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Research article

CO_2 capture and storage: A way forward for sustainable environment

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ABSTRACT

The quest for a sustainable environment and combating global warming, carbon capture, and storage (CCS) has become the primary resort. A complete shift from non-renewable resources to renewable resources is currently impossible due to its major share in energy generation; making CCS an imperative need of the time. This study, therefore, aims to examine the reckoning of carbon dioxide (CO_2), measurement methods, and its efficient capture and storage technologies with an ambition to combat global warming and achieve environmental sustainability. Conventionally, physical, geological and biological proxies are used to measure CO_2. The recent methods for CO_2 analyses are spectrometry, electrochemical gas sensors, and gas chromatography. Various procedures such as pre, post, and oxyfuel combustion, and use of algae, biochar, and charcoal are the promising ways for CO_2 sequestration. However, the efficient implementation of CCS lies in the application of nanotechnology that, in the future, could provide a better condition for the environment and economic outlooks. The captured carbon can be stored in the earth crust for trillions of years, but its leakage during storage can raise many issues including its emissions in the atmosphere and soil acidification. Therefore, global and collective efforts are required to explore, optimize and implement new techniques for CCS to achieve high environmental sustainability and combat the issues of global warming.

1. Introduction

The excessive release of carbon dioxide (CO_2) from industries, power plants, and other sources is playing a critical role in the global climate and Earth's life cycle (Al-Maamary et al., 2017). CO_2 concentration has increased from 280 to 400 ppm with 0.8 °C increase in global surface temperature (Pachauri et al., 2014). Recently, CO_2 concentration has mounted up to a keeling curve of 408.8 ppm (Kumar et al., 2017), with a prediction of 600–700 ppm at the end of this century leading to an increased average surface temperature of 4.5–5 °C (Leung et al., 2014). The critical factors affecting CO_2 concentration are uncertain economic, sociological, and technological changes along with human and natural developments (Nakicenovic et al., 2000).

The emissions of other greenhouse gases (GHG), besides CO_2, including methane (CH_4), nitrous oxide (N_2O), hydro-fluorocarbon (HFC), perfluorocarbons and sulfur hexafluoride (SF_6) have also increased drastically during last few decades (Al-Maamary et al., 2017; Ouda et al., 2016). Intergovernmental Panel on Climate Change (IPCC) believes that in order to prevent our planet from a catastrophic collapse, there should be 50–80% reduction in GHG emissions by 2050 (Pachauri et al., 2014). Around 190 countries were gathered in Paris (Conference of Parties-COP 21) during December 2015 to limit the CO_2 concentration for controlling the average temperature rise to 2 °C by the end of this century. The recommended strategies by COP 21 include promoting energy conservation and efficiency, employing renewable and low carbon fuels, adapting geoengineering strategies like afforestation, and most importantly developing CO_2 capture and storage (CCS) techniques (Leung et al., 2014; Kumar et al., 2017). Consequently, CCS is widely accepted as a promising tool, if not ideal, in lowering the global CO_2 emissions (Chalmers and Gibbins, 2007; Odenberger and Johnsson, 2010).

Globally, CO_2 emitted from power plants is around 40% of the total CO_2 emissions (Alonso et al., 2017) and under business as usual model, it is expected to increase up to 60% by the end of this century (Kumar et al., 2017). The transportation sector is responsible for about 20% of the total global CO_2 emissions. Similarly, building and agriculture sectors are contributing around 17% of total CO_2 emissions (Pachauri et al., 2014). CO_2 concentration due to forestry and other land use

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(FOLU) has reduced from 17 to 11%, whereas there is 10% increase in CO_2 concentration due to fossil fuel burning from 1970 to 2010. If all the forested area is recovered, it will only mitigate 11% of the global CO_2 emissions, while 65% emissions that are coming from fossil fuel burning will remain the primary strategic issue (Pachauri et al., 2014). Therefore, new and efficient technologies like CCS for fast removal of CO_2 from the atmosphere in order to combat global warming has gained significant attention in recent years.

CCS is mainly dependent upon the type of combustion process and volume of CO_2, its absorption, separation, and transportation for storage or reuse purposes (Leung et al., 2014). CCS technologies can help in restricting the global average temperature rise to 2 °C by reducing CO_2 emissions from different energy-intensive facilities (Leung et al., 2014). The main CCS technologies include post, pre, and oxyfuel combustion, while the post-combustion is the most mature technology. Coal gasification is the economic CCS technology for CO_2 capture, but it is not suitable for gas-fired plants. It is a retrofit technology as it utilizes most of the infrastructure of the existing power plant. At small scale, it has proved to recover CO_2 at a rate of 800 t/day (Leung et al., 2014).

In oxyfuel combustion, the use of pure oxygen instead of air eliminates the need for de-NOx of flue gas that contains 80–98% CO_2 thus making it an efficient technology for CO_2 removal. However, the process is energy intensive along with the intensification of the corrosion process due to high SO_2 concentration (Araújo and de Medeiros, 2017). In pre-combustion CCS, fuel is pretreated in a gasifier under low O_2 pressure, and syngas ($CO + H_2$) is produced (Leung et al., 2014). Due to the high concentration of CO_2 in the fuel gas, its separation becomes easier than other techniques with the production of H_2 as an energy carrier. This offsets the operational cost of technology to some extent (Araújo and de Medeiros, 2017). The CCS technologies still require further improvements to tackle the limitations of high cost, insufficient investment, lack of incentives, and infrastructure (Kumar et al., 2017), which was the focus of this study.

This paper aims to examine the recent trends in CCS technologies with an ambition to significantly reduce the CO_2 emissions in order to combat global warming and achieve environmental sustainability. The measurement of CO_2 and the factors affecting its measurement are also discussed in detail. The findings would develop a thorough understanding of different proxies being employed to reconstruct past climatic conditions, as both CCS and CO_2 measurement techniques are critically reviewed in this study.

2. CO_2 measurement methods

Scientists employ proxies to construct past climate since instrumental record dates to a post-industrial era only (Mann, 2002; Li et al., 2010). These proxies are divided into physical, biological, glaciological, chemical and geological proxies (Fig. 1). Out of these, some are engaged in measuring paleo CO_2 directly, whereas other proxies can measure it indirectly (Readinger, 2006; Gornitz, 2009; Kaufman et al., 2016). All these proxies are beneficial at the individual level with multiple benefits. However, data with high resolution and well-dated information can only be obtained by employing a multi-proxy approach as individual proxies have some limitations as summarized in Table 1.

2.1. Physical proxies

Careful examination of physical properties of rocks can reveal the climatic setting at the formation period (Gornitz, 2009). For example, rust color indicates oxidation and sea level change, green color exhibits some photosynthetic activity, and the white color depicts the bleaching phenomenon. Texture tells how sediments are transported; how far they are brought here and lastly how were the energetic environmental conditions such as wind speed and water flow. If the rock has coarse sand grains, then it is formed under turbulent conditions. Conversely, if the sediment contains smaller clay particles, then it is formed under calm and still conditions (Beus and Morales, 2003; Gornitz, 2009). Shape and thickness of sediment layer provide plenty of information about conditions under what these were deposited, suitable conditions for biological activity, the direction of the wind and water flow, and the pattern of deposition (Beus and Morales, 2003; Gornitz, 2009). Source of sediments can easily be identified by measuring its ease of magnetization; if it readily gets magnetized, then it is by some volcanic eruption or some geological unit containing elements like iron (Gornitz, 2009; Maxbauer et al., 2016). The physical proxies give a birds-eye view of the climatic conditions of past. However, scientists need to seek help from other proxies as discussed below in order to build some authentic opinion.

2.2. Glaciological proxies

The ice sheets deposited at all continents, especially in Antarctica and Greenland in the forms of glaciers can serve the purpose of historical CO_2 concentration measurement for the period dating back to hundreds of centuries. There are two primary projects launched; one is the Greenland Ice Core Project, and other is the Vostok Ice Core Project. Antarctica is providing data up to 0.1 and 0.4 million years respectively (Readinger, 2006; Kaufman et al., 2016). Scientists drill deep holes into the ice sheet having 4–5 inches diameter and 1-meter length and study the composition of air and dust trapped inside the extracted ice cores by gas chromatography (Mann, 2002; MacFarling Meure et al., 2006; Veettil et al., 2017). Age-depth relationships are determined by employing ice flow models, radio-isotopes dating and chrono-stratigraphic markers (MacFarling Meure et al., 2006; Veettil et al., 2017). The first one is exponential, for instance, the first thousand meters specifies 50 thousand years and following 50 meters may stipulate 0.1 million years due to deformation and immense compaction (Readinger, 2006). Hence, one can get accurate measurements up to 10 thousand years only (Kaufman et al., 2016; Veettil et al., 2017). The decay of radioactive isotopes of oxygen and hydrogen occurs at a constant rate after alpha and beta emissions are employed to date ice cores (Readinger, 2006; Veettil et al., 2017). Annual layers and reference horizons, in the form of chronostratigraphic markers, provide information about seasonal variation and major volcanic eruptions. These eruptions injected a significant amount of SO_2 and ash into the atmosphere (MacFarling Meure et al., 2006; Readinger, 2006; Li et al., 2010). The influx of SO_2 hence reduces pH of snow layers that is measured by electrical conductivity method (Veettil et al., 2017). Ice lenses and glands are formed due to melting feature in the upper layer of glaciers. Their relative frequency explains the peak summer temperatures. These structures are easily identified because of air bubbles deficiency (Readinger, 2006). Furthermore, ice cores are used to predict several meteorological parameters like amount of precipitation, solar activity, sea salt concentration, air temperature, atmospheric composition, and atmospheric circulation variations (Abram et al., 2013; Veettil et al., 2017).

2.3. Stable isotopic measurement

Oxygen has three isotopic forms such as ^{18}O, ^{17}O, and ^{16}O with the relative abundance of 0.2%, 0.04%, 99.76% respectively (O'brien et al., 1995; Readinger, 2006). Water molecules ($H_2{}^{16}O$) are lighter with higher vapor pressure and low vaporization energy with a high concentration in clouds as compared to $H_2{}^{18}O$ (McDermott, 2004; Kaufman et al., 2016; Shao et al., 2017). Conversely, as the air mass moves towards the poles, the condensation occurs, and heavier molecules due to their lower vapor pressure preferentially condense. Thus, precipitation become richer, and clouds are more depleted in heavier molecules (Readinger, 2006; Kaufman et al., 2016; Veettil et al., 2017). Air temperature will determine the concentration of heavier molecules in the condensate (Readinger, 2006). This temperature dependence of oxygen isotope makes it a good climate proxy (Readinger, 2006; Li et al., 2010; Mayewski et al., 2017). Based on the facts mentioned above, it is