Chapter 1
Introduction

Abstract Since the industrial revolution in 1750, human activities have resulted in a 40% increase in the atmospheric concentration of CO_2, thereby leading to rapid global warming. To mitigate the global warming and climate change caused by huge anthropogenic CO_2 emissions, different strategies, action plans, and economic instruments have been proposed and implemented around the world. In this chapter, the significance and importance of climate change and global warming are illustrated. An overview of several important formal meetings of the United Nations Framework Convention on Climate Change (UNFCCC) Parties, i.e., Conferences of the Parties (COP), is provided to reveal key milestones in dealing with global greenhouse gas emissions. One such method uses accelerated carbonation of alkaline wastes to capture and utilize CO_2, the theoretical and practical considerations of which are presented in 19 Chapters in this book.

1.1 Climate Change and Global Warming: Significance and Importance

Greenhouse gases (GHGs) are gases in the atmosphere that can absorb and emit radiation within the thermal infrared range, thereby leading to the greenhouse effect. Without GHG, the average temperature of Earth's surface would be approximately 0 °F (−18 °C), rather than present average of 59 °F (15 °C) [1, 2]. Of the gases affecting the ambient temperature of the Earth, the following are most interesting because they are known as long-lived greenhouse gases (LLGHGs):

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCs)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)

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The most abundant GHGs in the atmosphere of the Earth are water vapor (H_2O), CO_2, CH_4, N_2O, O_3, and CFCs. These gases can be discharged into the atmosphere by natural and anthropogenic sources. However, since the beginning of the industrial revolution, human activities have produced a 40% increase in the atmospheric concentration of CO_2, from 280 ppm in 1750 to 400 ppm in 2015. The rapid increase of CO_2 concentration in the atmosphere has spurred worldwide concerns of global climate change from government, industrial, and academic groups. Anthropogenic emissions of CO_2 mainly come from combustion of carbon-based fossil fuels (such as coal, oil, and natural gas), along with deforestation, soil erosion, and animal agriculture. It is noted that the major anthropogenic GHGs are CO_2, CH_4, N_2O, SF_6, HFCs, and PFCs, which are regulated under the international Kyoto Protocol treaty. The global warming potential (GWP) depends on both the efficiency of the molecule as a GHG and its atmospheric lifetime. CO_2 is defined to have a GWP of one over all time period. For instance, methane has an atmospheric lifetime of 12 ± 3 years, resulting in a GWP value of 72 over a timescale of 20 years [3].

1.1.1 Kyoto Protocol in 1997

The Kyoto Protocol is an international treaty signed in 1997, which extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC). The Kyoto Protocol was adopted in Kyoto (Japan), and originally aimed to attain, by 2012, a reduction of global GHG emissions at least 5% less than the observed levels in 1990. A total of six GHGs, including CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6, were regulated in the Kyoto Protocol, which came into effect in 2005. As a result of the Kyoto Protocol, the European Union (EU) issued a global reduction aim of GHG levels by 8%. The Protocol defines three flexibility mechanisms to meet the emission limitation commitment for the Annex I Parties, which include international emissions trading (IET), the clean development mechanism (CDM), and joint implementation (JI). The economic basis for providing this flexibility is that the marginal cost of reducing emissions differs among countries [4].

To negotiate the Kyoto Protocol for establishing legally binding obligations of reducing GHG emissions for developed countries, the United Nations Climate Change Conferences (UNCCC) are held annually in the framework of the UNFCCC. They serve as the formal meeting of the UNFCCC Parties, i.e., Conferences of the Parties (COP), which assess the progress in dealing with climate change. The first UNCCC (COP 1) was held at Berlin, Germany, in 1995. From 2011, the COP meetings have also been used to negotiate the Paris Agreement, as part of the Durban platform activities (adopted at COP 17 in 2011), until its conclusion in 2015.

1.1.2 Cancún Agreement (COP 16) in 2010

The 2010 UNFCCC, officially referred as the 16th session of the Conference of the Parties (COP 16), was held at Cancún, Mexico, in 2010. The agreement includes voluntary pledges made by 76 countries to control GHG emissions. At the time of the agreement, these countries were collectively responsible for 85% of annual global CO_2 emission. The most significant outcome was the agreement for a "Green Climate Fund (GCF)" and a "Climate Technology Centre," adopted by the states' parties. The GCF aimed to distribute US$100 billion per year by 2020 to assist poorer countries in financing emission reductions and adapting to climate change. It also asked rich countries to reduce their GHG emissions as pledged in the Copenhagen Accord and planed to reduce the emissions for developing countries. However, at that time, the funding of the GCF was not agreed upon.

1.1.3 Durban Agreement (COP 17) in 2011

COP 17 meeting was held at Durban, South Africa, in 2011. In this meeting, the implementation of carbon capture and storage (CCS) technologies was regarded as eligible for clean development mechanism (CDM) projects and activities. However, the geological storage of CO_2 demonstrated around the world still faces many uncertainties and risks, such as accidental leakage of CO_2, environmental impacts, and public acceptance. On the other hand, carbon capture, utilization, and storage (CCUS) have recently received global attention as a viable option for reducing CO_2 emissions from industries and/or power plants [5–8]. In this meeting, the creation of the GCF was also discussed.

1.1.4 Paris Agreement (COP 21) in 2015

The COP 21 meeting was held at Paris (France) in 2015. Negotiations resulted in the adoption of the Paris Agreement, which represented a consensus of the representatives of the 196 parties, to govern climate change reduction measures starting from 2020. The agreement will become legally binding only if at least 55 counties, which together produce at least 55% of the global GHG emissions, ratify the agreement [9]. The agreement ended the work of the Durban platform which was established during COP 17. The expected key result of COP 21 was highlighted by the below statement:

> Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.

The agreement also called for “zero net anthropogenic GHG emissions” to be reached by 2050. Prior to the conference, a total of 146 national climate panels each publicly presented draft national climate contributions, called intended nationally determined contributions (INDCs), which was estimated to limit global warming to 2.7 °C by 2100. For instance, the EU suggested the INDC should set a binding target for at least a 40% domestic reduction in GHG emissions by 2030, compared to 1990 [10]. It also suggested that the regulated GHGs by EU members should include CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3.

1.2 Mitigation and Adaptation

The ocean is the major short-term sink in nature because of the imbalance between CO_2 concentrations in the ocean and the atmosphere. Although the natural sink is very important, offering −0.5 °C of temperature reduction following an overshoot [11], the major application of anthropogenic sinks, such as carbon capture utilization and storage (CCUS) and rapid reforestation, is also required to achieve a plateau at 2 °C. Without technologies that remove CO_2 from the atmosphere, the 350 CO_2 ppm target is out of reach in the twenty-first century [11].

To mitigate rapid global warming and adapt to the climate change caused by huge anthropogenic CO_2 emissions, different strategies and tools from various aspects have been proposed and implemented. Action plans and practical technologies have been executed to pursue scientific solutions for overcoming the challenges of global warming [12, 13]. According to the international energy agency (IEA) report, the strategies for reducing CO_2 emissions include the following: (1) improving overall energy efficiency, (2) implementing carbon capture and storage (CCS) technologies, and (3) utilizing renewable energy and material recycling [14]. Among the above strategies, the CCS technologies could reduce CO_2 emissions by 9–50% in industrial sectors, compared to the present level, by 2050 and could mitigate cumulative global climate change by 15–55% in 2100 [15].

Putting a price on carbon emission can also help shift the burden of the environmental damage back to those who can reduce it. There are two types of carbon pricing instruments that can be utilized to accelerate the CO_2 emission reduction: (1) emissions trading systems (ETS) and (2) carbon taxes. The choice of carbon pricing tools depends on national and economic circumstances. The ETS is sometimes referred to as a cap-and-trade system. It caps the total level of greenhouse gas emissions and allows industries with low emissions to sell their extra allowances to larger emitters. By creating a platform of supply and demand for emission allowances, an ETS can effectively establish a market price for GHG emissions, ensuring that the emitters will be kept within their pre-allocated carbon budget. Conversely, a carbon tax directly sets a price on carbon by defining a tax rate on the GHG emissions (or the carbon content) of fossil fuels. It is different from an ETS because the emission reduction outcome of a carbon tax is not predefined but the carbon price is.

1.3 Structure and Contents of This Book

This book provides comprehensive information on CO_2 capture and utilization using alkaline wastes via accelerated carbonation technology from theoretical and practical considerations, presented in the following 19 chapters. This book should be beneficial to readers who take scientific and practical interests in the current and future *accelerated carbonation technology* for CO_2 mineralization and utilization. Engineers, scientists, government officers, and project managers will find this book an essential reference on CO_2 mineralization and utilization.

In Part I, a broad review on challenges and opportunities for global warming issues is provided, including post-combustion carbon capture, storage and utilization (Chap. 2), CO_2 mineralization and utilization via accelerated carbonation (Chap. 3), and environmental impact assessment (EIA) and carbon capture and storage (CCS) guidance (Chap. 4).

In Part II, the integrated waste treatment via ex situ accelerated carbonation is systematically presented, in terms of theories and principles (Chap. 5), analytical methods for carbonation material (Chap. 6), mechanisms and modelling (Chap. 7), practices and applications (Chap. 8). Chapter 9 covers the system analysis methodology, including response surface methodology (RSM), life cycle assessment (LCA), cost–benefit analysis (CBA), and 3E (Engineering, Environmental, and Economic) triangle model.

In Part III, various types of feedstock for CO_2 mineralization are illustrated, including natural silicate and carbonate minerals (Chap. 10), iron and steel slags (Chap. 11), fly ash, bottom ash, and dust (Chap. 12) and paper industry, construction, and mining process wastes (Chap. 13).

In Part IV, the valorization of carbonization product as green materials is discussed, including utilization of carbonation product as green materials (Chap. 14), supplementary cementitious materials (SCMs) in cement mortar (Chap. 15), and aggregates and other high-value products (Chap. 16).

In Part V, the concepts of integral approach for waste treatment and resource recovery are illustrated. First, the carbon capture with flue gas purification (e.g., SO_x, NO_x, and particulate matter) via process integration and intensification is provided in Chap. 17. After that, the importance and significance of waste-to-resource (WTR) supply chain are discussed, in terms of barriers, challenges, strategies, and action plans (Chap. 18). Following that the principles of system optimization, such as (1) mathematical programming approach, (2) graphical presentation for optimization, and (3) comprehensive performance evaluation, are introduced to demonstrate the best available technology (Chap. 19). Moreover, several demonstration and action plans around the world are reviewed. Finally, the prospective and perspective on the strategies toward zero waste for sustainability are provided in Chap. 20.

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