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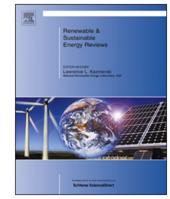

An overview of current status of carbon dioxide capture and storage technologies

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A B S T R A C T

Global warming and climate change concerns have triggered global efforts to reduce the concentration of atmospheric carbon dioxide (CO_2). Carbon dioxide capture and storage (CCS) is considered a crucial strategy for meeting CO_2 emission reduction targets. In this paper, various aspects of CCS are reviewed and discussed including the state of the art technologies for CO_2 capture, separation, transport, storage, leakage, monitoring, and life cycle analysis. The selection of specific CO_2 capture technology heavily depends on the type of CO_2 generating plant and fuel used. Among those CO_2 separation processes, absorption is the most mature and commonly adopted due to its higher efficiency and lower cost. Pipeline is considered to be the most viable solution for large volume of CO_2 transport. Among those geological formations for CO_2 storage, enhanced oil recovery is mature and has been practiced for many years but its economical viability for anthropogenic sources needs to be demonstrated. There are growing interests in CO_2 storage in saline aquifers due to their enormous potential storage capacity and several projects are in the pipeline for demonstration of its viability. There are multiple hurdles to CCS deployment including the absence of a clear business case for CCS investment and the absence of robust economic incentives to support the additional high capital and operating costs of the whole CCS process.

Contents

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1. Introduction

Rapid economic growth has contributed to today's ever increasing demand for energy. An obvious consequence of this is an increase in the use of fuels, particularly conventional fossil fuels (i.e. coal, oil and natural gas) that have become key energy sources since the industrial revolution. However, the abundant use of fossil fuels has become a cause of concern due to their adverse effects on the environment, particularly related to the emission of carbon dioxide (CO_2), a major anthropogenic greenhouse gas (GHG). According to the Emission Database for Global Atmospheric Research [1], global emission of CO_2 was 33.4 billion tonnes in 2011, which is 48% more than that of two decades ago. Over the past century, atmospheric CO_2 level has increased more than 39%, from 280 ppm during pre-industrial time [2] to the record high level of 400 ppm in May 2013 with a corresponding increase in global surface temperature of about 0.8 °C [3]. Without climate change mitigation policies it is estimated that global GHG emission in 2030 will increase by 25–90% over the year 2000 level, with CO_2-equivalent concentrations in the atmosphere growing to as much as 600–1550 ppm [4].

The Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report (AR5) issued in 2013–14 confirmed the 4th Assessment Report's assertion that global warming of our climate system is unequivocal and is associated with the observed increase in anthropogenic greenhouse gas concentrations [2,5]. Furthermore, it is mentioned that 1983–2012 was likely the warmest 30 years period of the last 1400 years in Northern Hemisphere. The same IPCC report (AR5) indicates that to avoid the worst effects of climate change occurring, it is necessary to keep the temperature rise less than 2 °C relative to preindustrial levels and that CO_2 emissions should be reduced globally by 41–72% by 2050 and by 78–118% by 2100 with respect to 2010 levels [5]. Although there was not any binding agreement on CO_2 emission control in the last United Nations Climate Change Conference (COP19) held in November 2013 in Warsaw, Poland, participating countries unanimously looked forward a green economy leading to sustainable development. The IPCC has conducted a comprehensive review on various CCS technologies providing a valuable reference for researchers and policy makers in developing their GHG emission reduction program [6]. However, most of the information can be dated back to 2005 or before and there are a lot of changes since then. Moreover, reviews in literature only account for separate aspects of the CCS technology chain, with a focus on either capture, transport, storage or environmental impact [7–13]. The purpose of this paper is to provide a holistic review on the state of the art of CCS technologies and various relevant aspects, including CO_2 capture (Section 3), separation (Section 4), transport (Section 5), utilization (Section 6), storage (Section 7), life cycle GHG assessment (Section 8), and leakage and monitoring (Section 9). An updated status and outlook for CCS projects together with a discussion on the barriers for commercial deployment (Section 10) will also be provided.

2. Approaches to mitigate global climate change

Different approaches are considered and adopted by various countries to reduce their CO_2 emissions, including

- improve energy efficiency and promote energy conservation;
- increase usage of low carbon fuels, including natural gas, hydrogen or nuclear power;
- deploy renewable energy, such as solar, wind, hydropower and bioenergy;
- apply geoengineering approaches, e.g. afforestation and reforestation; and
- CO_2 capture and storage (CCS).

Table 1 compares the application areas, advantages and limitations of these different approaches. Some of these approaches deal with source emissions reduction, such as adopting clean fuels, clean coal technologies, while others adopt demand-side management, i.e. energy conservation. Each approach has intrinsic advantages and limitations that will condition its applicability. It is unlikely that adopting a single approach or strategy can adequately meet the IPCC goal of CO_2 reduction, i.e. 50–85% by 2050 from 2000 levels, and therefore, a complimentary portfolio of CO_2 emission reduction strategies needs to be developed. Amongst the different approaches, CCS can reduce CO_2 emissions (typically 85–90%) from large point emission sources, such as power production utilities, and energy intensive emitters, e.g. cement kiln plants. In this approach, CO_2 is first captured from the flue/fuel gases, separated from the sorbent, transported and then either stored permanently or reutilized industrially.

CCS includes a portfolio of technologies, involving different processes for CO_2 capture, separation, transport, storage and monitoring that are separately discussed in the following sections.

3. CO_2 capture technologies

CO_2 is formed during combustion and the type of combustion process directly affects the choice of an appropriate CO_2 removal process. CO_2 capture technologies are available in the market but are costly in general, and contribute to around 70–80% of the total cost of a full CCS system including capture, transport and storage [14]. Therefore, significant R&D efforts are focused on the reduction of operating costs and energy penalty. There are three main CO_2 capture systems associated with different combustion processes, namely, post-combustion, pre-combustion and oxyfuel combustion. These three technologies are shown in Fig. 1 and discussed in the following sections.

3.1. Post-combustion

This process removes CO_2 from the flue gas after combustion has taken place. Post-combustion technologies are the preferred