Carbon Capture, Utilisation and Storage – What are the Real Challenges & Costs?

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1 ABSTRACT

The requirement for efficient and long-term Carbon Capture, Utilisation and Storage (CCUS) facilities is well understood and a number of countries and operators are leading the way in deploying CCUS technology as a medium-term instrument to decarbonise energy supplies and industrial processes. CCUS offers the opportunity for Net Zero fast-wins across a range of industries and indeed, some contributors may view CCUS as a new revenue stream for the 21st Century. [1]

This paper will draw upon several recent CCUS projects that have been successfully completed within the UK and globally. It will look at costs, economics and the technical challenges associated with each step in the CCUS value chain: capture, transportation and handling, facilities and processing, subsurface injection and storage.

Capture – CCUS typically traps CO_2 at much lower concentrations and pressures than those found in conventional Acid Gas Removal Units (AGRU). This requires new approaches and demands new technical solutions to ensure that the economic justification is robust.

Transportation & Handling - It may seem obvious, but CO_2 does not behave like natural gas or hydrogen, and the options for transportation via pipeline are different. Designers and operators may elect to move CO_2 as refrigerated liquid, ambient-temperature gas or super-critical dense-phase fluid. Each choice has technical challenges and commercial advantages; depending on the location, route and surrounding infrastructure. Densely populated areas need to be navigated with extreme diligence. Onshore, offshore and near-shore pipelines have special considerations and different cost profiles. Export via road tanker, rail or shipping is possible for operations far from sequestration sites, but these possibilities have limitations.

Facilities & Processing - Industrial-scale CCUS processing is a relatively new industry, so design errors can occur, and these are often expensive and time-consuming to correct. The counterpoint to this is that design and operational risks can be overstated, and the CO2 processing facility design becomes too conservative. Capital costs increase and the economic justification for the project is weakened.

Subsurface Injection and Storage – Enhanced Oil Recovery (EOR) and long-term disposal/sequestration are both options [2]. A risk to projects that cover the value chain is that design subtly and expectation can be lost at the interfaces. The impact of impurities and contaminants can be overlooked, and abnormal operation discounted, this is especially true for CCUS, with many owners expecting to store waste CO_2 permanently.

Scalability – Recent CCUS projects have ranged from experimental scientific programmes that demonstrate proof of concept to world-scale National Oil Company (NOC) projects supported by licensor technology. The technical and economic similarities and differences across the range and scale of these projects can often be surprising and insightful. This paper will present the CAPEX and OPEX comparisons at

different plant capacities, reflecting the technology selection choices made at differing plant scales.

2 SCOPE

The scope of this paper and presentation will cover four carbon capture and utilisation projects that have recently been executed by Penspen on behalf of their clients. Penspen was involved in these projects during the design stages. Costs are presented later within this paper and for that reason of commercial confidentiality, the projects reported here have been anonymised. A summary of these projects is detailed below.

- Project 1 - A Near-shore CO_2 processing and injection test facility located in Northern Europe
- Project 2 - An onshore CO_2 processing and injection test facility located in Northern Europe
- Project 3 – An onshore CO_2 transport pipeline located in Northern Europe
- Project 4 – An onshore CCUS processing, export and injection facility located in the Middle East.

The capacities for these projects ranged from 50,000 tonnes/year processing capacity up to 7,000,000 tonnes/year. This represents a significant variation in scale, from test plant to a world-scale CCUS facility. This paper should provide summary of some of the technical challenges and commercial insights that have been learnt from executing four CCUS projects at a variety of scales.

2.1 PROJECT 1 - A NEAR-SHORE CO_2 PROCESSING & INJECTION TEST FACILITY LOCATED IN NORTHERN EUROPE

Project 1 was a cost and concept study for a permanently manned injection facility. The plant was designed to import liquid CO_2 via road tanker at 21 bara and -18°C, storing up to 2 weeks of inventory in refrigerated storage vessels. Import of Liquid CO_2 by road tanker presented a significant logistical challenge. The facility is designed to import approximately 1000 tonnes a week of inventory, the equivalent of up to 8 road tankers per day, potentially an almost continuous offloading operating, requiring a large team of drivers and staff to co-ordinate and implement.

CO_2 export was via an onshore pipeline to the shore and then an offshore pipeline to subsea wellhead injection. The export and injection facilities operated in dense-phase at around 80 bar. A schematic of the configuration is presented here.

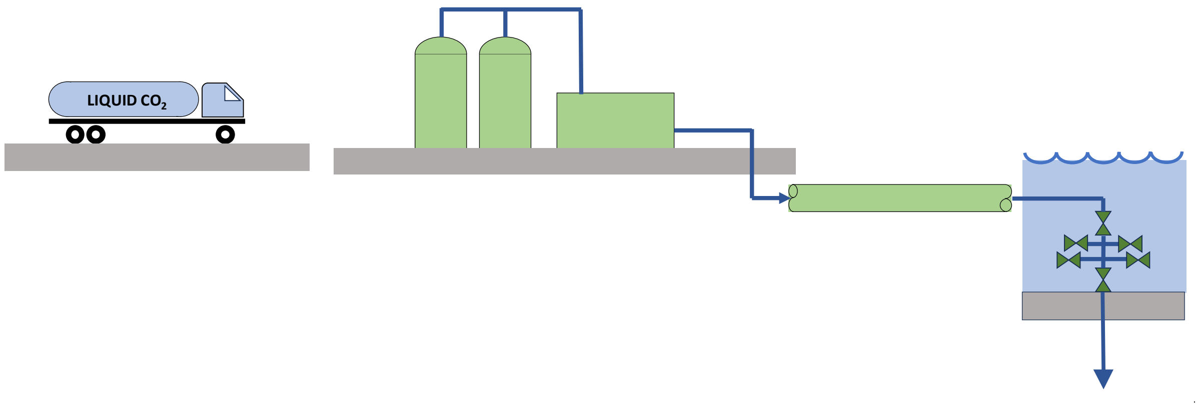

Figure 1 Schematic Diagram of Project 1

A Near-Shore CO_2 Processing & Injection Test Facility Located in Northern Europe

2.2 PROJECT 2 - AN ONSHORE CO_2 PROCESSING & INJECTION TEST FACILITY LOCATED IN NORTHERN EUROPE

Project 2 was similar to Project 1 - a cost and concept study for a permanently manned injection facility. The plant was designed to import dense phase CO_2 via an onshore buried pipeline. The source of the CO_2 feedstock was an industrial facility located several kilometres aways from the test facility. Design processing capacity for this test facility was 50,000 tonnes per year.

CO_2 export and disposal were via an onshore pipeline to an onshore injection wellhead. The export and injection facilities operated in the dense-phase at around 80 bar. A schematic of the configuration is presented here.

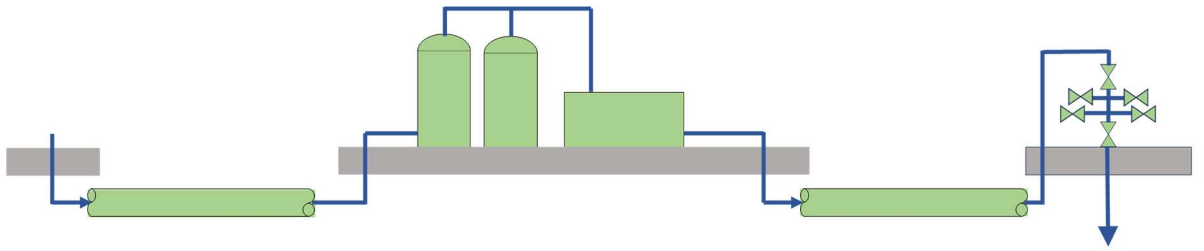

Figure 2 Schematic Diagram of Project 2

An Onshore CO_2 Processing & Injection Test Facility Located in Northern Europe

2.3 PROJECT 3 – AN ONSHORE CO_2 TRANSPORT PIPELINE LOCATED IN NORTHERN EUROPE

Project 3 was a pre-FEED pipeline routing and feasibility study for the transport of up to 7,000,000 tonnes per year of dense phase CO_2. The overall length of the pipeline routing was ~50km, and the operating pressure of the pipeline was ~ 110 bar. The pipeline connected an industrial supplier of dense-phase CO_2 to a near-shore export facility. The pipeline routing passed through an industrial zone and negotiated around a national park. A schematic of the configuration is presented here.

Figure 3 Schematic Diagram of Project 3

An Onshore CO_2 Transport Pipeline located in Northern Europe

2.4 PROJECT 4 – AN ONSHORE CCUS PROCESSING, EXPORT & INJECTION FACILITY LOCATED IN THE MIDDLE EAST.

Project 4 was a FEED project for a brownfield CO_2 capture plant; the facility processed 2,500,000 tonnes per year of low-pressure CO_2 captured from a range of process units operating across the facility. The CCUS facility was retrofitted into the existing complex. The export facility consisted of an export compression and dehydration system, a high-pressure CO_2 transmission network, and dense phase injection at ~140 bar. A schematic of the configuration is presented here.

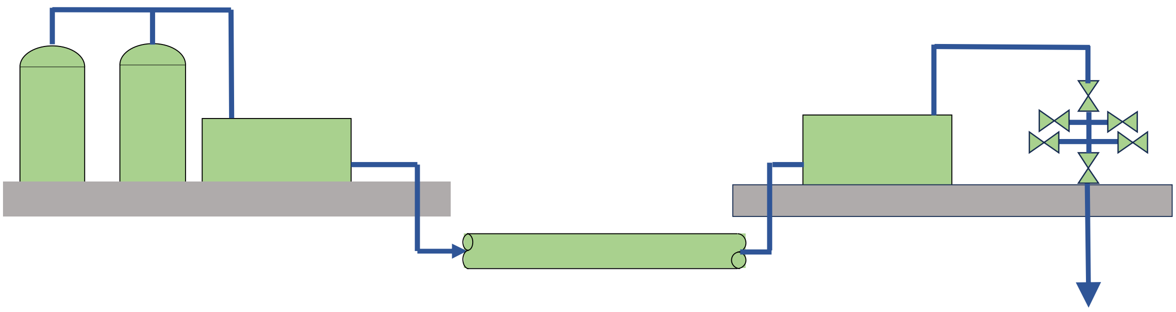

Figure 4 Schematic Diagram of Project 4

An Onshore CCUS Processing, Export & Injection Facilities located in the Middle East.

3 CO_2 Physical Chemistry and Thermodynamic Properties

The physical chemistry and thermodynamic properties of CO_2 are significantly different from those of Natural Gas. Sufficient attention needs to be applied when designing systems that process pure CO_2, even greater attention needs to be applied when designing systems that process CO_2 contaminated with small amounts of other compounds, since these can significantly alter the behaviour of the gas, discussed in more detail below. Figure 5 below shows a Phase Diagram for pure CO_2, for CCUS system there exist two acceptable operating zones:

- Low Pressure Gaseous CO_2 below 30 bar and above -10°C.
- Dense Phase Super Critical CO_2 above 80 bar and above -50°C.

Operating outside these zones risks processing a condensing gas, or boiling liquid, as the CO_2 crosses the vapour liquid equilibrium line. Managing a boiling liquid or a condensing gas through a processing facility is always problematic, the physical properties of the fluid change dramatically and in unexpected ways, equipment can be catastrophically damaged, leading to plant shut down.

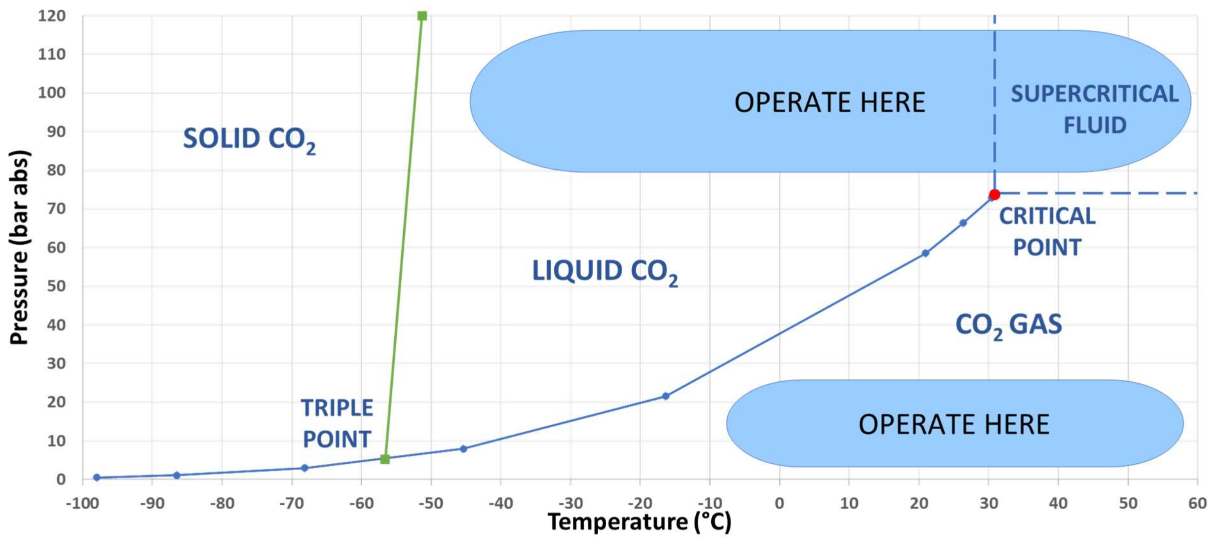

Figure 5 Phase Envelope for pure CO_2

The situation becomes more complex, when we consider the potential for contamination with components such SO_2, NO_2 and N_2. Figure 6 below shows how trace amounts of contaminants dramatically alter the behaviour of the CO_2 phase envelope.

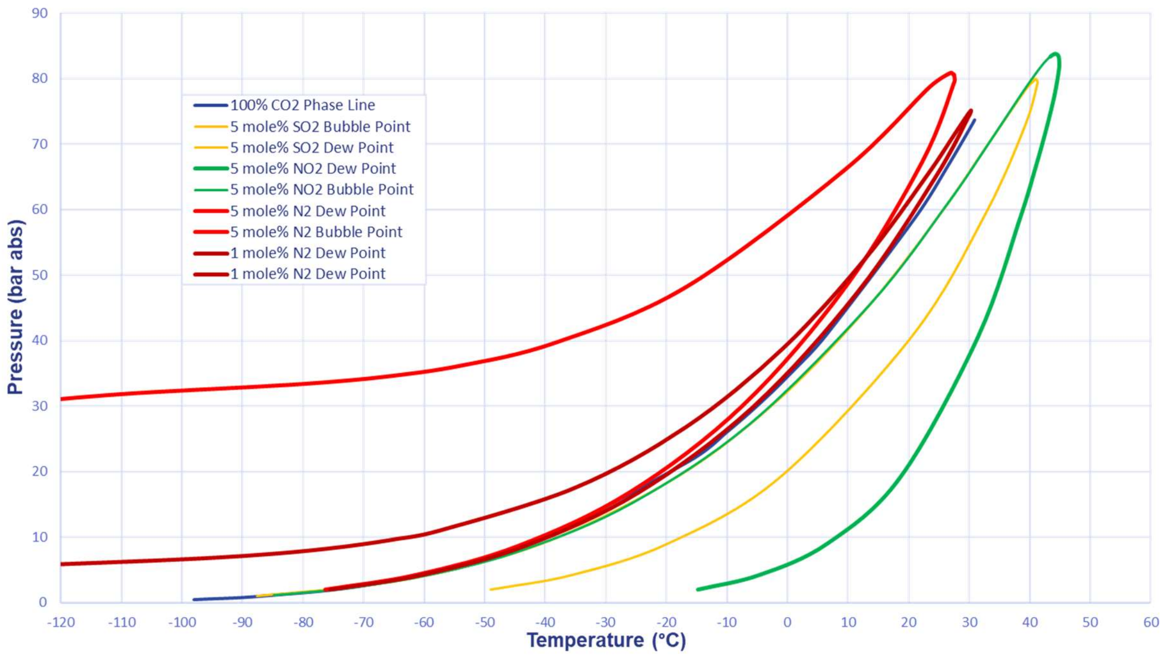

Figure 6 Phase Envelope showing the effects of contaminants on CO_2

Trace amounts of these elements may have no significant impact on the operation of the pipeline, or it is possible small quantities of liquids would start to condense out and pool in piping low points potentially leading to corrosion and other metallurgy issues. Liquid mist and droplets carried in a gas stream can cause damage to equipment and affect instrumentation.

Here we can see very real risks to projects that do not consider the entire value chain for this route to decarbonisation. A off-specification CO_2 producer can initiate a failure in downstream equipment that may not be revealed for a significant period of time.

4 COSTS METRICS

Total Installed Cost Capital Expenditure (TIC CAPEX) costs for the projects summaries here varied from US$ 70,000,000 to US$ 600,000,000. As expected, economies of scale dominated the analysis.

For pipelines TIC CAPEX costs were between US$ 200,000 and US$ 300,000/km.MTA CO_2 transported. At low flowrates and short distances fixed costs dominate the economics; which is to be expected. For higher flowrates and longer distances pipeline costs per km reduced.

For the CCUS facilities TIC CAPEX Costs were between \$200 to \$600 tonnes/year CO_2 Processed.

5 CONCLUSIONS

The requirement for efficient and long-term carbon capture and storage facilities is well understood. Several countries and operators are leading the way in deploying CCUS technology as a medium-term instrument to decarbonise our energy supplies. Hard-to-abate industries are looking at CCUS as a more substantial tool for decarbonisation.

Carbon dioxide does not behave like natural gas or hydrogen, and the options for transporting it via pipeline are different. Designers and operators may elect to move CO_2 as a refrigerated liquid, by road, rail or shipping, or they can transport CO_2 via pipeline as an ambient temperature gas or as a super-critical dense phase fluid. Each choice has technical challenges and commercial advantages, depending on the location, route and surrounding infrastructure.

A risk to many projects that cover processing facilities, import and export pipelines, and injection facilities, irrespective of the technology and application, is that design subtly and expectation can be lost at the interfaces. The impact of impurities and contaminants can be overlooked, and abnormal operations can be discounted. This is especially true for CCUS, with many owners expecting to store waste CO_2 permanently. A recent example of where this goes wrong is the Denbury Pipeline rupture at Satartia (2020); a pipeline weld failed due to unexpected axial stress. Denbury had not fully accounted for the consequences of such a rupture and had not informed the local emergency services of the rupture or the particular risks from a CO_2 release.

Penspen's recent CCUS projects have ranged from experimental scientific programmes that demonstrate proof of concept to world scale NOC infrastructure projects supported by licensor technology. The technical and economic similarities and differences across the range and scale of these projects can often be surprising and insightful.

6 REFERENCES

1 IEA (2022), Carbon Capture, Utilisation and Storage, IEA, Paris https://www.iea.org/reports/carbon-capture-utilisation-and-storage-2.

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