energies

MDPI

*Editorial*

# Advances in Carbon Capture, Utilization and Storage (CCUS)

**Cheng Cao [1], Haonan Zhu [1,*] and Zhengmeng Hou [2,*]**

[1] State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, China; caochengcn@163.com
[2] Institute of Subsurface Energy Systems, Clausthal University of Technology, 38678 Clausthal-Zellerfeld, Germany
* Correspondence: zhuhaonan86@163.com (H.Z.); hou@tu-clausthal.de (Z.H.)

Carbon Capture, Utilization, and Storage (CCUS) technology is essential for mitigating climate change as it captures $CO_2$ and either utilizes it for chemical applications or stores it in geological formations. Captured $CO_2$ can be injected into depleted oil and gas reservoirs to enhance oil recovery or can be stored directly in underground reservoirs, such as depleted oil and gas fields or deep saline aquifers. Despite their potential, most CCUS technologies are still in the early stages of development, with ongoing advancements and innovative solutions emerging rapidly. To help researchers stay abreast of the latest developments and promote the research, development, and field implementation of CCUS, we initiated a call for papers with the support of relevant academic journals. A total of ten papers related to CCUS technology and development were received and published in this Special Issue.

$CO_2$ capture is the first step in CCUS. Scholars are constantly searching for low-energy and efficient $CO_2$ separation and purification methods. Moioli et al. [1] proposed using a flexible potassium taurate process to treat flue gas from coal-fired power plants. Using potassium taurate solvent requires less energy than MEA solvent, and it is also less toxic and corrosive. Compared with the fixed mode, the degree of $CO_2$ separation in the flexible mode is controllable and can be flexibly adjusted according to changes in carbon tax prices and electricity prices to minimize energy and income losses. Therefore, using potassium taurate in flexible mode is economically feasible. Guo et al. [2] prepared N/O co-doped porous carbons (NOPCs) from corn silk accompanied by $Na_2CO_3$ activation. The optimized sample exhibited a large specific surface area, numerous ultramicropores, and a high pyrrolic nitrogen content, leading to enhanced $CO_2$ adsorption capacity and potentially offering a cost-effective alternative to $CO_2$ capture.

$CO_2$ utilization technologies, which are considered a cost-effective way to reduce carbon emissions, have drawn considerable attention from the academic community through experimental studies and numerical simulations. Cruz et al. [3] conducted an experiment to quantify the impact of chemical reactions caused by the dissolution of supercritical $CO_2$ ($SCCO_2$) in formation water on capillary phenomena. Thin sections were prepared from various reservoir rocks and allowed to statically react with brine rich in $s_CCO_2$ for 21 days. Post-reaction samples were then observed using instruments to assess the geochemical reactions. The results indicated that the geochemical reactions preferentially dissolved calcite, while other minerals were preserved. Short-term geochemical reactions did not significantly affect the physical properties of the samples or the capillary displacement mechanisms. Górecki et al. [4] demonstrated the applicability of the Smoothed Particle Method (SPH) for the numerical simulation of loose dry ice compaction processes. This study aimed to optimize the energy efficiency of this process by systematically exploring the effects of particle packing density (PPD) and mass scaling (MS) parameters on the consistency of the simulated and experimental outputs. This study will help reduce the energy consumption of these production processes. Wetzel et al. [5] assessed the hydromechanical impacts of $CO_2$ storage in coal seams through numerical simulations, evaluating the risks associated with $CO_2$ injection in Poland's Upper Silesian Coal Basin. Their findings indicate



**Citation:** Cao, C.; Zhu, H.; Hou, Z. Advances in Carbon Capture, Utilization and Storage (CCUS). *Energies* **2024**, *17*, 4784. https://doi.org/10.3390/en17194784

Received: 11 September 2024
Accepted: 24 September 2024
Published: 25 September 2024

that while $CO_2$ injection can cause vertical displacements, the risk of fault reactivation is low under the simulated conditions, providing insights for safe and sustainable $CO_2$ storage operations.

Accurate estimation of carbon emissions is critical for formulating targeted emission reduction plans. Feng et al. [6] developed a hybrid analysis framework that integrates the Logarithmic Mean Divisia Index (LMDI) decomposition method with the Long-range Energy Alternatives Planning (LEAP) system. Applying various data processing methods and Tapio decoupling theory, they assessed and forecasted $CO_2$ emissions in the Yancheng Economic Development Zone from 2020 to 2035 and identified optimal emission reduction strategies for the region. Xie et al. [7] explored the carbon–energy–water (CEW) nexus in China's coal power industry within the context of carbon neutrality. By developing the ATPCC assessment tool, the research evaluates trade-offs between carbon emissions, energy consumption, water usage, and financial profits within the industry. The findings suggest that while CCUS can reduce emissions, it may also increase energy and water consumption, necessitating a comprehensive understanding of the CEW nexus.

Raising public awareness and advancing the development of new CCUS technologies are essential to facilitate their implementation. Sitinjak et al. [8] investigated public perception towards CCUS in the JABODETABEK region of Indonesia. This study reveals a generally favorable attitude towards carbon capture and utilization (CCU) but resistance to carbon capture and storage (CCS) due to lack of knowledge and fear. The research underscores the importance of public education to enhance understanding and acceptance of CCUS initiatives. Huang et al. [9] employed the Latent Dirichlet Allocation (LDA) topic model and Derwent patent data to examine the evolution of CCUS technology topics. The study found a shift in application levels, with emerging fields like computer science gaining attention. This forecasts the maturity and trends in key CCUS technologies, highlighting the growing role of universities and research institutes in China's R&D landscape. Hou et al. [10] proposed six strategic priorities for China to achieve its dual carbon goals. This paper discusses the potential and challenges of conventional and advanced CCUS technologies. It introduces the concept of Carbon Capture, Circular Utilization, and Storage (CCCUS), emphasizing the role of biomethanation for renewable energy storage and the carbon circular economy, with significant potential for $CO_2$ storage and energy storage.

The papers published in this Special Issue cover cutting-edge research on advanced CCUS technologies, technology trends, and risk assessment. We believe that these studies will contribute to the development of CCUS-related theoretical, experimental, and numerical simulation methods and provide guidance for the engineering application of CCUS technology. To promote the development of this technology, it is necessary to strengthen exploration in these research directions, including improving the economy and efficiency of CCUS technologies, developing new technologies and methods, optimizing the integration and scalability of these technologies, etc.

**Funding:** This research received no external funding.

**Acknowledgments:** The Guest Editors would like to thank the reviewers for their work, which helped the authors improve their manuscripts.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Moioli, S.; Spatolisano, E.; Pellegrini, L.A. Techno-Economic Assessment for the Best Flexible Operation of the CO2 Removal Section by Potassium Taurate Solvent in a Coal-Fired Power Plant. *Energies* **2024**, *17*, 1736. [CrossRef]
2. Guo, C.; Sun, Y.; Ren, H.; Wang, B.; Tong, X.; Wang, X.; Niu, Y.; Wu, J. Biomass Based N/O Codoped Porous Carbons with Abundant Ultramicropores for Highly Selective CO2 Adsorption. *Energies* **2023**, *16*, 5222. [CrossRef]
3. Cruz, F.; Dang, S.; Curtis, M.; Rai, C. Effect of Geochemical Reactivity on ScCO2–Brine–Rock Capillary Displacement: Implications for Carbon Geostorage. *Energies* **2023**, *16*, 7333. [CrossRef]

4. Górecki, J.; Berdychowski, M.; Gawrońska, E.; Wałęsa, K. Influence of PPD and Mass Scaling Parameter on the Goodness of Fit of Dry Ice Compaction Curve Obtained in Numerical Simulations Utilizing Smoothed Particle Method (SPH) for Improving the Energy Efficiency of Dry Ice Compaction Process. *Energies* **2023**, *16*, 7194. [CrossRef]
5. Wetzel, M.; Otto, C.; Chen, M.; Masum, S.; Thomas, H.; Urych, T.; Bezak, B.; Kempka, T. Hydromechanical Impacts of $CO_2$ Storage in Coal Seams of the Upper Silesian Coal Basin (Poland). *Energies* **2023**, *16*, 3279. [CrossRef]
6. Feng, D.; Xu, W.; Gao, X.; Yang, Y.; Feng, S.; Yang, X.; Li, H. Carbon Emission Prediction and the Reduction Pathway in Industrial Parks: A Scenario Analysis Based on the Integration of the LEAP Model with LMDI Decomposition. *Energies* **2023**, *16*, 7356. [CrossRef]
7. Xie, Y.; Qi, J.; Zhang, R.; Jiao, X.; Shirkey, G.; Ren, S. Toward a Carbon-Neutral State: A Carbon–Energy–Water Nexus Perspective of China's Coal Power Industry. *Energies* **2022**, *15*, 4466. [CrossRef]
8. Sitinjak, C.; Ebennezer, S.; Ober, J. Exploring Public Attitudes and Acceptance of CCUS Technologies in JABODETABEK: A Cross-Sectional Study. *Energies* **2023**, *16*, 4026. [CrossRef]
9. Huang, L.; Hou, Z.; Fang, Y.; Liu, J.; Shi, T. Evolution of CCUS Technologies Using LDA Topic Model and Derwent Patent Data. *Energies* **2023**, *16*, 2556. [CrossRef]
10. Hou, Z.; Luo, J.; Xie, Y.; Wu, L.; Huang, L.; Xiong, Y. Carbon Circular Utilization and Partially Geological Sequestration: Potentialities, Challenges, and Trends. *Energies* **2022**, *16*, 324. [CrossRef]