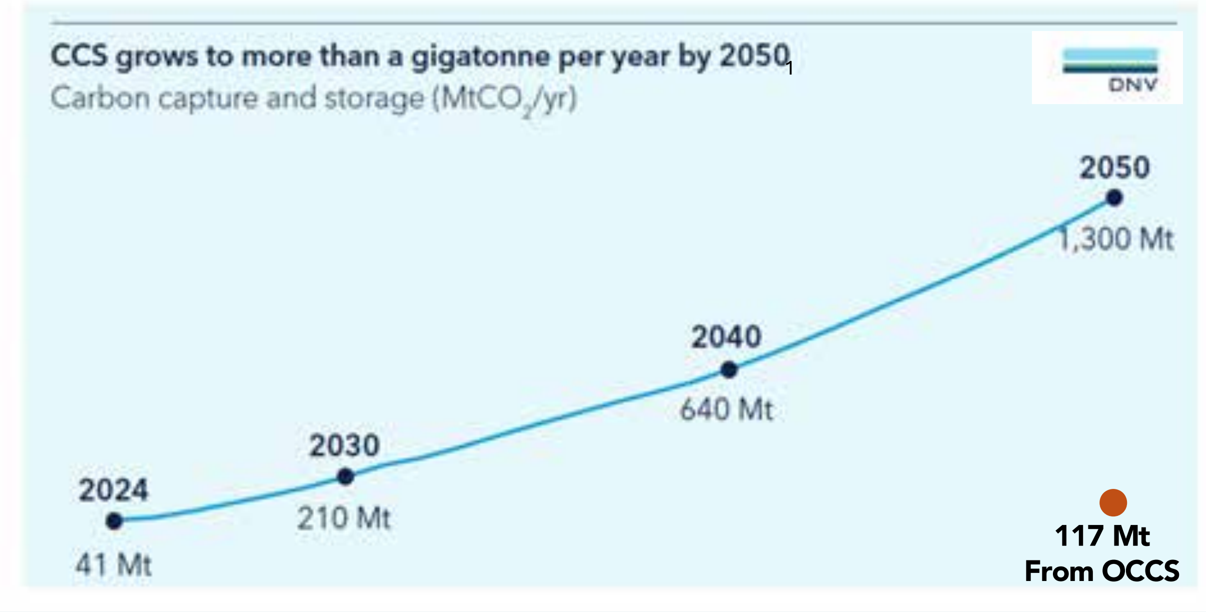
Challenges		Stopgaps that enabled Project CAPTURED
Safe STS transfer of LCO_2 unproven at scale, with no established **operational protocols**.	Safety	Established operational procedures by adapting **existing** LNG and LPG transfer **protocols**
Applicable **regulatory** frameworks are fragmented and incomplete, revealing **gaps** in OCCS deployment.	Regulatory	Collaborated with authorities to obtain **regulatory sandboxing** and **one-off reclassification** of CO_2
Utilisation of onboard captured CO_2 still nascent, with limited **offtake pathways**.	Utilisation	Secured an offtaker who assumed **first-of-a-kind risk** to use captured CO_2 as feedstock
Custody transfer of CO_2 lacks standardised **metrological assurance** for quality and quantity.	Quantity and quality	**Sampled** and **quantified** CO_2 transferred at custody transfer points, with surveyor witnessing sampling
Lack of standardised methodologies hampers **GHG emissions accounting** across CO_2 value chain.	GHG emissions savings	**LCA** will quantify GHG emissions reduction and net climate benefits; to be **independently verified**

CCUS projects are in train globally

Projected OCCS volumes a tenth of that ashore; must tap on shore-based CCUS ecosystem to scale

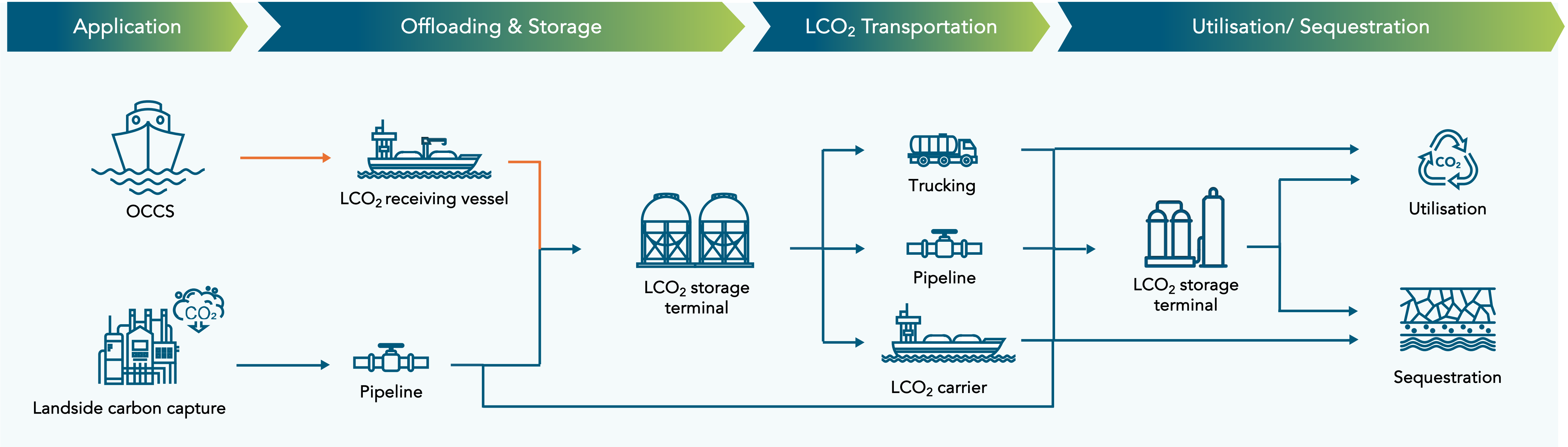




Sources:
[1]DNV (2025) "Energy Transition Outlook: CCS to 2050"
[2]Global CCS Institute (2024), "Global Status of CCS 2024: Collaborating for a Net-Zero Future"; GCMD-BCG analysis (2024)

OCCS must integrate with broader CCUS ecosystem

Must build on shared infrastructure, common standards and robust certification frameworks



Key considerations:

- How can CO_2 custody transfer be **standardised** across ships, tanks and pipelines?
- What fit-for-purpose **Monitoring, Reporting, and Verification (MRV)** frameworks need to be developed to track custody and integrity across CO_2 supply chains?
- Who is responsible for **conditioning** CO_2 to meet downstream infrastructure and end-user specifications?

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Thank you!

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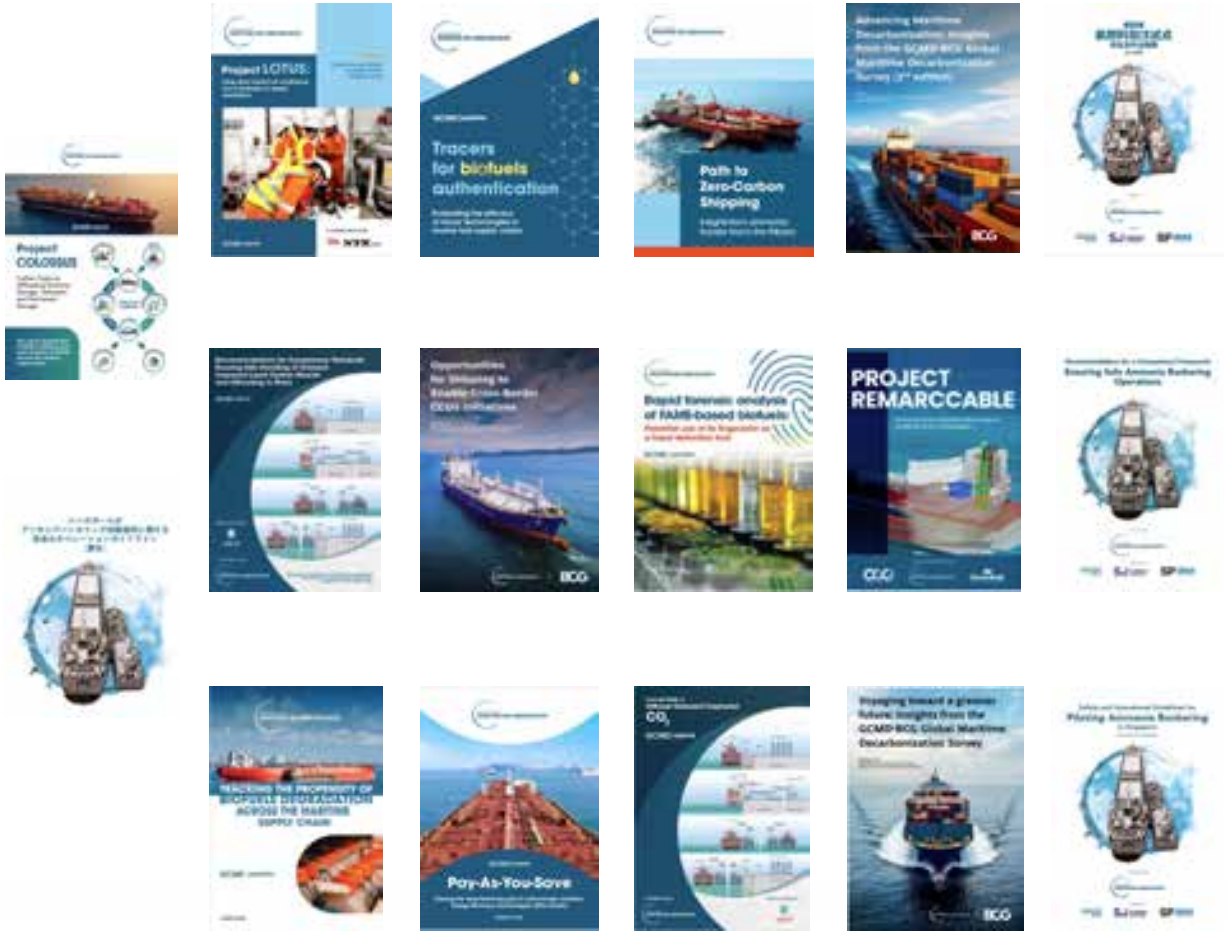

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Governing framework of OCCS and its value chain

OCCS on vessels → Offloading and storage → LCO_2 transportation → Utilisation/ Permanent storage

International

IMO

London Protocol

MARPOL Convention

MSC and sub-committees
- Correspondence group on development of a safety regulatory framework to support the reduction of GHG emissions from ships using new technologies and alternative fuels
- Sub-committees:
  - Sub-Committee on Carriage of Cargoes and Containers
  - Sub-Committee on Ship Design and Construction
  - Sub-Committee on Ship Systems and Equipment

MEPC
- Correspondence Group on measurement and verification of non-CO2 GHG emissions and onboard carbon capture at IMO
- GESAMP-LCA working group

United Nations Environment Programme

Basel Convention

Regional and national

China

CCS Guide for Onboard Liquid CO_2 Loading/Unloading (2024 & 2025)

Regulations on Road Transport of the People's Republic of China

- GB 18180 – Safe Operations for LPG Ships
- GB/T 44412-2024 – LNG Bunkering for Ships
- CCS LNG Bunkering Vessel Code (2023)
- CCS LNG Bunkering Guidelines (2021)
- SY/T 7029-2016 – LNG STS Transfer Guidelines
- CCS Ship To Ship Transfer Guide for Petroleum, Chemicals and Liquefied Gases

Administrative Provisions on the Road Transport of Dangerous Goods

Regulations on the Safety Management of Hazardous Chemicals

General rules for identification of hazardous wastes (GB 5085.7-2007)

European Union

EU ETS: Directive 2003/87/EC (amended by Directive (EU) 2023/959, in particular Article 12(3b)); Regulation 2018/2066 (MRR); Commission Delegated Regulation (EU) 2024/2620

RED III, Commission Delegated Regulation (EU) 2023/1185

Legend
- Rules and regulations, standards and guidelines considered for Project CAPTURED
- Concerning the cross-border movement of waste