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A systematic review of key challenges of CO_2 transport via pipelines

V.E. Onyebuchi, A. Kolios*, D.P. Hanak, C. Biliyok, V. Manovic

School of Water, Energy and Environment (SWEE), Cranfield University, Cranfield, Bedfordshire MK43 0AL, United Kingdom

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ABSTRACT

Transport of carbon dioxide (CO_2) via pipeline from the point of capture to a geologically suitable location for either sequestration or enhanced hydrocarbon recovery is a vital aspect of the carbon capture and storage (CCS) chain. This means of CO_2 transport has a number of advantages over other means of CO_2 transport, such as truck, rail, and ship. Pipelines ensure continuous transport of CO_2 from the capture point to the storage site, which is essential to transport the amount of CO_2 captured from the source facilities, such as fossil fuel power plants, operating in a continuous manner. Furthermore, using pipelines is regarded as more economical than other means of CO_2 transport

The greatest challenges of CO_2 transport via pipelines are related to integrity, flow assurance, capital and operating costs, and health, safety and environmental factors. Deployment of CCS pipeline projects is based either on point-to-point transport, in which case a specific source matches a specific storage point, or through the development of pipeline networks with a backbone CO_2 pipeline. In the latter case, the CO_2 streams, which are characterised by a varying impurity level and handled by the individual operators, are linked to the backbone CO_2 pipeline for further compression and transport. This may pose some additional challenges.

This review involves a systematic evaluation of various challenges that delay the deployment of CO_2 pipeline transport and is based on an extensive survey of the literature. It is aimed at confidence-building in the technology and improving economics in the long run. Moreover, the knowledge gaps were identified, including lack of analyses on a holistic assessment of component impurities, corrosion consideration at the conceptual stage, the effect of elevation on CO_2 dense phase characteristics, permissible water levels in liquefied CO_2, and commercial risks associated with project abandonment or cancellation resulting from high project capital and operating costs.

1. Introduction

1.1. Background

The latest Intergovernmental Panel on Climate Change (IPCC) report revealed that anthropogenic greenhouse gas emissions have remained the dominant cause of global warming and climate change since the 1950s, and warned that this trend will continue to intensify if anthropogenic CO_2 emissions are not abated [1]. Similarly, one of the key outcomes of the COP21 agreement is to keep the mean earth temperature below 2 °C above pre-industrial levels and a further commitment to decrease it to below 1.5 °C by 2050 [2]. Knoope et al. [3] reported that to mitigate drastic climate change, global CO_2 emissions should be cut by 50–85% compared to 2000 emission levels. Yet, the worldwide emissions from combustion of fossil fuels climbed to an all-time high of 34 $GtCO_2$ in 2011 [4]. Furthermore, 32 $GtCO_2$ was emitted in 2015, as reported by Kennedy et al. [5], showing a partial decoupling between the growth in global CO_2 emissions and that of the global economy [6]. It has been also reported that reduction in the CO_2 emission will put a ceiling on the mean earth temperature increase of between 2 and 2.4 °C [7–9].

Importantly, the power sector of 2050 is expected to rely primarily on renewable energy sources (RES), with support from fossil fuel power generation with CO_2 capture and storage (CCS), and nuclear power plants [10]. However, differences in operating patterns, and hence interaction between these technologies, will affect the operation of the energy network [11,12]. Although CCS is expected to impose significant efficiency and economic penalties [13], and cannot be perceived as an ultimate solution to climate change, its integration to the fossil fuel power plant fleet will act, at least, as a bridge to a clean, reliable and sustainable energy supply [14].

Different countries continue to strike a balance between the need to mitigate climate change by reducing CO_2 emission and utilisation of fossil fuels for power generation and industrial processes. For this

* Corresponding author.
E-mail address: a.kolios@cranfield.ac.uk (A. Kolios).

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reason, fossil fuels constitute a substantial share in the global energy mix [15–19]. Obviously, there is some tension between the two views on the future shape of the global energy system. One is advocating the necessity to cut CO_2 emissions and the other promotes continued operation of fossil fuel power plants and carbon-intensive industrial processes. In the latter case, it is considered that these carbon-intensive processes are imperative for the maintenance of both the competitive economies and a high living standard [20–26].

With the continued consumption of fossil fuels, considerable and continuous reduction in the amount of CO_2 emission from power and industrial plants can be achieved through CCS technology [27–30]. The CCS chain has been applied for enhanced oil recovery (EOR) for many years, but its application for climate change mitigation has only been considered recently [31]. In the CCS chain, CO_2 is captured from large-scale emitters, such as fossil fuel power plants, using various CO_2 capture and separation technologies, compressed and purified, and finally transported to a storage site, where it is injected underground and usually stored in a depleted oil and gas reservoir or deep saline aquifer for a long period of time. Depending on the CO_2 phase, its transport can be carried out via a pipeline (dense phase) or by trucks, rail, and ships (liquid phase) (Fig. 1).

The approach employed in most CCS demonstration projects to date, such as the Boundary Dam, Petra Nova, and ROAD projects, is mainly based on point-to-point transport. The exceptions are the projects that utilise existing pipelines, including in oil and gas or EOR pipelines. EOR is a process that has been in use for decades to improve hydrocarbon recovery from oil reservoirs. In this process, high-pressure CO_2 is injected into the reservoir to increase its pressure, thereby improving its hydrocarbon yield.

Importantly, transport of CO_2 via pipelines has a number of advantages over other means of CO_2 transport, including transport by trucks, rail, and ships. CO_2 transport to a suitable place for sequestration, in terms of space and secure storage, usually requires the use of pipelines, especially where continuous flow from the CO_2 capture facility is required [33]. Furthermore, pipelines allow transporting a larger amount of CO_2, which could have been captured from a number of point sources, over long distances in a more economic manner compared to other means of CO_2 transport. There are, however, a number of challenges for CO_2 transport via pipelines that must be resolved for successful deployment of CCS systems. Although these challenges are unlikely to prevent complete deployment of the system [21], this means of transport is regarded as a high-risk component of the CCC chain [34,35] (Fig. 2).

1.2. Overview of CO_2 transport via pipelines

Pipeline engineering with reference to hydrocarbon transport has a long history. Namely, there is considerable experience in the field of oil and gas transport, including EOR enhanced oil recovery [16,32,36]. However, transporting CO_2 streams containing impurities, as opposed to pure CO_2 streams, imposes additional challanges. Several studies highlighted that various issues should be considered when it comes to the transport of captured CO_2 containing impurities, such as operating pressure, repressurisation intervals and pipe integrity. This is irrespective of the mode of transport, whether in gaseous, liquid or supercritical phases across a difficult terrain [15,16,32,36–40].

In the US, pure CO_2 is regularly transported via onshore pipelines over long distances [41]. Most of these CO_2 pipelines were designed purposely for EOR [40]. Although some CCS projects consider CO_2 transport from fossil fuel power plants or other industrial sources, the majority of CO_2 that is being transported comes from natural sources [37,42–46]. It has been reported that CO_2 with impurities is transported via pipeline systems in the US and Canada. An example of such system is the 325 km pipeline transporting CO_2 that contains ~0.9% hydrogen sulphide (H_2S) from a North Dakota, US, gasification plant to Saskatchewan, Canada for EOR. Importantly, such onshore CO_2 pipeline systems have been operational for more than 30 years without any significant incidents caused by corrosion [47,48]. However, there is a lack of extensive experience of CO_2 transport via offshore pipelines over long distances.

Over the last decade, there has been slow but steady progress in the development of large scale industrial processes (LSIP) CCS projects. Several authors have shown insights into the design of pipelines and the operational philosophy for CO_2 streams from some of the first

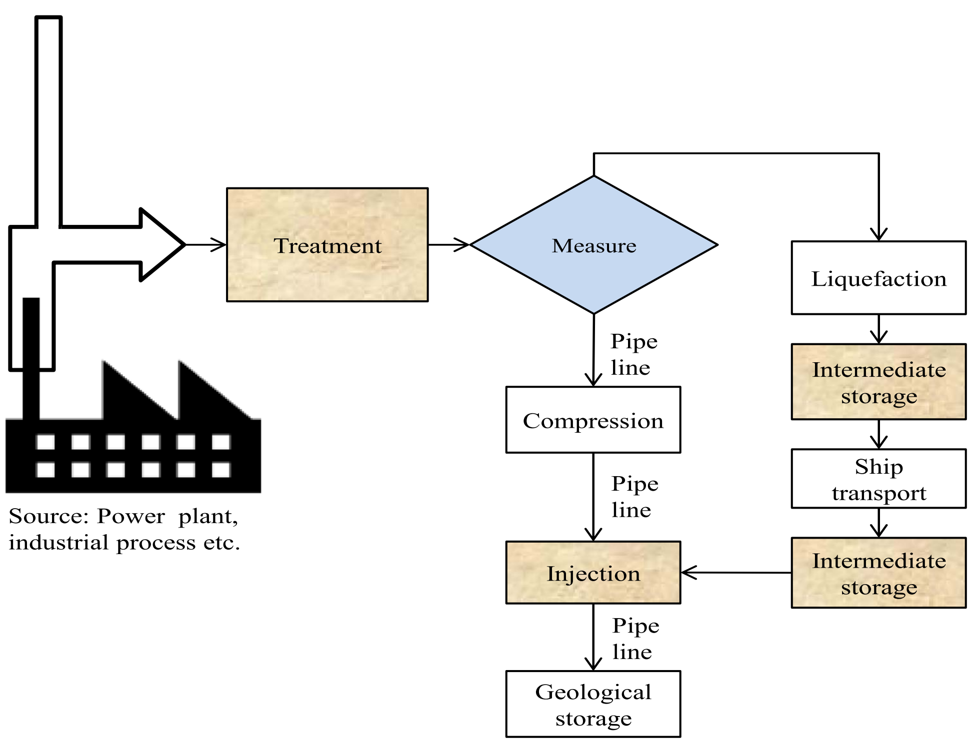

Fig. 1. Liquefaction and compression transport schemes (Adapted from Spinelli et al. [32]. Copyright 2012 The International Society of Offshore and Polar Engineers).