1. Introduction

As the world continues to grapple with the pressing issue of climate change, the development and implementation of carbon capture, utilisation, and storage (CCUS) technologies are becoming increasingly important. In their recent report, the IPCC indicated that without the implementation of CCUS technology, it will be extremely difficult to meet global climate targets [1]. The goal of this Special Issue of the MDPI journal *Energies* is to showcase the latest advancements in CCUS technology and to highlight its potential to play a key role in the transition to a sustainable, low-carbon future.

The concept of CCUS is based on capturing carbon dioxide (CO$_2$) emissions from industrial processes, transporting them elsewhere, and either utilising them in various industrial processes or storing them underground [2]. This process has the potential to significantly reduce carbon emissions and to help mitigate the effects of climate change [3]. However, CCUS is no magic bullet, and must be part of a larger strategy that includes reducing greenhouse gas emissions and transitioning to renewable energy sources. In this Special Issue, the paper from Nawaz et al. [4] peered over 4000 articles published between 2007 and 2021, and analysed trends in publishing, the dominant contributing authors, institutions, and countries, and the most cited publications in the CCUS regime. The article also discusses the rapid growth in research on carbon capture and utilization technologies over the years.

One of the key challenges of CCUS technology is capturing CO$_2$ emissions. There are various methods of capturing CO$_2$, including post-combustion capture, pre-combustion capture, and oxyfuel combustion. The high cost of the technology is a challenging issue for all these technologies. Capturing and storing CO$_2$ is expensive and requires significant investment [5]. However, significant advancements have been made in developing cost-effective CCUS technologies, such as using advanced materials, alternative solvents, and innovative process designs [6]. This Special Issue presents three papers for each aspect of the technological advancement stated above.

Firstly, the contribution from Ansone-Bertina et al. [7] presents their research on creating advanced composite adsorbent materials that can effectively capture CO$_2$. They tested three different metal–organic frameworks (MOFs), which showed excellent stability and reliable CO$_2$ capture performance, even after 20 cycles. This research could help find new ways to reduce the amount of CO$_2$ and slow down climate change.

Furthermore, the research of Ali et al. [8] discusses the use of alternative solvents, i.e., ionic liquids (ILs) and deep eutectic solvents (DESs), for absorption-based carbon capture. ILs and DESs can be recycled consistently with low vapor pressure and toxicity. This paper presents an overview of the functionalization of ILs and DESs to enhance CO$_2$ capture and convert CO$_2$ into valuable products, with relevant economic perspectives and drawbacks.

Just as importantly, Rehman and Lal [9] provide an insight into “innovative process design” for CCUS with a review of the use of natural gas hydrates (NGHs) in carbon dioxide capture and storage (CCS). Gas hydrate technologies are garnering increased interest for
carbon dioxide emission mitigation, while providing an alternate pathway for natural gas storage. The critical challenges that hinder commercial applications are their cost of operation and the risks associated with development [10]. Indeed, some state-of-the-art developments can lead to technological breakthroughs in terms of future energy supplies and simultaneous climate change mitigation.

Carbon utilisation is another aspect of CCUS that has the potential to yield significant economic benefits. Carbon utilisation involves the conversion of CO$_2$ into value-added products, such as chemicals, fuels, building materials, and transportation. This has the potential to create new markets for carbon-based products and reduce the reliance on fossil fuels [11].

Carbon storage is another critical component of CCUS. CO$_2$ can be safely stored underground in geological formations, such as depleted oil and gas reservoirs, deep saline aquifers, and unminable coal seams [12]. However, the long-term safety and security of CO$_2$ storage must be ensured. This requires robust monitoring and verification processes to ensure that CO$_2$ remains securely stored underground and does not leak into the atmosphere [13]. Moreover, the safe transportation of captured CO$_2$ to these storage sites requires the development of reliable technologies and viable business models [14]. The study conducted by Gong et al. [15] explores how to capture CO$_2$ and transport it safely for underground storage. The researchers used a computer program to model different ways to clean the CO$_2$ gas and turn it into a liquid that can be transported. This could potentially help us reduce the technological problems associated with CO$_2$ transportation and storage.

The articles in this Special Issue highlight the latest advancements in CCUS technology and showcase the potential for its widespread adoption, with key themes to promote innovation and active collaboration between industry, academia, and governments. Indeed, CCUS is a complex and multidisciplinary field, and its success will require the collaboration of experts from various disciplines and sectors [16]. The articles showcase the latest advancements in materials science, process design, and application. These innovations have the potential to significantly reduce the cost of CCUS technology and make it more accessible to a wider range of industries.

Conflicts of Interest: The authors declare no conflict of interest.

References


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