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Editorial

Special Issue “CO_2 Capture and Renewable Energy”

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This book contains the successful submissions [1–6] to the Special Issue of *Energies* on the wide subject area of “CO_2 Capture and Renewable Energy”.

The urgently-needed carbon neutral economy can only be accomplished through a portfolio of strategies, among which CO_2 capture and renewable energy will need to play a decisive role.

The widespread adoption of renewable energy is an unquestionable part of the solution against climate change. Even though hydropower has traditionally led renewable electricity generation, wind and solar are growing fast. These technologies have rapidly evolved from niche to mainstream thanks to policy drivers, technology developments and international co-operation that have reduced their cost, making them the cheapest source of electricity in many markets. However, dispatchable renewables, such as hydropower, bioenergy, concentration solar power and geothermal, will still be critical to maintain electricity security, together with other low-carbon generation, energy storage and robust electricity networks. Renewables will also play a significant role to produce heat in the industry and the residential sector, while reducing the emissions from the transport sector. Biomethane, produced by biogas upgrading, is also known as renewable natural gas. This can be directly blended with, or fully replace natural gas in existing pipelines and end-user equipment, with the added advantage of being carbon neutral.

In the transition to a sustainable energy economy, based on renewables and green energy sources, CO_2 capture and storage (CCS) will be of paramount importance for abating CO_2 emissions from existing infrastructure in the power and the industrial sectors. Furthermore, there are many industries which are very hard or impossible to decarbonise in the short term, such as the cement sector, in which CO_2 emission are intrinsic to the production process. In such cases, CCS will be mandatory to achieve the goal of net zero emissions. Alternatively, the captured CO_2 can be utilised (CCU) in various applications. The latter approach is receiving more attention as it provides an added value to the captured CO_2. However, it is important to highlight that if the origin of the CO_2 is fossil, only CCS or long-term CCU, such as enhanced oil recovery or construction materials, will contribute to combat climate change. Shorter-lived CCU, such as chemicals and synthetic fuels, can only provide neutral emissions pathways in a circular economy when making use of CO_2 from biogenic origin (biomass), or of CO_2 previously removed from the atmosphere by technological means (known as direct air capture: DAC). Permanent CO_2 removal technologies, such as bioenergy with carbon capture and storage (BECCS) and direct air capture and storage (DACS) are foreseen as necessary in the medium term to compensate for emissions from the hard-to-abate sectors, and in the long term, even to remove atmospheric CO_2 from past emissions.

In this Special Issue, an interesting collection of works covering the topics referred above are presented. The publications include three Research Articles and three Review Articles.

Almeida et al. [1] report the preparation of ZSM-5 extrudates with potential for adsorption-based biogas upgrading. The extrudates were prepared using a silica-based binder, and the adsorption equilibrium of CO_2, CH_4 and H_2O was determined. The extrudates have mechanical resistance at least comparable to commercial zeolites, a surface area reduction lower than 10% when compared to the pristine powders, and similar CO_2/CH_4 selectivity.

Plaza et al. [2] review the progress of CO_2 capture technologies already evaluated in the cement industry at pilot scale, and the established plans for near-future commercial demonstration. The authors highlight the necessity of CCUS to abate at least the 65% of emissions intrinsically related to the cement production process (calcination of limestone). Five large scale projects are on the pipeline to demonstrate CO_2 capture in the cement sector, and these involve different technologies, such as amine absorption, adsorption, calcium looping, and direct capture through indirect heating for calcination.

The developments in the wider area of CCUS are reviewed by Regufe et al. [3]. The authors frame the need for CCUS with the historic evolution and the latest data regarding CO_2 emissions. Then, they briefly review the different types of CO_2 capture technologies and their technology readiness level. This is followed by a general overview of the current progress of CCUS facilities and their barriers to deployment, with special focus on BECCS and DAC. Finally, the status, cost, and prospects of CCUS in industrial processes are also briefly overviewed.

Ribeiro et al. [4] evaluate the potential of Zn(dcpa) metal-organic framework (MOF) for application in CO_2 capture and biogas upgrading. The adsorption equilibrium of CO_2, CH_4, and N_2 is reported. An interesting finding is highlighted: the isotherm of CO_2 at 273 K has a stepwise shape with hysteresis assumed to be related with two metastable structures of the MOF. The authors provide an interpretation of this behaviour in terms of the osmotic thermodynamic theory.

The possibility of implanting virgin ivy plants on house walls and roofs to fix atmospheric CO_2 is proposed by Krzywanski and co-workers [5]. According to these authors, this approach should be considered among the climate change mitigation portfolio, as it could lead to an annual CO_2 removal of over 3.5 Gt (*ca.* 7% of global greenhouse gas emissions), while releasing oxygen, reducing dust in the environment, and lowering the air temperature.

Wahiba et al. [6] review the latest advances in small-scale carbon capture systems, with special focus in decentralized, small-scale combined heat and power (CHP) cogeneration facilities, including micro gas turbines (mGT) coupled to post-combustion amine absorption, hybrid solid state fuel cell systems coupled to mGT and chemical looping for H_2 generation, and biomass-fired organic Rankine cycle (ORC) coupled to post-combustion amine absorption. The main challenges of integrating amine scrubbing post-combustion carbon capture into mGT are identified as the high volumetric flow rate of the exhaust gas, its low CO_2 concentration (1.5 vol%), and its O_2 content that leads to solvent degradation, which results in a high energy penalty. Exhaust gas recirculation (EGR) reduces the amount of exhaust gas fed to the capture unit and increases its CO_2 concentration, thus reducing the energy penalty and the capital costs. The EGR ratio is limited by an optimal O_2 concentration at the combustor inlet, but CO_2 can be further enriched making use of S-EGR. Humidification is found to increase mGT cycle efficiency, compensating energy losses from EGR. The authors highlight that hybrid fuel cell systems coupled to mGT and chemical looping for H_2 generation have the major benefit of 100% capture, while ORC-based biomass-fired micro-CHP integrated with post-combustion capture can offer net atmospheric removal of CO_2. Carbon capture is found to be the costliest phase of CCUS supply chain, specially at small-scale applications. Truck and railroad tankers are identified as a lower cost option for CO_2 transport in small scale applications compared to large-scale pipelines.

In sum, we believe this collection of articles is an important contribution to the open literature in the areas of CO_2 Capture and Renewable Energy.

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