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What do we need to know to make CO_2 shipping for CCS a reality?

1. Why is CO_2 shipping relevant to decarbonisation in the UK?

This report provides a summary of the concepts and factors relevant to the shipping of CO_2 in liquid form, in the UK and elsewhere, for the purpose of broadening the geographic reach of Carbon Capture and Storage (CCS) envelopes. We present an understanding of the existing technical capabilities to ship CO_2 as a first step towards appraising potential capability, likely timeliness, and the pace of scale-up required for CO_2 shipping to play an integral role in the challenges that UK industries face to meet their decarbonisation targets. This may also, therefore, inform potential policy action, which is timely and relevant at a time when the UK Government has indicated that an expanded set of non-pipeline transport (NPT) options would be needed to support the UK Government's recently published 'CCUS Vision'[1] to create a competitive carbon capture market.

Technical details presented within this summary are largely based on the "Achieving a European market for CO_2 transport by ship" report by the CCS Association in collaboration with Zero Emissions Platform (ZEP), published in January 2024[2], which will be referred to as the 'CCSA-ZEP report' in this summary. Other sections address relevant properties of CO_2 in its different forms and answer specific questions that may be of interest to policy makers.

Many experts working on the implementation of CCS across Europe believe that NPT, and ship transport in particular, is essential to enable CO_2 transport at sufficient scale. There are many sites without the necessary access to pipelines or directly to geological storage sites. In such instances, CO_2 non-pipeline transport will need to become an integral part of the carbon management approach and policies that support it. Central to the question of enabling NPT of CO_2 is the gap between the cost of emitting CO_2 (which is relatively low) and the cost of implementing CCS (which is relatively high). Policies under development that could help close this gap include those related to the EU ETS system, the UK ETS and other emitter subsidies and infrastructure funding mechanisms.

The CCSA-ZEP report concludes that successful implementation of CCS to meet climate goals will rely on CO_2 transport growing at a sufficient scale to match – at least at the same rate as – capture and storage capacity, and that CO_2 shipping is a critical solution for industry emitters (hubs) without access to pipelines. The ZEP-CCSA report highlights the risk that this scale would be achieved too late.

[1] Report available at: https://www.gov.uk/government/news/new-vision-to-create-competitive-carbon-capture-market-follows-unprecedented-20-billion-investment

[2] The CCSA-ZEP report available at: https://zeroemissionsplatform.eu/wp-content/uploads/ZEP_report_HD.pdf

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Peter Webb, Visiting Research Fellow, OIES and Energy Consultant
Ian Phillips, Director, Energy Transition Advisory Limited

How is CO_2 different from any other gas, and what does that mean for shipping?

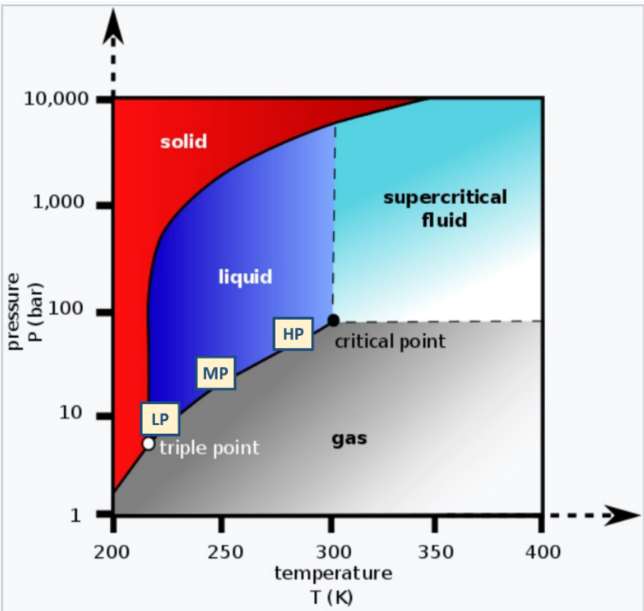
Carbon dioxide (CO_2), at room temperature and pressure, is a colourless gas with a faint odour and a sour taste. It is relatively inert; in that it does not support the combustion of most materials. At atmospheric concentrations, which are just over 0.04% by volume, it is harmless. CO_2 is slightly soluble in water, forming a weakly acidic solution and (with an atomic weight of 44) compared to other gases and liquids it is relatively dense.

Industrially, it can be captured from flue gases and from limekilns and it is produced as a by-product from the manufacture of hydrogen, which itself can be used for the synthesis of ammonia. It can be captured from other sources as well.

While at atmospheric pressure on cooling it freezes directly from a gas to a solid at -78°C, if put under pressure and then cooled, it does change from a gas into a liquid form. The higher the pressure, the higher the liquefaction temperature which is relevant for handling and shipping. It is also noteworthy that some low-level impurities affect some of these phase change behaviours.

From a safety and hazards perspective, prolonged exposure of humans to concentrations of 5% carbon dioxide and above may cause unconsciousness and even death. Risks that are particularly relevant to shipping and transport are that a large-volume leak can displace air causing asphyxia, and that a high-pressure leak can cause localised short-term freezing due to the Joule Thompson effect, with the risk of a "jet freeze" that could be lethal to anyone in the way.

Figure 1: Pressure vs. temperature CO_2 phase diagram; including approximate pressure – temperature combinations for low pressure 'LP', medium pressure 'MP', and high pressure 'HP' shipping conditions described later in the paper



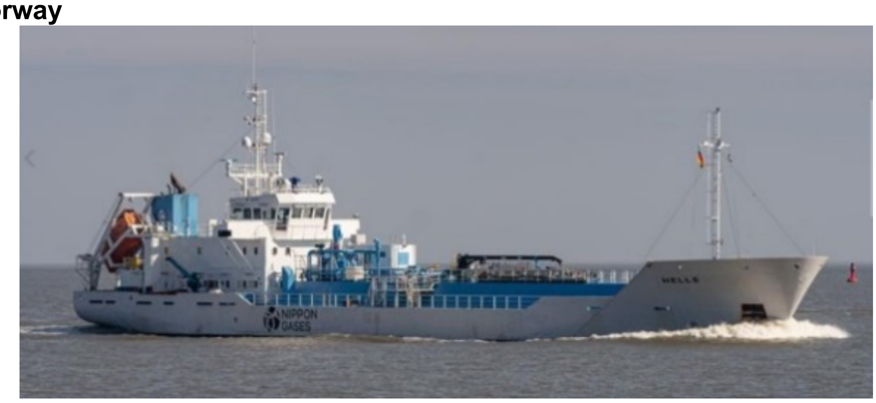
2. What is the history and status of shipping liquified gas and CO_2?

The seaborne transport of liquefied gases began in 1934[3] when two combined oil/LPG tankers were put into operation. The ships, based on oil tankers, were converted by fitting small, riveted, pressure vessels for the carriage of LPG into cargo tank spaces. This enabled transport over long distances of substantial volumes of LPG which had distinct advantages as a domestic and commercial fuel. More recently shipping solutions for food-grade CO_2 in small liquid gas tankers have been established, and a total of four CO_2 carriers with a capacity of between 1,000-2,000m^3 have been operating for some time.

Existing gas carriers for LPG, ethylene and natural gas fall into three main categories: pressurised, semi-refrigerated (semi-ref) and fully refrigerated[4]. The design and operation of CO_2 carriers is most similar to existing semi-ref LPG carriers. When CO_2 is carried in the Low-Pressure (LP) configuration (7-9 bars and -55°C), the cargo condition is practically the same as for the semi-ref LPG carriers currently in operation. In fact, in 2019, there were six ~10,000m^3 LPG/ethylene carriers owned by IM Skaugen of Norway which were also approved for the carriage of CO_2. On the other hand, the development of larger vessels to transport the higher volumes associated with CCS is still at the early stages.

The practice of transporting liquefied and pressurised gases has been regulated by the International Maritime Organisation (IMO) since the 1960s. The regulations are known as the International Gas Code, or IGC. Gas carriers, like other ships, are exposed to the vagaries of the marine environment including, for example, collisions and groundings. Despite this, there has never been an accident resulting in loss of cargo tank integrity, with subsequent cargo release[5]. The IGC also covers the transportation of CO_2, allowing some minor relaxations due to the non-combustible nature of the CO_2 cargo. International regulations for the transportation of CO_2 by ship are therefore well established[6].

Figure 2: M/T Helle CO_2 Tanker built in 1999, cargo capacity 1,240 tons, operated by Larvik Shipping Norway



Source: Marinetraffic.com

As global CO_2 markets develop, the size of CO_2 tankers is expected to increase, and many believe that due to geographical distribution of emitters, CO_2 shipping should play a role. Furthermore, CO_2 shipping is expected to be more important in Europe than in the United States and China, where announced CCS projects rely more on onshore pipeline infrastructure and onshore storage.

[3] St James Shipping, Introduction to LPG transport, link
[4] ZEP, The Costs of CO_2 Transport post-demonstration CCS in the EU, page 16 link, 2019
[5] ZEP, The Costs of CO_2 Transport post-demonstration CCS in the EU, page 16, section 3.4 para 3; link, 2019
[6] Again, from ZEP, The Costs of CO_2 Transport post-demonstration CCS in the EU, page 16 link, 2019

3. Which CO_2 shipping projects are already in the development pipeline?

It is no surprise that leading European projects are progressing the construction of CO_2 carriers (three under construction and more under consideration/discussion with the shipyards). These are also progressing construction of CO_2 terminals, either for loading or unloading CO_2 at the emitting source or emitters' hub side or at the storage side, respectively.

The first Northern Lights CO_2 tankers that are in production (as of early 2024) are 60% completed. The two sister ships have a cargo capacity of 7,500m^3, have a length over all (LOA) of 130m, and are on schedule to set sail in 2024. They will be similar in size to many LPG carriers that are operating today. In addition, two 22,000m^3 liquefied CO_2 carriers have been ordered by Capital Marine[7] from the Hyundai Mipo Dockyard (HMD) in South Korea. Each are to be 160m long and capable of transporting LPG and ammonia in addition to CO_2 at -55°C. These are due to be delivered in 2025-2026. The builders (owners of HMD) have designs for 30,000m^3, 40,000m^3, and 74,000m^3 CO_2 carriers.

By way of comparison, the cargo capacity of the Standard LNG carriers in operation today is in a range around 150,000m^3.[8] One technical constraint that would apply to CO_2 carried at high pressure, when compared to another gas carried at close to atmospheric pressure (as is the case with the larger LNG carriers), is the difficulty to construct very large pressure chambers because the strength which is generally in proportion to surface area of the chamber (or square of chamber size) requires strength in proportion to the volume (or cube) of the chamber size.

Given the size of comparable 20,000m^3 gas carriers, it seems reasonable to estimate that the size of future 20,000 tonne and 40,000 tonne CO_2 carriers could be in the range of 150-180m LOA.[9] This is much smaller than Standard 150,000m^3 LNG carriers which are generally around 300m LOA. Other LNG carriers like the Q-flex and Q-max are longer still.[10] As with all shipping, new vessels are constructed where the balance of cost and quality is best. This currently means China – and potentially South Korea – but it could be anywhere that LPG or LNG tankers are built. That said, the build location can be influenced by local government regulations and subsidies.

CO_2 transport by ship is currently developing where relatively large emitters (e.g., large cement plants with carbon capture rates of approximatively 1mtpa or more) get into long-term charter agreements with specific storage site locations within short distances in the same region. The fuel for propulsion can be the same as for any other cargo vessel, though a low-carbon option is more likely given the application of the ships themselves. For example, the Northern Lights vessels combine LNG-powered propulsion with wind-assisted technology. Note that while LNG carriers with LNG-powered propulsion systems have the option of using natural gas boil off (from the liquid cargo), this advantage does not apply to CO_2 carriers. Nonetheless, the principles on the decarbonization of shipping, like the IMO decarbonisation strategy[11], apply equally to cargo vessels and CO_2 carriers alike.

IRENA assert that "*in the short term, advanced biofuels will play a key role in the reduction of* CO_2 *emissions. In the medium and long-term, green hydrogen-based fuels are set to be the backbone for the sector's decarbonisation. Renewable e-ammonia will play a pivotal role; where 183 million tonnes of renewable ammonia for international shipping alone will be needed by 2050, a comparable amount to today's ammonia global production*."[12] Onboard carbon capture is also an option.

[7] According to Riviera News, Capital Maritime orders world's largest LCO_2 carriers, July 2023, link
[8] Science Direct (2016). Natural Gas Carrier, link.
[9] For example this 20,000m3 LNG Carrier and Bunkering Vessel is 160m LOA; enricgroup.com 2022 link
[10] Q-flex 315m, as per Riviera Q-flex LNG ships, 2008 link; Q-max 344m as per Portnews QatarEnergy agreement, 2024 link.
[11] IMO (2023). Strategy on reduction of GHG emissions from ships, link.
[12] IRENA (2021). A Pathway to Decarbonise the Shipping Sector by 2050, link.

Figure 3: CO_2 ships in production Q4 2023

Source: Northern Lights JV; Dalian Shipbuilding Offshore Co. Ltd

The ship transportation cost strongly depends on the volumes transported and the distance. Large emitters located relatively close to storage sites can benefit from low ship transportation costs. On the other hand, this model requires the construction of a dedicated liquefied CO_2 loading terminal at the emitters site, which is a highly capital-intensive investment for emitters. This model may also entail critical limitations to the ship's design or operation due to the geographical location of the emitter and any draught restrictions or operational constraints due to passage through congested areas.

With respect to the question of whether a high volume of additional shipping, transporting CO_2, would lead to significant congestion of the seaways: (a) any congestion seems likely to be concentrated at points of loading and unloading or the approaching channels and the level of congestion would depend also on other seaborne traffic – and this deserves more analysis, and (b) the impact of congestion on the shipping of CO_2 would be that cargo boil-off, as-and-when the cargo warms up, would be proportional to the total time of transit so a congestion delay measured in days may lead to a loss of cargo.

4. What about timelines, critical path and rate defining steps?

Timelines for Front End Engineering Design (FEED), Pre-FEED, permitting and construction can be extensive. As for all major engineering projects: assess, concept-select and pre-FEED can be 12-24 months; FEED itself can be 12-24 months; and final design and construction can be 12-36 months depending on scale and complexity. From end-to-end across capture, liquefaction, transport and storage, there are many different engineering and construction challenges to address, in addition to the fact that for early projects all parts will have to be designed, built, and commissioned simultaneously.

With respect to other factors that impact rate of development and rollout, the first is establishing government support including the creation of coherent business models across the value chain, agreeing level and form of any subsidies, and providing sufficient policy certainty for investors. Then comes the challenge of coordinating multiple projects, investors, and operators along the value chain. They must all commit at the same time.

In addition to the sequential steps of feasibility, design and build described above, rate-defining steps include the provision of skills and labour, developing fit-for-purpose regulation and efficient permitting regimes. There is also the lead time of major components such as amine plants for capture, compressors for liquefaction, ship and repurposing or drilling wells to access geological storage. With respect to the ships, the build time (once plans are agreed) is likely to be 12-24 months which applies equally to cruise ships, cargo vessels and the Northern Lights CO_2 carriers under construction.

5. What pressure and temperature conditions could apply to CO_2 transport onboard the ship?

Whilst CO_2 transportation can be undertaken in gaseous, liquid, or solid form, the liquid phase provides both the high density and ease of handling required for meaningful bulk transportation.

Given the temperature and pressure of its triple point (5.4 bar, -56°C), CO_2 needs to be pressurised to achieve a stable liquid state. This is a defining feature of CO_2 transportation. While other gases like natural gas need *either* pressure *or* temperature to achieve liquefaction, CO_2 will always need pressure and, in most cases, some cooling of the temperature as well.

Figure 4: Pressure and temperature ranges of the three conditions considered for CO_2 transportation[13]

	Low pressure	Medium pressure	High Pressure
Temperature (degC)	-55 to -40	-30 to -20	0 to 15
Pressure (Barg)	5 to 10	15 to 20	35 to 50
Density (kg/m3)	1170 to 1120	1080 to 1030	930 to 820
Tonnes cargo weight per m3	1.2 to 1.1	1.1 to 1.0	0.9 to 0.8

Source: CCSA-ZEP report

Note: There is some rounding in these numbers

The mass that can be transported in a CO_2 tank increases with the difference in density between the liquid and gaseous phases. Counter-intuitively, the mass of CO_2 that can be transported in a given tank is lower at higher pressure/higher temperature than it is for a lower pressure/low temperature condition.

Transport at higher pressure and ambient temperature requires less energy in the CO_2 liquefaction process (being more compression and less cryogenic) but requires a larger tank volume for the same mass due to reduced density. Higher pressure transportation also allows greater tolerance of CO_2 impurities, simplified loading systems due to the higher temperature envelope and facilitates potential direct-to-store applications, further simplifying the value chain and potential speed of deployment.

Conventional wisdom according to the CCSA-ZEP report is that medium pressure (MP) would be preferred up to 20,000 tonnes and low pressure (LP) for larger cargos. This in contrast to LPG ships which have the MP to LP switch over at 10,000m^3. However higher pressure (HP) solutions, specifically for shipping 'direct-to-store' are also being developed, and there is a credible prospect of both HP and LP carriers with up to 40,000 tonne capacity.

With respect to 'direct-to-store' applications, the HP transport configuration enables injection directly into the geological storage. This can take longer than to unload a CO_2 carrier directly into onshore CO_2 tanks and means that as ships arrive and depart the rate of injection is intermittent, but both these are, in theory, technically possible with the advantage that they cut out port of delivery and onshore temporary storage and transit to final geological storage pipeline costs. For offshore direct-to-store applications a large buoy-based connection system is required similar to those used for oilfield

[13] Orchard et al (2021). The status and challenges of CO_2 shipping, link.

applications, as well as (potentially) injection pumps to control CO_2 injection pressure. Note, however, that intermittent injection of CO_2 has not been tested at scale, and some reservoir engineers have expressed the view that steady injection rates would be preferable, from a reservoir management perspective.

With respect to the conditions under which the CO_2 is liquefied and transported (low pressure between 6-8 barg[14], medium pressure 16-19 barg or high pressure 35-45 barg) this depends on:

a. Volumes to be transported – larger ship sizes are easier and more efficiently designed and constructed at low design pressures; and

b. Whether and/or how CO_2 is liquefied and stored[15] at both loading (close to emitter's site) and unloading (storage), which drives capital requirements for the storage tank and equipment; this also drives the operational expenses and procedures required for maintaining an efficient supply chain.

CO_2 well injection rates are expected to be lower than the normal discharging rate for liquefied CO_2 ships, so buffer storage tanks may be required at the unloading terminal close to the sequestration site[16]. If the site is expected to receive liquid CO_2 from various sources, then the required buffer storage capacities will be high (3-5 ship cargoes – potentially as much as 100,000 tonnes of storage).

Different pressure-temperature configurations have slightly different safety implications. At ambient (i.e. relatively higher) temperatures, there is lower intrinsic cryogenic risk, and higher pressure to manage. At the lower temperatures the intrinsic cryogenic risk increases, and pressure containment is less of an issue. In the case of a leak, however, the Joules Thompson freezing effect would be substantial for all configurations. And in all cases a catastrophic failure would lead to a large cloud of invisible asphyxiant which could be expected to disperse within 10-15 minutes[17].

Energy costs for the different pressure-temperature configurations are primarily driven by the need for cooling (at loading) or warming (at unloading) of the cargo of CO_2. For this reason the LP and MP configurations are likely to incur higher energy costs. Note, however, that for a full understanding of costs, a full "end-to-end" cost analysis is required.

Some analysts[18] have proposed and modelled the use of shipping CO_2 in the much larger standard LNG carriers. While there may be apparent economic advantages, there is an industry view that while technically possible, in practice the time, expense and complexity of cleaning out transport tanks between different cargo loads, as well as the need for different safety procedures and handling techniques, would make this option sub-economic[19].

It is also technically possible to use CO_2 carriers as temporary storage, but in a similar way, this is expensive, and it may be unlikely to happen within the context of an efficient market.

6. What determines the capacity of CO_2 shipping required?

This section sets out the key factors that influence CO_2 shipping requirements and provide a basic indicator of the numbers and capacity of carriers required for a range of transportation distances. The main determinants are:

Cargo: volume, distance to travel, and condition (pressure, temperature) of CO_2;

Carriers: capacity, ship speed, operating constraints like restricted waters and weather;

[14] Note: 'barg' indicates bar on a gauge, i.e. bar above prevailing atmospheric pressure.
[15] Onshore storage is usually essential to bridge the gap between CO_2 production and the ship schedule.
[16] Offshore CO_2 storage is generally uneconomic, so unloading (and direct injection) would take a little longer.
[17] Based on DNV trials at the Spadeadam test site, link , 2015
[18] TSE, Decarbonized gas: ship LNG out, take CO_2 back? link, 2023
[19] This constraint would equally apply to LPG/Ethylene carriers loading CO_2 when not carrying their primary cargo.

Ports for loading and discharging: distance from open water, time to berth, berth constraints (tide, weather, congestion, pilotage and towing), cargo transfer rate, reliability of delivery/reception of nominated cargo parcel, port and port services availability, prevailing weather conditions; and

Other factors: transit of restricted waterways (canals, rivers), bunkering constraints (availability of fuel), spare fleet capacity to accommodate outages, shore tank buffer capacity, injection rate

Most of these parameters are straightforward. The more complex ones are discussed below.

Gas carrier capacity is determined by the total useable volume of the tanks and the shipping conditions, as explained above. Typically, the usable/pumpable volume is around 92-96% of actual volume for a Type C tank vessel[20], which allows for a cargo heel.

The transit speeds for both the loaded and unloaded leg of the round trip have a direct impact on the total cycle time as does time spent in port, at reduced speed, and any seen or unforeseen delays. Whilst increased transit speed enables transportation of more cargo, it requires greater power with increased emissions/larger energy storage.

Loading and discharge ports: the key relevant factor is the time taken to either load or discharge the carrier taken from the moment of reducing speed prior to entry and until regaining transit speed on leaving the port. This includes the time required to enter the port, manoeuvre to, and moor up at the berth, connect transfer hoses, undertake the cargo transfer, complete the loading and associated documentation, disconnect, un-moor, leave the berth and exit the port. This will involve tug assistance and probably a pilot (depending on familiarity). Additional time may be required due to port congestion, waiting for the designated berth, bunkering if not able to be undertaken simultaneously, and any scheduled or unscheduled maintenance.

A further factor is the ability to receive the cargo parcel at the time of arrival. This will be largely dictated by the regularity of CO_2 arriving at the loading/onward transmission from the port and the interim storage of the terminal itself. Based on offshore shuttle tanker operations, it is typical to nominate a 3-day loading window for the cargoes scheduled for a calendar month at the beginning of the previous month. For efficient terminal operations it is necessary to have enough interim storage to receive a full cargo, facilitate the loading windows plus having a tolerance for unscheduled occurrences. It is debatable how much interim storage capacity will be required over and above the designated parcel size but having at least 140% of the carry capacity is a good starting point.

Having unreliable CO_2 inflow (or outflow for a discharge port), ports with significant non availability, and only a small number of carriers in the system would be good reasons to have additional interim storage capacity. There is a clear benefit in having compatibility of carriers that are operating in the area with a cooperation/backup arrangement to reduce the need for contingent capacity.

Availability of the desired bunker fuels at either the loading or discharge port is also important as is the ability to undertake bunkering simultaneously with a loading or discharge operation.

7. How much CO_2 can one ship move in a year?

A worked example is provided here.

A 20,000-tonne cargo liquified CO_2 ship with a one-week round trip time can transport approximately one million tonnes of CO_2 per annum, assuming there are no logistical nor weather delays.

[20] Type ‘C’ Tanks: These tanks are designed as cryogenic pressure vessels, using conventional pressure vessel codes, and the dominant design criteria is the vapour pressure. Most common shapes are cylindrical and bi-lobe. Type ‘C’ tanks are used in both, LPG and LNG carriers, dominant in the latter. Source Marineinsight.com

Figure 5: Worked example of 20,000 tonne ship with one-week round trip, assuming 13 knots and 90% utilisation[21]

Hours	Outbound	Return	Distance (nm)*
Loading	24		
Departing	2		
En route	50		585
Approach**	6		
Unloading	24		
Departing		2	
En-route		50	585
Approach		10	
Total hours	**106**	**62**	

000's Tonnes	Delivered
Per week	20
per year	1040

Assumptions (as per CCSA-ZEP report)

Carrier	Speed	Liquid/'loaded'	13	knots	Gaseous /'unloaded'	13	knots
	Utilisation factor		90	%			
Loading Terminal		hours			**Offload Terminal**		
	Hold time	6			Hold time	2	
	Passage in	4			Passage in	4	
	At berth	24			At berth	24	
	Passage out	2			Passage out	2	
	Total Time	36			Total Time	32	

Source: https://sea-distances.org/

Note: *Milford Haven to Immingham 593nm; Milford Haven to Peterhead 627nm. **Approach is hold time plus passage in

Excludes weather delays, logistical delays including port infrastructure outages and force majeure

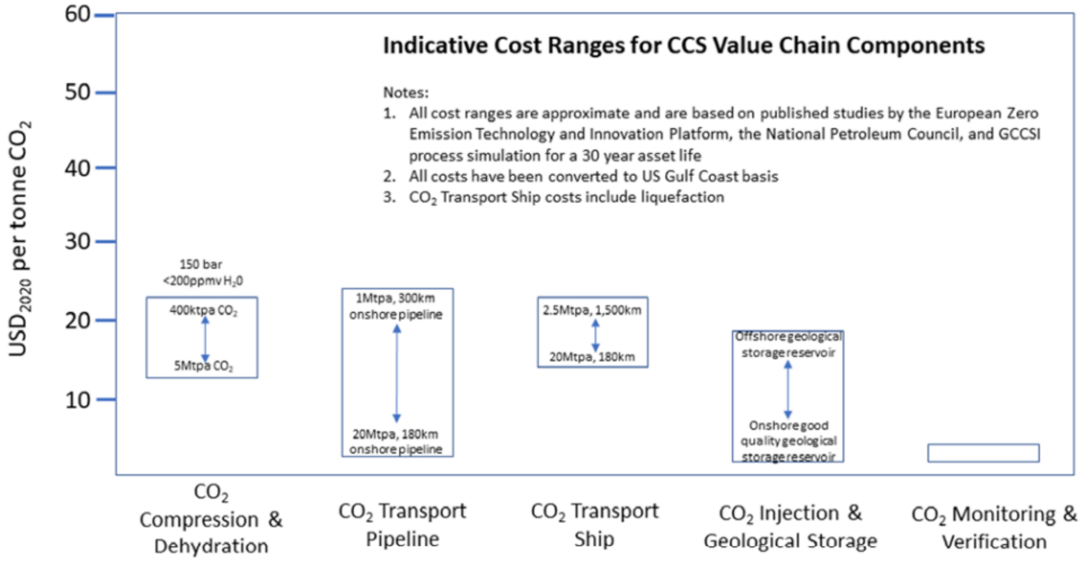
8. What about the transport costs?

Operational cost of CO_2 transport by ship: typically, normal yearly ship operational costs fall into three categories: fixed, fuel, and port fees. Fixed costs are associated with the administration, insurance, crew, maintenance, and repair. Crew and maintenance costs depend on the equipment type and size of the vessel. Port or harbour fees vary between various regions of the world, where the fee is based on the capacity of the ship. The third element is the fuel cost which is variable and based on the size of the vessel, engine type, the type of fuel used, the cost of the fuel and the voyage, which is a function of the distance between two ports.

Comparable CCS value chain costs in the US Gulf Coast have been analysed by the Global CCS Institute and indicative unit shipping costs were estimated in the range of 15–24 USD/tCO_2, including liquefaction.

[21] An analysis of fleet size vs. carrier capacity vs. sea distance is available in the CCSA-ZEP report

Figure 6. Indicative Cost Ranges for CCS Value Chain Components (excluding capture) – US Gulf Coast



Source: Global CCS Institute[22,23]

9. How important is CO_2 composition and the impurities?

Depending on the feedstock and the CO_2 generating and capture processes, CO_2 streams captured from industrial sources or power generation contain various impurities (that is, stream components other than CO_2). The impurities differ in their concentrations but also in their physical and chemical properties, which create several areas of concern:

- Health: impurities at low concentrations in the CO_2 cargo may be toxic (e.g., hydrogen sulphide or carbon monoxide) and could have an impact on release. Impurities should be assessed case-by-case.
- Safety/Integrity: minor components may be corrosive. For instance, components such as SO_x, NO_x, O_2 and H_2S, can react together in the absence of free water to produce corrosive components. CO_2 with free water creates carbonic acid, which is highly corrosive. Hydrogen can cause an embrittlement of steels.
- Phase behaviour: some impurities materially change the phase envelope of CO_2, potentially creating issues with keeping the CO_2 in a liquid phase where the deviation of the phase envelope from pure CO_2 increases with decreasing temperature.

Additional purification of the CO_2 stream increases capture costs. Chemical effects also include metal corrosion. The composition of the CO_2 stream can also influence the injectivity and the storage capacity, due to physical effects (such as density or viscosity changes) and geochemical reactions in the reservoir. In case of a leakage, toxic and ecotoxic effects of impurities contained in the leaking CO_2 stream could impact the environment surrounding the storage complex (see ISO TR 27921).

[22] Global CCS Institute, TECHNOLOGY READINESS AND COSTS OF CCS, page 38, link, 2021
[23] The Zero Emissions Platform (ZEP) 2019 report analyses the costs of CO_2 transport in more detail. https://zeroemissionsplatform.eu/document/the-costs-of-CO2-transport/

10. What about the future for CO_2 shipping across the wider European region?

As of today in Europe, one project, The Northern Lights, with a contracted CO_2 shipping capacity of 2 million tonnes per annum has taken a Final Investment Decision (FID). Based on a review of projects currently under development, the CCSA-ZEP report estimates that up to 39.5 million tonnes of CO_2 could be transported per year by 2030. The corresponding fleet of dedicated CO_2 carriers is evaluated between 6 (3 ordered and 3 anticipated, all related to Northern Lights) and 40 vessels.

An educated estimate for the number of vessels required by 2030 is in the range 10-20 vessels. However, should every project come to fruition in the short term, which is unlikely, the total number of vessels could exceed 50. This estimation is purely indicative and aims to provide a view of the potential future market. The capacity of future European storage sites compatible with ship transport could exceed 50 million tonnes per year by 2030[24]. Vessels are expected to be contracted for specific point-to-point CO_2 transport and will not be available for spot-market transport by 2030.

Acknowledgement

With thanks to Dragon LNG for part-sponsoring this summary of the latest developments in CO_2 liquefaction, loading, and shipping, and to the contributors to the CCSA-ZEP report on which this Energy Insight paper is based.

[24] Source: CCSA-ZEP report