Chapter 2

Establishment of Asia CCS/CCUS Value Chain as a Collective Framework in the Asia Pacific Region

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2.1. Introduction

CCS Networks can offer considerable benefit in supporting large scale and cost effective decarbonisation for industrial and power generation facilities globally. This section goes into detail to discuss these benefits including a demonstration through the development of a hypothetical CCS network design in Southeast Asia.

2.2. Understanding Clusters, Hubs, and Networks

2.2.1. Clusters

Many emissions-intensive industrial and power generation facilities globally are located in close proximity to one another. This is often for several reasons including energy supplies, power generation facilities, common feedstocks or common product distributions networks.

This provides the opportunity for CO_2 emitters in close proximity to each other to join together to form what is known as an emissions cluster. These emissions clusters can then be connected to large-scale CO_2 storage sites using strategically designed transport infrastructure for the total CO_2 produced from the emissions cluster.

The costs of a pipeline, possibly compression facilities, or ships and shipping infrastructure can be reduced on a cost per tonne of CO_2 basis if shared or only spent once rather than multiple times.

Like the physical infrastructure required, associated activities such as community consultation, government approvals, negotiations with property owners and so on, can be reduced on a cost per tonne basis.

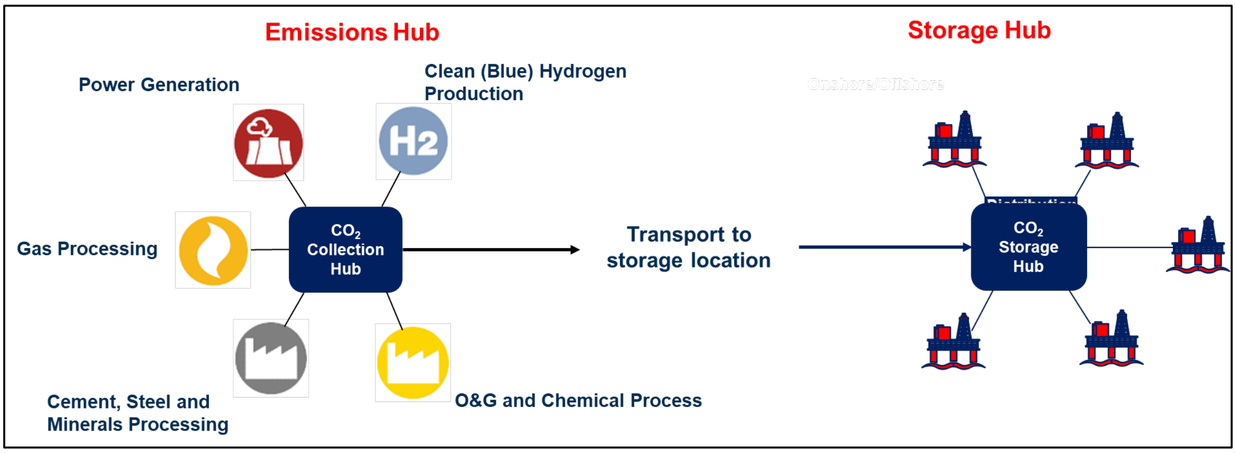
There can also be storage clusters, where CO_2 is distributed amongst a group of neighboring geological storage locations and/or oil fields suitable for enhanced oil recovery (EOR).

2.2.2. CCS Hubs

Hubs are very common in natural gas distribution systems globally, where pipeline networks bring together gas from many different production fields to distribute gas to dispersed markets.

CCS hubs work in a similar manner to natural gas distribution systems, acting as the central collection or distribution points for CO_2. One hub would service the collection of CO_2 from a emissions cluster or distribution of CO_2 to a storage cluster.

Figure 2.1. CCS Emissions and Storage Hubs



Source: GCCSI.

2.2.3. CCS Networks

A CCS network brings together all elements of the CCS value chain necessary to capture, transport, and store CO_2 for multiple emitting-intensive industries, including CCS hubs, emissions clusters, transport, injection, and storage.

As the network of emitters supplying CO_2 grows, the transport and storage infrastructure may increase to multiple transport pipelines, a greater number of ships with added port infrastructure, additional injection facilities, and storage locations.

Areas where there is a high density of CO_2 emitting industries and nearby suitable storage are considered excellent sites for hub and cluster developments supporting CCS network growth.

2.3. Strategic Benefit of CCS Networks

CCS networks are essential to secure the future of emissions-intensive industries and encourage future investments. This will be especially important as CO_2 emission reduction strategies become increasingly more necessary as a result of mechanisms such as climate protection policies or the introduction of a price on carbon emissions.

CCS networks offer several advantages for network participants, compared with vertically integrated CCS projects.

2.3.1. Cost Reductions through Shared Infrastructure

Industrial clusters create an opportunity to reduce cost by allowing multiple parties to share the often-expensive infrastructure for CCS. Larger capacity infrastructure also delivers economies of scale reducing the unit cost of CO_2 transport and storage.

Shared infrastructure with sufficient proven storage capacity can also allow facilities to separate their investment decisions from the development of the network. This is important to maximise the deployment and exploitation of CCS and its benefits at scale.

2.3.2. Enabling the Use of CCS for Smaller Emissions Sources

Many industrial facilities, including refineries, gas processing, hydrogen and fertiliser production and other chemicals generate CO_2 either through the conversion of feedstocks to products, or the use of high-temperature heat. However, compared to the typical emissions from large-scale emissions sources such as fossil fuel power stations, the volumes of emissions from these industrial processes can be small. Developing vertically integrated CCS projects at this small scale is often uneconomic. However, where they are located reasonably close to each other, the emissions from many small sources can be combined and can utilise shared CO_2 compression, transport and storage infrastructure accessing economies of scale that would not be available to any individual emission source.

It is important to understand that the number of smaller industrial facilities worldwide contribute significant cumulative CO_2 emissions that are unavoidable as long as the facilities continue to operate. The development of large-scale and strategically located infrastructure will enable the lower cost and full-scale deployment of CCS in industrial clusters, reducing cost and risk to smaller emissions sources.

2.3.3. Enabling CCS in Regions without Access to Suitable Local Storage

Networks offer an avenue for reducing emissions for industries in regions that do not have locally available storage. Regions with limited to no storage can leverage CCS networks to provide lower-cost transport either by pipeline or shipping to access storage in regions with abundant storage.

2.3.4. Enabling Low-Carbon Industrial Production

In many industries, such as steel, cement and chemicals, CCS is the only available technology capable of breaking the link between production and emissions of greenhouse gases. Operators able to connect their facilities to a CCS hub and cluster arrangement could effectively protect themselves and their investments against potential high future carbon prices, while regions that use CCS to establish themselves as ‘low carbon industrial zones' could see significant advantages in the race to attract and maintain investment.

In an increasingly carbon-constrained world, the development of emissions clusters will attract investment, increase industry engagement, and encourage the development of further projects in each location, thereby accelerating the development of a broader CCS industry.

2.3.5. Reduced Exposure to Resource Constraints

Resource constraints can manifest in many different ways for CCS. The supply of raw materials for the CCS equipment, equipment manufacturing and the workforce resources required to build and operate the infrastructure necessary to transport and store CO_2 may all be constrained given the potential demand for CCS in meeting global net zero commitments.

CCS networks may require additional resources during development and construction due to their scale versus a single vertically integrated CCS project; however, the workforce resources and equipment on a total number basis will be less when compared to the number of vertically integrated CCS projects that would be required to transport and store CO_2 from each of the emissions sources that could contribute to a CCS network.

This benefit will also extend to land availability and managing congestion in existing or new pipeline or shipping corridors, which could be limited for some existing emissions clusters located in densely populated areas or a highly congested shipping region.

2.4. CCS transportation methods

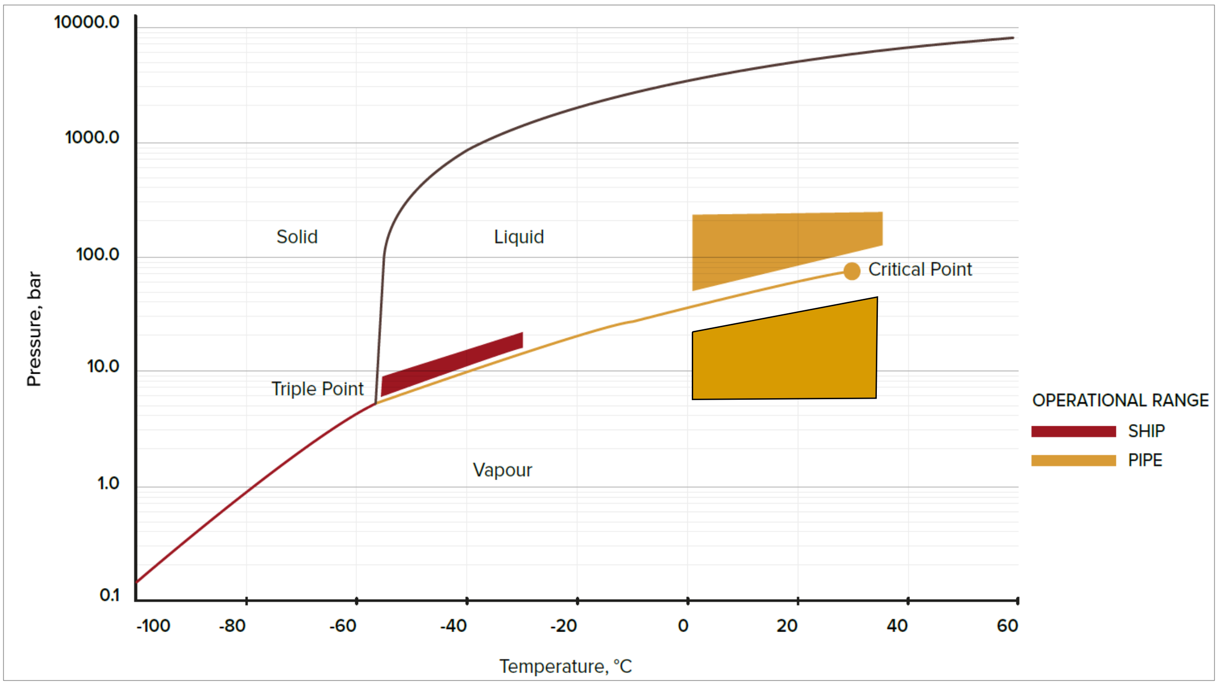
Several transport methods for transporting CO_2 from the emissions sources to a storage location for a CCS network include pipelines, ships, trucks, and rail.

2.4.1. Pipeline

Pipeline transport is the most commonly used mode of transport for CO_2 and is likely to remain so for the foreseeable future. Globally, the Institute tracks over 9,600km of operating CO_2 pipelines, primarily in the United States, and many more are in various stages of development.

Pipeline transport requires the CO_2 once captured to be compressed in either its gaseous phase or to dense or supercritical conditions beyond the critical point for ongoing transport to the storage location. Gas phase compression typically consists of a multi-stage compressor to raise the CO_2 to the desired pressure for transport. To compress to dense phase conditions a multi-stage compressor brings the CO_2 to the critical pressure of 74 bara after which the CO_2 behaves similar to a liquid and dense phase pumping can be used to continue to raise the CO_2 to the desired pressure for transport.

Figure 2.2. Pressure and Temperature Status Diagram of CO_2. Note the Small Area for the Transport of CO_2 Near the CO_2 Triple Point



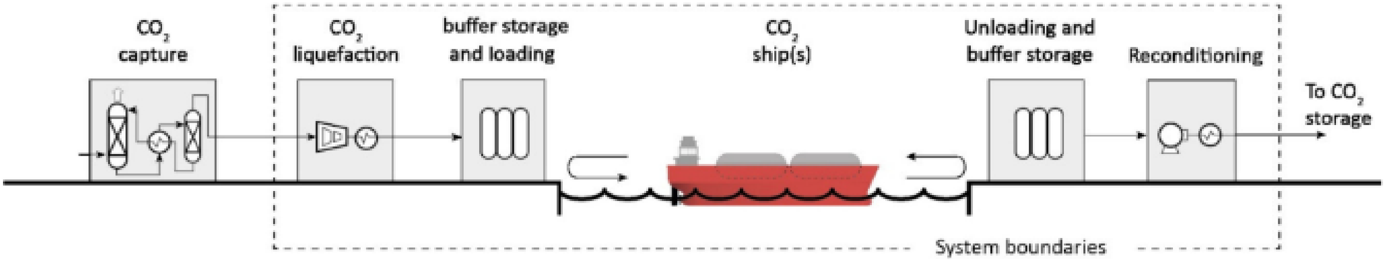
Source: GCCSI.

Water removal is essential to prevent corrosion of downstream pipeline infrastructure and enable the use of low-cost carbon steel versus higher metallurgical steel at a more significant cost. Water removal is often before, integrated with or following initial compression using dedicated drying equipment such as glycol dehydration or molecular sieves.

2.4.2. Shipping

The shipping supply chain for CCS consists of the following elements in Figure 2.3.

Figure 2.3. Main components for shipping logistics for CCS



Source: Roussanaly et al., 2021.

Liquefaction

Liquefaction involves the compression and liquifying of CO_2 prior to storage and transport by ship.

Liquefaction processes are typically divided into two methods:

- Internal cooling system ('open' system) where CO_2 is compressed to near the critical pressure before being decompressed to the transport pressure.
- External refrigeration system ('closed' system) where the CO_2 is compressed to the transport pressure and then liquified using an external refrigeration system.

Open systems are simpler in configuration but are typically less efficient.

The choice of liquefaction method depends on a number of factors (IEAGHG, 2020):

- The state of the CO_2 before liquefaction (either pressurised, at 70-100 bar abs, or at no or low pressure, at 1-2 bar abs source pressure).
- The required transport condition.
- The temperature of available cooling water.
- Availability/desirability of an external refrigeration system (e.g. using ammonia).

The liquefaction process is often the most energy intensive step in the ship transport value chain, requiring 11-14% more energy than the compression energy required for pipeline transport (IEAGHG, 2020).

The removal of water is essential at the conditions for liquefying CO_2 to prevent ice formation. Dehydration can occur through the compression and condensation steps of the liquefaction process. Alternatively, the CO_2 can be dehydrated prior to liquefaction using glycol dehydration or molecular sieve technology. Non-condensibles are typically removed through fractionation following liquefaction.

Buffer Storage

The flow of CO_2 from their sources and subsequent liquefaction of CO_2 is a continuous process. However, shipping operates discretely or in batches. To ensure that the flow of CO_2 remains continuous, buffer storage is required. Typical buffer storage consists of pressure vessels that are horizontal, vertical or spherical in shape. The shape considered is dictated by the area available for storage and costs.

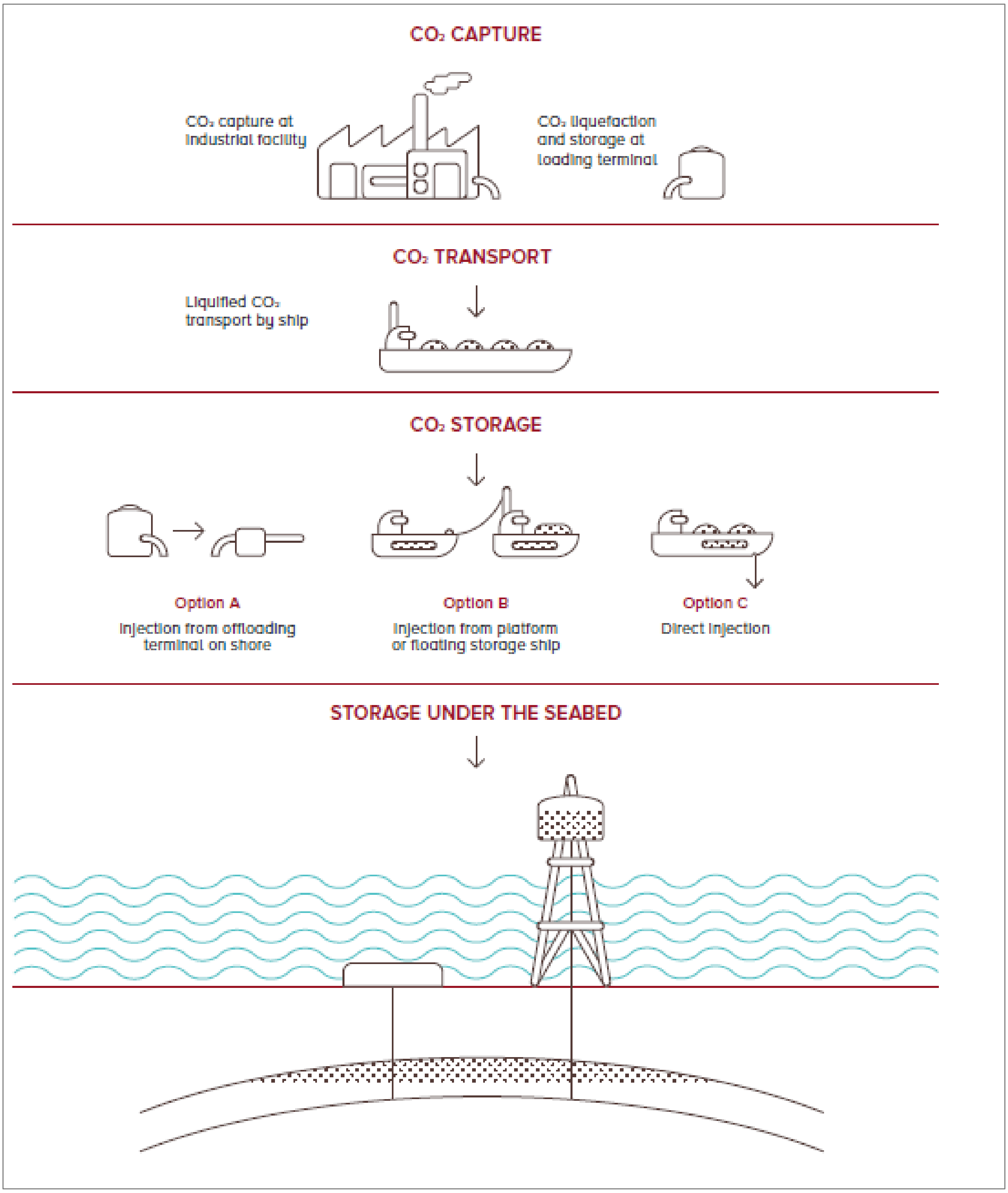
The capacity for buffer storage is important when designing shipping infrastructure. The capacity is based on factors including ship size and ship logistics. BEIS (2018) cites several literature sources that choose capacities between 100-150% of the ship capacity with 120% based on experience with LNG shipping balancing flexibility and cost being considered for the shipping cost study in the report.

Loading and Offloading Facilities

Loading of CO_2 from the onshore buffer storage to the CO_2 carrier can be performed using conventional articulated loading arms that are commonly used for cryogenic liquids like LPG or LNG.

The offloading scheme in Figure 2.4 illustrates the three basic options for offloading CO_2 from a ship to an injection site. If storage is onshore, the CO_2 is unloaded into an intermediate storage tank at the terminal (Option A) from where it can be piped to the onshore storage site. If the storage site is offshore, the ship could unload to an intermediate floating vessel, platform or buoy mooring anchor (Option B), or alternatively inject the CO_2 directly into the storage reservoir from the ship (Option C). Regarding Options B and C, the IEAGHG Shipping study identified that offshore unloading, although present in the literature, is largely unknown when compared to onshore unloading (IEAGHG, 2020). Also, the infrastructure and ship design vary significantly between Options B and C.

Figure 2.4. Offloading Options from Ship to Reservoir



Source: GCCSI.

CO_2 Ships

CO_2 is transported by ship in a liquid state at conditions near the triple point (Figure 2.2). Transporting near the triple point means the density of liquid CO_2 is much higher than in a gaseous state, enabling a larger amount of CO_2 transported per ship. Based on the density of CO_2, ships are categorised as low, medium and high pressure.

Ships used today for food-grade CO_2 transport are referred to as medium-pressure ships – they are designed to transport CO_2 as 'refrigerated liquid', at conditions in the range of 15-20 bar abs and -20 to -30°C, which is similar to liquefied petroleum gas (LPG) carriers. The existing size and number of these ships are limited. To date, there are only a few operational vessels specifically designed for the transport of CO_2, with a capacity in the range of 900-1,250 m^3 (Brownsort, 2015). Most of them were converted from LPG carriers.

For large-scale CCS applications, larger ships would be required than those available today. The majority would require more than one tank. For larger ships, CO_2 conditions of 5-9 bara and lower temperature -55°C are proposed and are categorised as low-pressure. The lower pressure is advantageous to reduce the thickness of the tank's walls, which helps lower the weight of the ship and reduces transport costs. Ships for the transport of CO_2 at low pressure would have a comparable design to typical LPG ships, with large, cylindrical tanks. This concept, however, requires the most energy for the liquefaction (cooling) of the gas.

Conditioning

Conditioning of the CO_2 corresponds to bringing the temperature and pressure of the liquified CO_2 to the desired conditions for further transport to the storage location. This process is fairly standard for cryogenic gases, with LNG regasification a good example. Heating is simple through cryogenic heat exchangers using air or seawater with compression handled by dense phase pumps.

2.4.3. Rail and Truck

Rail and trucks are an alternative means for connecting sources of CO_2 to CCS networks. Both transport CO_2 under cryogenic conditions, similar to shipping. Rail can enable large-scale transport but is typically only cost-effective if existing rail infrastructure can transport the CO_2 part or all of the desired distance to the storage location. If new rail infrastructure is required, pipelines typically offer a more cost-effective and flexible transport method. Trucking of CO_2 has been considered or employed for pilot or first-of-a-kind projects globally. Costs and logistics limit trucking for large-scale CCS projects; however, trucking can offer an opportunity to transport CO_2 from isolated industrial emitters to a CCS hub for further transport and storage.

2.5. CCS Transport Cost Trends

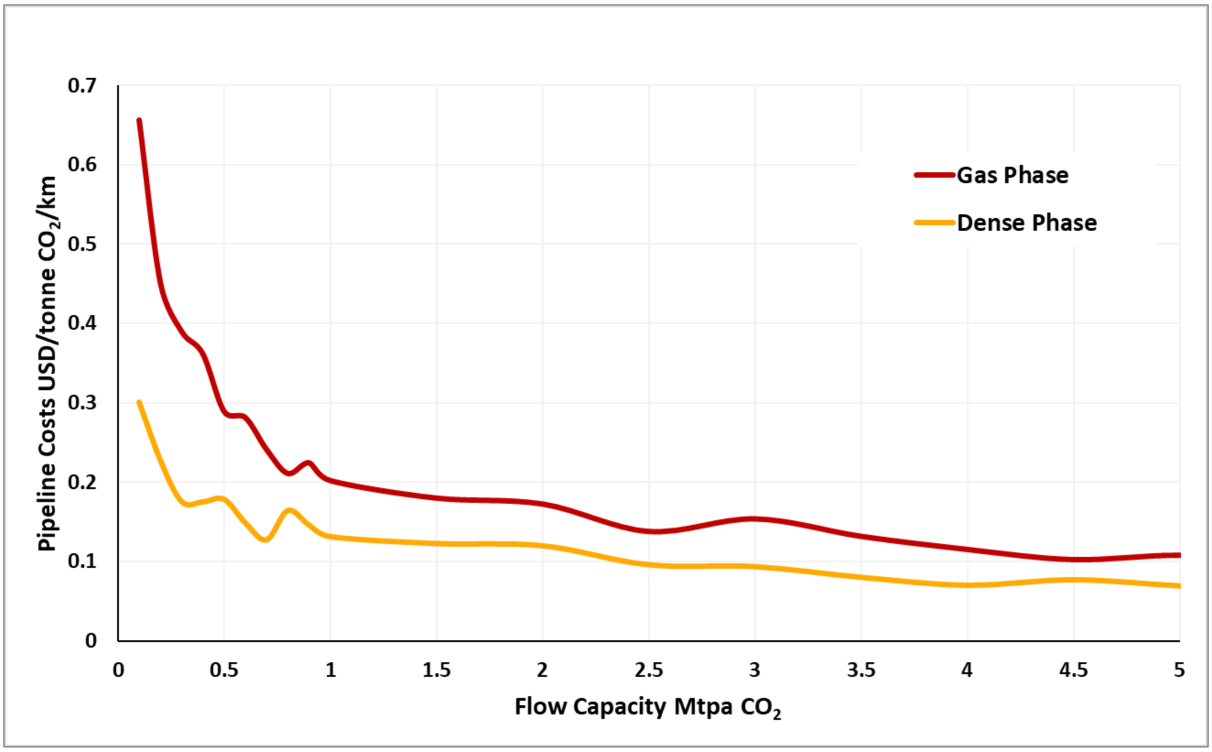
To understand how a network can support lowering costs for emissions sources, it is essential to outline the cost trends associated with key large-scale transport methods for CCS, including pipelines and shipping.

Pipelines

Pipeline transport network design is strongly influenced by cost trends for pipelines and CO_2 compression. An existing GCCSI report (GCCSI, 2021) highlighted the general trends for pipelines and CO_2 compression that should be considered when initially designing a CCS network:

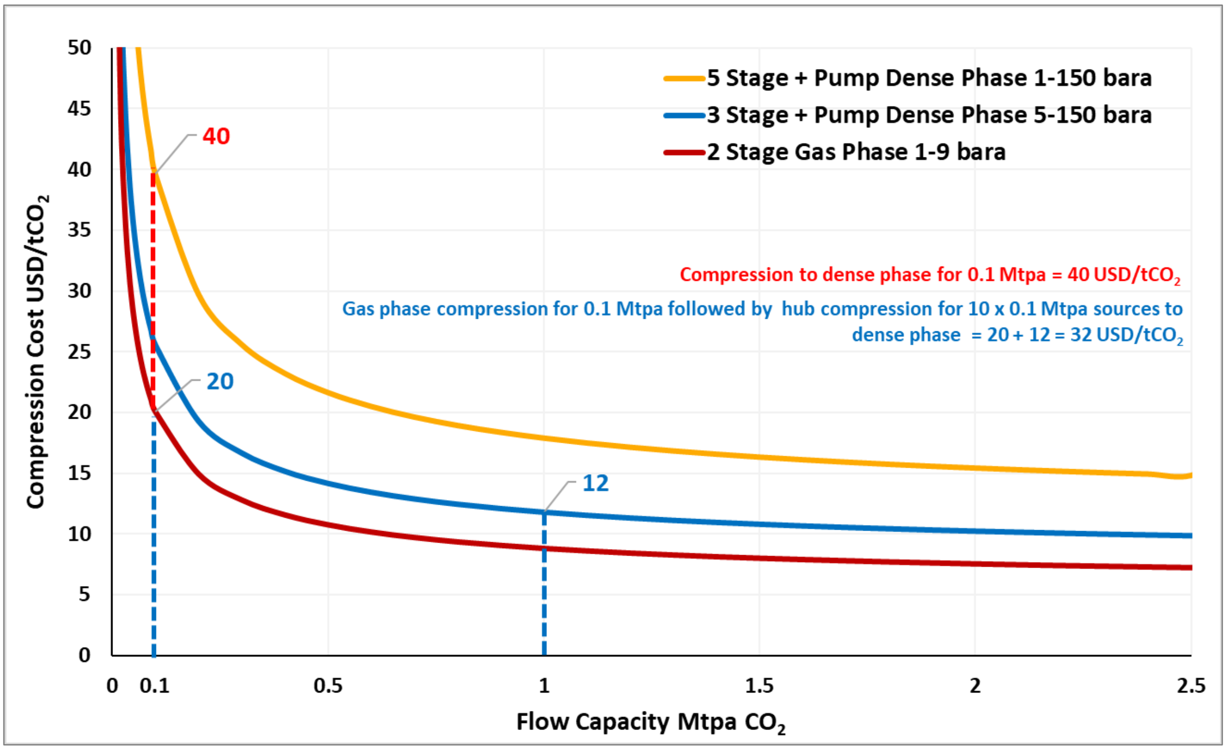
- Both pipelines and compression are strongly affected by economies of scale. Above a flow capacity of 1 Mtpa, further economies of scale offer a much smaller benefit.
- For short transport distances, gas phase transport is generally cheaper than dense phase transport due to lower initial compression costs and should be considered for transporting CO_2 sources to a CCS hub for further compression to dense phase conditions for ongoing transport.
- For long-distance pipelines, dense-phase transport is generally more cost-effective.

Figure 2.5. Indicative Costs of CO_2 Pipelines - Dense Phase (> 74 bara) and Gas Phase



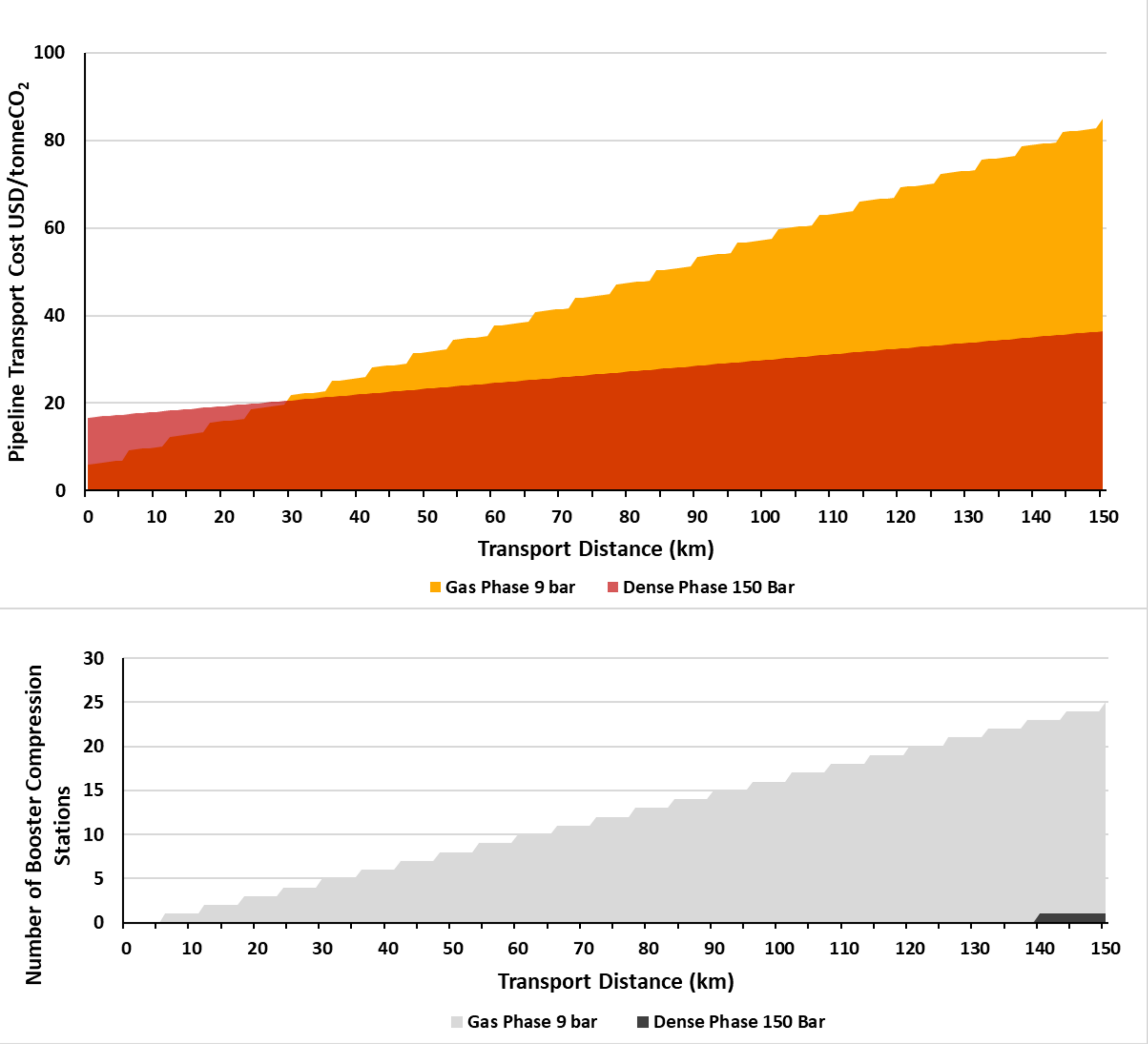
Source: GCCSI.

Figure 2.6. Costs of Gas Phase and Dense Phase Compression with Scenarios for Compressions Costs



Source: GCCSI.

Figure 2.7. Comparison between Gas Phase and Dense Phase Transport by Distance for a 1 Mtpa Flow Capacity Demonstrating the Benefit for Gas Phase Transport for Short Distance and Dense Phase Transport for Longer Distances



Note: Gas phase transport assumes pipeline operation between a maximum of 9 bara and minimum 5 bara. This results in gas booster compression required every 7km. Dense phase transport assumes pipeline operation between a maximum of 150 bara and minimum 100 bara, above the critical pressure. This results in dense phase booster pumping required every 140km.
Source: GCCSI.

Shipping

For ship-based transport, beyond economies of scale the design pressure of CO_2 ship storage and the size of the ship influence transport costs. The following table provides general factors that influence the costs for the two pressures proposed for ship-based transport for CCS. Generally, for large-scale transport of CO_2, low-pressure conditions are favoured; for small-scale transportation, either medium-pressure or low-pressure is considered.

Table 2.1. Positive and Negative Factors of Medium and Low-Pressure Ships

Factor	Medium Pressure	Low Pressure
CO_2 density	1 060 kg/m^3 Less CO_2 is transported per tank for a fixed volume, and larger volume capacity is required for a fixed mass	1 153 kg/m^3 More CO_2 is transported per tank for a fixed volume, and smaller tanks are required for a fixed mass
Liquefaction	Lower energy requirement for liquefaction (cooling and compression).	Greater energy requirement for liquefaction (around 10% higher).
Transport and storage tank design	Greater wall thickness is required, increasing weight and cost per volume stored and affecting workability. Storage tanks must be smaller, requiring more tanks and therefore higher capital and operational costs. Less expensive materials such as carbon steel may be used (depending on impurity levels, see next section).	Wall thickness can be lower, reducing weight and cost. Storage tanks can be larger, resulting in lower operational and investment cost. Higher quality material may be required to handle the lower temperature (close to -50°C), increasing material costs, but not the installation cost.
Ship design and operation	Greater number of tanks increases required ship size, increasing cost. Higher fuel consumption due to increased weight of tanks.	Lower number of tanks reduces required ship size, reducing cost. Lower operational and investment cost due to lower weight of tanks.
Heel	4%, greater impact on transport capacity.	1.6%, lower impact on transport capacity.
Water content limit	More strict requirements to avoid hydrate formation than Low P.	Less strict requirements – up to 100 ppmv.
Dry ice formation	Little dry ice formation in the event of a pressure drop.	As the condition is close to the triple point, the margins for formation of dry ice are smaller with implications for required control systems and relief valve streams.

Source: IEAGHG (2020).

Pipelines or Shipping

In some cases, there may be a choice between pipeline transport and shipping to manage costs of transport amongst several other factors. Existing studies have compared the two transport methods for large scale CO_2 transport and agree on the following conclusions:

- For an individual project, the choice between piped or shipped CO_2 will be mainly defined by cost optimisation.
- Generally, pipelines have lower costs than ships for transporting large quantities of CO_2 over short distances, while ships have lower costs over long distances.
- Pipeline costs are roughly proportional to distance, while shipping costs are only marginally influenced by distance.
- Costs of a pipeline generally consist for the most part of CAPEX (e.g. 75%–95%), while the costs of ships consist for the most part of OPEX (e.g. 60%–80%).
- A ship can be less costly than pipelines not only for single sources but also for CCS clusters during ramp up given the flexibility to adapt CO_2 shipping routes in contrast to pipelines.
- Due to the different CAPEX–OPEX structure, shipping might be used during the first-of-a-kind CCS deployment to limit investments upfront, reducing financial risk. Pipelines could be used in regions with well-established CCS infrastructure already available.

CO_2 shipping can also offer a more flexible alternative to pipelines for offshore storage and during the overseas movement of $CO_{2,}$ especially where there is variability in sources, demand, and storage sites. There are four major advantages of shipping over pipelines:

- Shipping enables the scale of a project to be rapidly increased if the market demands. Whilst additional or larger ships can be added to increasing CO_2 supply, the capacity of a pipelines needs to be defined from the initiation of the project. This presents an issue of over-engineering a pipeline anticipating greater demand or limiting the demand to pipeline design.
- Shipping enables a single ship, or shuttle shipping to load from multiple CO_2 sources and offload to a single storage site. From a storage perspective, this increases the economics of multi-user offtake agreements. From a capture perspective, this enables various-sized capture facilities, most likely industrial sources clustered in the same region to access transport and storage at a lower cost.
- Shipping routes can be changed, and new storage sites can be utilised if the original storage site becomes unusable. For example, if a storage site does not have the injection rates and total capacity required for the corresponding capture rates, the ship can be moved to another storage site. Re-routing a pipe or developing new pipelines would cost significantly more, or may not be feasible at all.

- Upon the closure of a CCS facility, a ship can be re-routed, sold, or reused, whereas a pipeline needs to be removed at a cost.

2.6. Hypothetical CCS Network Design and Costs

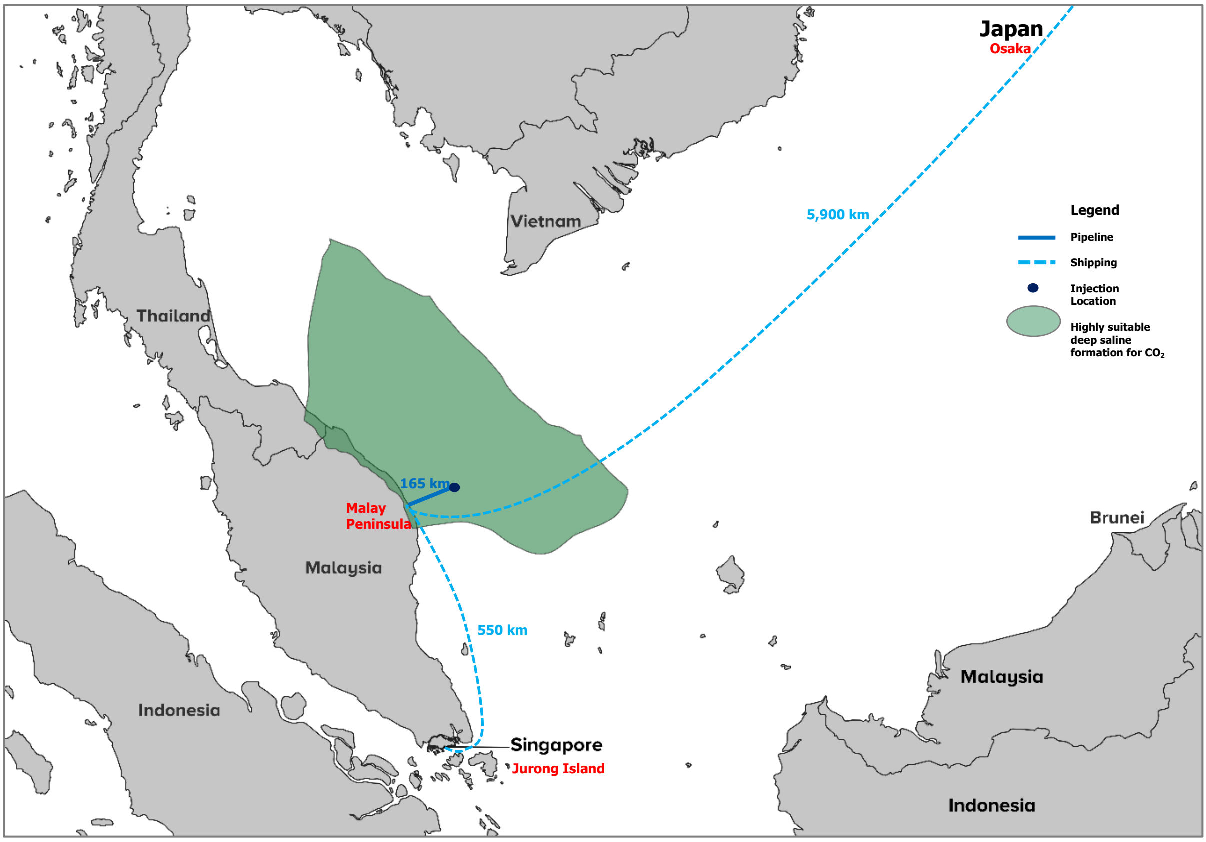
This section focuses on the design and cost of a hypothetical CCS network in the APAC region. This CCS network is then compared to the costs of individual vertically integrated CCS projects for all CO_2 sources considered in the study to demonstrate their cost benefits.

The CCS network covers various aspects of networks design, including multiple characteristics promoting the use of networks globally, including shared infrastructure for multiple CO_2 sources or emissions clusters and international transport of CO_2, supporting industries with limited or no locally available storage.

2.6.1. CCS Network Configuration

The map in Figure 2.8 shows the hypothetical CCS network that has been conceived for this study.

Figure 2.8. Proposed CCS Network on the Malay Peninsula



Source: GCCSI.

The hypothetical CCS network is centered around highly suitable storage in offshore waters off the Malay Peninsula on the east coast of Malaysia. Industrial clusters on the Malay Peninsula, Jurong Island Singapore and Osaka Japan supply the CO_2 that requires storage.

CO_2 from emissions sources in Jurong Island Singapore and Osaka Japan form CCS hubs where CO_2 is transported by ship to Malay Peninsula for further pipeline transport with local Malay Peninsula CO_2 sources to the offshore injection location.

2.6.2. Vertically Integrated CCS Project Configuration

The vertically integrated projects follow the same intended routes given in Figure 2.8. The key difference between the vertically integrated projects and the CCS network is the infrastructure design to transport the CO_2 from each source to the storage location in the Malay Peninsula, Malaysia.

2.6.3. CCS Network Emissions Sources

The emissions sources considered in this study were derived from estimates from operating data for industrial and power generation facilities located in each of Osaka, Japan, Jurong Island, Singapore, and the Malay Peninsula, Malaysia, using publicly available databases and GCCSI subscribed databases.

The following facilities and emissions were considered for transport of CO_2 for this CCS network. The names of each facility remain undisclosed, however the emissions generated will be representative of the expected emissions that could suit CCS in each location.

Table 2.2. Osaka, Japan, Industrial Emissions

Industry	Plant	CO_2 Emissions (Mtpa)
Refining	Refinery 1	0.9
	Refinery 2	1.4
Chemical	Chemical Plant 1	0.5
	Chemical Plant 2	0.3
	Chemical Plant 3	1.0
	Chemical Plant 4	0.7
	Chemical Plant 5	0.3
	Chemical Plant 6	0.1
	Chemical Plant 7	0.1
Steel	Steel Plant 1	3.1
Power	Power Plant 1	3.2
Total		11.5

Source: GCCSI

Table 2.3. Jurong Island, Singapore, Industrial Emissions

Industry	Plant	CO_2 Emissions (Mtpa)
Refining	Refinery 3	1.8
	Refinery 4	1.2
Chemical	Chemical Plant 8	0.4
	Chemical Plant 9	0.5
	Chemical Plant 10	0.1
	Chemical Plant 11	0.2
	Chemical Plant 12	0.9
	Chemical Plant 13	4.1
	Chemical Plant 14	0.5
	Chemical Plant 15	1.5
	Chemical Plant 16	1.0
	Chemical Plant 17	1.1
	Chemical Plant 18	0.4
	Chemical Plant 19	0.2
Power	Power Plant 4	1.6
	Power Plant 5	2.5
	Power Plant 6	0.4
	Power Plant 7	3.0
	Power Plant 8	0.1
	Power Plant 9	2.4
	Power Plant 10	2.9
Total		26.8

Source: GCCSI.

Table 2.4. Malay Peninsula, Malaysia, Industrial Emissions

Industry	Plant	CO_2 Emissions (Mtpa)
Refining	Refinery 5	0.5
Chemical	Chemical Plant 20	0.4
	Chemical Plant 21	1.9
	Chemical Plant 22	0.5
	Chemical Plant 23	0.3
	Chemical Plant 24	0.1
	Chemical Plant 25	0.2
	Chemical Plant 26	0.2
Power	Power Plant 2	2.0
	Power Plant 3	1.4
Total		7.5

Source: GCCSI.

2.6.4. Design Basis

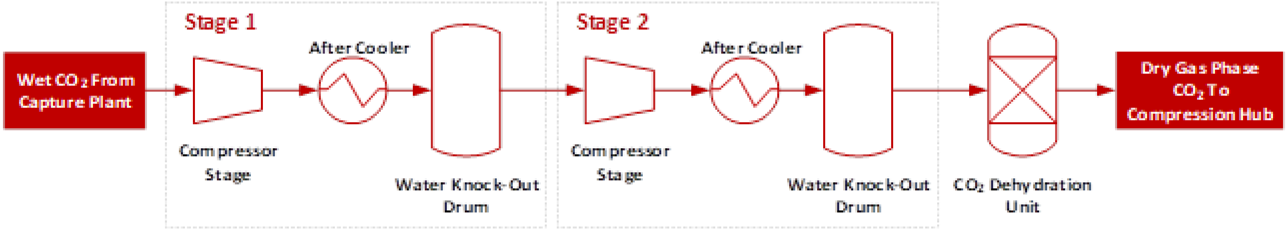
The following design assumptions were used in the design of the CCS network.

- **Transport from Osaka, Japan, and Jurong Island, Singapore, to the Malay Peninsula**

CCS Network Design

- CO_2 from each source plant (power generation or industrial plant) in Osaka, Japan, and Jurong Island, Singapore, is assumed to require 5km of piping to reach the CO_2 port for liquefaction for ship transport. For some CO_2 sources the distance may be less following more rigorous design, however for this level of design this is sufficient.
- Each CO_2 source in Osaka, Japan, and Jurong Island, Singapore, is compressed modestly on-site at each capture facility and remains in the gas phase followed by CO_2 dehydration. Two-stage compression is employed, sufficient to deliver CO_2 at 7 bar abs (6 bar gauge) for liquefaction at the port in preparation for shipping.

Figure 2.9. Gas-Phase Two-Stage Compression and Dehydration Located at Each Burrup Peninsula CO_2 Source Plant



Source: GCCSI.

- CO_2 transport from Osaka, Japan, to the Malay Peninsula, Malaysia, is a distance of 5400 km and from Jurong Island, Singapore, to the Malay Peninsula, Malaysia, is a distance of 500km.
- Ships are designed for low pressure CO_2 storage at 7 bar abs and for total volumes of 43,000 m^3 CO_2, or 50,000 tonne CO_2. Low pressure transport is considered for this study due to the large scale volumes and distances travelled by ship in this study, noting that is yet to be proven at a commercial scale.
- Onshore source liquefaction, storage and loading facilities in either Osaka, Japan, and Jurong Island, Singapore, are sized for the overall CO_2 volumes for each location.
- Onshore destination unloading, storage and conditioning facilities on the Malay Peninsula, Malaysia, are sized for the overall CO_2 volumes for each location.

- Storage at both the source and destination locations is sized at 120% of the overall ship capacity for a given shipping transport stage based on experience in LNG shipping and to balance the flexibility and cost efficiency (BEIS, 2018) .
- The duration of mooring, loading, and departure at the export hub is set to 12 hours (ZEP, 2011).
- The average shipping speed during transport is assumed to be 26 km/h (14 knots) (ZEP, 2011)
- The duration of mooring, unloading, and departure at the receiving facility is considered to be 12 hours (ZEP, 2011)
- A ship is considered to operate 8400 hours per year, leaving 360 hours for annual maintenance and repairs (ZEP, 2011).

Vertically Integrated CCS Projects

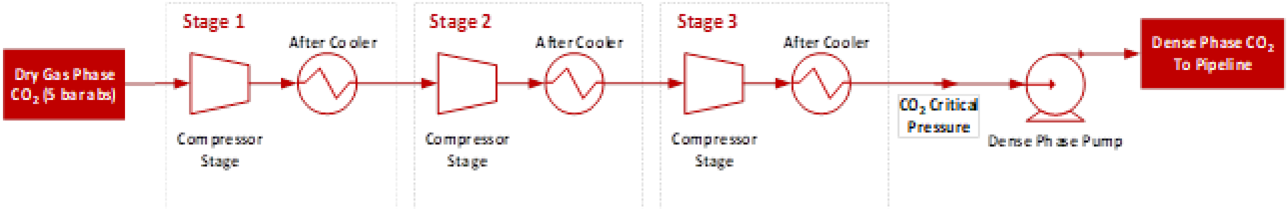
Key design assumptions from the CCS network design are applicable for each of the vertically integrated projects. Ship size remains unchanged, however in more detailed design would focus on optimisation of ship size to meet the scale of each CO_2 source.

➢ Transport from the Malay Peninsula to the Storage Location

CCS Network Design

- CO_2 from each source plant (power generation or industrial plant) on the Malay Peninsula, Malaysia, is assumed to require 5km of piping to reach a CO_2 compression hub for further transport. For some CO_2 sources the distance may be less following more rigorous design, however for this level of design this is sufficient.
- Each CO_2 source on the Malay Peninsula, Malaysia, is compressed modestly on-site at each capture facility and remains in the gas phase followed by CO_2 dehydration. Two-stage compression is employed, sufficient to deliver CO_2 to the CO_2 compression hub at 5 bar abs (6 bar gauge)
- The CCS compression hub has three-stage gas compression compressing the aggregated dry CO_2 from 5 bar abs up to the CO_2 critical pressure (approximately 73.8 bar abs). Above the critical pressure CO_2 is in the dense phase and behaves like a liquid and can be pumped. A dense phase pump provides the necessary compression above the critical pressure to ensure CO_2 can be transported to the storage location at the required injection pressure.

Figure 2.10. Three-Stage Compression and Umping Arrangement at Main Compression Hub



Source: GCCSI.

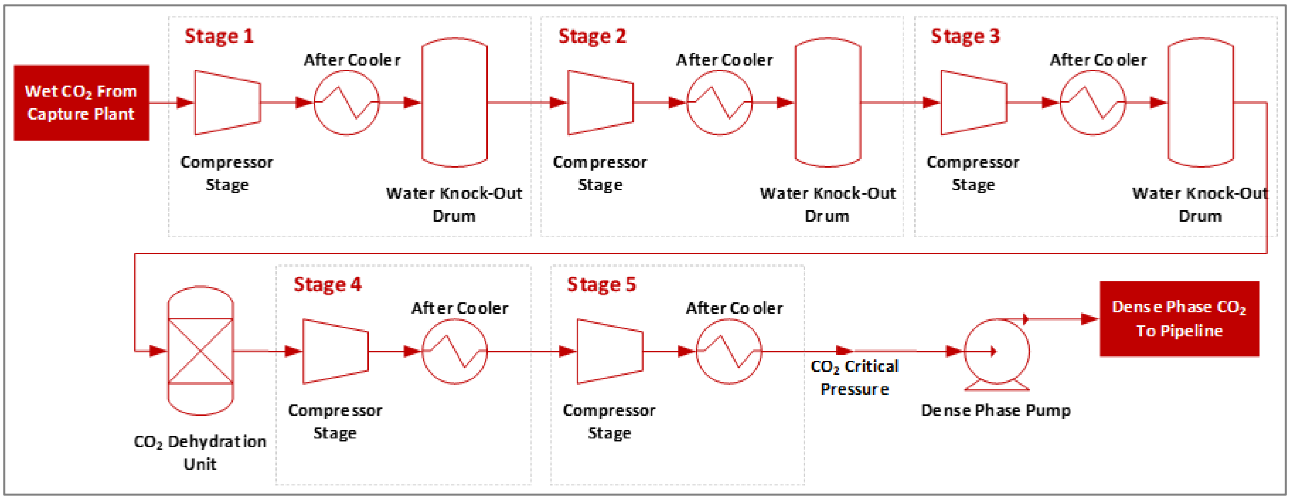
- Each CO_2 source from Osaka, Japan, and Jurong Island, Singapore, undergoes conditioning to bring the CO_2 up to be transported to the storage location at the required injection pressure. For this study heating of the CO_2 is incorporated in the conditioning costs with the unloading facilities for ship-based transport. Dense phase pumping has been assumed to bring the CO_2 up to the required transport pressure.
- CO_2 is transported from the Malay Peninsula 165km by offshore pipeline to the injection location.

Vertically Integrated CCS Projects

Key design assumptions from the CCS network design are applicable for each of the vertically integrated projects with the inclusion of the following assumptions.

- Each CO_2 source on the Malay Peninsula, Malaysia, is compressed by five-stage compression and dense phase pumping with dehydration providing the necessary compression to ensure CO_2 is at conditions for transport to the storage location.

Figure 2.11. Five-stage compression, Dehydration, and Dense Phase Pumping



Source: GCCSI.

➢ Other general assumptions and data

Pipeline and Compression

- All pipelines are sized for the overall CO_2 flow expected for that given pipeline up to the maximum standard nominal pipe size of 600mm for dense phase transport and 900mm for gas phase transport.
- Dense-phase CO_2 lines sized for 2 m/s CO_2 velocity (Peletiri et al., 2018)
- Gas-phase CO_2 lines sized for 20 m/s CO_2 velocity (Sinnot and Towler, 2009, p.259)
- Steel schedule 160 piping was selected for dense/supercritical phase CO_2. With a maximum allowable working pressure of 253 bar (Atlas Steels, 2010), this pipe has thicker walls than conventional schedule 40 piping and is suitable for the pressures seen in CO_2 transport.
- Steel schedule 40 piping was selected for gas phase CO_2.
- Dense/supercritical phase operations must stay between two limits:
  - Pressure must be well above the critical pressure to avoid two-phase behaviour which can introduce mechanical stress and risk to piping integrity. In this study, that minimum pressure has been selected as 100 bar abs.
  - Pressure must remain below the safe operating pressure for the pipeline. This has been taken as 10% below the 253 bar abs maximum allowable working pressure, or 227.7 bar abs.
- Compression station elevation is 10m above sea level.
- The endpoint of offshore pipeline at the Malay Peninsula is 100m below sea level (sea floor).
- Destination pressure target for injection is 100 bar abs (ENI S.p.A, 2018, p. 10).
- Discharge temperature of CO_2 at the compression hub is 50°C.
- Seawater temperature is 25°C (affects CO_2 cooling in offshore lines).
- Overall heat transfer coefficient for the pipeline in seawater is 44.7 $W/m^2/K$ (Drescher et al., 2013, p.3055). This is used to model cooling in offshore pipelines.
- Soil temperature is 25°C (for CO_2 cooling in buried onshore line).
- 20% was added to route length to account for fittings losses when calculating pressure drop.
- The pressure ratio of each stage of compression is assumed to be the same.

- CO_2 is cooled to 50°C after each stage of compression. The high humidity rules out conventional cooling towers for cooling. It is anticipated that either air-cooling or seawater cooling will be used.
- Maximum power consumption for a compression train (all stages/pumps) is 40 MW electric. For cases requiring more power than this, multiple trains were used to keep individual power consumption below 40 MW (Mccollum and Ogden, 2006).

Shipping

- 10% was added to route length to account for weather events and other factors that may impact the shipping route taken.
- Boil-off during ship transport is neglected (ZEP, 2011)
- It is assumed the jetty length, ship length, and draft at loading ports are all acceptable for this case study.

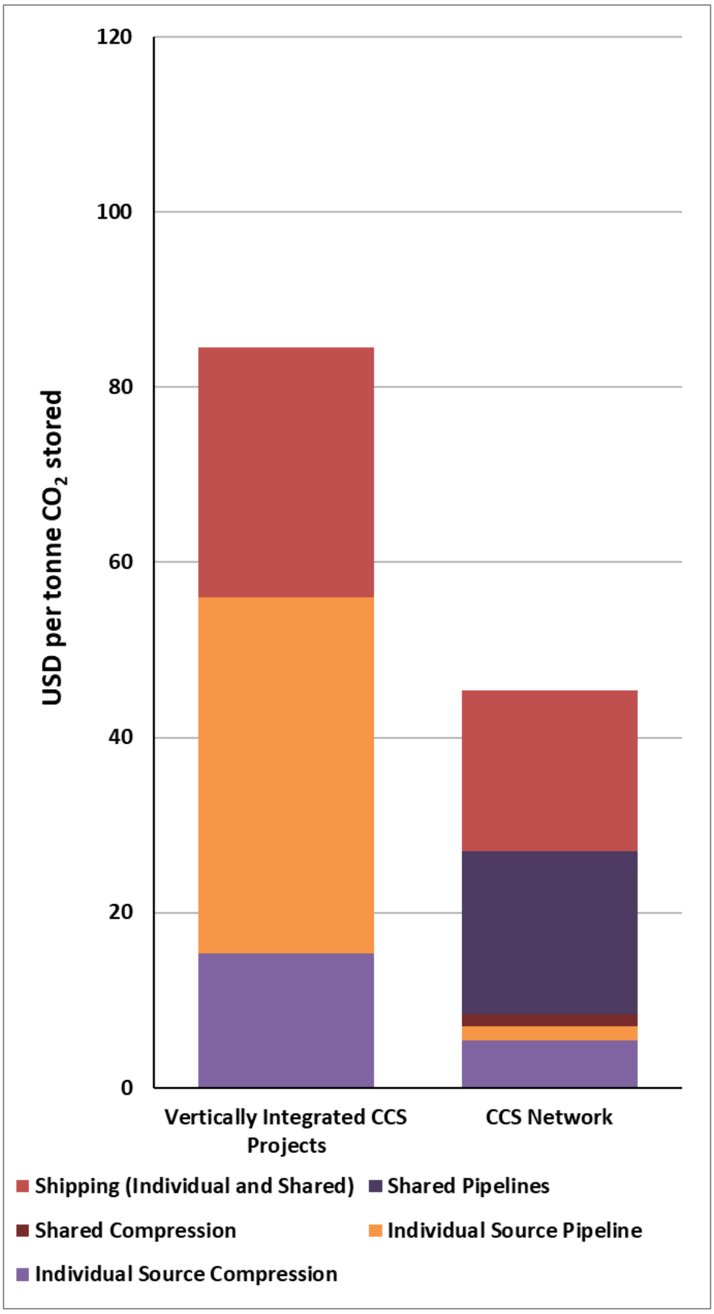
2.6.5. Cost Basis

The methods for estimating the capital and operating costs for the compression, pipelines and shipping infrastructure for the CCS network design are given in Appendix B. All costs shown are in United States dollars (USD) unless otherwise stated.

2.6.6. CCS Network Design Costs

A summary of the average cost components for the CCS network against the average costs for each of the individual vertically integrated CCS projects is given in Figure 2.12.

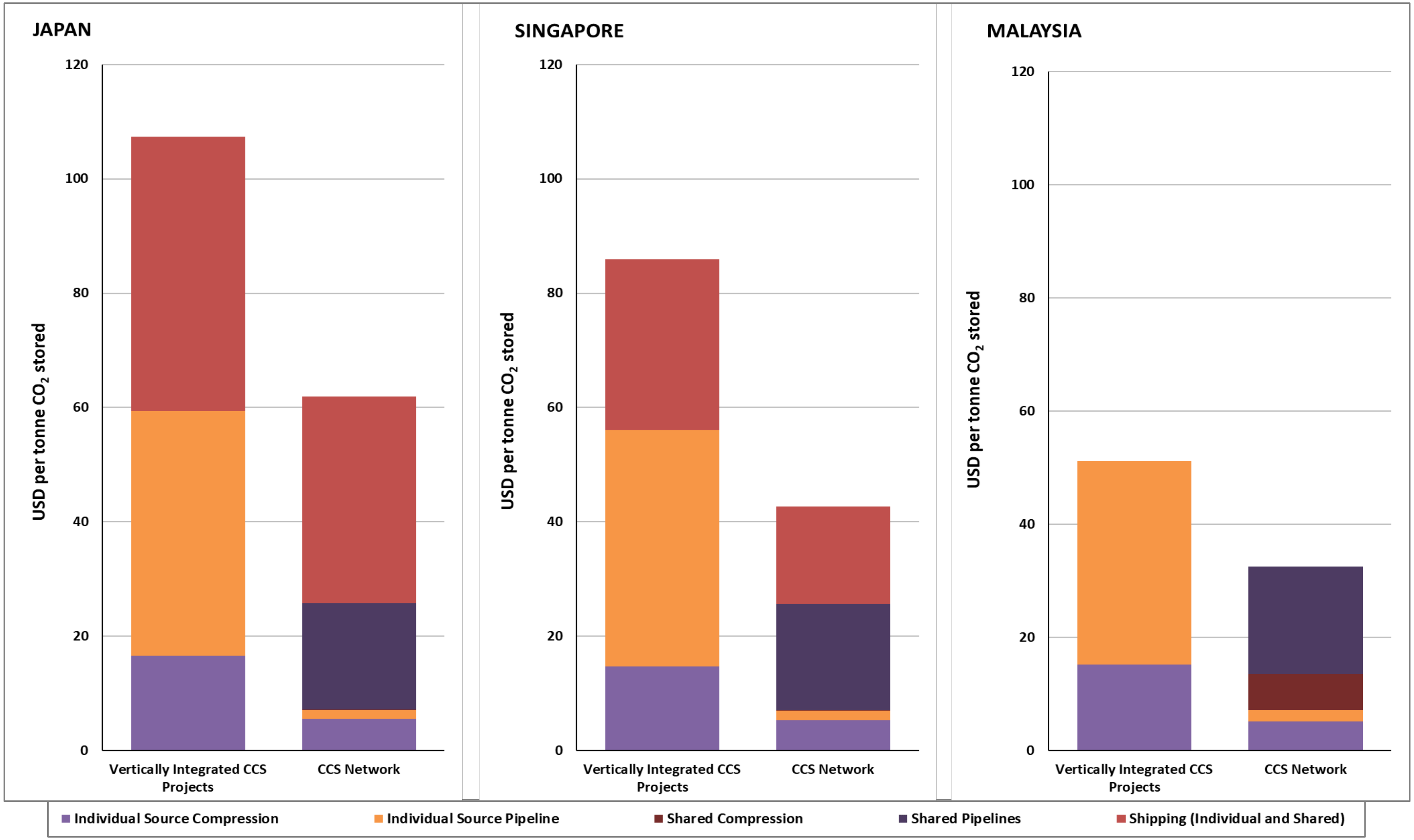
Figure 2.12. Overall Levelised Cost of Transport for the CCS Network Against the Vertically Integrated CCS Projects



Source: GCCSI

We can see clearly from an overall cost to store the CO_2 from the emitters supported by the CO_2 network is reduced by 45%. The cost benefits apply to all shared transport methods in this CCS network, including pipelines and shipping. While there is a substantial reduction in costs overall, the impact will vary for each of the emissions clusters and the individual emitters within each emissions cluster.

Figure 2.13. Levelised costs of transport for the CCS network against vertically integrated CCS projects for Japan, Singapore and Malaysia



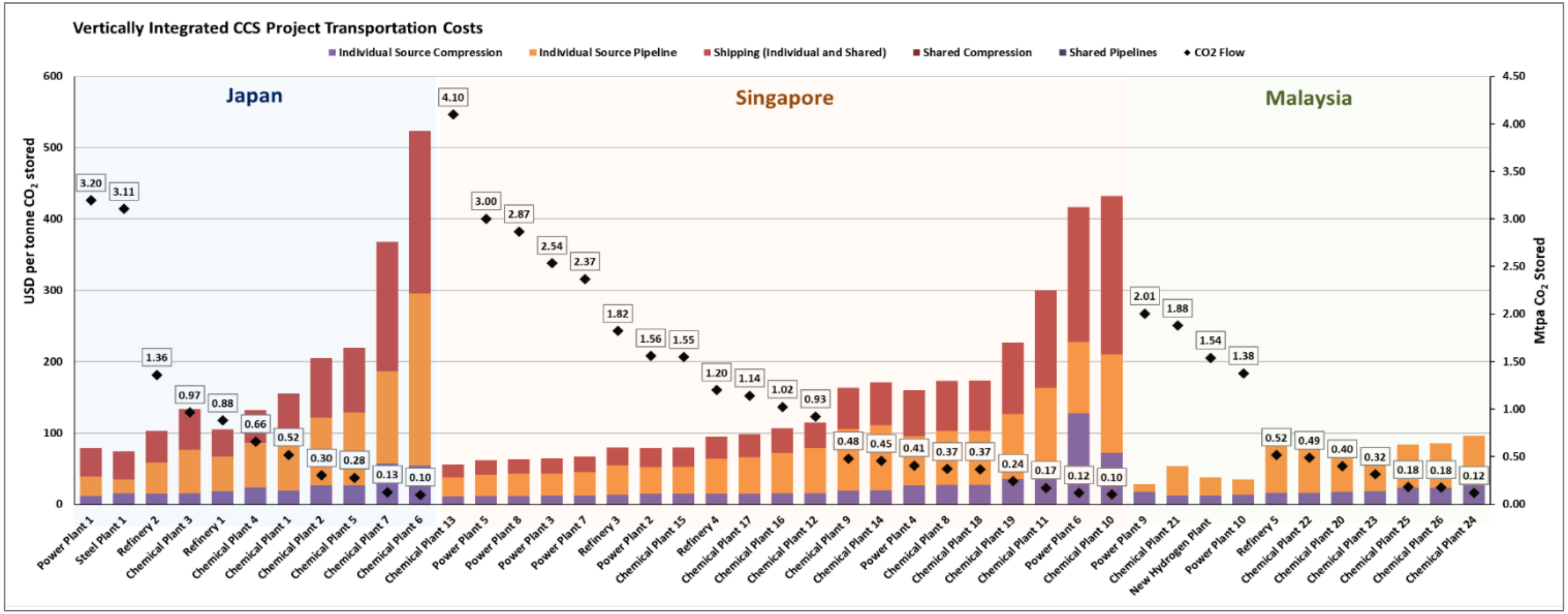
Source: GCCSI.

Figure 2.13 further details the cost benefits to each of the emissions clusters. We can see that the reduction in costs is generally similar for each of the emissions clusters, ranging from 37% to 50%. However, on a cost-per-tonne basis, this results in a considerably greater reduction the further the transport distance. This highlights how regional CCS networks could allow emissions clusters with limited or no locally available storage to gain access to regional storage opportunities cost-effectively if given support to develop.

Emission sources in each emissions cluster will see varying cost benefits depending on the scale of their emissions. CCS networks enable the shared transport and storage costs to be evenly distributed across all emissions sources on a cost-per-tonne basis. Therefore, the benefit for shared transport can be significantly greater for smaller emissions sources where CCS may otherwise be cost-prohibitive.

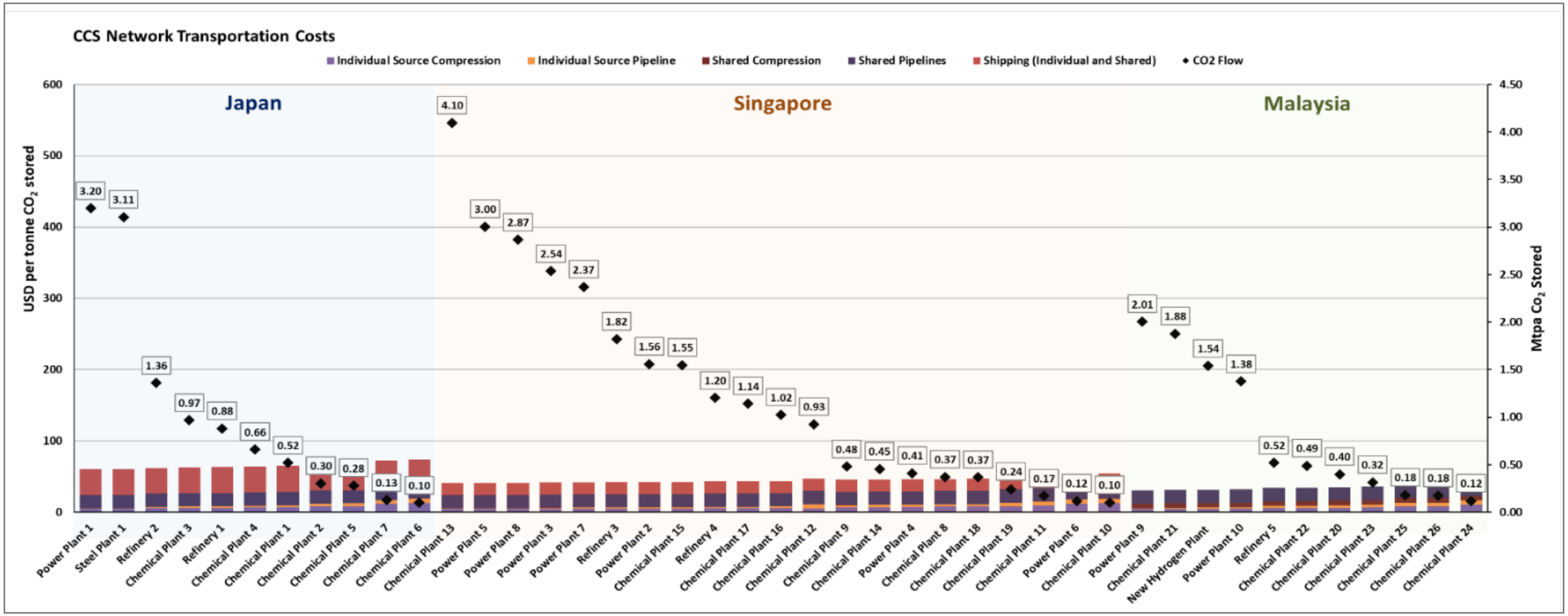
This is evident when comparing the costs of the individual source to storage CCS project versus the CCS network for each emissions source in Figure 2.14. For each emissions cluster the emissions sources are displayed from largest to smallest total CO_2 emissions to see the cost trends with scale of CO_2 flow.

Figure 2.14. Levelised Costs of Transport for the CCS Network Against Individual Source to Storage CCS Projects for Each Emissions Source



Source: GCCSI.

Figure 2.15. *Continued*



Source: GCCSI.

While all emissions sources see a reduction on a cost-per-tonne basis through shared infrastructure, the emissions sources with smaller total CO_2 emissions see the greatest benefit. For smaller emission sources in Japan and Singapore, the shared costs for CCS networks offer up to a 90% reduction.

2.6.7. Conclusions and Recommendations

The development of CCS hubs and clusters, bringing together a number of different CO_2 emissions sources and/or storage sites in a connected network, offers participants several advantages over vertically integrated CCS projects. Benefits include reduced costs and risk, enabling more cost-effective transport and storage from small volume sources, and maintaining investment and jobs in high-emitting industrial regions.

Actions that should be considered by project proponents and governments to facilitate the development of CCS hub and cluster networks include:

- Identification of emissions clusters and storage resources that could support the development of CCS networks in each country and regionally. This provides the initial starting point for strategically developing CCS networks.
- Support with resources and funding for the appraisal of CO_2 storage resources in a given country or region. Locally available storage resources will always be more cost-effective than leveraging regional storage resources. Identifying surplus storage resources for the needs of the current emission sources allows for opportunities for low-emissions industry growth and provides storage resources to neighbouring countries with limited or no locally available storage.
- Identify avenues for incorporating new industries (i.e. clean hydrogen or ammonia) with existing emissions clusters early in developing CCS networks.
- Early identification of regional CCS network opportunities. Regional CCS networks will in most cases be more complex with the transboundary movement of CO_2. Early identification of these CCS networks will enable project proponents and governments to work through the necessary steps to facilitate their development.
- Identify opportunities to fast-track the development of first-mover CCS networks to expedite knowledge growth and accelerate the development of further CCS networks.
- Well-planned, early engagement with stakeholders and the community in the vicinity of emissions clusters and potential CCS networks.

2.7. Regional Legal and Institutional Frameworks Necessary to Support CCS Hub and CO_2 Transport Networks

2.7.1. Introduction

Large-scale deployment of CCS in the region will require a coordinated effort between countries in Southeast Asia, to develop frameworks and platforms for successful and timely project delivery. Integrated upstream policy and robust institutional frameworks will be key to underpin regional project implementation. In addition, coordinated institutional frameworks, including coherent decarbonisation strategies, project approval and procurement strategies, and investment plans, will reduce project risk and enable capital investment.

In August 2023, the World Economic Forum (WEF) released a report, *'How (and why) to boost carbon capture, usage and storage to move towards net zero'*, in which they express support for boosting innovation in CCUS and call on further significant public and private investment in R&D. The report encourages governments to invest in CCUS infrastructure and to develop industrial clusters to generate economies of scale. The WEF argues that once CCS technologies become mainstream, governments need to consider making CCUS a legal requirement for most polluting industries. The WEF concludes that '*it is vital for governments to make CCUS policy a national priority, since UN IPCC assessments make it clear that the transition to net-zero cannot be delayed if the world is to avoid a humanitarian crisis on an unprecedented scale*'. (World Economic Forum, 2023)

In Southeast Asia, interest in CCUS is growing and as of July 2023, there are 13 commercial CCS facilities located in Indonesia (8), Malaysia (3), Thailand (1), and Timor-Leste (1). Only the Kasawari project in Malaysia is in construction, while the remaining eleven facilities are in development. The average capture capacity of these projects is 1.9 Mtpa. CCS development in ASEAN is considered at nascent stage.

In June 2021, a significant milestone was reached with the establishment of the Asia CCUS Network, which aims to facilitate collaboration on the deployment of CCUS in Asia. Regional approaches to CO_2 transport and storage infrastructure could enable faster and more widespread uptake of CCS in Southeast Asia. In particular, the development of large, shared CO_2 storage resources that can be accessed by multiple facilities and countries could support CCS investment in locations where storage capacity is either limited or where its development faces delays. In addition, as demonstrated in the previous section, economies of scale could be realised through establishment of industrial clusters that could access transport networks and shared storage facilities. (IEA, 2021a)

Project proponents in Southeast Asia continue to voice concern that existing frameworks will not support commercial scale deployment of CCS. There are many critical issues relating to CO_2 transport and storage that remain unaddressed by national legislation. Although there have been some noteworthy developments in the region over the past year, the absence of CCS-specific legislation remains a significant barrier and one which must be overcome for countries and industry to realise their commitments to emissions reduction. Timely action is essential in this regard, and the consequences of further delay are likely to prove significant.

Where countries are already involved in regional structures (such as the European Union or ASEAN), it makes sense for countries to employ collaborative efforts to achieve climate commitments as a collective. Regional cooperation will require robust legal and institutional frameworks to guide coordinated efforts towards the large-scale deployment of CCS.

The EU has succeeded in creating a regional directive for CCS, which covers related activities of all member states. In contrast to the EU, there is no overarching governing body for ASEAN with decision making powers equal to the EU Parliament, and there is a substantial disparity in income levels amongst the ASEAN member countries, both of which could pose a challenge for regional cooperation. Nevertheless, the cooperation between member states on CCS under the EU Directive could provide a good example to ASEAN nations, and the Directive could act as a guide in the development of a regional CCS framework for Southeast Asia. The EU Directive is discussed further in Section 2.7.2.

Legal and institutional frameworks necessary for the deployment of CCS cover a broad spectrum of activities across the lifecycle of a CCS project, and will necessarily include international, national and domestic aspects. The diagram below sets out key elements to be considered in CCS-related legal and institutional frameworks to be developed for the region.

Table 2.5. Components of CCS-Specific Legal and Institutional Frameworks

Legal Frameworks	Institutional Frameworks
• Transboundary regulation of CO_2 transport and storage • Interaction with wider international and national maritime laws • Alignment with wider health and safety legislation • Classification and ownership of CO_2 • Access/rights to potential storage sites • Authorisation of storage activities • Monitoring and verification obligations • Closure and post-closure aspects of operations	• Partnering on CCS R&D activities • Coordinated project planning and development • Coordinated government and company procurement frameworks • Coordinated project investment activities • Coordinated effort to access international funding, including development finance and export credit opportunities

Legal Frameworks	Institutional Frameworks
• Rights and responsibilities of operators and relevant authorities across the full project lifecycle • Treatment of long-term liability • Financial security • Carbon markets • Risk management across all stages of the CCS project lifecycle • GHG emissions accounting and reporting frameworks	

Source: GCCSI.

A comprehensive CCS legal and regulatory framework for the region must balance competing interests of international, national and local governments, and private sector stakeholders, including financiers, insurers and the public. Legal and institutional frameworks for the region as a whole, should therefore carefully consider existing CCS legislation (international and national) and address potential conflicts that could delay transboundary CCS operations.

2.7.2. Regional Legal and Regulatory Frameworks for Southeast Asia

The most critical issues to consider in the development of a regional legal framework for CCS in Southeast Asia are discussed below.

2.7.2.1. International Legal Frameworks - London Protocol Implications for Transboundary Transport and Storage of CO_2

The emergence of new markets and applications for CCS technologies, enhanced or revised national commitments to achieving net-zero and wider commercial opportunities afforded by the deployment of CCS networks, has led to greater interest in CCS project opportunities beyond national boundaries. In recent years, this focus has also been strengthened further by the development of several regional cooperation initiatives aimed at advancing deployment of the technology, most notably, the development of a transboundary transport and storage project off the coast of Norway in the North Sea.

2.7.2.2. Transboundary transport of CO_2

Project proponents, policymakers and regulators have to consider the legal implications of transporting captured CO_2 across territorial boundaries, and between nations. The most significant of these legal and regulatory considerations is found within Article 6 of the

London Protocol, which prohibits '*the export of wastes or other matter to other countries for dumping or incineration at sea*'. Prior to 2009, the transboundary transportation of CO_2 for geological storage was prohibited under this provision. However, in October 2009, an amendment to Article 6 of the Protocol was adopted by the Parties to enable transboundary movement of CO_2, for the purpose of subsequent offshore geological storage.

The 2009 amendment requires an agreement or arrangement be reached between countries who wish to export and receive the CO_2, whether the export is to a Contracting or non-Contracting Party (International Maritime Organisation, 2018). While an agreement refers to a legally binding agreement, which could be a Memorandum of Agreement or a treaty between the two countries, an arrangement is a non-binding agreement such as a Memorandum of Understanding (MoU). Any agreement or arrangement, must ensure that the standards of the Protocol are fully observed, including the confirmation and allocation of permitting responsibilities between the exporting and receiving country. The requirement applies to any arrangement or agreement between Contracting parties, as well as those between Contracting and non-contracting Parties.

Notwithstanding the adoption of the amendment in 2009, an insufficient number of parties have ratified for it to enter into force. Two thirds of the Protocol's Parties will be required to ratify, for the amendment to enter into force for all Parties. To date, only ten countries have ratified the amendment: Norway, Sweden, Finland, Netherlands, Estonia, United Kingdom, the Islamic Republic of Iran, Denmark, Belgium and the Republic of Korea.

At the 2019 meeting of the Contracting Parties to the Protocol, a joint proposal was submitted by the governments of Norway and Netherlands, in an attempt to address the impasse. The proposal, which was ultimately agreed to by the Parties, enables the provisional application of the 2009 amendment, giving 'consent to cross-border transport of carbon dioxide for the purpose of geological storage without entering into non-compliance with international commitments.'

The resulting agreement enables those countries, who wish to export their CO_2 for storage in another country's territorial waters, to avail themselves of the provisions of the 2009 amendment, in advance of its entry into force. Parties wishing to undertake activities of this nature will be required to provide a declaration of provisional application and notification of any arrangements or agreements to the International Maritime Organisation. Parties will however be required to meet the standards prescribed by the Protocol.

The removal of this legal barrier is considered a key driver for enabling several CCS projects to move forward. Project proponents developing a project that includes the transport of CO_2 from countries to a storage site in another country's territorial waters, would also be able to avail themselves of these provisions.

2.7.2.3. Storage of CO_2 - Allocation of Responsibilities

The transaction-based nature of CO_2 export agreements or arrangements brings to light several issues that exporting and receiving parties will need to consider. The Guidance on the implementation of the London Protocol, (the Guidance) published in the report of the 35th meeting of the Contracting Parties, provides specific information and recommendations that clarify Annex 2 obligations for export situations (International Maritime Organisation, 2013). The Guidance's allocation of responsibilities relating to Annex 2 within agreements is discussed below.

CO_2 Stream Properties

Regarding the properties of the CO_2 stream, it is considered most likely that the exporting country would characterise the composition, properties and quantity of the CO_2 stream. The exporting country would share this characterisation with the importing country, so that the agreement or arrangement reflects the expected quality of the CO_2 stream and any special precautions or mitigatory measures that may be needed to secure import and storage of the CO_2 stream. The country receiving the CO_2 stream would need to reassure itself of the quality of the characterisation and may undertake its own characterisation if necessary.

Disposal Site Selection and Characterisation

The country receiving the CO_2 is considered better suited to select and assess the storage site and should share the characterisation with the exporting country. In this regard, competent authorities in both countries are encouraged to apply the Specific Guidelines (NOAA, 2007) and share data. However, in the case of export between Contracting and non-Contracting Parties, the responsibility for ensuring that the site assessment is sufficiently rigorous, lies with the Contracting Party and to this end, the Party should be satisfied that the provisions of Section 6 of the Specific Guidelines on selection and assessment of a storage site are reflected in the agreement.

Assessment of Potential Effects

Similarly, the receiving country, in whose territory the storage site will be situated, should assess the potential effects of storage and share the information with the exporting country. A Contracting Party, in the case of CO_2 export transaction with a non-Contracting State, should ensure that the assessment of potential effects has been undertaken in accordance with Section 7 (Assessment of Potential Effects) of the Specific Guidelines. The country receiving the exported CO_2 for storage will undertake verification of compliance and field monitoring and risk management arrangements but would need to share this assessment with the exporting country. In the case of export to a Non-contracting Party, a Contracting Party should ensure that the provisions of Section 8 (Monitoring and Risk Management) of the Specific Guidelines have been considered in the

CO_2 export agreement.

Permit and Permit Conditions

Annex 2 of the Protocol requires that any permit issued must contain data and information relating to the types and sources of material to be dumped, the location of the dump sites, the method of dumping and monitoring and reporting requirements. These permits are also required to be regularly reviewed. A Contracting Party in the transaction must ensure that the agreement considers Section 9 of the Specific Guidelines in this regard and provides for the review of a non-Contracting Party's permits.

2.7.2.4. Acceptance and Application of the London Protocol and Its Amendments

One example of the practical application of the London Protocol as it relates to the transboundary transport of CO_2, is the collaboration between European countries to establish a cross-border, open-source CO_2 transport and storage network in the North Sea (Northern Lights Project). To enable this transboundary transport project within the confines of the London Protocol, Norway, the Netherlands, and Denmark have deposited declarations of provisional application of the 2009 amendment to Article 6 of the London Protocol, and Finland and Belgium are preparing such declarations. Further, on 26 September 2022, Denmark and Belgium availed themselves of the provisional application of the 2009 amendment and signed the first bilateral arrangement on cross-border transportation of CO_2 for the purpose of permanent geological storage. (European Commission, 2022a)

There remains uncertainty however, with a number of national governments who are Parties to the London Protocol still to commit to adoption of the Protocol's amendments or enter into formal agreements with other nations to enable transboundary movement of CO_2. While several European Parties have entered into these agreements to facilitate projects in the North Sea, formal adoption and agreement has been slower in other parts of the world where transboundary operations are proposed.

Amongst Southeast-Asian nations, the Philippines is the only nation that has ascended to the London Protocol but has not yet ratified the 2009 amendment to Article 6.

Australia is making progress towards regional cooperation on CCS. The recent recommendation by the Australian government's House Standing Committee on Climate Change, Energy, Environment and Water to ratify the 2009 amendment, is an important step in recognising both the significance of the Protocol and the role of CCS in the region. Further, the subsequent passing of legislation by the Australian parliament to enable a permit to be granted for the export of carbon dioxide streams from carbon dioxide capture processes for the purpose of sequestration into a sub-seabed geological formation, is another important step towards full ratification.

In addition to the London Protocol and other maritime agreements, attention must also be given to the wider body of domestic and international law that will apply to operations of this nature. Analysis suggests a variety of laws will apply to transboundary transport and storage operations, including environmental, health and safety laws. Policymakers and regulators must ensure that these too will not present further barriers to regional collaboration on CCS.

2.7.3. Regional Legal and Regulatory Frameworks for CCS

2.7.3.1. Cooperative Legal Framework – EU Directive Case Study

Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide (the CCS Directive) provides a good example of an established legal framework between nations in a specific region, in this case the European Union (EU), for cooperation on the environmentally safe storage of CO_2. The implementation of the CCS Directive is underpinned by the Treaty on the Functioning of the European Union (TFEU), which established the European Community and governing structures (e.g. the Committee of the Regions) and includes the framework for economic, social and territorial cohesion of the European Community (European Commission, 2022b) The CCS Directive provides guidance across the entire life cycle of a CCS project, including CO_2 capture, transport and environmentally safe storage in geological formations in the EU. EU Member States were obliged to transpose the CCS Directive into national laws.

On 30 September 2022, the European Commission released a '*Commission services analysis paper for the Information Exchange Group (IEG) under Directive 2009/31/EC*' (the Paper) discussing the EU legal framework for cross-border CO_2 transport and storage in the context of the London Protocol. The purpose of the Paper was to assess the alignment of the CCS Directive with the London Protocol provisions, and to clarify what is required for countries in the European Economic Area (EEA) to comply with the provisions of Article 6 of the Protocol (European Commission, 2022b)

The Paper concludes as follows:

'There is a substantive alignment between the requirements of the London Protocol and the legal framework in place in the EEA for the capture, cross-border transport and safe geological storage of carbon dioxide between EU Member States and EEA countries.

Therefore, Directive 2009/31 and Directive 2003/87, which bind all the Member States, can act as a relevant 'arrangement' between the Parties in the meaning of Art. 6(2) of the London Protocol. Similarly, the EEA treaty and the incorporation of the two directives concerned in the EEA legal regime provides the necessary arrangement with EEA partners.

Member States that are party to the London protocol could conclude additional bilateral arrangements with other EU Member States and EEA partner countries only on issues that are not covered by the directives. These additional bilateral arrangements should be strictly *limited to the residual issues not covered by EU law and they should not refer to the subject matters covered by EU rules.'*

The key advantage of having the provisions of the London Protocol included in Directive 2009/31 (CCS Directive), is that the Directive becomes an acceptable 'arrangement' between CO_2 exporting and importing countries under Article 6 of the London Protocol. Both countries are therefore compliant with the requirements of Article 6, and a Contracting Party to the Protocol will not have to ratify the amended Article 6. A declaration of provisional application, and a notification of the arrangement created under the Paper must still be submitted to the IMO. The advantage of having Directive 2003/87 (Directive establishing the EU ETS) tied to the CCS Directive is that it creates a mechanism for emissions trading and surrendering of allowances in the case of CO_2 leakage during transport and storage between Member States and EEA countries.

The creation of an overarching arrangement that complies with the provisions of the London Protocol could substantially reduce the time to establish bilateral agreements between exporters and importers of CO_2 in the same region, and standardise issues governed under such an arrangement across participating countries. It would also lead to much less complicated bilateral agreements, which would only cover residual issues not embodied in the overarching arrangement.

Issues that must be covered by an overarching arrangement (to comply with Article 6 of the Protocol) include:

- *'confirmation and allocation of permitting responsibilities between the exporting and receiving countries, consistent with the provisions of this Protocol and other applicable international law; and*
- *in the case of export to non-Contracting Parties, provisions at a minimum equivalent to those contained in this Protocol, including those relating to the issuance of permits and permit conditions for complying with the provisions of annex 2, to ensure that the agreement or arrangement does not derogate from the obligations of Contracting Parties under this Protocol to protect and preserve the marine environment'*. (Government of the United Kingdom, 2009)

Any specific issues involving country boundaries, facilities, infrastructure, etc. would be covered in the bilateral agreement between the exporting and importing countries.

A cooperative regional framework for the deployment of CCS in Southeast Asia could follow the same model as the EU, in particular:

- Developing a regional legal framework with regulatory provisions for CCS (similar to the EU's CCS Directive), under ASEAN. Such a framework should consider creating a platform for trading of carbon credits between ASEAN countries and facilitation of physical movement and storage of CO_2 between ASEAN countries.
- Aligning the regional framework with the London Protocol provisions. Such a regional framework could act as a legitimate 'arrangement' between Southeast Asian nations

who wish to enter into transboundary CO_2 transport and storage transactions. Bilateral agreements/arrangements between Southeast Asian nations would then only need to cover any specific issues not covered by the regional framework.
- Adopting existing national legislation related to site selection, permitting procedures, health and safety requirements, and other provisions across the CCS value chain, into the regional framework.
- Recommending or encouraging the adoption of the regional framework into national legislation, recognising the impact on each country's respective NDC.

2.7.3.2. Cooperative Regulatory Framework

The development of CCS regulations to facilitate project development and operations in Southeast Asia is limited, although Indonesia and Malaysia have made progress in this regard. Legislation in many nations would see CCS operations regulated under existing regimes governing oil and gas or mining operations, however there is uncertainty as to their capacity to adequately regulate commercial-scale deployment of CCS.

Key issues to address in CCS-specific regulations (that may not be adequately covered in existing industry frameworks) include:

- Classification and ownership of CO_2
- Access or rights to potential storage sites
- Authorisation of storage activities
- Monitoring and verification obligations
- Closure and post-closure activities
- Treatment of liability (also beyond site closure)

The '*ASEAN Guidelines on Good Regulatory Practice*' establishes principles to the preparation and application of technical regulations. The aim of these guidelines is to assist ASEAN Member States in meeting their international obligations under the World Trade Organisation's Technical Barriers to Trade (TBT) Agreement. These guidelines could provide a starting point for the development of CCS-specific regulations, as they have already been accepted by ASEAN Member States and set out a clear path for development of technical regulations and regulatory cooperation in the region. (The ASEAN Secretariat, 2019)

Australia is far advanced in terms of CCS regulation, and its regulatory approach could provide good guidance for CCS regulations in ASEAN. In 2005, the Ministerial Council on Mineral and Petroleum Resources (MCMPR) published the Australian Regulatory Guiding Principles for Carbon Dioxide Capture and Geological Storage, '*to facilitate the introduction of CCS activities in an efficient, effective and safe manner*'. (Ministerial Council on Mineral and Petroleum Resources (MCMPR), 2005) Subsequently, the Offshore Petroleum and Greenhouse Gas Storage Act 2006 was enacted, supported by five regulations, governing GHG injection and storage activities, resource management and administration, environment, safety and regulatory levies respectively.

The National Offshore Petroleum Titles Administrator (NOPTA) and the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) perform regulatory functions for offshore greenhouse gas storage activities:

- NOPTA administers offshore greenhouse gas storage titles in Australian Commonwealth waters.
- NOPTA publishes information about titles and applications on the National Electronic Approvals System (NEATS) website.
- NOPSEMA independently regulates offshore petroleum and greenhouse gas storage health and safety, well integrity, and environmental management.
- NOPSEMA also assesses and accepts environment plans. (Department of Industry, n.d.)

The Australian regulatory model may provide a reference point for regulators for the development of a Southeast Asian regional regulatory framework.

2.7.3.3. Enabling Policies

To successfully deliver cross-border CCS projects, reduce project risk and attract the necessary investment, enabling policies must be developed that:

- Support stable, long-term revenue streams by placing an appropriate value on captured CO_2 (carbon pricing).
- Overcome value chain risk by establishing CCS networks and hubs (moving away from a single-emitter-to-single-storage-facility model, where risk of unavailability of one component affects the whole value chain).
- Manage long-term storage liability during and beyond the CCS facility's operating period.
- De-risk projects through government funding support – this may be in the form of direct capital grants, operating subsidies, tax credits and exemptions, risk sharing models for transport infrastructure, regulated asset base, contracts for difference, regulated carbon markets, etc.
- Enable storage resource appraisal in the region, which will be key for cross-boundary operations.

2.7.4. Models for Regional CCS Cooperation

Article 6 of the Paris Agreement forms the basis for international cooperation to meet Nationally Determined Contributions (NDCs). In particular, Articles 6.1, 6.2 and 6.4 set out the broad guidelines under which countries could cooperate to achieve their respective goals.

'Article 6.1. Parties recognize that some Parties choose to pursue voluntary cooperation in the implementation of their NDCs to allow for higher ambition in their mitigation and adaptation actions and to promote sustainable development and environmental integrity.

Article 6.2. Parties shall, where engaging on a voluntary basis in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards NDCs, promote sustainable development and ensure environmental integrity and transparency, including in governance, and shall apply robust accounting to ensure, inter alia, the avoidance of double counting, consistent with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

Article 6.4. A mechanism to contribute to the mitigation of GHG emissions and support sustainable development is hereby established under the authority and guidance of the [Conference of the Parties (COP)] for use by Parties on a voluntary basis. It shall be supervised by a body designated by the COP, and shall aim:

(a) To promote the mitigation of GHG emissions while fostering sustainable development;

(b) To incentivize and facilitate participation in the mitigation of GHG emissions by public and private entities authorized by a Party;

(c) To contribute to the reduction of emission levels in the host Party, which will benefit from mitigation activities resulting in emission reductions that can also be used by another Party to fulfil its NDC; and

(d) To deliver an overall mitigation in global emissions.'

Key to the successful implementation of a cooperation mechanism will be the establishment of an accounting framework that addresses diversity of target types, and individual actions and measurements proposed by participating countries. Such an accounting framework should avoid double counting and 'hot air' transfers (credits for activities that would have happened anyway under Business as Usual).

In a recent paper published by the IEAGHG (IEAGHG, 2023), various models for international cooperation on CCS are identified and the merits of each discussed. These models broadly consider the application of Article 6 to CCS through two potential approaches:

- Trading of emissions allowances and reduction/removal credits arising from linked carbon markets or emissions trading systems
- Targeted approaches that base cooperation on demand for and supply of carbon storage across country boundaries (and related creation of offsets)

These approaches are not mutually exclusive, but aim to create two tradeable units, namely a carbon reduction/removal unit (CRRU) and a carbon storage unit (CSU) that could be traded under three potential models, to meet the requirements of a successful accounting framework:

Model 1 – Linked carbon pricing policies between countries (trading of CRRUs)

Under this model, CRRUs are awarded to operators of CO_2 capture facilities or a CCS project with several entities cooperating. Trading of CRRUs could take place either directly between governments or involve companies for compliance or voluntary purposes.

Model 2 – Voluntary system of storage targets for fossil fuel producers (using CSUs to drive CCS deployment)

Under this model, fossil fuel companies with net zero targets voluntarily implement CSUs to track progress and demonstrate achievement of net zero emissions (bottom-up approach). Governments could support this by requiring national fossil fuel suppliers to demonstrate commitment to geological storage. This type of supply-side offsetting is currently being considered by both the UK and the Netherlands.

Model 3 – Multilateral 'CCS club' of Parties to the Paris Agreement (select group of countries with a common interest in fossil fuel production and CCS, adopting CSUs as a means to cooperate on a plurilateral basis)

This model follows the same principles as Model 2 but is based on country pledges to geological storage, as opposed to corporate targets (top-down approach). The aim would be to establish a system of CSU transfers between member countries, initially under bilaterally agreed quotas, and evolving to CSU transfers between member countries with storage targets in their respective NDCs. (IEAGHG, 2023)

Below, we discuss some issues around these models, and their potential to support cooperation on CCS in Southeast Asia.

2.7.5. Integrated Regional Emissions Trading System (ETS)

Carbon markets provide an additional and important lever to reach net zero by 2050, but it should not be seen as the silver bullet to fight climate change. Companies must reduce their carbon footprint as a first action, through avoidance and removal projects, including CCS (technology-based removal) before considering offsets.

Carbon markets operate on either a compliance or voluntary basis. Compliance markets are regulatory markets where carbon allowances/credits are traded to meet regulatory targets or obligations. Voluntary markets are unregulated, and credits are traded on a non-obligation basis. Voluntary markets are still in early stages of development, however in 2022, the World Bank reported that the total value of the global voluntary carbon markets exceeded US$1 billion and continues to grow (The World Bank Group, 2022) It is estimated that the economic opportunities that could be created through a Southeast Asian carbon market will be US$10 billion by 2030. (Bain & Company, 2021)

ASEAN nations are at various stages of development in terms of committed emissions reduction targets, and formulation of legal and regulatory frameworks for CCS. The establishment of an integrated carbon market for the region may therefore be challenging, or at least a long process.

In a number of ASEAN Member States, carbon pricing and carbon markets have been or are in the process of being developed for both the public and private sectors. On 2 August 2023, the Financial Services Authority of Indonesia (Otoritas Jasa Keuangan, or OJK) issued 'Rule no. 14 of 2023 on Carbon Trading on Carbon Exchange'. This rule sets out the standard criteria for carbon units that will be traded on a carbon exchange, as well as the licensing requirements for any company that wants to apply to become a carbon exchange. (Baker McKenzie, 2023) Indonesia aims to launch onshore trading by the end of 2023. The Rule allows the facilitation by an exchange of cross-border trade, which opens up the possibility of a Southeast Asian carbon market.

Most offset transactions in Southeast Asia are however done through brokers or directly by developers, with a large variance in margins and low correlation with quality. Also, the carbon futures market is still immature. (Bain & Company, 2021) An integrated (regional) credible carbon trading exchange could address these issues, and provide transparency, quality and price certainty to traders.

It is important to explicitly show the role that CCS should play in carbon markets, e.g. circumstances under which CCS projects could generate carbon credits; and clarity on the facility that could claim credits (capture facility or storage facility) to avoid double counting.

In March 2023, JSA published a *'Handbook for CCS Carbon Credits'*, reporting the outcomes of an international workshop held to discuss global carbon markets as a way towards ASEAN decarbonisation. (JOGMEC, 2023) The report advocates for the recognition of the value CCS projects add to reducing CO_2, and a conversion of that value to carbon credits that could improve economic efficiency of these projects. The report discusses a number of current carbon emission trading schemes around the world, and how leveraging existing methodologies could accelerate the implementation of a carbon market in Southeast Asia.

Currently only a few carbon trading schemes include CCS as an eligible method. Amongst these are the Australian ACCU Scheme, the (ACR), the Verified Carbon Standard (VCS), Puro.earth (CCS methodology does not cover CO_2 captured from fossil fuels) and Canada's Alberta Emission Offset Scheme (AEOS). The table below gives a high-level overview of the key CCS provisions of each of these schemes.

Table 2.6. Overview of CCS in Key Carbon Trading Schemes

(as of January 2023)

	ACR (USA)	AEOS (Alberta, Canada)	ACCU (Australia)	Puro.earth (International)	VCS (International)
Purpose	Compliance (California compliance offset programme) and voluntary	Compliance offset for TIER	Compliance offset for safeguard mechanism, and voluntary	Voluntary	Voluntary (eligible for compliance offset in some areas)
Approved CCS method/ guideline	2015	2015	2021	2022	2023 (tentative)
Legal framework	US federal/state	Canada federal/province	Australia commonwealth/province	US EPA (Class I, II, IV) or EU CCS Directive Equivalent	-
Applicability	CCS and CO2- EOR	CCS and CO2- EOR	CCS	DACCS and BECCS with EOR+	CCS, DACCS, BECCS (tentative)
Projects	5 projects	1CCS (Quest) 1CO2-EOR (MEglobal)	Moomba	AspiraDAC project, BECCS Norway	n/a
Credit buffer	10% (optional)or private insurance	0%~50% depending on project type for EOR	3%	10% for all projects (not just CCS)	Determined per project based on risk assessment

	ACR (USA)	AEOS (Alberta, Canada)	ACCU (Australia)	Puro.earth (International)	VCS (International)
		None for CCS			
Long-term monitoring	Minimum of 5 years of monitoring after end of project term.	Minimum of 10 years after end of crediting period	15 years of extended accounting period after end of crediting period	n/a	Minimum of 10 years required for combined duration of monitoring post- injection until storage site closure and post- closure.
Site closure	Only reference is made to 'transfer of responsibility'	Reference to post-closure monitoring in accordance with the appliable regulation	Reference to extended account period monitoring in 107ccordance with the appliable regulation	n/a	Storage site closure conditions need to be specified and closure plan needs to be documented.

Source: Mitsubishi Research Institute (JOGMEC Handbook for CCS Carbon Credits).

These schemes with CCS methodologies could act as a base for the design of a Southeast Asia CCS methodology to be incorporated into a regional emission trading system. Inputs from ASEAN Member States will be imperative, as the business and regulatory environments vary between countries.

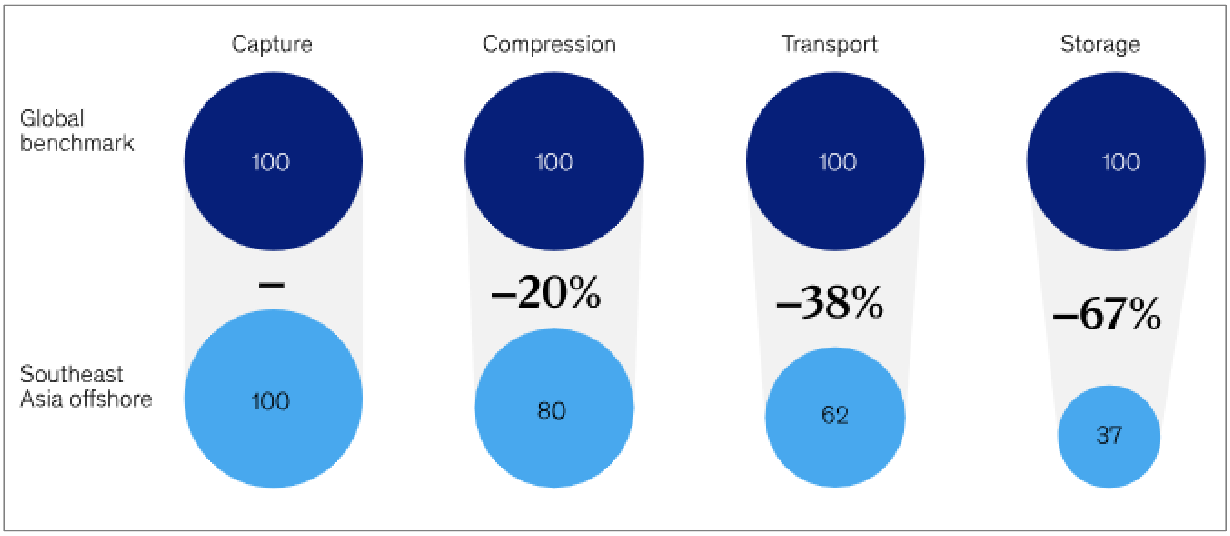
Linking ETSs is challenging on a technical, legal and political level, as it requires a high degree of harmonisation between the ETSs scope of coverage, emissions caps, legal nature of allowances, method of allowance allocation, MRV, methodological consistency, eligibility of offsets, etc. In addition, voluntary and compliance markets are becoming increasingly intertwined. Clear and consistent rules around CCS and carbon markets will be imperative for the success of a regional carbon credits trading system.

2.7.6. Project Considerations

2.7.6.1. Cost competitiveness of Southeast Asia

CCS projects in Southeast Asia have the potential to attract significant investment, since capture, utilisation and storage costs compare very well against global benchmarks – storage costs are estimated to be around 65% lower than the global average. (McKinsey & Company, 2023)This competitive advantage could contribute to better NPVs for CCS projects in the region than elsewhere in the world. However, this will only materialise in an environment of policy certainty and stable revenue streams based on an appropriate value placed on captured CO_2.

Figure 2.16. Carbon Capture, Utilisation, and Storage Costs in Southeast Asia, Compared to global Benchmarks



Source: McKinsey & Company.

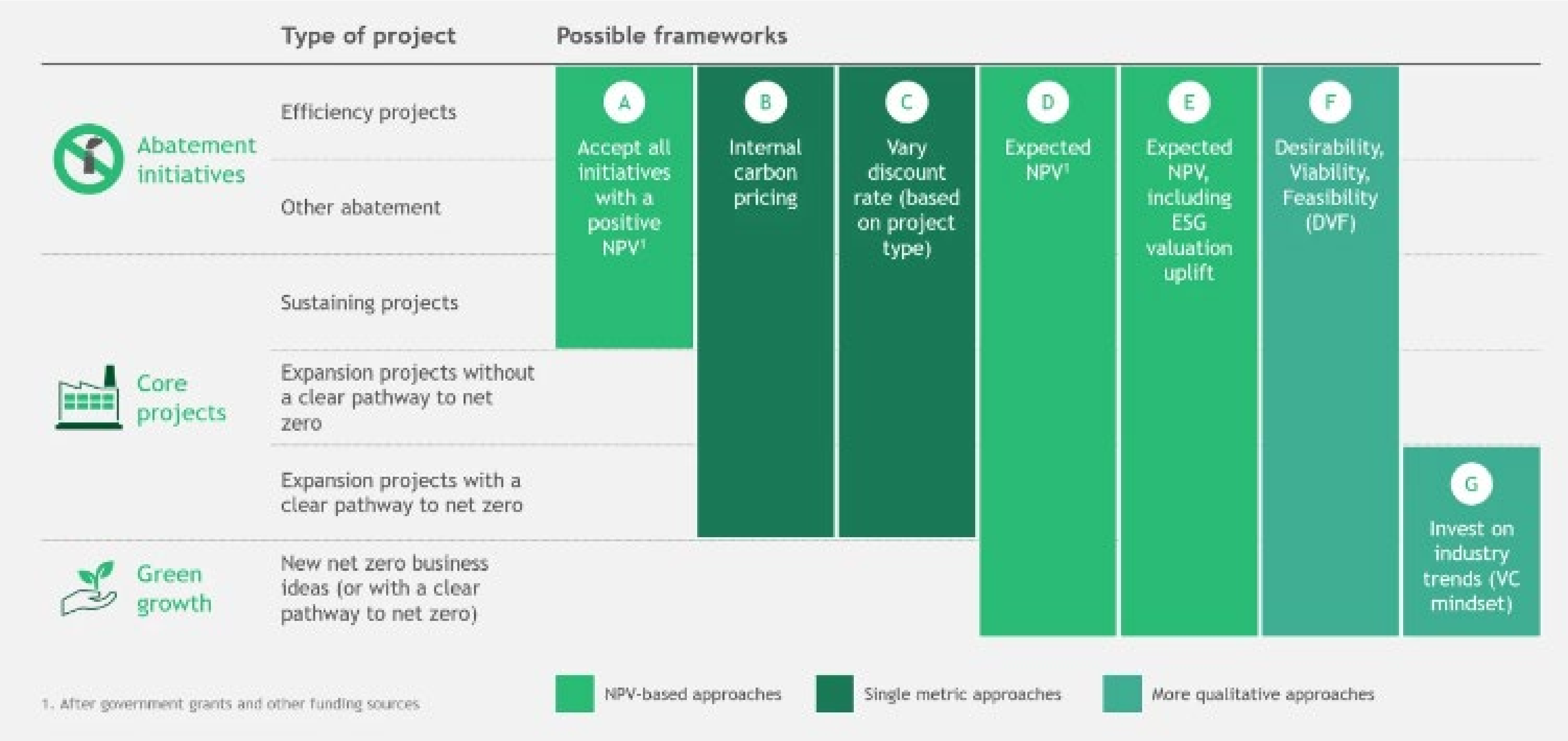
To capitalise on this advantage, development of enabling policies, and collaboration between the public and private sector to develop business models that will ensure commercial viability of CCS projects, will be key to attract the investment needed for large-scale deployment of CCS in the region.

2.7.7. Integrated Investment Frameworks

International financial support is essential for the deployment of CCS in Southeast Asia. This will include access to grants and loans from commercial banks and development finance institutions, as well as partnerships with industry players outside ASEAN. Government to government funding could also be an avenue for funds to flow from the greater APAC region to ASEAN, to achieve the climate goals as a collective in APAC.

Investors are increasingly looking to companies that have integrated sustainability built into their strategies and performance measures, and markets are actively pricing debt and equity based on climate performance. Boston Consulting Group (BCG) notes seven frameworks that are essential for investors to evaluate green and abatement projects: (Boston Consulting Group, 2022)

Figure 2.17. Frameworks for Evaluating Green Investments



Type of project

Possible frameworks

Abatement initiatives

- Efficiency projects
- Other abatement

Core projects

- Sustaining projects
- Expansion projects without a clear pathway to net zero
- Expansion projects with a clear pathway to net zero

Green growth

- New net zero business ideas (or with a clear pathway to net zero)

A Accept all initiatives with a positive NPV[1]

B Internal carbon pricing

C Vary discount rate (based on project type)

D Expected NPV[1]

E Expected NPV, including ESG valuation uplift

F Desirability, Viability, Feasibility (DVF)

G Invest on industry trends (VC mindset)

🟩 NPV-based approaches

🟩 Single metric approaches

🟩 More qualitative approaches

[1] After government grants and other funding sources

Source: Boston Consulting Group

Note, abatement initiatives are included in the types of projects investors will be interested in as part of a sustainable investment portfolio; and NPV-based approaches feature strongly in these frameworks. Based on the cost competitiveness discussion above, this places CCS projects in Southeast Asia in a good position to attract international private funding.

BCG also comments that '*for core and abatement projects, perhaps the most obvious factor to incorporate is a carbon price*'. Carbon pricing can be established either through carbon taxes or emissions trading systems (ETS). One example of an ETS is a cap-and-trade system (such as the EU's ETS), where supply and demand will determine the carbon price (price of a carbon credit unit). Further examples include voluntary offsets and baseline compliance offsets.

Carbon markets are important in the fight against climate change and investors will be more likely to invest in countries or regions with active carbon markets. An active carbon market in Southeast Asia, placing a value on abated carbon emissions in the region, will underpin investment in abatement projects such as CCS.

2.7.8. Institutional Frameworks in Southeast Asia

For successful deployment of CCS in Southeast Asia, collaboration should extend beyond cooperation between national governments. Companies in the region could form partnerships and work together on cross-sector CCS value chains, creating materiality to increase government buy-in, accelerating technology development, bringing together capabilities across the value chain, and de-risking project execution. (McKinsey & Company, 2023)

Collaboration and/or partnerships between companies could be beneficial in the following areas:

- Partnering on CCS R&D activities, including co-funding and sharing of relevant technical information.
- Coordinated project planning and development, which may take the form of joint ventures to perform environmental studies, feasibility and FEED studies, and delivery of pilot projects.
- Coordinated government and company procurement frameworks.
- Coordinated project development activities, including co-development of project approval timelines and milestones, stakeholder and community engagement activities, collaboration with academic institutions, non-governmental organisations, the media, etc.
- Coordinated efforts to access international funding, including development finance and export credit opportunities.

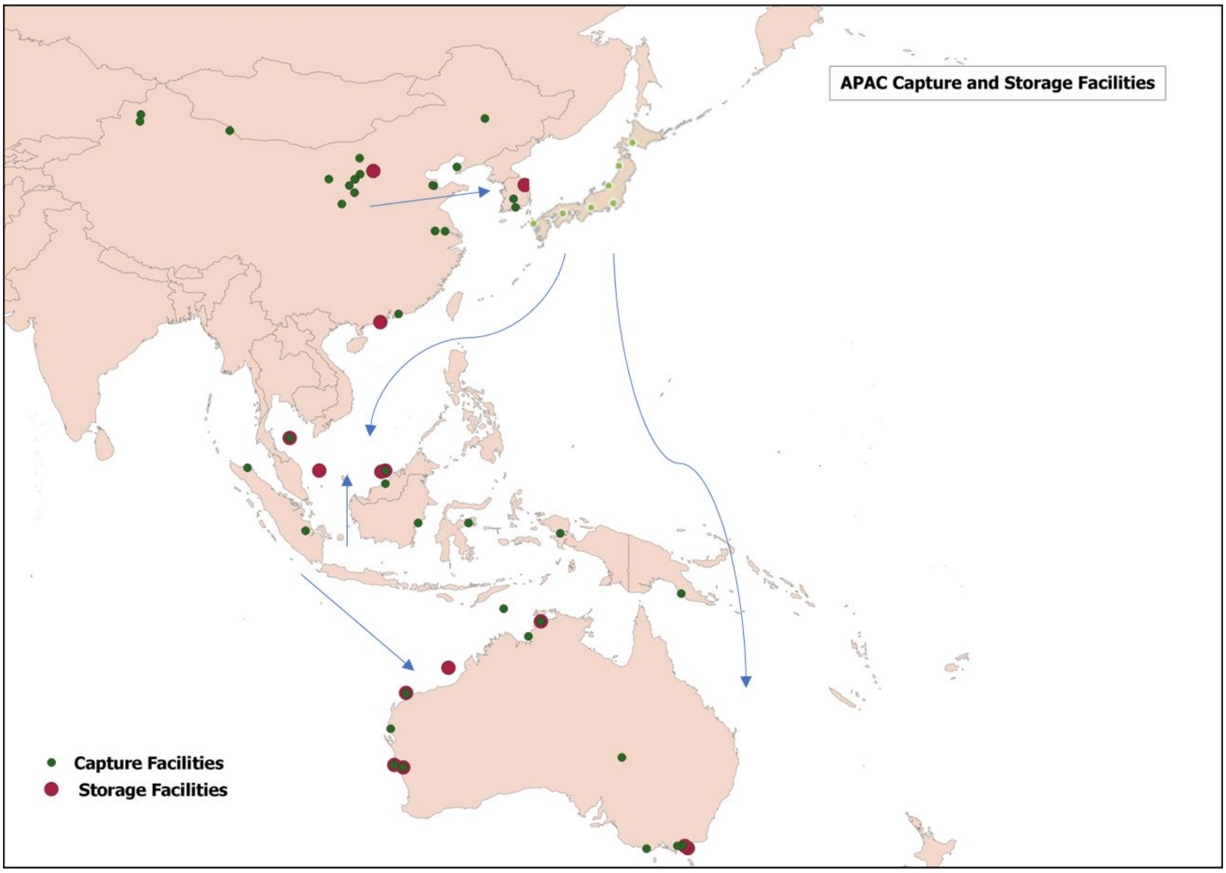
2.8. Asian CCS Value Chain Centre

The Global CCS Institute's CCS Readiness Index 2018 revealed Southeast Asian nations generally have low CCS readiness. Notably, Indonesia, Malaysia, Thailand, Viet Nam and the Philippines individually scored between 21-31 out of a possible 100. (Global CCS Institute, 2018)This is mainly due to policy uncertainty and lack of a clear enabling regulatory environment for CCS. There have been some policy developments in the region since 2018, however the conclusions of 2018 remain valid in 2023.

2.8.1. The Opportunity

Southeast Asia and the wider APAC region present a significant opportunity for CO_2 flows, as indicated in the map below (showing existing facilities in development or operation), and addressing the policy and regulations barrier, this region could see significant activity in CCS.

Figure 2.18. Potential pan-Asia CO_2 Capture and Underground Storage Network



Source: GCCSI.

Whilst there are clear challenges to the large-scale deployment of CCS in Southeast Asia, it is imperative for governments and companies in the region to take decisive action in terms of collaboration on policy and project development, to elevate the region as a significant contributor to global decarbonisation efforts.

CCS has many challenges, ranging from economic viability, regulatory gaps in some countries, the need for capacity building, cross-boundary cooperation, etc. For CCS to succeed, collaboration between government, industry, financial institutions, researchers, and international organisations will be imperative. To simplify collaboration efforts, one organisation acting on behalf of the region could lead to more efficient and expedient processes, and avoid duplication of work and multiple efforts towards the same goal.

The establishment of a centralised body, such as a CCS Value Chain Centre (VCC), to coordinate and administer regional efforts, could accelerate CCS deployment in the region. At the international workshop hosted by METI, JOGMEC and IETA – 'Global carbon markets and CCS: Towards ASEAN decarbonisation', it was recommended that collaboration around CCUS in Southeast Asia should also take maximum advantage of the frameworks developed by the Asia Zero Emissions Community (AZEC) – an initiative jointly initiated by Japan and Indonesia in 2022 (Asia Zero Emission Community, 2022), and the Asia Energy Transition Initiative (AETI) – an initiative of the Japanese government to support the energy transition through funding, development of technologies and capacity building on decarbonisation technologies in Asian countries. (Government of Japan (METI), 2022).

AZEC – a potential platform for the establishment of a VCC

On 4 March 2023, the Ministers of eleven APAC countries, including the majority of ASEAN nations, met to discuss collaboration on the energy transition and decarbonisation efforts. A joint statement was released, in which these countries agree to cooperate and act on initiatives, including CCUS. (Asia Zero Emission Community (AZEC), 2023a) It was stated that '*promotion of international cooperation for CCUS/Carbon recycling development in Asia is highly desirable*.' The joint statement further indicates that the participating countries commit to take collaborative actions through the AZEC platform aimed at:

- *'development, demonstration, and* ***deployment of decarbonization strategies, plans, businesses and technologies*** *such as energy efficiency, renewables, hydrogen, ammonia, energy storage, bioenergy, carbon capture, utilization and storage (CCUS);*
- ***financial support for investments in decarbonization infrastructure*** *including the power grid and the development of clean energy supply chains, including for critical minerals and materials;*
- ***development, harmonization, and securing interoperability of standards*** *of decarbonization technologies, and strengthening of human resource capacity in the area.* (Asia Zero Emission Community (AZEC), 2023b)

The first meeting of AZEC was held in June 2023, in which ERIA participated and highlighted several transition matters, including transition technology and finance challenges. Out of this meeting, three research projects were identified – developing a masterplan for hydrogen and ammonia, the introduction and utilisation of CCS, and acceleration of utilising the Bilateral Crediting Mechanism. (ERIA, 2023)

These public commitments enhance the potential for a regional body, coordinating decarbonisation efforts, to be supported by ASEAN nations. The AZEC collaboration could provide an ideal platform to establish a VCC, not only for ASEAN, but also including significant trading partners in the broader APAC region, who bring a wealth of expertise and experience in the development of standards, regulatory frameworks and cooperation agreements.

2.8.2. Focus Areas for a CCS VCC

The VCC should develop a programme of work to lay the foundation for regional cooperation on CCS. This may include the following:

2.8.2.1. Policy, Regulations, and Standards

The VCC, as a coordinating body, could review and make recommendations on how existing national policies, legislation and regulatory frameworks could be adapted to accommodate and enable regional CCS activities, including identification of near- and mid-term activities to support national regulators and policymakers to align national CCS policies to enable collaboration in the region. In collaboration with national policymakers and regulators, the VCC could implement the ASEAN CCS Roadmap currently under development by the ASEAN Center for Energy. As a regional body, the VCC could act as an advisory body, tasked with monitoring national CCS legislation and regulation development in the region, in line with the ASEAN CCS Roadmap and make recommendations to regulators as appropriate.

In addition, the VCC could coordinate the development of an ASEAN CCS Regulatory Principles guideline, based on the existing 'ASEAN Guidelines on Good Regulatory Practice' to provide guidance on the approach to developing CCS-specific regulation for the region.

The VCC could also play a role in the standardisation of CCS, based on international standards and global best practice and through collaboration with other associations in the climate change space.

One opportunity available to the VCC is to collaborate with the International Association of Oil and Gas Producers (IOGP), who launched a Carbon Capture, Transportation and Storage Committee in 2022, to share technical lessons learned from pilot projects, and to accelerate the standardisation of CCS technologies and processes, to improve cost, scheduling, risk and safety, which will underpin widespread deployment of CCS technologies. The IOGP Committee identified five deliverables for 2022-23, including:

- Review existing CCS standards and guides, and develop proposals for amendments or new standards based on operators' practical experience and best practice.

- Recommend practice(s) for measuring, monitoring and verification plans, including post-injection and closure, to mitigate long-term storage liabilities.
- Develop a common methodology to address evaluation of net CO_2 avoidance based on a lifecycle approach.
- Provide risk assessment tools and checklists for storage projects.
- Propose a standard economic methodology to compare different carbon capture technologies mainly in upstream facilities.

APAC members of the IOGP include Petronas, PTTEP, Pertamina, Brunei Shell Petroleum, CNOOC, INPEX, Kazmunai Gas, ONGC, Prime Energy, Woodside Energy, SOCAR, NCOC, Beach Energy, and Australian Energy Producers. (IOGP, 2022)

2.8.2.2. Network and Infrastructure Planning

Infrastructure planning and development across the region will have to be done as a collaborative effort between countries, to maximise potential for CCS deployment. Coordination of these activities could be undertaken by the VCC, including establishing and overseeing working groups between ASEAN nations, to accelerate the various aspects of CO_2 capture, transport, and storage. This may include planning and development of CCS networks, hubs and pipeline infrastructure, and appraisal and development of storage resources. These activities could be undertaken by multi-governmental working groups, as appropriate, connecting emitters, storage operators and network service providers in the region. Working groups could be reporting directly to the VCC.

In terms of transporting CO_2 cross-boundary, the VCC could also coordinate the development of cross-border and cross-sector CCS hubs, transport and storage networks, planning of transboundary transport routes, and the development of transboundary CO_2 transport agreements (bilateral agreements/arrangements required under the London Protocol). Similar to the EU, the VCC could develop an overarching regional arrangement under Article 6 of the London Protocol. This will reduce complexity of bilateral agreements, in that bilateral agreements will only deal with residual matters not provided for in the regional arrangement.

2.8.2.3. Funding for CCS Infrastructure/Projects

As with any large cross-border infrastructure project, including pipelines, there will be transboundary regulatory issues that must be resolved to reduce uncertainty for investors and lenders. In instances where CO_2 exporters and importers have completely separate planning and approval processes or potentially contradictory standards and permitting requirements, project sponsors will look for certainty embedded in bilateral agreements or treaties between nations for transboundary movement of CO_2.

To support investment in CCS projects in the region and to provide certainty to project sponsors and financiers, the VCC could act as a representative body for ASEAN countries, seeking foreign direct investment and other forms of climate finance. A coordinated multi-national approach will enhance negotiation power and reduce counterparty risk for investors.

The VCC could also coordinate broader climate commitments for ASEAN nations, including government funding support for cross-boundary projects and networks, international finance accessibility, the broader energy transition across the region, emissions reduction targets, and a potential integrated carbon market.

2.8.2.4. Storage Resource Appraisal and Development

For regional coordination of storage activities, it would be important to keep a database of storage resources in the region, with details of characterisation, stage of development, capacity, permitting status, etc. In support of the development of European storage resources, the EC funded the Storage Potential in Europe (CO2StoP) project, through which onshore and offshore storage capacity in EU member states was assessed. The project created a dataset of geological parameters, which could be consistently applied for all regional storage resource assessments. The database is publicly accessible and provide storage data per country. (SETIS, 2020)

The CO2StoP project methodology is said to have made significant progress towards calculating probabilistic estimates of the CO_2 storage resources in Europe, in a way that will allow comparisons with other regions, such as the U.S. The IEA has recommended that the first step in all CO_2 storage estimates should be to estimate the Technically Accessible CO_2 Storage Resource (TASR). CO2StoP's calculation engine is capable of producing a TASR that is very similar to that of the US Geological Survey. The CO2StoP methodology could therefore provide a basis from which an ASEAN calculation engine could be developed.

Similar to the EU, the VCC could become the official custodian of an ASEAN geological storage calculation engine and database, accessible to project proponents in the region. The VCC would be well placed to coordinate data gathering and inputs, and to centrally maintain the system in collaboration with national authorities. Streamlining CCS regulatory processes across the region will be important to ensure regulatory requirements do not delay deployment of CCS. The VCC could set up a task force or working group comprising of regulators from ASEAN member countries, to streamline national licencing and permitting processes across the lifecycle of a storage project, i.e. from exploration to post-closure monitoring.

The VCC could also coordinate the development of a regional framework for risk assessment and management of CO_2 storage in geological formations. Such a framework could also include monitoring plans for storage facilities, and the VCC may take on the role to perform third party verification for storage facilities in the region. This will ensure consistency and may reduce the time it takes to perform these activities.