GLOBAL CCS INSTITUTE

CARBON DIOXIDE (CO_2) DISTRIBUTION INFRASTRUCTURE

The opportunities and challenges confronting CO_2 transport for the purposes of carbon capture and storage (CCS)

An observation paper

AUGUST 2012

CAVEAT

There is a growing volume of material being written on the development of CCS generally, and specifically on CO_2 transport (mostly pipelines). The examples cited in this paper have been selected for illustrative purposes only and are clearly not drawn from an exhaustive number of sources. As an observation paper, the views expressed in this paper do not necessarily reflect those of the Global CCS Institute or its Membership.

It is noted that the Intergovernmental Panel on Climate Change 2005 *Special Report on Carbon Dioxide Capture and Storage* (Chapter 4) provides a comprehensive technical assessment of CO_2 transport options.

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CHAPTER ONE

INTRODUCTION

Context

The aim of this paper is to provide a non-technical summary of a selected number of publicly released and peer-reviewed studies on carbon dioxide (CO_2) distribution infrastructure (networks) as applied to carbon capture and storage (CCS).

CCS consists of four components:

1. emissions sources (where CO_2 emissions are produced);
2. CO_2 capture (where a physical or chemical separation process isolates CO_2 from other components in the exhaust gas – for which CO_2 streams are often differentiated by costs, pressure and purity);
3. CO_2 transport (moving the captured CO_2 from point source to a sink); and
4. CO_2 storage (where CO_2 is injected into a geological formation and subsequently isolated from the atmosphere).

CCS is recognised by the United Nations Framework Convention on Climate Change (UNFCCC) as a technically-legitimate mitigation option, capable of delivering permanent abatement outcomes. It is also recognised as an eligible project level activity in the Clean Development Mechanism (CDM). This demonstrates that CCS activities can be readily and systematically institutionalised (and rewarded) in market-based mechanisms, and is internationally accepted as being consistent with the sustainability development requirements of developing countries.

CCS has the potential to deliver one of the largest emissions abatement outcomes of all possible mitigation options in the global challenge of avoiding dangerous levels of climate change. The International Energy Agency (IEA) estimates that CCS could contribute about 20 per cent of the required abatement to hold atmospheric concentrations of greenhouse gases to 450 parts per million (ppm) by 2050. The Intergovernmental Panel on Climate Change (IPCC) estimates that CCS could contribute between 15 and 55 per cent of the required abatement by 2100[1].

CCS can also drive negative emissions (removing greenhouse gas emissions from the atmosphere) when combined with carbon neutral energy feedstocks (such as sustainable biomass) and permanently storing the captured emissions deep in the geological sub-surface.

The primary focus of this paper is on the transport of CO_2 by pipeline. Much of the publicly available literature concurs that pipelines will be the most likely option used for transporting a large majority of the gigatonnes of CO_2 ($GtCO_2$) that will potentially be required to be captured and stored in the decades to come. This scale of mitigation is considered to be imperative within the context of the global community preserving a carbon budget (the allowable volume of greenhouse gas emissions to be released) that may avoid dangerous levels of climate change.

The paper does not specifically focus on CO_2 capture or storage solutions. It recognises however that CO_2 will not be transported at scale unless there is a sufficient and reliable source of CO_2 as well as sufficient, secure, safe and available long term storage options. These activities will consequently require the establishment of property rights, appropriate regulations governing the long term liability, monitoring, measurement and verification (MMV) of sites, as well as effective compliance regimes across the CCS chain.

In practice, least cost development of an integrated CCS project will depend on the optimal design of all CCS components including:

- capture (number of CO_2 sources, volume of CO_2, quality of CO_2 stream),
- transport (pipeline sizes, flow rates, pipeline siting and distances); and
- storage (the number, type and location of injection wells and the permeability and injectivity of the supporting geology).

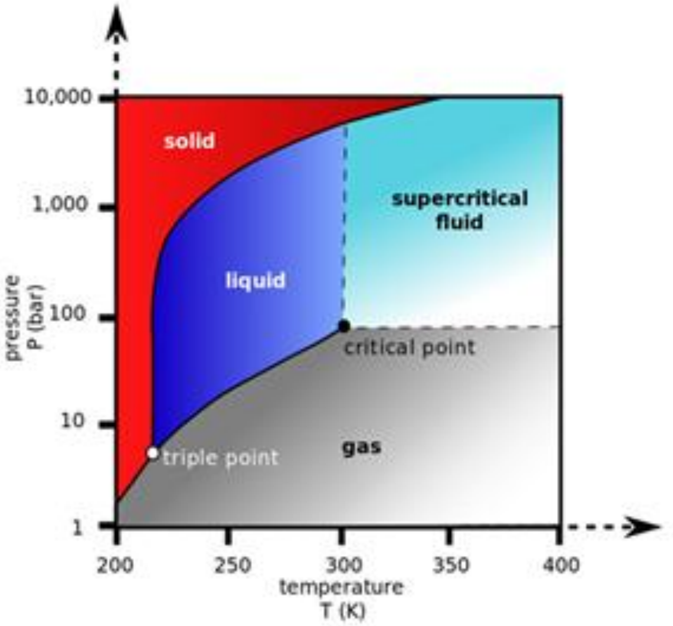
While the main drivers for investing in CCS can differ across the various components, the decisions of all actors mobilised across the CCS chain (CO_2 emitters/capture; CO_2 transport operators, and geological storage operators) will necessarily impact on each other.

Pipelines can transport large volumes of CO_2 at high pressures and through relatively small diameter pipes. The CO_2 gas being moved must first be transformed to a dense phase – also referred to as a supercritical fluid – where it behaves like a compressible liquid (see Diagram 1). The transition to a dense phase also reduces the volume of CO_2 by many orders of magnitude (see **Diagram 2**).

The resulting CO_2 stream lends itself to being easily transported by pipelines over long distances due to its relatively low friction on a per unit mass of CO_2 basis, with a density of between 500~900kg/m^3.

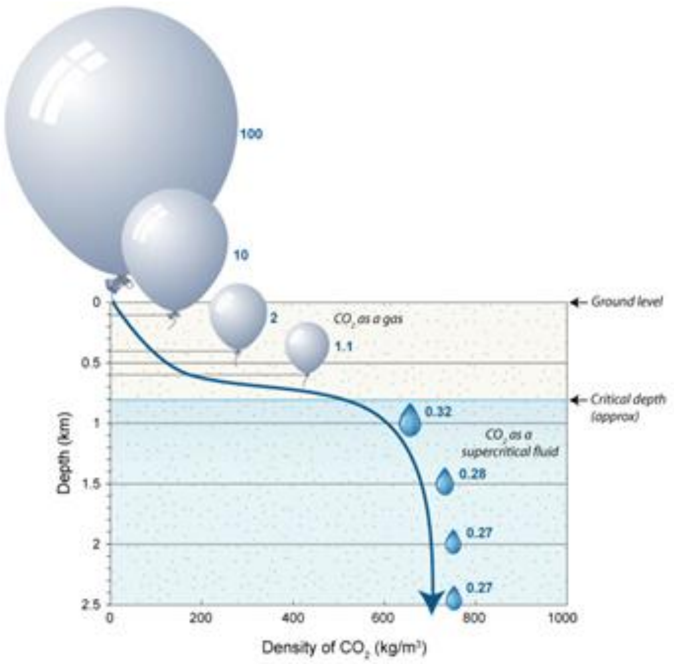
CO_2 can also be transported by the use of trucks, ships and barges similar to those used for Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG). While literature generally views these options as viable, they are considered to be relatively costly for large-scale movements of CO_2. This may have as much to do with their limited transport capacity relative to the amount of CO_2 needing to be moved, as it does the accessibility of transport options linking the CO_2 needing to be captured to the sinks being targeted.

Diagram 1: Dense phase of CO_2



source: http://en.wikipedia.org/wiki/File:Carbon_dioxide_pressure-temperature_phase_diagram.svg

Diagram 2: Volume of CO_2



Source: CO2CRC

Box 1 provides a hypothetical example of the scale of the commercial volume of CO_2 that may need to be moved between CO_2 sources to permanent storage sites in 2050. The daily volume of CO_2 needing to be handled could be some 2.5 times the current volume of oil being produced and transported. An important consideration is however the average distance required to move the CO_2 relative to oil, which some surveys suggest could be much shorter.

Box 1 – Volume of CO_2 versus oil

Assuming that supercritical CO_2 has a density of 700 kg/m^3, 8.27 $GtCO_2$ a year needs to be captured and permanently stored (as per IEA Blue Map scenario), and the global daily oil production is 80 million barrels, then the following calculations hold true:

CO_2	8.2	Gt pa abatement
	700	kg/m^3 (density)
	3.2	$x10^7$ m^3 daily
OIL	80	million barrels daily
	0.16	m^3 (~ 1 barrel of oil)
	1.3	$x10^7$ m^3 daily
ratio	**2.5**	

Calculation: M Bonner, Global CCS Institute.

While the design and operation of CO_2 pipelines is often considered similar to that of natural gas pipelines, there are differences between them. A major difference is that CO_2 is normally transported as a supercritical fluid. To maintain its supercritical state, the CO_2 is transported at very high pressures ranging from 1,800 to 2,700 pounds per square inch (psi) or equivalently about 12,400 to 18,600 kilopascals (kPa). These pressures tend to be higher than the operating pressures used in most natural gas pipelines, which can typically range between 200 to 1,500 psi (or 1,380 to 10,340 kPa). This means that booster stations (pumps) are needed along the pipeline route to maintain the necessary pipeline pressure. The increase in pressure of these CO_2 pipelines also typically requires thicker walled pipes than that used for natural gas transportation.

It is clear that the development of CO_2 networks can build upon already extensive technical, operational and regulatory experiences of the natural gas and CO_2 pipelines used for EOR. As illustrated, the scale of the CO2 needing to be transported for geological storage projects will however be very much larger.

When compared to the literature available on CO_2 capture and storage, there is less analytical work available on CO_2 pipelines including an examination of size, configuration, commercial structures and regulations of national pipeline systems. This could reflect a general perception among the CCS community that CO_2 transport-related issues are not considered major barriers to a critical deployment path for CCS at this time.

Outside of the US, Canada and Norway, existing worldwide experience of CO_2 pipelines is relatively limited. In the US, there is over 6,000 km of dedicated pipelines transporting between 45 $MtCO_2$ and 55 $MtCO_2$ per year from natural and anthropogenic sources.

A recent study states for CO_2 pipelines that there is "... no need for innovation on a component level, [and as such] the assessment of CO_2 transport will have a different character than that of the capture and compression parts of CCS."[2]

In 2005, the IPCC's Special Report on CCS concluded that "there is no indication that the problems for CO_2 pipelines are any more challenging than those set by hydrocarbon pipelines in similar areas or that cannot be resolved."[3]

While it may be generally true that CO_2 distribution networks present fewer hurdles to the wide-scale deployment of CCS than capture processes and/or storage solutions, this component is far from simple and lends itself to many complex considerations of design, planning, and operation.

There are four major challenges affecting the development of CO_2 pipeline infrastructure.

1. Engineering design, including:
   - an increasing need to transport CO_2 over longer distances for storage purposes and across ever more challenging terrains (e.g. closer to urban centres and offshore);
   - the physico-chemical properties of CO_2 streams derived from capture processes — CO_2 streams from pre and post-combustion capture plants will likely have varying levels of impurities such as solid sulphur or liquid water that not only affect behaviour, but may also require an increasing complexity of design compared to existing CO_2 pipelines for enhanced oil recovery (EOR) purposes;
   - matching CO_2 supply (capture) with demand (storage) – the amount and quality of CO_2 supplied from power and industrial sources are likely to be highly variable at any point in time, which will

necessitate careful operational management of CO_2 flows to avoid phase changes within the pipeline; and

- pipeline operations will, by their very nature, involve dynamic flows over irregular periods (from seconds to weeks) for reasons like routine start-up or maintenance and seasonal variations – this requires balancing and coordinating the technical specifications across the CCS chain.

2. Policy and regulatory issues:
   - economic regulation and supporting complementary policies;
   - optimised network design to meet short and long-term policy objectives, including issues such as financing, increasing capacity over time and flexibility;
   - legal barriers, such as restrictions on CO_2 transport across jurisdictional borders; and
   - regulatory models and variations in regimes between jurisdictions.
3. The evolution of fit-for-purpose standards, where common entry specifications for CO_2 pressures, temperatures and concentrations of impurities may be required where multiple CO_2 sources connect to the same pipeline network, and this may subsequently impact on CO_2 capture technology choices (including costs of capture, compression and drying technologies needing to be employed).
4. Overall cost and capacity of pipeline investments and financing options:
   - levelised costs of pipelines; and
   - business and finance models consistent with uncertainties in CO_2 demand, high capital expenditures, long payback periods, oversized pipes; and limited visibility of future CO_2 prices.

This paper is formatted into five chapters:

- Chapter 1 introduces networks and some of the issues affecting their design, construction and operation;
- Chapter 2 explores policy related issues including ownership structures, markets, incentives and other forms of government interventions;
- Chapter 2 also identifies important standards that may guide network design and construction;
- Chapter 3 looks at the economics of networks, including levelised costs, relative cost components, network optimisation, and financing arrangements;
- Chapter 4 examines key regulatory elements that can affect the social licence to construct and operate a network; and
- Chapter 5 consolidates areas of agreement.

CHAPTER TWO

CHARACTERISATION OF CO_2 NETWORKS

Context

CO_2 distribution networks can comprise one or a combination of transport modes, including: truck, ship (liquefied or compressed), train and pipeline (new and existing, offshore and onshore).

At the core of the design of an efficient and effective CO_2 transport network are questions of how, how much, where and when CO_2 will be captured, and where can it be adequately, safely and securely stored.

The establishment of a CCS network in its simplest form includes the planning, construction and operation of a pipeline linking the supply of an individual CO_2 capture facility with the demand for CO_2 from a single storage facility (this is an example of a point-to-point system).

At the other end of the spectrum is the development of nationally planned or integrated pipelines, designed to accommodate an expected growing supply of CO_2 from multiple point sources, ever-fluctuating volumes over the economic life of the pipeline asset as carbon constraint thresholds change, and an expected growing demand for CO_2 as appropriately characterised storage sites are discovered.

The fewer the potential number of capture sites, the simpler it may be to determine whether a less centralised system consisting of dedicated pipelines is a better fit for purpose. A key consideration of a more centralised approach involving a nationally planned network is a realisation that the network may need to be designed to operate sub-optimally in the early years with oversized diameter pipelines and underutilised capacity as demand for CO_2 builds.

There seems to be significantly less industry experience available in CO_2 pipeline design and operation for the purpose of permanent geological storage application than there is in hydrocarbon pipeline operations. There is however a growing volume of technical literature that comprehensively calls for specific issues to be explored with a view to being able to adequately manage and/or remedy the associated risks. One example is Det Norske Veritas (DNV) Recommended Practice (DNV-RP-J202) Design and Operation of CO_2 pipelines.

As indicated, it may not be a simple matter of applying the engineering and scientific understandings of natural gas pipelines or CO_2 pipelines for EOR to CO_2 pipelines for the purpose of permanent storage, nor is it evident that market structures will necessarily evolve similarly.

Current and future CO_2 networks

Outside of the US, Canada and Norway, existing worldwide experiences in CO_2 pipelines are relatively limited. In the US, there is over 6,000 km of dedicated CO_2 pipelines, transporting more than 45 $MtCO_2$ per year from natural and anthropogenic sources.[4] Almost 75 per cent of these were built in the 1980-90s.[5]

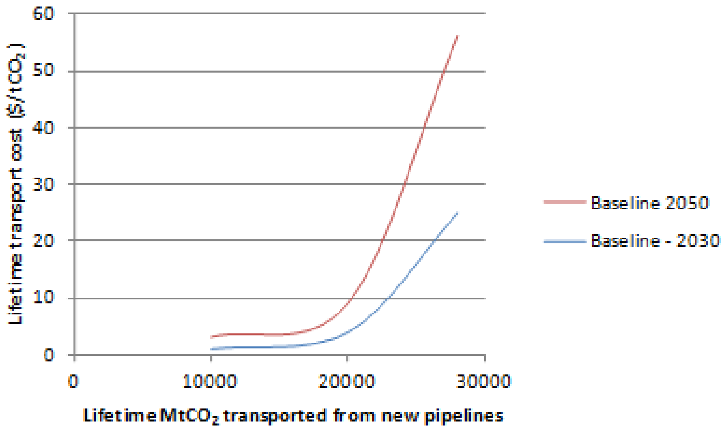
The only offshore pipeline for CO_2 is the Snohvit project (Norway), which has been operational since 2008 and covers some 150 km linking Hammerfest to the Snohvit field under the Barents Sea.

The IEA's Blue Map indicates that it may be possible to store 80 per cent of the captured CO_2 in 2030 (a cumulative transport of 1.44 $GtCO_2$ per year, worldwide) to deliver on a 450 ppm without incurring excessive pipeline costs.

By connecting the requisite number of integrated CCS projects in the IEA analysis on a point-to-point pipeline basis, the overall pipeline length required could exceed 43,000 km (with a median distance between sources and sinks of about 80 km).

The marginal cost for connecting a CO_2 source to sink is estimated to be about US$5/t$CO_2$ transported, rising to around US$30/t$CO_2$ transported in 2050 as combinations of less attractive sources and sinks are utilised,as illustrated in **Diagram 3**[6].

DIAGRAM 3 – Marginal costs of CO_2 transport



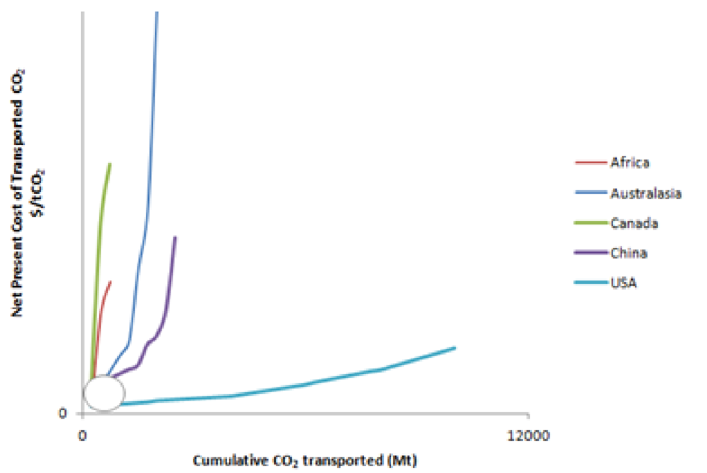
Source: Element energy (2010): Global CCS Pipeline Infrastructure – Final March 2010, p. 14

Diagram 4 shows the IEA's estimates for the respective marginal costs of CO_2 pipelines for various countries. This demonstrates that there can be substantial differences of pipeline cost effectiveness depending on geographic location. For example, CO_2 pipelines seem very cost effective for China and the US, while perhaps relatively more costly for countries like Australia which incurs potentially costlier linkage combinations of CO_2 capture sources and storage sites.

The IEA's analysis suggests that where integrated networks are developed (as opposed to point-to-point), about a 25 per cent reduction in total pipeline kilometres and costs may be achieved. The net present value (NPV) of the global capital required and ongoing costs of pipelines to 2050 could amount to US$60 billion. The analysis indicates the possibility of a post 2050 investment bottleneck, with only about 15 per cent of the CO_2 emissions reduction target achieved through matching existing sources with sinks. The sufficiency of pipeline infrastructure past this point in time is found wanting as CO_2 transport distances necessarily increase (as does scale of investment) to link capture sources with new storage sites further afield. Of course, over time there is a greater potential for point source emissions with capture facilities to be located closer to identified and viable storage options. This may offset the need for increases in pipeline length.

DIAGRAM 4 – Marginal costs of CO_2 transport by region

Note: NPV costs exclude: initial compression, storage, depreciation, tax or financing.



Source: Element energy (2010): Global CCS Pipeline Infrastructure – Final March 2010, p. 14

As CCS is deployed globally over time, the cost of CO_2 pipeline infrastructure could be expected to rise further due to the demand for competing pipeline uses such as water, oil, gas, and chemicals. Correspondingly, there could be increasing competition for limited pipeline route access especially through more densely populated locations. This could impose further cost pressures in regards to pipeline design and construction (including higher specified materials and more valuable land acquisitions).

The US experience

The relatively small scale of CO_2 pipeline in the US is evident when compared to the network of natural gas pipelines comprising over 2,000,000 km of distributed pipelines built since the 1950s. Indeed, the scale of the US natural gas network is much larger today than the total amount of CO_2 pipeline expected to be needed in the US by 2050.[7]

There are 36 CO_2 pipelines currently operating in the US, with six crossing provincial/state boundaries and one crossing an international border into Canada. These pipelines are operated by 21 different companies, with a third of them operating as federally-regulated interstate pipelines, and all being covered under the US federal pipeline safety program.[8]

A list of the major North American CO_2 pipelines can be found in **Attachment 1**.

Many of these pipelines transport naturally-sourced CO_2 for EOR purposes, as opposed to anthropogenic sourced CO_2. This suggests that many of the incentives that drove these investments were associated with EOR, including federal tax incentives such as EOR tax credits.

The demand for additional CO_2 pipeline capacity will likely unfold relatively slowly, and in an incremental and geographically dispersed manner as new dedicated capture plants and storage facilities are brought online. In the US at least, this seems to suggest that the expansion to the existing network of CO_2 pipelines required under a 450 ppm scenario is not seen as a major obstacle for the commercial deployment of CCS. Some 75 per cent of new pipelines needing to be built between now and 2050 is expected to be required after 2030.[9]

Other experiences

There are a number of CO_2 storage hubs being explored in Australia that aim to utilise common user infrastructure to transport the captured CO_2 from multiple capture plants to a centralised storage facility. For example, CarbonNet is a government-industry partnership led by the Victorian Government, with funding assistance from the Australian Government, that aims to collect between 3 to 5MtCO_2 a year primarily from brown coal fired generators and transport as a network via common user infrastructure to ultimately geologically store onshore.

The South West Hub in Western Australia (also known as the Collie Hub) is also a storage hub project (using a CO_2 pipeline network) being supported by both industry and the Western Australian and Australian Governments. It aims to collect between 2.5 to 7.5 MtCO_2 per annum from a local and highly concentrated area of heavy industry including: coal-based urea plant, alumina production and coal fired power generation. The planning for CO_2 transportation has commenced with the commissioning of a detailed mapping exercise of the proposed pipeline route.

An Environmental Approvals Strategy has been mapped for the Collie Hub pipeline project. The strategy outlines the range of licences, permits and approvals that need to be obtained to build the pipeline (and the timelines associated with obtaining them). A recent progress report cites that the long lead times associated with obtaining some of the approvals requires planning to have commenced well in advance, and that this is particularly evident in the case of approvals associated with constructing and operating CO_2 pipelines.

In Canada, Enhance Energy's Alberta Carbon CO_2 Trunk Line will receive CA$495 million in funding over 15 years from the Alberta Government's CA$2 billion CCS Fund, as well as securing two large emitting customers. A 240 km CO_2 pipeline will have the capacity to transport about 14 MtCO_2 a year in a dense phase for EOR purposes. Pipeline construction will start in 2012 and is expected to be complete by the end of 2013.

The Rotterdam Climate Initiative (RCI) in the Netherlands is another example of a major hub project. It aims to realise the full-scale application of CCS by 2025 by capturing, transporting and storing more than 17 MtCO2-e a year. The RCI recently released some interim learnings, observing:

- the challenge to developing the transport business cases is to mix the goal of the 'grand scheme' with being as flexible as possible to connect to the reality of single projects; and
- make and assess transport business cases as early as possible; these cases give the best insights in the real bottlenecks in the region.

Pipeline operation

There are three basic types of CO_2 pipeline operation including utility; common carrier; or unregulated private carriers.

Interstate natural gas pipelines began in the US as private carriers owning the commodity they carried. The *Natural Gas Act* of 1938 resulted in them being regulated as utilities (i.e. natural monopolies) and not as common carriers. As such, the construction and siting, entry and exit, asset sales, securities, rates, tariffs, and terms of service are subject to regulatory oversight. Over time, the US Federal Energy Regulatory Commission (FERC) regulated interstate natural gas pipelines as having to provide for open access requirements and no longer owning the gas they transported.

Common carriage is where pipelines are available on a fee for service basis to transport CO_2. Operators tend not to own the commodity being transported. A private carrier structure is where pipeline owners transport CO_2 on a fairly ad-hoc basis and are not licensed to offer a fee for service to the general public.

Unlike oil pipelines in the US (which have evolved as common carriers as they do not own the oil they carry), and more akin to the early development of natural gas pipelines in the US, many current CO_2 pipelines operate as private carriers, transporting for the most part CO_2 for the pipeline's owners. In such cases, the pipeline owner owns the CO_2 in the pipeline until it is ultimately sold once delivered to a third party owned oil field (such as for EOR). This may potentially require many individual contracts to be negotiated between the pipeline owner and the transport customer/s.

A common carrier tends to be legally bound to transport third party CO_2 as long as there is sufficient capacity and does so on a non-discriminatory basis (i.e. according to published tariffs). An issue commonly associated with common carriage is the need for pipeline operators to accommodate new customers. This will generally be done by rationing pipeline capacity on a pro-rata basis to existing customers, leading to the possibility of CO_2 capture facilities having to vent surplus CO_2 as a result of reduced pipeline capacity.

Pipeline layout and routing

While it is still unclear how business models for CO_2 pipelines may evolve as CCS is commercially deployed (say post 2020), it is clear that such models will need to deal with a different mix of CO_2 supply sources (power plants, industrial applications) and delivery locations than is the case currently for natural gas.

Natural gas pipeline networks are essentially characterised by point-to-point arrangements, linking many individual gas sources (producing wells and processing plants) with many individual delivery points (comprising both large and small end users). CO_2 pipelines for storage purposes however could be expected to be built to initially link relatively small numbers of large output sources of CO_2 with relatively small numbers of injection sites. But similar to the construction of large volume natural gas pipelines, the construction of CO_2 pipelines may typically proceed on the basis of contracted demand (CO_2 off-take customers) for a substantial portion of the pipeline capacity.

For example, the development of CO_2 pipelines could be established on the back of a single dedicated pipeline linking a single CO_2 point source to a single sink (maybe to take advantage of an EOR opportunity). As networks inevitably evolve into more complex arrangements over time for storage purposes, the upfront planning and development of national CO_2 networks may be increasingly worthy of government consideration and/or engagement.

There are many potential configurations linking capture facilities with storage sites. Different scenarios will have different implications for the optimisation (i.e. least cost) of network planning, construction and operation. The different configurations include:

- a dedicated pipeline (e.g. private carrier) linking a single CO_2 capture source to a single storage site (sink);
- single dedicated pipelines each linking multiple CO_2 point sources to a single sink;
- single dedicated pipelines each linking multiple CO_2 point sources to multiple sinks;
- a common user pipeline linking multiple CO_2 point sources to a single sink; and
- a common user pipeline linking multiple CO_2 point sources to multiple sinks.

The routing of pipelines can encompass:

- onshore and/or offshore;
- short and long distances;
- transported and stored within a single jurisdiction; or
- transported and stored cross-boundary in other countries (noting the implication of this scenario is that pipeline owners will need to comply with one or more sovereign laws and regulations and/or supra-national laws).

In the early phases of a fledgling CCS industry, CO_2 capture projects are likely to require a dedicated pipeline system that would for the most part link them to a nearby storage site. In the power sector, there is a general reluctance by capture facilities to own or operate pipelines or storage facilities. Depending on the complexity of operations, it might well make commercial sense for a single entity to control the entire CCS project (i.e. vertically integrate capture, transport and sequestration) so as to better manage the commercial, regulatory and liability risks – this might be through owning the infrastructure and/or sub-contracting the pipeline businesses.

Over time, with an increasing imperative to reduce transportation costs for longer distance transportation, the consideration of sharing larger diameter pipes across a greater density of CO_2 capture plants may become commercially attractive.

An important consideration for transporting the CO_2 between capture source and storage facility is the specification of the CO_2 stream. The CO_2 stream needs to have a high degree of consistency across the CCS chain. The quality of CO_2 captured will inevitably differ according to whether or not the CO_2 has been captured within an oxidative capture environment such as a post-combustion process, or within a reductive capture environment such as pre-combustion process. Such conditions will also impact on the cost and operational performance of pipelines.

Quality of CO_2 stream and associated risks

The phase transition of CO_2 is a critical aspect of CO_2 transport. Under normal pressure and temperature, CO_2 presents as a vapour. The phase that the CO_2 is likely to be in when transported is known as a single phase (i.e. a stream of pressurised liquefied gas).

Regulatory specifications addressing the level of impurities in the CO_2 stream will affect the thermodynamics of the transported plume (i.e. the gas, liquid or solid phase as determined by critical pressures and temperatures). Specifications also address its toxicity, density, viscosity, water solubility, the extent to which corrosion of the pipeline may occur, and the behaviour and legality of the injected plume in geological reservoirs (such as the London Protocol's classification condition of a 'predominantly CO_2' waste stream).

As a general rule of thumb, the higher the level of CO_2 concentration (i.e. purity) in the stream, the higher the relative capture costs.

There is often a presumption that CO_2 pipelines pose no higher risk/s than that which is already tolerated for transporting hydrocarbons (such as natural gas, oil). While much of the literature supports the use of hydrocarbon pipelines as an analogue that can assist in the development of CO_2 pipeline infrastructure, some commentators indicate the inherent differences of CO_2 pipelines. For example, while leak detection is as equally important for natural gas and oil pipelines as it is for CO_2 pipelines, the impact of impurities (such as SO_x, NO_x, O_2 and H_2S) and water content of a CO_2 stream can lead to corrosion rates that potentially yield a higher frequency of failures in CO_2 pipelines than natural gas pipelines.[10]

It is important to note that the operational experience of onshore CO_2 pipelines to date does not highlight internal corrosion to be a significant pipeline failure event, but this may be a result of a common type of capture process (i.e. post-combustion or pre-combustion). The risk of external corrosion is also not considered to be substantially different to prevailing hydrocarbon pipelines.[11] The IPCC also confirms that the corrosion rate of carbon steel in dry (as defined in terms of parts per million by volume H_2O) supercritical CO_2 is low.

One reason why the prevailing understanding of the engineering of CO_2 pipelines for EOR purposes may not easily translate to CO_2 pipelines for storage purposes is that some 85 per cent of the CO_2 used in the US is from natural sources[12] – this is estimated to be between 45 to 55 $MtCO_2$ per year.[13] Natural sources tend to produce purer streams of CO_2 than anthropogenic sources captured from fossil fuel combustion processes, and from gas processing.[14]

Impurities in the CO_2 stream can impact on the hydraulic parameters of pipeline operations such as pressure and temperature, as well as density and viscosity of fluids, and as such the supercritical point. This has implications for the need (and hence cost) of booster stations at various distances of the pipeline, as well as the choice of pipeline material (noting that wet CO_2 acts as a solvent that can affect the long term integrity of the materials used in construction such as valve seals, gaskets and gland packing).[15]

The nature of CO_2 pipeline related risks depend largely on the dispersion behaviour of the CO_2 plume if released to atmosphere (intentionally or unintentionally) as influenced by the phase of the CO_2 as well as the release site's characteristics.

The potential impacts of pipeline related releases of CO_2 streams depend largely on factors such as the:[16]

- distribution of population surrounding the pipelines;
- pipeline diameter;
- thermodynamic properties of CO_2 (including pressure and temperature);

- material (and material thickness);
- soil coverage;
- risk mitigation options;
- assumed failure scenarios including frequency of failures;
- meteorological assumptions; and
- composition and phase of CO_2 stream (including flow of toxicity and corrosiveness due to impurities).

Within a context of risk mitigation and potential remedy requirements, any release of emissions to atmosphere (be it controlled for maintenance or safety reasons, or uncontrolled as an unforeseen event) could see the CO_2 stream expand as the pressure drops. This effectively cools the pipeline's content. On release to atmosphere, the CO_2 will present as a solid phase (like snow) and not as a liquid.

This subsequently influences the shape of the CO_2 'cloud' that is released, and determines its dispersion behaviour (when the cloud interacts with prevailing topographical and meteorological conditions). As CO_2 clouds are heavier than the atmosphere, they will tend to stay close to the ground and flow into low points, potentially causing zones where the oxygen content is reduced. An intentional release of CO_2 from a pipeline could perceivably be due to either operational requirements (for safety reasons to mitigate the potential for adverse events such as corrosion, construction or material defects, ground movement or operational errors) and would likely be compliant with industry accepted and well documented practices, and/or through third party interference (i.e. vandalism, sabotage etc).

Operators often need to manage risk by striking a balance between minimising the engineering risks (often presented by increased flow rates and failure rates) and the economics of operation.

It is interesting to note that there is no international standard for the application of a threshold for the relationship of exposure to CO_2 and the probability of human fatality.[17] There is however substantial literature on the relative hazards of CO_2 and standards by the US Occupational Health and Safety Administration (OHSA) and by the National Institute for Occupational Safety and Health (NIOSH).

Pipeline risk events can be managed through an accepted hierarchy of strategies to remedy if needed (DNV identify these to be: prevention, control, mitigation, protection and uncontrolled release). For example, there are a range of mitigation options that can assist in reducing the probability of large releases due to third party interference, including:

- engineering safeguards to reduce the duration and scale of, and exposure to CO_2 release/s (potentially through pipeline sectioning with check or block valves to reduce the risk and/or operational/maintenance reasons);
- providing a physical protection for the pipeline such as increasing soil coverage or use of concrete sheet shields (which can reduce the probability of failure by a factor of 10), or the use of higher quality pipeline materials (such as adjusting the pipeline's wall thickness, selection of materials, and cathodic protection to help reduce the incidence of corrosion);

- registering pipelines in a public atabase so as to inform third party operations and potentially avoid damage from other activities; and/or
- making the notification of intended digging activities by third parties a mandatory condition.

Pipeline scale-up

The successful large-scale deployment of CCS needed to help contain atmospheric greenhouse gas emissions to a concentration of 450 ppm will inevitably require a cumulative global investment of tens of billions of dollars to construct the many thousands of kilometres of dedicated CO_2 pipelines.

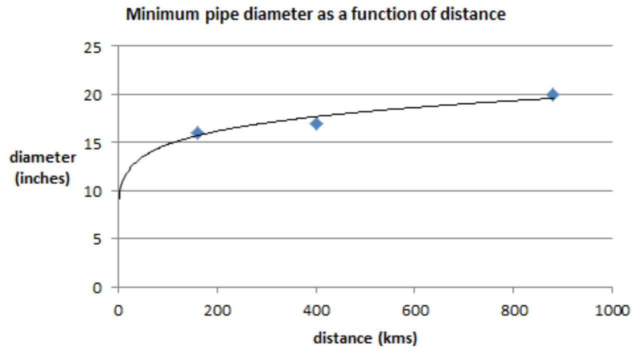
Research undertaken for the IEA Greenhouse Gas Abatement Programme predicts that by about 2030, 1.44 $GtCO_2$ per annum of captured CO_2 will need to be transported for less than on average 100 km in distance.

To highlight the scale up challenge that faces such a widespread deployment of CCS, the length of pipeline needed to transport CO_2 in the US alone could be in the range of 24,000 to 105,000 km by 2030.[18]

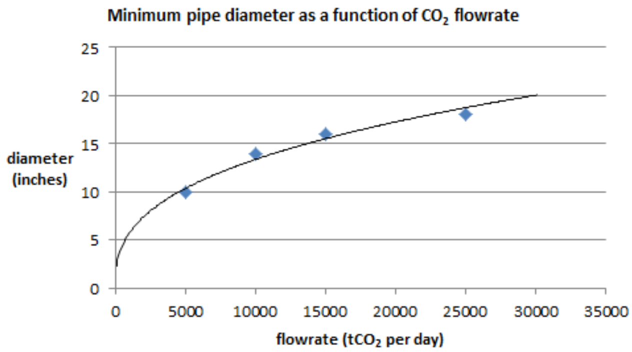
Box 2 illustrates the correlation of the volume of CO_2 needing to be handled and distances travelled to the diameter of pipes needed and the potential costs incurred (about US$50,000 per inch diameter per 1.6 km is cited as one gross estimate of pipeline costs).

BOX 2 – Pipeline diameters

Assume that 3.5 $MtCO_2$ is captured annually from a 500MW coal fired plant (equates to about 80 per cent capture rate) and provides a daily off-take of 9,600 tCO_2. At 700 psi (4,800 kPa) and a 100 per cent utilisation rate, the following chart illustrates the pipeline diameters that would be needed to move the CO_2 as a function of distance.



Similarly, the following chart illustrates the minimum pipeline diameter needed as a function of CO_2 flow rate over an 80 km distance.



It is clear that as the volume of CO_2 off-take per day and distances travelled increase so too does the diameter of pipeline needed. For example, emissions from eight such plants could require 30 inch CO_2 pipes.

Source: diagrams: DOE/NETL-2010/1447 p. 10, 11.

DIAGRAM 5 – Total costs of a 16 inch pipeline (US Midwest)

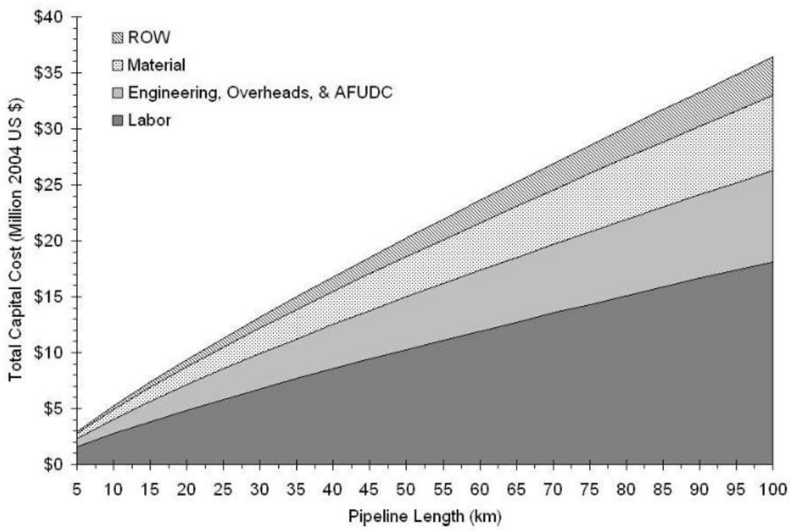


Diagram 5 serves to illustrate indicative total costs of a 16 inch pipeline of various lengths in the US Midwest.[19]

The NPV of establishing a sufficient global CO_2 distribution network is estimated to be around US$60 billion (excluding the costs of capture and storage). Within a context of CCS having the potential to deliver the single largest emissions abatement outcome under a 450 ppm scenario by 2050 at an estimated cost of about US$100 billion per annum, the scale of investment required for transport infrastructure is clearly affordable.[20]

CHAPTER THREE

POLICY

Context

The barriers and opportunities relating to CO_2 pipeline infrastructure to support CCS (including CO_2 for EOR purposes) will necessarily depend on the assumptions CCS actors make about the timing, scope, and configuration of the anticipated growth in the current pipeline network. As such, it seems reasonable to presume that the development of CO_2 pipelines for storage purposes will be largely driven by the enactment of legally binding restrictions on industrially produced CO_2 emissions. Currently, CO_2 pipelines are more associated with commercially attractive (i.e. no regret) business as usual commercial applications.

The lack of CCS operational experience, the absence of sufficient and long-term policy, financial, and regulatory drivers, and large uncertainties on the locations, capacities and timing of sources and sinks can serve to undermine and/or delay the commercial development of large scale CCS pipeline infrastructures. These barriers inevitably affect all components of CCS.

By far the most important challenge facing CO_2 pipeline developers is either the absence or insufficiency (in many locations) of a long term value for CO_2 abatement. An exception is where CO_2 is transported for enhanced hydrocarbon recovery (gas and oil). Where national governments adopt stringent CO_2 emission reduction targets, and where the market fails to provide sufficient reward for private investors to invest in CCS related mitigation activities, governments may choose to intervene and provide support for CO_2 pipeline investment.

There exists substantial uncertainty surrounding the establishment of mandatory carbon constraints, including: whether they will be imposed (mandated emission reduction targets are subject to sovereign decision making); their timing and stringency; and manner of imposition of CO_2 controls on industrial facilities. However, it may be reasonable to assume that governments will manage any such transition to a carbon constrained environment in such a way that avoids imposing abrupt and unnecessary economic costs to its economy in giving effect to a lower carbon signature. This suggests that it is unlikely that national CO_2 pipeline networks will be needed imminently, allowing for a gradual expansion of related infrastructure over time as allowable levels of CO_2 emissions tighten.

A major uncertainty for future CO_2 pipeline networks is where and when geologic storage sites will be located, both nationally and internationally. The associated costs of pipeline construction and operation may be expected to influence to some degree the future sequencing of geologic storage sites.

It is also evident that simply mandating a requirement for carbon capture does not fundamentally change the distances required by CO_2 pipelines, the associated costs of transportation, the physical location of sinks and CO_2 sources, or the potential for adverse reactions from population centres.

An important consideration for governments therefore in the design of CCS friendly policies (such as mandating capture readiness) could be to recognise that in waiting for a specific storage site to be validated, and/or the rules and incentives for cross-border CO_2 transport to be agreed to, some capture sources may choose to delay their planning for capture rather than risk developing assets that could become economically stranded in the future.

These types of factors will also inevitably affect the efficacy of policies to encourage CO_2 pipeline investments, and emphasises the importance of designing and sequencing a whole-of-CCS chain of policies to address the significant logistical challenges of capturing, transporting, injecting and storing very large flows and stocks of CO_2.

There may also be a range of competing issues for government consideration. For instance, regulatory frameworks often need to strike a balance between promoting private sector competition among pipeline operators while ensuring that CO_2 capture sources are able to meet their emission management obligations through having access to dedicated and sufficient transport capacity. This necessarily draws a discussion on the potential for monopolistic market structures arising, government policies and regulations that can provide for the construction of a large pipeline rather than a number of smaller ones, and the efficiency of large pipeline operators versus small operators.

Pipeline ownership

There are a broad number of possible approaches to pipeline ownership, ranging from privatised, public and public:private partnerships. There are four basic combinations to CO_2 pipeline ownership, including:

- vertically-integrated, privately-owned model (where pipeline ownership and operation are integrated with the CO_2 capture and storage facility);
- shared private ownership model (CO_2 producer/s enters into a contract with a storage facility and a pipeline operator (may be different entities):
- for example, a group of coal fired utilities could collaborate as contract CO_2 shippers to sponsor a pipeline and storage facility (operated by a specialist).
- government and/or public utility ownership model (involves government financing and/or ownership of pipeline and possibly storage facilities); and
- government-private shared ownership arrangement.

While vertical integration is one means for an organisation interested in CCS to reduce its associated commercial risk and transaction costs, the benefits of competitive markets are significant. As such, governments might explore the potential to facilitate the emergence of such competitive markets (encourage competition in pipeline investment) when considering whether to intervene and support the development and/or operation of CO_2 pipelines.

When assessing the potential to establish a competitive approach to investment in and operation of CO_2 pipelines, governments might consider three main factors:

- the extent and nature of public financial support required to achieve independent and financial viability of CCS:
  - commercial viability can be defined as a situation not requiring direct or indirect financial support from governments;
  - need to ensure that the costs and benefits of CCS can be internalised to the greatest extent possible so that government financial support may be withdrawn over time; and
  - the value of CO_2 (i.e. as determined by the price of emission permits under a cap and trade emissions trading scheme – which is also equivalent to the costs avoided by a CO_2 emitter using CCS) may not cover the full costs of CCS especially during its early stages of development.
- the likely economic organisation of the CCS chain:
  - assumes CCS actors have the tools to not only address the associated risks but also to capture the surplus value in the CCS chain that will arise (this is a key motivation for private sector participation).
- the incidence of projects that may not permit competitive investment in pipelines.
  - vertical integration may make sense where there are CCS projects comprising of a single large volume emitter and a single large sink that is available and sufficient for storage – operators still have every incentive to minimise their costs all along the CCS chain.

Pipelines may traverse areas that are intrastate (do not cross sub-national borders), interstate (crosses sub-national borders), and/or international (crosses national borders).

Dedicated pipelines (i.e. parties enter into a contract to develop a pipeline to carry CO_2 under specific terms and conditions) tend not to invoke economic regulation, nor do they typically attract or require government assistance.

Where there is a more open access model (i.e. pipelines are developed with significant government involvement including government regulation) governments tend to invoke conditions that define rights of access (open access or common carrier) and subject operators to economic regulation (rate setting) and other forms of compliance oversight.

Although some degree of vertical integration might be expected, the ownership structures across the various CCS components will generally involve the interests of multiple owners. This suggests that there are often a number of independent decision making processes and profit strategies associated with any particular investment.

A single pipeline owner linking multiple sources to a storage site may incur substantial transaction costs when striking complex contracts and agreements with third parties to secure service rents from CO_2 point sources (including costs of temporary storage) and pay fees to storage service providers.

A challenge for pipeline owners in establishing fees is that the prevailing market value of CO_2 can be quite separate to the economics of CO_2 pipelines. A market value for CO_2 (as determined under an emissions trading scheme) generally reflects the scarcity of allowable CO_2 emissions in the market and not the aggregated costs of physically moving CO_2 long distances by pipeline to access storage sites, or the costs of complying with local regulations including monitoring, measurement and verification (MMV) obligations.

But regardless of how the fees for pipeline services are determined (i.e. be it total cost plus some mark-up independent and/or linked to CO_2 prices, and/or linked to a percentage of total value of the CCS chain revenues, or regulated tariffs), operators will expect to earn an acceptable return on investment.

The choice of pipeline pricing strategy can impact on CO_2 point source profit margins and as such, CO_2 point sources may be better off owning and operating large capacity pipelines where CO_2 market values are relatively high (>€35)[21].

Pipelines are often characterised as being 'indivisible' and tend to operate as a natural monopoly – indivisibility means that no matter what the specification of a pipeline is, an entire pipeline of requisite length is required to render a service to transport CO_2 from a recipient point to delivery point. The corollary to this is that half the pipe length cannot carry half the flow of CO_2 between these points.

A natural monopoly occurs when, due to the economies of scale, the maximum efficiency of production and distribution is realised through a single supplier. From a societal perspective, it may be worthy of government consideration for a large pipeline to be constructed rather than say multiple smaller point-to-point pipelines.

In a fledgling industry sector like CCS, private investors will manage risks in accordance with their perceived rewards and threats. For pipelines, decisions may be further complicated by a need to invest in oversized pipelines to accommodate the phase-in of future capture plants. For private carriers, this will often be at the expense of realising an immediate return on the overcapacity – potentially introducing risk premiums above the weighted average cost of capital.

Potential role of government

It is clearly difficult for governments and the private sector alike to form upfront an accurate and long term view of the future requirements of a CO_2 pipeline network – either at a regional or national level – and especially one that balances the respective challenges of technology maturity, flexibility, scalability, net benefits/costs, risks, and regulatory permitting requirements. This is due to the inherent uncertainty of future capture sources and storage potentials (including EOR), the specificity of pipeline routes, and the variable geographical and economic circumstances.

While there may be a lesser expectation of a role for governments in the early phases of CO_2 pipeline development where EOR projects dominate the landscape, the importance of such a role increases as more pipelines are constructed and regulations become necessary for pipeline siting and environmental performance (and the like).

At one end of the spectrum for example, there may be little to no government oversight of CO_2 transport tariff rates, with rates essentially set through contractual agreements. Governments may instead prefer to monitor costs, rates, and performances on a periodic review basis. At the other extreme, there could be government ownership of or participation in (such as provide financial guarantees) actual CO_2 pipeline projects.[22]

To assist the establishment of sufficient CO_2 distribution networks, governments (at both national and sub-national levels) can assume a number of complementary roles to the private sector. In general, interventions might be considered economically efficient and equitable when the value of the prevailing drivers for CCS (such as CO_2 re-use and market incentives) are lacking and/or considered to be insufficient to deliver on the government's emission reduction objectives. For example, governments could:[23]

- establish for all CCS actors, effective and efficient conditions for permitting (i.e. social licences to operate) including clear and concise fit for purpose legislation, regulation/s and oversight;
- address market failures and barriers (an example for pipeline infrastructure may be the provision of public support for the facilitation of oversized infrastructure to provide for the future phase-in of capture plants); and/or
- act as an owner-operator of CO_2 network assets in the absence of markets being able to provide a sufficient level of investment.

CO_2 pricing will clearly be a major driver of future investment in large scale CCS projects. While government involvement in establishing pipeline infrastructure might help drive down costs at the margin (i.e. lower discount and investment hurdle rates, access to global capital etc), it can also help send strong signals to financial markets of the political commitment to support the deployment of CCS and enhance the ability of national compliance with international climate change obligations (i.e. emissions reduction targets).

There may also be a public benefit from governments supporting the construction of oversized pipelines in the early years, especially if future climate change regimes are expected to drive strong demand for CO_2 capture and storage through ever more stringent carbon constraints.

Analysis indicates that larger capacity pipelines tend to have lower costs per tonne of CO_2 shipped than smaller pipelines when compared under similar ownership structures. This is not to suggest however that smaller capacity pipelines are necessarily inferior options (in terms of profitability and risk) under various combinations of ownership, profit strategies, transaction costs (especially in regards to contract negotiations), and the location and distance between sources and sinks.[24]

Another reason for public intervention might be to help reduce the economic risks associated with the upfront capital needed for pipeline infrastructure investment, and this can reduce the overall cost of a pipeline project on a discounted cash flow basis. This might be serviced through the development of predictable and efficient economic policy instruments and long term regulatory frameworks, and/or encouraging social and political awareness and acceptance of the importance of CCS to deliver on core government policy objectives.

Outside of any consideration of government ownership and operation of pipeline assets and/or partnering with the private sector to fund such projects, legislation with accompanying economic regulations may be necessary to ensure that the owners of assets operating as a natural monopoly (i.e. extracting monopoly rents where prices are set at levels much higher than the marginal cost of production) are compelled to provide access to third parties and charge access fees (regulated tariffs) at prices set by a process of determining efficient costs that equate with efficient prices.

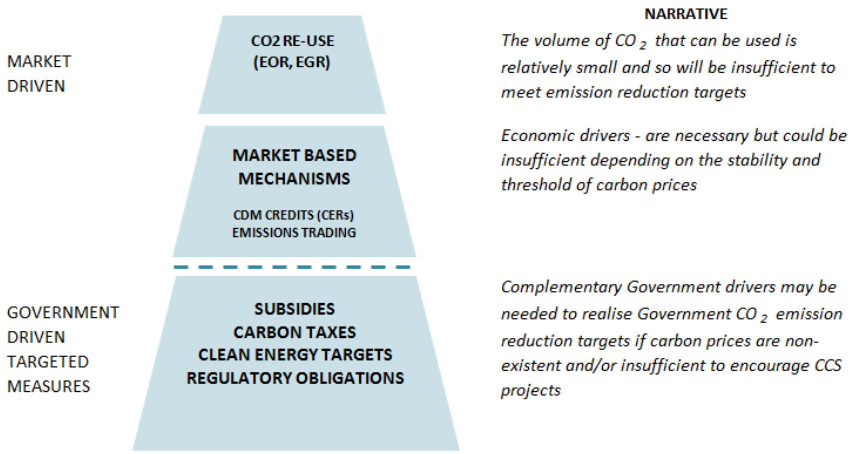
It might also be considered reasonable to assume that if governments take on the investment initiative for CO_2 networks, a lower discount rate might be adopted compared to if there is no government involvement. This can effectively lower the carbon price threshold needed for such an investment to break-even (i.e. NPV = 0).

An Australian study observes that "… if government(s) want to mandate CCS (including transport) for all CO_2 emitters, then government should underwrite the infrastructure necessary to implement such a mandate". It suggests that "… a statutory body could ... build, own and operate the main transport links between source and storage, comprising of inlet and intermediate compressors, long distance pipeline and associated facilities." It also indicates that one financing option is to "... raise funds by issuing bonds ... in a form similar to those that were issued in the 1990s for large investments in pipelines, roads and water projects ... offering significant tax advantages for investors ... which could be privatised and the bonds redeemed in the same manner as the natural gas industry was after some 20 years of public ownership."[25]

Incentives for CO_2 pipelines

The general drivers for CCS investment are illustrated in **Diagram 6**[26] as follows:

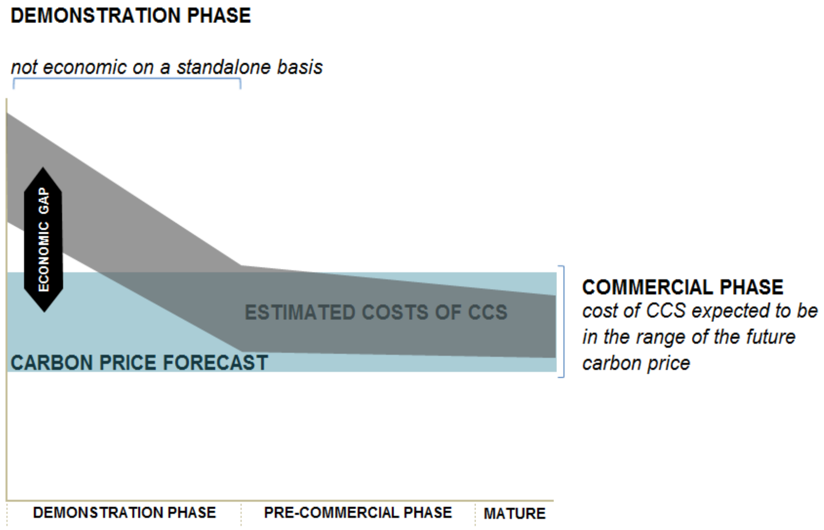
DIAGRAM 6 – Incentives for pipeline investment



Source: Slagter, W and Wellenstein, E: Drivers and barriers towards large scale carbon capture and storage deployment and possible government responses - current insights from the Dutch perspective, International Journal of Greenhouse Gas Control 4(2011) page 5739

There are many varied reasons why the private sector may decide to invest in CCS projects. CO_2 emitters could for example carry increasing expectations of having to pay for the right to pollute over time and that CCS presents as a long-lived and commercially attractive mitigation option (see **Diagram 7**), and/or are ambitious to optimise their share of government support that may be on offer.

DIAGRAM 7 – Innovation phases of CCS



Source: McKinsey, 2008 as cited in Slagter, W and Wellenstein, E: Drivers and barriers towards large scale carbon capture and storage deployment and possible government responses - current insights from the Dutch perspective, International Journal of Greenhouse Gas Control 4(2011) page 5739

The use of CO_2 for EOR (among other CO_2 uses) is often cited as an activity that can indirectly help drive CCS infrastructure and operations, as well as directly improve the CCS community's understanding of related activities (such as CO_2 injection and the geology of storage formations). While the primary aim of EOR is not the permanent storage of CO_2, its processes, including transport of fluids by pipelines, share many obvious common traits with CCS.

The use of CO_2 as an economic driver of CCS is unlikely to be singularly sufficient to encourage investors to finance CCS projects, and so other complementary measures are likely to be required.

Regardless of whether a CO_2 distribution network is publicly or privately (or a combination of both) owned, investment decisions will be shaped by a number of priorities such as the:

- potential net benefits (pricing risk, rates of return and associated opportunity cost);
- alignment with broader objectives including environmental benefits (i.e. in the case of CCS, the scale of CO_2 abatement to be delivered within a certain period);
- costs (i.e. up-front, ongoing, cost of finance, service costs, commercial gap between system costs and carbon price etc);
- operational flexibility (i.e. ability to accommodate future additional CO_2 supply, connection of multiple storage sites over time, daily fluctuating volumes of CO_2, management of upstream (capture) and downstream (storage) operational demands, etc);

- overall robustness of the investment case (e.g. can economic viability be sustained if pipeline utilisation falls below a certain threshold);
- overall complexity of conducting business (e.g. including planning issues, regulatory requirements and approvals); and
- ability of multiple stakeholders to agree on design and business models to deliver infrastructure in a timely manner (i.e. most investments will likely include a consortia of interests).

UNFCCC mechanisms (including the Clean Development Mechanism)

The Kyoto Protocol provides for the compliance arrangements for developed countries to deliver on their negotiated emission reduction targets. It currently consists of three market-based mechanisms called flexibility mechanisms, and includes:

1. Joint Implementation (whereby developed countries can claim credit for the emission reductions generated from project level investments in other developed countries);
2. the CDM (whereby developed countries can claim tradable offset credits for the emission reductions generated from project level investments in developing countries); and
3. international emissions trading (whereby developed countries can trade emissions allowances for the purposes of meeting their emission reduction commitments).

The CDM was the first global environmental market mechanism (commenced operations in 2006 with a retrospective emission baseline starting in 2000). It essentially provides for developed countries to invest in emission reduction projects that assist in creating sustainable development in developing countries. This in turn rewards project proponents with a tradable instrument (called a Certified Emission Reduction unit or CER) for additional abatement and financial outcomes which they can either choose to sell or use to legally acquit against their emission obligations.

The inclusion of a CCS project under a cap and trade (C&T) emissions trading scheme (like international emissions trading) differs to that of a baseline-credit (B-C) approach such as Joint Implementation and the CDM (also referred to as project based mechanisms).

In a C&T scenario, the emissions that are captured, transported, injected and geologically stored do not count towards an originating entity's gross carbon liability as they are never released to atmosphere. Emissions liability arise however for all fugitive emissions (leakage) within the CCS system (and permits acquired and acquitted) – including from capture, transport, injection and storage.

B-C approaches rely on establishing a 'with' and 'without' project emissions and financial investment baseline to demonstrate the extent to which the associated project 'effort' (abatement and investment) is additional to business as usual. As such, investments in supporting infrastructure (such as pipelines) are unlikely to generate abatement outcomes that in their own right can be rewarded.

Host governments in developing countries need to have in place effective policy and regulatory frameworks and/or governance arrangements that are capable of supporting the deployment of CCS projects under the CDM. In practice, many of the rules of CDM are given effect through domestic law, including:

1. the content and application of regulatory assessments (i.e. health, safety and environment (HSE));
2. HSE regulatory approvals required to carry out the project activity (including licenses, operating permits, planning permits etc); and
3. regulatory restrictions and/or conditions imposed on projects (including pollution controls; impacts on biodiversity; provisions to redress etc).

As of December 2011, there is a suite of established rules (called modalities and procedures) that provide for CCS project eligibility in the CDM.

Of current relevance to the further refinement of these rules is the possibility that some developing countries wanting to capture the CO_2 from their power and industrial processes will need to transport them to another developing/developed country for storage. This might be due to the poor economics of storing emissions locally and/or simply a lack of local and appropriate storage sites. The transboundary movement of CO_2 is a major outstanding issue for the CDM that is yet to be considered at the next international climate change conference in Doha (i.e. 18^{th} Session of the Conference of the Parties). It has direct implications for CO_2 pipelines in regards to the eligibility of transboundary CCS projects.

In the case of a vertically integrated CCS project with a single CO_2 source, pipeline and storage site, it may in principle be possible for the whole system to receive CDM credits (CERs) related to the net difference between the emissions produced from the CCS project and the project's agreed emission baseline (assuming there is a net abatement outcome). This is possibly simplified if there is a single entity owner for all CCS elements.

However, there are a number of key challenges to including more complex integrated CO_2 networks in a project based mechanism like the CDM such as crediting periods and project boundaries.

Crediting periods create temporal boundaries for a particular CDM project activity. Project boundaries create physical limits for a project activity. Simplistically, all project level abatement must take place within these two boundaries, and proven to be additional to an established emissions baseline in order to generate CERs which can then be traded.

It is unclear whether a new source of CO_2 connecting to an existing CCS CDM project activity can be included within that specific project activity, or whether it constitutes a new project activity. This is further complicated where it commences sometime after the start of the crediting period, and continues beyond the end of the crediting period of the original CDM project activity.

Multiple ownership arrangements and liability issues associated with CO_2 leakage events also create uncertainty as illustrated by the examples below:

- if a country involved in CCS infrastructure was not an eligible country for receipt of CERs (i.e. has not ratified the Kyoto Protocol or is not a developed country), whereas other countries were eligible;
- if enhanced hydrocarbon recovery was a fundamental driver of the CCS project (challenging the additionality requirement of such investments); or
- if national legislation mandates the use of CCS then it is potentially considered a business as usual activity.

Fit-for-purpose performance standards

The establishment of international standards could also potentially serve to present CO_2 pipeline projects as being more publicly acceptable, as well as guide both regulators and operators alike to minimise any burdens associated with securing permitting approvals, siting characterisation, construction and operationalisation of new CO_2 pipelines.

Improving the efficiency of these factors may be especially beneficial to CCS deployment when considering the need for timely mitigation action, and the volumes of CO_2 that will need to be transported between large scale CO_2 capture plants and storage sites.

Global CCS developments are still in an early stage of the innovation cycle, and this partly explains why the focus of governments to date has mostly been on providing public support for demonstration scale projects.

Actors mobilised in the CCS chain have tended to avoid placing too much emphasis on institutionalising nascent and evolving CCS standards (i.e. which generally guide what to implement) and best practice guides (i.e. how to implement) due to the limited amount of project level data currently available to inform the setting of appropriate performance thresholds.

The setting of standards today on the basis of incomplete information could potentially lead to overly conservative permitting requirements being imposed on demonstration and pre-commercial CCS projects, and this could undermine the ability of proponents to proceed with affordable, innovative and often first of a kind demonstration projects.

In May 2011, Standards Council of Canada (SCC) submitted a proposal to the International Standards Organization (ISO) to develop an internationally agreed and voluntary standard/s for carbon capture and storage (CCS). The ISO has subsequently agreed to pursue a proposed program (TC-265) of work that includes the full life cycle of a CCS system, and intends to establish a separate working group (WG) to develop a standard covering CO_2 transport.

The ISO proposal recognises that a number of international and national standards already cover pipelines, and indicates a degree of acceptance that the transport of CO_2 is not much different than hydrocarbons. But it also recognises that CO_2 pipelines are unique and therefore appropriate for standardisation.

The scope of the Transport WG is yet to be agreed to but is expected to cover: environmental planning and management, risk management, quantification and verification, and other related activities but exclude equipment and materials used in pipelines.

Pipeline operators rely on standard procedures to govern normal operations, maintenance (i.e. pipeline monitoring and repair) and emergencies (such as emergency responses and the analysis of pipeline accidents). In the US, the integrity of pipelines for example is generally monitored using in-line inspection (ILI) tools. Where pipelines are not inspectable by ILIs, well established alternative direct assessment techniques can be employed in which data from indirect measurements define locations where a pipeline is to be directly examined and the integrity of the pipeline segment assessed.[27]

While there are no known accredited private, national or international standards specific to the integrated CCS chain, there is a growing body of technical standards for pipelines, both directly and indirectly applicable to CO_2 operations.

The ISO proposal acknowledges one private sector standard that could be used as a basis for the development of an international standard. This is DNV's *Design and Operation of CO_2 Pipelines* (DNV-RP-J202). DNV-RP-202 draws upon several other standards including: ISO 13623 (*Petroleum and Natural Gas Industries - Pipeline Transportation Systems*, 2nd Edition 15 June 2009); DNV-OS-F101 (*Submarine Pipeline Systems*, October 2007); and the American Society of Mechanical Engineers (ASME) ASME-B31.4 - *Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids* (2006).

DNV-RP-202 also identifies a number of relevant risk assessment standards that cover all phases of pipeline networks from the conceptual development, operation and abandonment of pipelines (including ISO 17776; ISO 31000 and NORSOK Z-013). The document aims at identifying and providing for the mitigation of operational threats such as controlled and uncontrolled releases of CO_2 and the associated consequences of both single event failures, and systematic failings in the pipeline systems. It also includes legal definitions as prescribed under the London Protocol; OSPAR Convention and the European Commission's (EC) CCS Directive.

Further, an existing ISO WG may well leverage and complement the work already undertaken by ISO TC67/SC2 on Pipeline Transportation Systems.

Non-government and inter-governmental organisations will also inevitably play an important role in establishing ISO standards for CO_2 pipelines. For example, the World Resources Institute's *CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport, and Storage*, and the IPCC's Special Report on CCS will provide valuable inputs into the future ISO work effort.

The classification of CO_2 is an important area for project proponents in regards to securing regulatory approval as well as operating pipelines. Categorisation of CO_2 has consequences for the design of pipelines in regards to wall thickness, materials and pressure testing, and the extent to which prescriptive and/or precautionary approaches are adopted/enforced for the management of associated risks.

For example, ISO-13623 and DNV-OS-F101 classifies CO_2 as a 'non-flammable fluid which are non-toxic gases at ambient temperature and atmospheric conditions'. ASME-B31.4 however classifies CO_2 in a dense phase as a 'Hazardous Liquid'.

ASME B31.4 also requires a maximum block valve spacing of 12 km (block valves are essential for isolating sections of pipelines during maintenance). In the United Kingdom's (UK) PD 8010-1, no specific distances are stipulated except to indicate that spacing should be determined by a safety evaluation. IGE/TD/1 recommends that the spacing of block valves be determined by considering factors such as pipeline pressure, population density, blowdown time and topography.[28]

Provision for the design and operation of supercritical CO_2 pipelines has also been made in US Federal Regulations (49CFR195, 2008[29]). There are also various other codes and standards relevant to pipeline design (noting that many could potentially be directly applicable to CO_2 pipelines with minimal changes to basic engineering and technical matters) including but not limited to:

- Australian Standard (AS2885): *Pipelines and Gas and Liquid Petroleum* (covering the design, construction, testing, operation and maintenance of petroleum pipelines)[30];
- the American Petroleum Institute (API) specification 5L, and the Chinese standard GB/T 9711-2005[31];
- API 5L (2007) lists pipeline specifications (i.e. available pipe types together with their dimensions and material properties)[32]; and
- in the UK, both onshore and offshore pipeline design needs to accord with PD8010 and the Institute of Gas Engineers recommendations (IGE/TD/1, 2001).
  - note that these regulations make no provision for the design of supercritical pipelines – the transportation of CO_2 as a gas is included in PD 8010-1.[33]

CHAPTER FOUR

ECONOMICS

Context

The economic viability of CCS may be undermined by requirements to move CO_2 long distances from point source/s of capture to appropriately characterised storage site/s (including onshore, offshore and/or transboundary).

The concept of one-size-fits all does not easily apply to CCS developments generally, or pipeline development specifically. Circumstances arise in terms of the size and locations of emitters, the phasing of emissions, distances to sinks, the availability, location and capacity of sinks and other factors that will all have a bearing on the configuration, costs and phasing (i.e. milestones) of investment in CO_2 pipelines.

Pipeline developers inevitably seek to minimise their project costs by optimising engineering scale and minimising technical and financial risks through phased implementation strategies and striking of contractual arrangements between relevant parties.

A timely construction and operation of a CO_2 pipeline project is contingent on successful planning, efficient approvals and consenting processes, and effective public consultation engagement (to understand and address the requirements of a diverse range of key stakeholders).

Pipeline infrastructure processes can take many years to secure all the necessary permits, and this can be exacerbated if projects span across multiple borders (a project can only really commence after all necessary permits have been secured from the responsible authorities in all countries). This may also include the establishment and publishing of tariffs.

As such, CCS infrastructure developers may choose to adopt the simplest configuration of pipeline design and decide to site them along routes that minimise these sorts of delays, rather than opt for options that provide opportunities to maximise CO_2 abatement potential or minimise cost outcomes from a societal perspective.

Cost of pipelines

CO_2 network costs are considered to be generally influenced by:

- the design and materials used;
- the length of pipelines needed;
- the architecture of systems (point-to-point, tree and branch, hub and spoke);
- energy consumption; regulatory arrangements (including permitting complexity); and
- the lack of and/or stridency of industrial or technical standards to guide design and operation.

One analysis completed for CO_2 transport costs in China for example illustrates that levelised costs are most sensitive to flow rates and upfront capital costs, which in turn is highly correlated to the need for larger pipeline diameters as longer distances are travelled.

DIAGRAM 8 – Breakdown of CCS project costs (Australian study)

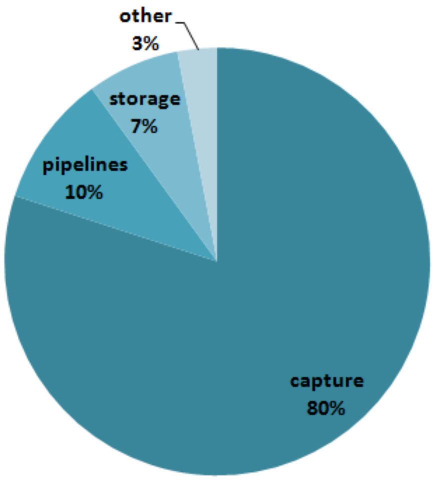


Diagram 8 indicates the total costs from an Australian study of the components of an integrated CCS project (on a dollar per tonne of avoided CO_2 basis). Pipelines contribute to about 10 per cent of the total cost.[34]

DIAGRAM 9 – Breakdown of CO_2 pipeline costs (Californian study)

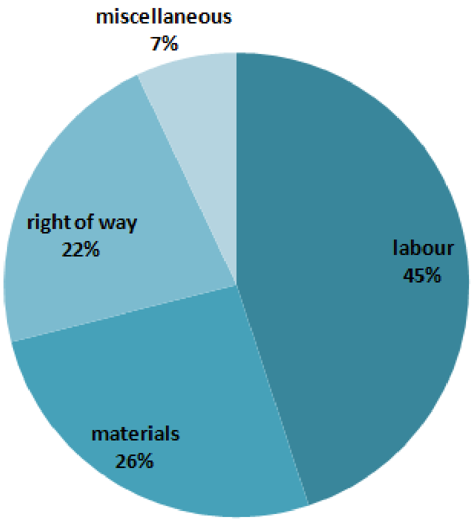


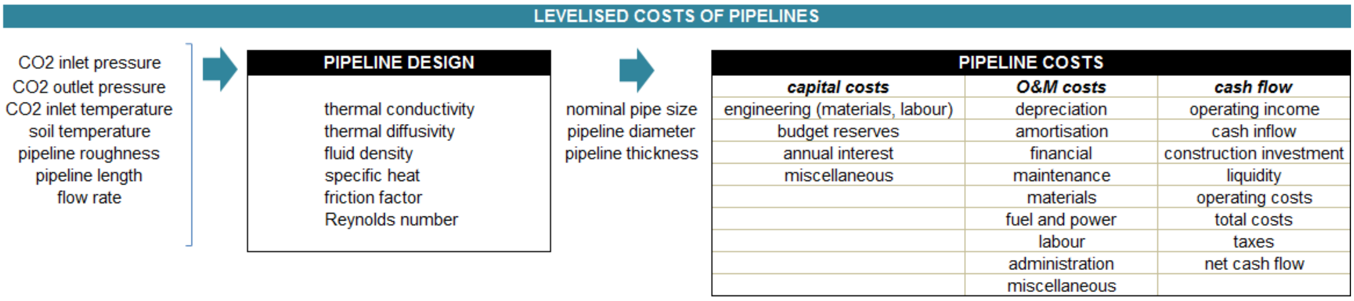
Diagram 9 illustrates the results of a University of California study of the total cost break down for the construction of CO_2 pipelines built in the US between 1991 and 2003.[35]

One study also indicates that the cost of constructing a CO_2 pipeline could on average be 10 per cent higher than that of a comparable natural gas pipeline.[36]

There are a number of well-defined approaches for estimating the cost of pipelines. In essence, they all identify three major cost components:

- construction (e.g. materials, labour, equipment, design, l and acquisition, insurance, project management);
- annual operational and maintenance costs (e.g. labour, maintenance, fuel costs); and
- end of project life abandonment costs.

DIAGRAM 10 – CO_2 pipeline levelised cost components



Materials: cost of line pipe, pipe coatings, cathodic protection, telecommunications equipment, data acquisition
Labour: cost of pipeline construction labour
Miscellaneous: cost of surveying, supervision, contingencies, freight, taxes, overheads, regulatory fees etc

Source: Lui, H and Gallagher, K S: Preparing to ramp up large scale CCS demonstrations: An engineering-economic assessment of CO2 pipelines transportation in China, International Journal of Greenhouse Gas Control 5(2011) page 798

The factors driving the cost of building and operating CO_2 pipelines are well understood by pipeline developers. Costs can vary enormously from project to project, depending upon the terrain traversed, international markets for steel, pipe and other facilities, the local market for contractors, and the diameter of pipes to mention just a few variables.

Material costs (such as steel) can account for as much as 15 to 35 per cent of this cost. Any subsequent increase in carbon and/or steel prices can result in even higher shares.[37]

Commercial pipeline developers often consider utilisation rates as low as 80 per cent and as high as 99 per cent to value a prevailing investment opportunity[38]. As the CO_2 needs to flow through the pipeline at about 1,800 to 2,700 psi (or 12,400 to 18,600 kPa), and depending on how the CO_2 is sourced, this could mean that additional compression is needed prior to entering the pipes, as well as line and booster compression along the length of the pipeline to sustain these pressures.

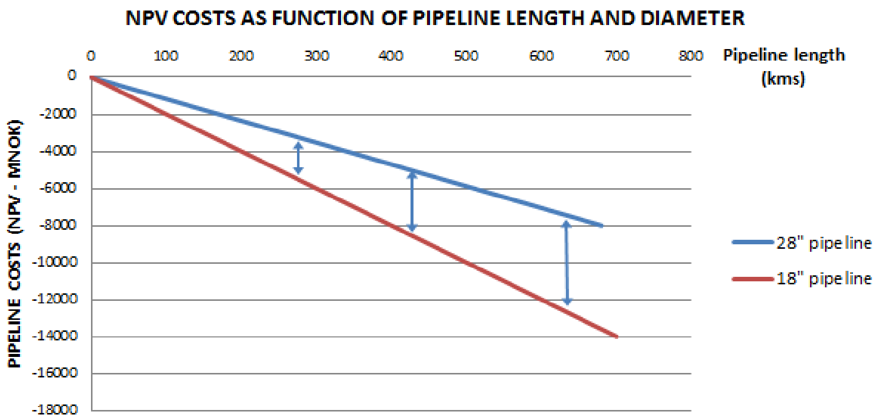
In regards to land acquisition costs for natural gas pipelines in the US, the purchase of an easement from all landowners to allow a right of way to construct and install can account for over 20 per cent of the total costs. This share may increase as pipes traverse higher valued land more closely located to population centres.

A major factor affecting the economics of pipeline infrastructure (among other factors such as infrastructure ownership and government involvement) is economies of scale.

Economies of scale

In addition to ensuring viable storage solutions for future new capture sources, nationally planned and/or integrated pipelines may benefit from large economies of scale, which in turn can further help the wide-scale deployment of CCS.

DIAGRAM 11 – Impact of pipeline length versus diameter on NPV costs



One study illustrates how the average cost per tonne of CO_2 transported can decrease with the increasing scale of pipeline diameters and lengths. Diagram 11 shows that when transport distances are long (>700 km), the potential differences in NPV costs between larger and smaller pipelines may indicate that the challenges of establishing a common pipeline might be worthwhile.[39]

As such, the economics of a CO_2 distribution network can generally benefit from: transporting larger volumes of CO_2 over longer distances to link CO_2 sources to storage facilities; consolidating complex and lengthy permitting procedures; as well as overall reductions in the costs of linking CO_2 sources to storage sites which tends to be influenced by the number of power plants and industrial CO_2 sources that can share the costs of a pipeline over a given distance.

While building a common pipeline over relatively short distances (say less than 100 km in length) may be less attractive when compared to alternative designs such as point-to-point, if the full potential for economies of scale can be realised through the use of fewer and larger pipeline diameters, then integrated pipeline networks could potentially reduce CO_2 transport costs and risks considerably.[40]

The economics of an integrated CCS project for example may be further improved by ensuring that pipelines that are initially oversized can achieve full utilisation in an efficient manner and that the captured CO_2 can be stored as soon as is possible after it has been captured at the point source.

Such an integrated approach may also better provide for smaller and possibly more expensive sources of captured CO_2 sited far from appropriate storage sites.

For both integrated and point-to-point infrastructure arrangements, a discounted cash flow analysis reveals that the following drivers have a decreasing order of importance:[41]

- the longer the pipeline length (or more challenging the terrain) the higher the pipeline fee/tariff required;
- the smaller the absolute capacity the higher the pipeline fee/tariff required;
- the higher the weighted average cost of capital (or discount rate) the higher the pipeline fee/tariff required;
- the longer the economic lifetime and loan period, the lower the pipeline fee/tariff required;
- the longer the delay between construction and operation, the higher the pipeline fee/tariff required; and
- the longer the construction period, the higher the pipeline fee/tariff required.

Where the cost difference between a point-to-point network and a nationally integrated CO_2 network is low and/or comparable, there may be little benefit for the existing point sources to integrate. This seems to be the case for the power sector in Europe, which is estimated to range between €1 tCO_2 to €4 tCO_2 for a point-to-point network and between €1 tCO_2 to €4.5 tCO_2 for an integrated system.[42]

These estimates roughly coincide with McKinsey's estimates of transport costs of between €4 tCO_2 (for onshore) and €6 tCO_2 for (offshore).[43] In addition to this, an engineering-economic study for China also yields levelised costs for the transport of CO_2 of between US$2 to $3 tCO_2 for onshore pipelines.[44]

The IEA's analysis puts the marginal cost for source to sink connection initially at around US$5 tCO_2 transported, rising to about $30 tCO_2 from 2050 onwards due to a larger number of smaller capture plants needing to link to higher cost storage sites (i.e. longer distances requiring larger pipes).[45]

The attractiveness of one network arrangement over the other becomes a little clearer when the cost differences are large, as may be the case for industrial applications where transport costs in Europe are estimated to range from between €1 t and €16 tCO_2. An integrated approach may also be considered to be a preferred strategy when providing for emission constraints relies heavily on the potential phase-in of additional CO_2 capture plants over time.[46]

Other important cost reduction considerations include:

- the technological learnings over time as a result of the successful deployment at large scale of integrated CCS demonstration projects; and[47]
- reduced risk premiums charged by engineering, procurement and construction (EPC) contracts to deliver pipeline infrastructure due to turnkey solutions driving lower construction costs.

Project financing

Project financing (i.e. the long term financing of infrastructure and industrial projects based upon the projected cash flows of the project rather than the balance sheets of the project sponsors) is an important consideration for CO_2 pipeline infrastructure.

Although pipelines can be financed through traditional methods (such as project finance, debt financing, and structured or other forms of cash-flow financing), the financing of future CO_2 pipelines to handle permanent storage may require different approaches. For example, finance arrangements may need to be given effect through a combination of project and corporate debt, as well as CO_2 contract commitments.

Corporate debt financing is the payment, in whole or in part, for a capital investment with borrowed funds. Structured finance and other forms of cash flow financing rely on cash flow, assets of the company, or revenue from the project being financed.

Short distanced pipelines (where a power plant is located at or near a storage site) are usually financed through corporate debt. Longer pipelines and 'backbone' pipelines may require more up-front project financing as supported by longer term contracts. Some commentators believe that other than EOR supported pipelines, any major construction effort will require some form of government financial support at least in the early development of CCS.

A project financing structure can involve a number of equity sponsors, as well as bank syndicates that provide loans to the operation. The loans are most commonly non-recourse loans, which are secured by the project assets and paid entirely from project cash flow, rather than from the general assets or creditworthiness of the project sponsors. Project lenders are usually given a lien (i.e. security of interest) on all assets, and are able to assume control of a project if the project company has difficulties complying with the loan terms.

In the current CO_2 pipeline industry, where CO_2 is shipped as a commodity for commercial re-use, the final investment decision process is straightforward – determined by a specific cash flow generated by the sale and purchase of the CO_2 used for EOR. There is an established price for CO_2, which adds certainty to purchase and sale negotiations. However, future CO_2 pipeline infrastructure for storage purposes generally lacks the certainty of such price signals.

A lack of CO_2 price signals can often serve to undermine the financing of CO_2 pipelines by: offering little basis in which to determine project cash flows – the foundation of project finance; the carbon price alone will unlikely be sufficient to cover the cost of CO_2 pipelines for permanent storage (i.e. without EOR) and as such may instil in capital markets a low propensity to support or build new pipelines; and also the extent to which governments are willing to intervene to support pipeline projects.[48]

The prevailing risk aversion by financial lenders to approve funding for CO_2 pipeline investments is also a reflection of the impact the global financial crisis has had since 2007-08. As such, the securitisation of debt financing for pipelines can be relatively expensive with very high upfront fees and significant margins.

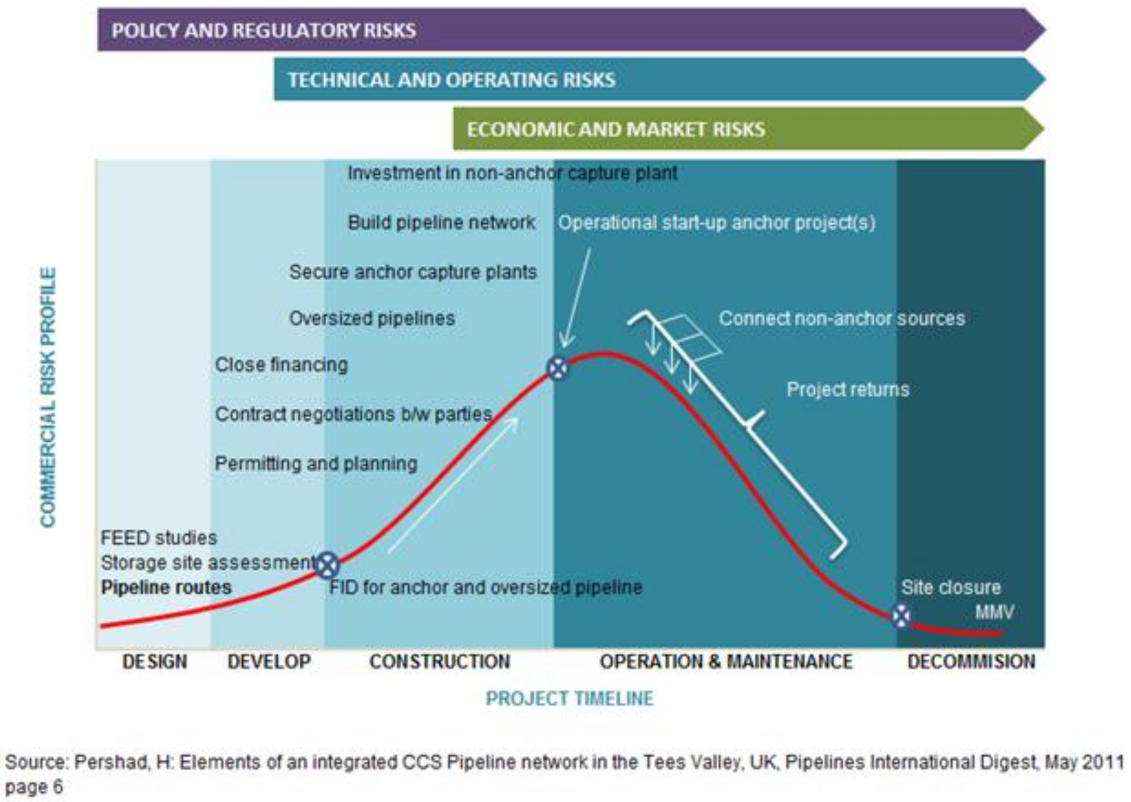
It is possible for investors to negotiate a broad range of debt to equity ratios. Debt financing tends to be cheaper than equity, but lenders tend to require higher levels of commercial certainty. Equity financing tends to bear the first risk of loss. Given the scale of finance sought, both approaches (and hybrids) often rely on the establishment of a consortium of sponsors. This can help mitigate the risk for any individual investor and can ensure the interests of different stakeholders are represented.

Where there are compelling strategic national interest reasons, national governments (and/or international organisations such as the World Bank) frequently facilitate the financing of large scale infrastructure projects. This can be either through direct investment (possibly through state owned industries which take an equity share) or by providing loan guarantees for projects in emerging markets where business risks tend to be higher.

Commercial considerations

The following chart (see Diagram 12) illustrates some of the commercial risks that a CO_2 pipeline project might experience across its lifecycle. The risk profile associated with achieving various milestones will change over time, and are often determined by the corresponding risks that affect both upstream (capture) and downstream (storage) activities as well.

DIAGRAM 12 – Commercial risks of a CO_2 pipeline project



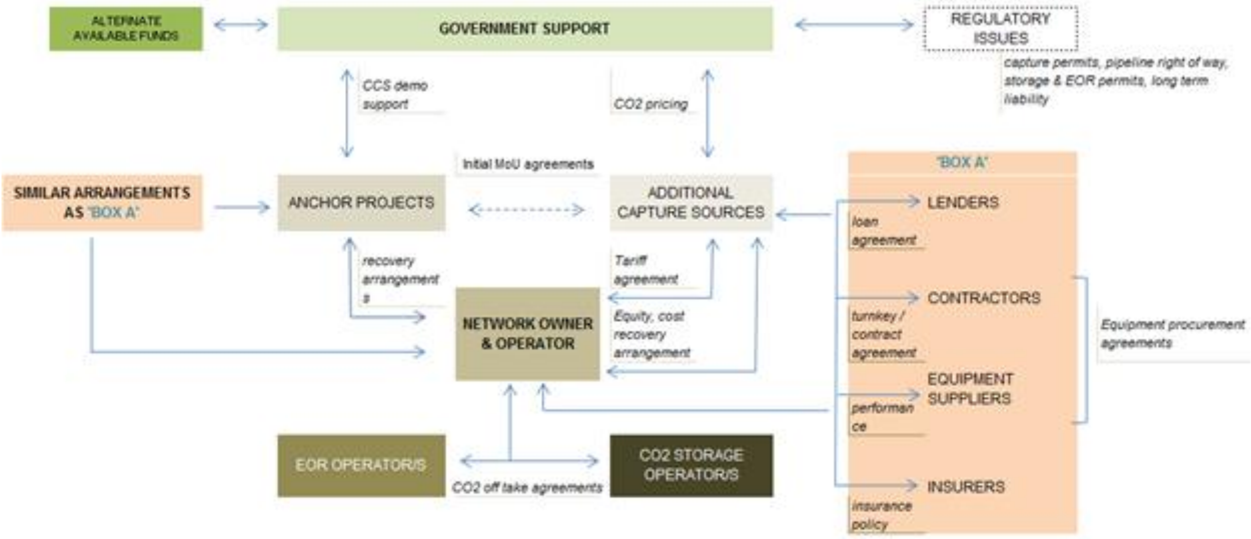
Source: Pershad, H (May 2011): Pipelines International Digest – Economics of an integrated CCS pipeline network in the Tees Valley, UK, p. 6

Investment in a CCS distribution network will typically proceed along a critical pathway that includes major milestones such as:

- the selection of initial CO_2 capture and storage projects (including sufficient anchor projects);
- assessing and understanding the policy, regulatory, technical, market, economic and reputational risks that may present themselves over the life of a project;
- final investment decisions (FID) influenced by: a capacity to manage or accept the risks as outlined above, scale of anchor projects, required sizing of the pipeline/s, and attractiveness of storage strategies (including temporary for operational purposes and permanent);
- the timely construction of the associated infrastructure; and
- optimal and sequential connection of CO_2 sources to the network over time.

The following chart (Diagram 13) illustrates the potential legal complexity of contractual arrangements and linkages needing to underpin the financing, construction and operation of a CO_2 network. Although the original diagram was drafted to illustrate a specific project, this diagram has been adapted to indicate more generic relationships.

DIAGRAM 13 – Interaction of actors and legal arrangements



Source: Pershad, H (May 2011): Pipelines International Digest – Economics of an integrated CCS pipeline network in the Tees Valley, UK, p. 7

Clearly there are many possible actors critical to CO_2 distribution network investments, including:

- the public sector (such as regulators, government engagement and support programs);
- the financial sector (i.e. lenders and insurers);
- technology manufacturers; engineering service providers (including skilled labour);
- off-take arrangements (for CO_2 suppliers and takers, such as EOR and storage operators); and
- network operators.

CHAPTER FIVE

REGULATORY

Context

As indicated previously, existing worldwide experience in CO_2 pipelines is relatively limited outside of the US, Canada and Norway. As such, the associated legal and regulatory frameworks for dense phase CO_2 pipelines tend to be fairly nascent.

Despite most of the prevailing experience of constructing and operating CO_2 pipelines residing in North America, there are no definitive national legal or regulatory frameworks established for CO_2 pipeline siting or rate regulations. There have however been well established safety regulations in the US for transporting CO_2 by pipeline in a supercritical state since 1991.

As the demand for CO_2 transport services expands in line with increasing multiple sources of CO_2, pipeline configurations will necessarily become more complex as they are required to service more remote storage sites (involving transboundary transport, interconnections, and potential surges in CO_2 supply).

As mentioned, if carbon constraints tighten over time within a jurisdiction, it could be expected that pipeline routing may need to increasingly encroach on more densely populated areas (and cross borders) as smaller CO_2 sources are linked to less economically attractive storage facilities. This may further complicate pipeline siting and routing approvals as regional concerns are more actively voiced by potentially affected populations, as well as serving to increase land acquisition costs as relative land values rise the closer they are to urban centres.

It is often useful to refer to other similar industrial applications for guidance in the development of future regulatory conditions for CO_2 pipelines. The obvious analogue for CO_2 pipelines is natural gas regulatory systems, given that the technology, scope, operation, commercial structure, and regulatory frameworks that characterise natural gas pipelines are similar.

There are however key points of differentiation between CO_2 pipeline operations and natural gas pipeline operations in that the latter transports a valuable commodity from its production point to its highest valued consumer market whereas the former for permanent storage purposes effectively transports a costly industrial waste stream to a point of disposal. This is not the case for EOR purposes where CO_2 represents a valuable commodity.

Other major differences in design are that CO_2 pipelines tend to: operate at higher operational pressures; be constructed with thicker pipes; need CO_2 resistant elastomers around the valves and other fittings, as well as fracture arrestors to reduce fracture propagation (which is more likely in CO_2 pipelines due to slower decompression characteristics); and are designed to move supercritical fluids.[49]

United States experience

Nearly all oil pipelines in the US operate as common carriers. Regulatory oversight of the construction and operational safety of CO_2 pipelines falls under the jurisdiction of the Pipeline and Hazardous Materials Safety Administration (PHMSA) in the Department of Transportation. Section 195 of the Hazardous Materials Regulations governs the transport of CO_2 via pipelines including reporting requirements.

Section 195.4 states: *no person may transport ... carbon dioxide unless* ...[it] *is chemically compatible with both the pipeline, including all components, and any other commodity that it may come into contact with while in the pipeline*.

The FERC also provides regulatory oversight of oil and natural gas pipelines. Except for the PHMSA, there is no national regulatory system for the industry. CO_2 pipeline siting and operating issues largely falls to state authorities or federal land management agencies as appropriate such as the Surface Transportation Board (STB). Once the pipelines branch off to individual wells however, they cease to fall under the scope of the safety regulations.[50] Attachment 2 outlines the US regulatory framework as it currently applies to oil, natural gas and CO_2 pipelines.

Both CO_2 and oil pipeline operators may take pipelines out of service (i.e. leave the market) for economic reasons without federal approval, but natural gas pipelines must secure federal approval before ceasing operations. There is also a federal requirement to demonstrate that the construction of a new natural gas pipeline is in the public interest, however this does not apply to oil or CO_2. Unlike oil and natural gas pipelines, CO_2 pipelines do not have publicly advertised tariffs either.

CO_2 pipelines for EOR purposes may offer limited insight into CO_2 leakage events as they tend to be located in fairly sparsely populated areas and relatively flat open countryside.

Regulatory considerations

The main regulatory considerations for CO_2 pipelines include:

- legal definition of CO_2 (classification as a waste or a commodity);
- regulatory efficiency and clarity – especially in regards to permitting arrangements and health and safety guidelines and procedures;
- quality of the CO_2 stream to be transported;
- CO_2 ownership and liability for localised impacts (e.g. effects on ground water, nuisance or harm, trespass etc):
  - CO_2 pipelines are considered to be relatively mature technologies and are only required to hold CO_2 streams for relatively short periods of time (with CO_2 ownership transferring once CO_2 leaves the pipeline) – this suggests that long term liability and technical performance are not generally considered to be highly problematic.
- basis for and publication of tariff rates;
- third party access rights:
  - common carriage CO_2 pipeline operators are legally obliged to accommodate all new entrants without discrimination and this sometimes requires network capacity to be rationed across all CO_2 capture facilities and/or CO_2 shippers to pay for any incremental expansion to network capacity if needed; and
  - such operators need to clarify with authorities that arrangements for third party access (incumbent and new users) are transparent and non-discriminatory.
- pipeline siting and routing (including property rights – easements, ownership etc);
- dispute resolution:
  - especially under common carriage where allocations to the existing pipeline capacity may be rationed downwards to accommodate new entrants and incumbents have a low capacity to accept such decisions.
- risk assessments:
  - the associated risk events for CO_2 pipelines generally includes damage (vandalism etc), corrosion, or leaks/blowouts (however these are considered reasonably rare events);
  - there is the potential for supercritical CO_2 to change phase as the pressure reduces, leading to a sudden temperature change – this could cause the CO_2 to solidify as it escapes and fall as a CO_2 snow potentially endangering oxygen breathing organisms (CO_2 is heavier than air, and can accumulate in low lying areas if ventilation is poor – this may have adverse health effects at concentrations above 10 per cent by volume) and/or creating stresses on the pipeline; and
  - a range of tools exists to ensure the safe operation of a pipeline, including: fracture arrestors, block valves to isolate pipe sections that are leaking, the use of high durometer elastomer seals, and automatic control systems that monitor volumetric flow rates and pressure fluctuations.[51]
- monitoring, measurement and verification (including CO_2 accounting protocols);
- transboundary movement;
- re-use existing pipelines:
  - in a niche number of cases, an existing pipeline may have both an appropriate capacity and location to connect source to sink – this may reduce the time and costs to deploy CCS; and
  - it may be possible to re-use existing natural gas pipelines for transporting CO_2, providing that pipeline integrity can be established and use with CO_2 meets appropriate design codes (i.e. operating pressures, materials performance, rights of way, and compatibility of minor components such as valves and O-rings).

- public engagement and consultation (i.e. obligations contained in planning laws).

Regulatory efficiency and clarity

National regulatory regimes for CO_2 pipelines may help to enhance clarity over the necessary regulatory oversight applicable to new CO_2 pipeline developments. Current US experience seems to indicate however that there is no evidence of market power abuse in the prevailing CO_2 driven EOR environment – transactions take place regularly and parties do not appear to be unduly litigious, and as consequence there has been little to no need to pursue broader economic regulation. But as motivation for transporting CO_2 shifts from EOR purposes to more storage purposes, potential market power issues are expected to arise. For instance, after off-take agreements conclude (i.e. a contract whereby the owner of CO_2 sells to a buyer) that may have initially supported the financing of the pipeline construction, a pipeline operator may be in a position to exercise market power to extract monopoly rents (i.e. to obtain value in excess of costs) from CO_2 sources.

A drive for national regulations to underpin CO_2 pipelines might ensure a timely and adequately scoped pipeline system that can be designed to meet national emission reduction policy objectives and/or CCS developments over time. This would require a high degree of harmonisation of both sub-national and national regulations and oversight (as is strived for by way of example in Australia through its Council of Australian Governments process), and as experienced in natural gas pipelines.

A more centralised (i.e. national) review and approval process for CO_2 pipelines may help lessen concerns of public acceptability (by ensuring nationally consistent permitting approaches especially to do with safety and environmental performance) and further facilitate implementation of national policy (i.e. deployment of CCS) by addressing barriers to entry, production controls, and containing consumer price increases.

The regulatory framework governing a national CO_2 pipeline infrastructure could however require a fundamentally different regulatory regime to that currently prevailing for EOR given the magnitude of the CO_2 requiring to be stored as a result of national and/or sub-national climate change policies.

The need for future national regulation may be expected to arise under conditions very different from today's EOR based applications. For example, conditions could require CO_2 pipeline infrastructure to be established to reliably facilitate national and international emission reduction commitments. If so, regulatory arrangements may need to ensure that pipelines that are initially oversized can be fully utilised in an efficient manner.

Although regulatory compliance costs tend to be insignificant when compared to operational and maintenance costs, they are often not easily distinguishable from other costs including safety, maintenance, and operations. The CO_2 pipeline industry might take note of compliance costs if they were to escalate as a result of duplicate reporting requirements or mandates that compliance standards exceed best practice standards.[52]

The quality of the CO_2 stream to be transported

A high quality stream of CO_2 can present fewer technical challenges to transportation processes than does a less pure stream (depending on the nature of the impurities, as nitrogen tends to present as much less of an issue than H_2 or H_2O). There can also be cost savings with a more pure stream of CO_2 as less compression and energy is needed to transport the CO_2 through the pipeline.

While the conditions for CO_2 carriage can be well articulated in individual contracts struck between the CO_2 point source and the pipeline owner (i.e. stipulating no unwanted elements or gases in the CO_2 stream), it is important that the CO_2 be of sufficient purity and quality so as to not compromise the safety and efficiency of the pipeline and/or the injection wells and storage reservoirs.

It also seems sensible that limits be established on the amount of water permitted in the CO_2 stream (or compounds that can chemically form water by reaction of different impurities such as oxygen reacting with reduced sulphur species to form water and solid sulphur) and subsequently allowed to enter the pipeline. Excessive amounts of water in the CO_2 stream can produce carbonic acid, risking corrosion of pipeline materials. It may prove less costly to dry (i.e. dewater) the CO_2 stream prior to transporting rather than build a pipeline with more corrosive resistant steel or liners.

Water in the CO_2 stream can be produced by:

- the combustion of fossil fuels in air or oxygen;
- heating of a solvent; or

- from industrial processes that produce CO_2.

While there are a number of drying technologies and processes that can be employed, there seems to be little general consensus on what an upper limit of water should be. Impurities in the CO_2 stream can further change the associated drying requirements and costs.

CO_2 pipelines in the US are currently not regulated in terms of either the purity or water content of the associated CO_2 stream.

Other important considerations for the CO_2 stream is the avoidance of nitrogen and methane concentrations that may preclude CO_2 reaching an operational dense phase. Also, high oxygen concentrations can lead to microbial related corrosion of both forged iron and steel. Oxygen can also lead to chemical reactions that affect the injection process and/or encourage aerobic bacterial growth in the geologic formation.

A strong development path for CO_2 pipelines could depend on CO_2 being classed as a ‘commodity’ that can be safely transported and stored without significant risks, rather than a ‘hazardous material’.[53]

In the US, CO_2 is not considered under prevailing regulations as a hazardous liquid, which covers design, pipe, valves, fittings, flange connections, welding, breakout tanks, leak detection, inspection, pumps, and compressors.

The classification of CO_2 as a hazardous matter or a pollutant could lead to greater regulatory oversight of related permitting requirements and safety inspections, compared to a classification of CO_2 as a commodity. This may add cost to CCS projects, as well as create a perception among communities that CCS projects should be looked upon relatively less favourably than they currently are.

The imposition of nationally uniform quality specifications for CO_2 composition in pipelines could impose cost premiums to CO_2 capture plants in terms of both capital investments required and operating costs. Such uniform quality specifications may however be necessary to help promote a national CO_2 pipeline infrastructure.

Basis for and publication of tariff rates

Tariffs are documents filed by the pipeline carriers with regulatory agencies detailing their terms and conditions of service and associated prices for various classes of customers. Tariffs regulating CO_2 pipelines may require the pipeline carriers to provide terms of their contract and rates. These regulations may also mandate that carriers provide such information in case of any regulatory dispute.

Public notice regulations involve making pipeline information publicly available when operators file or change tariffs, routes, or other pipeline characteristics. It may cover all rules and regulations governing the rates and charges for services in a clear, complete, and specific format.

While new connection services for transporting oil in the US are negotiated on a cost of service basis (i.e. price is based on the costs incurred to service a customer or as an average cost for a group of similar customers), natural gas pipelines can apply for negotiated rates (where terms are negotiated individually between the pipeline and the customer) or a regulated cost based rate. The approach taken for natural gas limits the potential for pipeline monopoly rents.

It is noted that regulated rates based on cost of service and/or authorised rates of return may not provide sufficient incentives to the private sector to undertake pipeline investment due to the risks inherent in such a nascent industry as CO_2 pipelines for storage purposes.[54]

Regardless of whether CO_2 pipelines are price regulated or not, the costs in the early stage will likely be able to be recovered by developers from contractual arrangements (i.e. charging negotiated rates using the levelised costs of pipelines as a guide and/or relying on market determined rates that approximate the marginal costs) with a sufficient number of customers.

As such, CO_2 pipeline operators could offer CO_2 shipping customers market based prices for their services at a negotiated transportation fee. This approach seems to better suit the development of early pipelines, especially where the CO_2 being transported is intended for EOR purposes.

Such an approach can create problems of market power as more CO_2 shippers seek the service of existing pipelines, and where pipeline operators have the bargaining advantage.

One remedy might be to have a system of maximum tariff rates; or a complaint process with regulatory review as is done with many intrastate pipelines and oil pipelines.[55]

In the US, the economic regulation of the terms and conditions of CO_2 pipelines service offerings (including rates and conditions of access) typically falls to sub-national governments unless they traverse federal lands. Currently, CO_2 pipelines are not required by national regulation to publish tariffs or any other information.

One issue that can significantly affect the economy of CO_2 pipelines is whether the construction and operational costs can be included in the electricity tariffs for regulated electric utilities. Because utility regulations tend to vary from jurisdiction to jurisdiction (say in the US, Australia etc), differences in the economic regulation of utilities can create economic inefficiencies that affect the attractiveness of investment in CO_2 pipelines.[56]

Pipeline siting and routing

Regulation of pipeline siting involves the notice and/or approval of the regulatory agency prior to construction of the pipelines. The rules for siting regulation primarily establish procedures for obtaining access to a pipeline corridor, and can involve national and sub-national jurisdiction, and/or pipeline operator discretion.

The factors affecting pipeline routing can include:

- the geography and geology along the route linking CO_2 point sources to sinks;
- rights of way (ROW) approvals and costs;
- the proximity of pipelines to population centres (including social preferences); and
- the ability to locate booster stations along the route.

A major objective of regulation for siting and routing is to provide for public engagement and participation in the permitting processes (there is a likelihood that public opposition to pipeline transport – not uniquely CO_2 related – could be high), as well as ensure that there are adequate environmental and land use review/s and assessments.

The expected growing demands on and for CO_2 pipeline networks over time may inevitably require installations to cross both sparsely and densely populated areas, as well as link multiple anthropogenic sources of CO_2 over longer distances to increasingly remote storage sites. It is estimated that globally about one third of the total pipelines required will need to be laid offshore.[57]

The ISO categorises five classes of locations for pipelines, varying from the very isolated from populations and human activities to within locations of urban buildings and heavy traffic (including above and below ground utilities).[58]

The extent to which any sort of industrial infrastructure activity is located within close proximity to population centres will have inevitable implications for local community acceptability of such proposed infrastructure – and this is equally true for CO_2 pipelines. Public scrutiny will likely focus on the safeguards needed to ensure that the design is safe for both above and/or below ground installations; that there is provision of adequate and appropriate levels of signage; and that owners can appropriately provide for and/or protect the assets from intentional and/or unintentional third party activity.

There are roles for both sub-national and national regulatory authorities in designating pipeline corridors (i.e. especially if it is considered a national interest corridor). As such, a well harmonised approach to routing and siting decisions and environmental impact assessments is important to avoid costly duplication and lengthy administrative delays.[59]

The siting of new CO_2 pipelines in the US is not regulated by any federal agency, and is predominantly the subject of sub-national regulations.[60] The concept of an ‘eminent domain’ provides for a sovereign power to seize private property without the owner’s consent in exchange for just compensation.

In the US, under the power of an eminent domain, a pipeline corporation can be given the right to acquire the property necessary for the construction of the pipeline. Some jurisdictions grant eminent domain power unconditionally and/or upon certain conditions. For example, Texas grants the right and power of eminent domain to pipelines that elect common carrier status for the transportation of CO_2. Other states grant the power without imposing common carrier status.

Cross-border CO_2 transport (transboundary) issues

Intrastate pipeline networks (i.e. contained within a single jurisdiction) could reasonably be expected to be regulated by appropriate jurisdictional authorities (especially if national and sub-national regulations are equally as stringent). Interstate pipeline networks (traversing more than one border) may better lend themselves for efficiency and administrative reasons to being regulated by an appropriate national authority (such as the PHMSA for pipelines safety in the US).

International treaties and subsequent rules of inclusion can also affect the scope for transboundary movements of CO_2 such as (among others): CDM (refer to previous discussion); the Basel Convention; and the London Convention and Protocol.

The EC's CCS Directive has removed the Basel Convention requirements for shipment of CO_2 within and between EU member states by disapplying the Transfrontier Shipment of Waste Regulation. The London Convention and Protocol poses a legal barrier to the transboundary movement of CO_2 where it is to be stored in geological formations under the sub-seabed. Similarly, the Bamako Convention on the ban on the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa may also pose a barrier to the transboundary movement of CO_2 within and out of Africa.

While the proposed amendment to the Protocol attempts to ensure that it does not act as an impediment to cross border CO_2 projects, it still needs to enter into legal force – currently too few Parties have ratified the amendment for it to enter into force. This issue is pertinent for many regions, including the North Sea, Irish Sea, Mediterranean Sea, Black Sea, Caspian Sea, Persian Gulf, Gulf of Mexico, South East Asia, West Africa, and for the coasts of India, China, Australia, Japan, and Brazil where there is significant potential for sub-seabed storage. The ratification of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) amendment is also needed to ensure projects can go ahead in the North East Atlantic zone.

It is clear that CO_2 pipelines must be constructed with due regard for protection of human health, society and the environment. In developed countries, these will likely be determined by national and regional planning requirements. In the case of developing countries, these may take the form of proxy regulations as imposed by international lenders. In all cases, approvals need to strike a balance between the need to protect people and the environment, and the need to provide for a timely deployment of large-scale CCS projects to mitigate the potential impacts of climate change.

CHAPTER SIX

CONCLUDING OBSERVATIONS

Context

A CO_2 distribution network is a major component of an integrated CCS system. A cost effective development of an integrated CCS project will depend on the optimal design of all CCS components including capture; transport and storage.

Much of the publicly available literature concurs that pipelines will be the most likely option used for transporting the gigatonnes of CO_2 that will potentially be required to be captured and stored in the decades to come. It is often presumed that pipelines are a technologically mature and relatively low cost component, and as such, not a material barrier to the wide-scale deployment of CCS.

Unlike the technical and cost challenges of CO_2 capture and the geological information and regulatory requirements of storage, CO_2 distribution networks tend to face more logistical challenges but are still heavily reliant on financial, political and social factors.

While the re-use of CO_2 is currently the main economic driver of CCS, it is unlikely to be singularly sufficient to encourage investors to finance CCS projects, and so other complementary measures are likely to be required. The future development of CO_2 pipelines for storage purposes will be driven largely by legally enforceable emission constraints (and associated prices of carbon), as opposed to current CO_2 pipelines that are more driven by commercially attractive commercial re-uses (such as EOR).

At this time there is significantly less industry experience available in CO_2 pipeline design and operation for the purpose of permanent geological storage application than there is in hydrocarbon (oil and gas) pipeline operations. Outside of the US, Canada and Norway, existing worldwide experiences in CO_2 pipelines are relatively limited.

A lack of CCS operational experience, an absence of sufficient and long-term carbon pricing regimes, regulatory drivers, and uncertainties surrounding locations, capacities and timing of CO_2 sources and sinks will continue to delay the commercial development of large scale CO_2 pipelines. The corollary to this is that it may be unlikely that national CO_2 pipeline networks will be needed imminently, allowing for a gradual expansion of related infrastructure over time as allowable levels of CO_2 emissions tighten.

It seems however that is not a simple matter of applying the engineering and scientific understandings of natural gas pipelines or CO_2 pipelines for EOR to CO_2 pipelines for permanent storage, nor is it evident that market structures will necessarily evolve similarly. For example, about 85 per cent of the CO_2 used in the US for EOR is sourced naturally which tends to present a purer stream of CO_2 – making the transport of CO_2 easier to provide for.

In locations where the case for pursuing an integrated pipeline infrastructure remains uncertain, developments will likely proceed in a stepwise fashion – this allows developers to gain experience from smaller scale point-to-point pipelines prior to considering more costly nationally and (potentially) internationally integrated systems capable of linking multiple CO_2 sources and sinks.

In locations where high uncertainty prevails over future CO_2 supply and/or storage sites, and/or carbon pricing policies, point-to-point networks may well be a preferred option that can help reduce the risk of potentially stranding assets. This approach may well be supplemented by ensuring that rights-of-way can be reserved to allow for future multiple pipelines along the same route. This can reduce the planning and consenting risks and timescales for subsequent projects without excessive up-front investment.

Analysis indicates that larger capacity pipelines tend to have lower costs per unit shipped than smaller pipelines when compared under similar ownership structures. Consequently, the development of a nationally integrated oversized CO_2 pipeline may also influence the locations of future CO_2 capture facilities and storage sites depending on the nature of the benefits of economies of scale realised (i.e. ensuring full utilisation of the pipeline capacity in an efficient manner).

The factors driving the cost of building and operating CO_2 pipelines are well understood by pipeline developers. Costs can vary enormously from project to project, depending upon the terrain traversed, international markets for steel, pipe and other facilities, the local market for contractors, and the diameter of pipes to mention just a few variables.

The IEA summarise well the policy issues associated with CO_2 pipelines, stating that CCS deployment may be affected by a lack of certainty about the provision of transport infrastructure, and the natural monopolies in transport could create a tendency to under-provide services.

Wherever possible, the potential to establish competitive markets in CO_2 pipeline investment should be pursued. Where this potential does not exist, collaboration among and/or negotiation between markets participants could be encouraged ahead of promoting vertical integration. Where vertical integration emerges as an effective approach to reducing the associated risks of a CO_2 pipeline, the potential to give effect to a competitive structure at some future stage should also be provided for.

While good arguments exist for a lesser role of government in the early phases of CO_2 pipeline development, especially where EOR projects dominate, the importance of government engagement will increase as more pipelines are constructed and regulations become necessary for pipeline siting, 3rd party access, and environmental performance (and the like).

It is clear that onerous or inappropriate regulations can provide a significant hurdle to private investment in CO_2 pipeline infrastructure. Although this is one area that is demanding of further clarification, areas of important regulatory oversight include:

- safety (i.e. taking account of special physical characteristics of dense phase CO_2 to ensure HSE considerations are completely identified and included);
- siting;
- tariff setting or fee structures;
- third party access; and
- the decommissioning of pipelines.

For example, a major regulatory challenge for CO_2 pipelines could be the uncertainty surrounding the classification of dense phase CO_2 and CO_2 streams with impurities from the capture processes. It does not seem necessary however to establish completely new designs, construction, permitting or safety regimes for CO_2 pipelines, as these conditions can be addressed in comparable ways to requirements already specified for existing hydrocarbon pipelines.

There are no known accredited private, national or international standards specific to the integrated CCS chain, but there is a growing body of technical standards for pipelines, both directly and indirectly applicable to CO_2 operations. Adherence to internationally agreed, fit-for-purpose, and voluntary standards could also help serve to present CO_2 pipeline projects to be more publicly acceptable, as well as guide both regulators and operators alike to minimise any burdens associated with securing permitting approvals, siting characterisation, construction and operationalisation of new CO_2 pipelines.

An important consideration for transporting the CO_2 between capture source and storage facility is the specification of the CO_2 stream. The CO_2 stream needs to have a high degree of consistency across the CCS chain, as the quality of CO_2 captured, which will inevitably differ according to whether or not the CO_2 has been captured within an oxidative capture environment such as a post-combustion process or a reductive capture environment such as pre-combustion process), will impact on the performance (cost and operational) of pipelines.

A renewed effort by the international community to further facilitate resolutions that allow for the transboundary movement of CO_2 especially in regards to the CDM and the signatories to the London Convention will also be highly beneficial for CCS and CO_2 pipeline developments in both developed and developing countries.

ATTACHMENT 1 – Major North American CO_2 pipelines[61]

PIPELINE	Owner/Operator	Length (mi)	Length (km)	Diameter (in)	Estimated Max Flow Capacity (MMcfpd)	Estimated Max Flow Capacity (million tons/yr)	Location
Adair	Apache	15	24	4	47	1.0	TX
Anton Irish	Oxy	40	64	8	77	1.6	TX
Beaver Creek	Devon	85	137				WY
Borger, TX to Camrick, OK	Chaparral Energy	86	138	4	47	1.0	TX, OK
Bravo	Oxy Permian	218	351	20	331	7.0	NM, TX
Centerline	Kinder Morgan	113	182	16	204	4.3	TX
Central Basin	Kinder Morgan	143	230	16	204	4.3	TX
Chaparral	Chaparral Energy	23	37	6	60	1.3	OK
Choctaw (aka NEJD)	Denbury Onshore, LLC	183	294	20	331	7.0	MS, LA
Comanche Creek (currently inactive)	PetroSource	120	193	6	60	1.3	TX
Cordona Lake	XTO	7	11	6	60	1.3	TX
Cortez	Kinder Morgan	502	808	30	1117	23.6	TX
Delta	Denbury Onshore, LLC	108	174	24	538	11.4	MS, LA
Dollarhide	Chevron	23	37	8	77	1.6	TX
El Mar	Kinder Morgan	35	56	6	60	1.3	TX
Enid-Purdy (Central Oklahoma)	Merit	117	188	8	77	1.6	OK
Este I to Welch, TX	ExxonMobil, et al	40	64	14	160	3.4	TX
Este II to Salt Creek Field	ExxonMobil	45	72	12	125	2.6	TX
Ford	Kinder Morgan	12	19	4	47	1.0	TX
Free State	Denbury Onshore, LLC	86	138	20	331	7.0	MS
Green Line I	Denbury Green Pipeline LLC	274	441	24	850	18.0	LA
Joffre Viking	Penn West Petroleum, Ltd	8	13	6	60	1.3	Alberta
Llaro	Trinity CO_2	53	85	12-8	77	1.6	NM
Lost Soldier/Werrz	Merit	29	47				WY
Mabee Lateral	Chevron	18	29	10	98	2.1	TX
McElmo Creek	Kinder Morgan	40	64	8	77	1.6	CO, UT
Means	ExxonMobil	35	56	12	125	2.6	TX
Monell	Anadarko			8	77	1.6	WY
North Ward Estes	Whiting	26	42	12	125	2.6	TX
North Cowden	Oxy Permian	8	13	8	77	1.6	TX
Pecos County	Kinder Morgan	26	42	8	77	1.6	TX
Powder River Basin CO_2 PL	Anadarko	125	201	16	204	4.3	WY
Raven Ridge	Chevron	160	257	16	204	4.3	WY, CO
Rosebud	Hess						NM
Sheep Mountain	Oxy Permian	408	656	24	538	11.4	TX
Shute Creek	ExxonMobil	30	48	30	1117	23.6	WY
Slaughter	Oxy Permian	35	56	12	125	2.6	TX
Sonat (reconditioned natural gas)	Denbury Onshore, LLC	50	80	18	150	3.2	MS
TransPetco	TransPetco	110	177	8	77	1.6	TX, OK
W. Texas	Trinity CO_2	60	97	12-8	77	1.6	TX, NM
Wellman	PetroSource	26	42	6	60	1.3	TX
White Frost	Core Energy, LLC	11	18	6	60	1.3	MI
Wyoming CO_2	ExxonMobil	112	180	20-16	204	4.3	WY
Canyon Reef Carriers	Kinder Morgan	139	224	16	204	4.3	TX
Dakota Gasification (Souris Valley)	Dakota Gasification	204	328	14-12	125	2.6	ND, Sask
Pikes Peak	SandRidge	40	64	8	77	1.6	TX
Val Verde	SandRidge	83	134	10	98	2.1	TX
	Totals:	4,111	6,611				

Note: Great Plains Pipeline to Weburn-Midale is denoted as Dakota Gasification (Souris Valley).

ATTACHMENT 2 – Regulatory framework: Oil, Natural Gas, and CO_2 pipelines[62]

Element	Oil Pipelines	Natural Gas Pipelines	CO_2 Pipelines
Rates Regulation Authority (Interstate)	FERC	FERC	None (Possibly STB)
Regulatory Regime	Common Carriage	Common Carriage / Contract Carriage	Private, Contract or Common Carriage
Ownership of Commodity	Mostly third-party ownership	Mandated that interstate pipelines only transports gas owned by others.	Common for CO_2 owned by pipeline owner / third-party
Tariffs / On-going regulatory oversight	Yes - rates are approved by FERC and increase indexed to PPI +/- an increment	Yes - Rates are periodically set by rate cases before FERC	No - STB would only look at rates if a dispute is brought before it.
Rate disputes	Every five years the increment to PPI is modified.	Rare for disputes outside of rate cases. However they can be brought before FERC	Uncommon due to ownership relationships and prearranged deals
Siting	State and local governments	FERC	State and local governments
Safety	PHMSA	PHMSA	PHMSA
Market Entry and Exit	Unregulated entry and exit	Need approval for both entry (construction) and exit (abandonment)	Unregulated entry and exit
Product Quality	"Batch" modes transport different products at different times.	Specifications individually set in tariff approved by FERC	No Federal Regulations*
Posting information	Tariff information is available on-line	Daily operational and tariff information is available on-line	None Required
Eminent Domain	Yes - Varies by state. More often if pipeline is a common carrier.	Yes	Varies by State Law

PPI = Producer Price Index

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