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Editorial

CCUS Strategies as Most Viable Option for Global Warming Mitigation

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The decarbonization of energy-consuming industrial sectors is nowadays becoming one of the most relevant challenges to counteract global warming and the consequences related to it. Many countries have already reduced their own carbon emission in numerous energy intensive sectors, such as transport, agriculture, electricity production, and others. Conversely, the conversion is difficult to perform in sectors such as the heavy industry [1]. Moreover, the transition towards large or complete usage of energy sources having net-zero carbon emissions is more difficult to achieve in the case of emerging economies. Therefore, Carbon Capture Utilization and Storage (CCUS) could become a crucial solution to satisfy the need for reducing the emissions in atmosphere related to the industrial production, and, at the same time, minimize the impact on the industrial and economic development. The International Energy Agency referred CCUS techniques as the main solution to reducing industrial CO_2 emissions after 2030 [2]. The European policy is currently going through this direction: within 2050, 50% of cement plant and up to 30% of ironworker and chemical plants, will reset their emission by adopting CCUS strategies [3].

The molecule of carbon dioxide consists of two atoms of oxygen, covalently double bonded with an atom of carbon. Since it is completely oxidized, this species is non-flammable [4]. The molecule is organized in a linear shape and does not present electric dipole. At room conditions, carbon dioxide appears in the gaseous state and has a density equal to 1.98 kg/m^3.

The techniques used for carbon capture are grouped in three main areas: pre-combustion, post-combustion and oxyfuel combustion. Pre-combustion techniques allow us to separate CO_2 prior tot combustion processes, to keep the carbon content in the exhausts below the maximum level permitted [5]. These techniques are applied when the concentration of carbon dioxide in the inlet stream is higher than 20% and allows to reduce the removal cost in the outlet streams. Post-combustion techniques are thought to treat flue-gases, produced from fuel combustion, and remove carbon dioxide produced during the process [6]. Since most of energy-intensive processes are still based mainly on the combustion of fossil fuels, post-combustion techniques are currently the most widespread [7]. The main applications can be classified as absorption, adsorption and separation via membranes [7]. The main challenges to overcome, to extend their usage, are costs related to the energy required and the scale of CO_2 emissions. Finally, oxyfuel combustion techniques are based on the use of pure oxygen, instead of air, for combustion processes. It allows for the production of exhaust streams only containing carbon dioxide and water and the separation of CO_2 is consequently easy to perform and costs less. To be applied, these techniques require high purity oxygen (at least 95% purity), the production cost of which represents the main limit for their diffusion.

In this context, the Special Issue entitled "Current Trend in Carbon Capture, Utilization and Storage" (CCUS) aims to provide a detailed state of the art about the technologies currently applied and described in literature and propose innovative option for high-efficiency carbon capture, reuse and storage. The present Editorial article aims to suggest, to researchers interested in CCUS, the order to follow for reading the articles contained

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in the SI, in order to make the overall reading as coherent, logical and chronological as possible.

In their review, Podder and colleagues [8] provided a statistical and geographical overview of carbon dioxide, and other green house gases, emissions, classified on source and sector. Once again, they confirmed the need of investing on CO_2 utilization technologies, since the release of this compound due to human activities, is widely larger than its recycling through photosynthesis or fixation, with a consequent accumulation in the atmosphere. In addition to the previously mentioned strategies, this manuscript deals with alternative solutions, such as direct capture from air, chemical looping combustion and gasification, ionic liquids-based technologies, biological CO_2 capture fixation and geological CO_2 capture. Finally, the article proposes the utilization of captured carbon dioxide to produce value-added chemicals and materials, such as carbonates, polycarbonates and supercritical fluids.

The diffusion of CCS processes needs to be promoted and supported by media and policy maker, in order to raise people's awareness. In this context, Emma ter Mors and colleagues studied in depth the CCS coverage in Dutch national newspaper from 2017 to 2019 and compared the results they produced with those of similar studies carried out between 1991 and 2011 [9]. While the perceived advantages related to CCS remained substantially unchanged between the two periods, the evaluation of disadvantages changed significantly, thus modifying the overall opinion on this theme. Between 1911 and 2011, the main perplexity regarded deployment costs and the not still reached maturity of CCS technologies. Conversely, their study proved that, with the constant auxilium of media, the need of reducing CO_2 emissions in the atmosphere is common believe. The discussion is now shifted on the possibility of finding more effective and costless solutions than CCS, while doubts about safety concerning are now marginal.

Following to these two articles, the Special Issue contains several proposes for high-efficiency abatement of CO_2 production and for its storage and final disposal.

Bortuzzo et al. [10] explored and described the CCS technologies that could be adopted on board ships. They firstly compared the main advantages and disadvantages. Despite the reduction of carbon emissions, the adoption of CCS strategies could improve the public's perception of the whole shipping industry. On the other side, these technologies are complex and costly and often requires storage space and disposal measure for safety requirements. For that reason, the article deals with Carbon Capture Technologies at different Technology Readiness Levels (TRLs). The authors established that the most appropriate option for application on board ships technology based on Calcium Hydroxide, since it showed the highest TRL.

The Calcium Looping process (CaL) exploits the reverse calcination of calcium carbonate and is considered one of the most viable options for improving the deployment of concentrated solar power (CSP). Atkinson and colleagues [11] proved that CSP-CaL processes need of high quantities of pressurized CO_2 and can be advantageously coupled with CCS techniques, thus favouring the development of a carbon capture, transportation and storage network in Canada. According to this study, numberless processes and technologies can be thought differently and redesigned, in order to reduce the emissions of carbon dioxide behind them, both in the industrial as in the research sector. The bio-fabrication of three-dimensional scaffolds, using 3D printers and cell containing bioinks, is gaining a continuously growing interest in medicine, especially for treating numerous pathologies, including ulcerative lesions due to diabetes [12]. In their work, Morelli et al. [13] proved the feasibility of using commercial 3D printers to carry out scientific studies in this field: after seven and twenty-one days of cell culture, the hUCMS (Umbilical Cord Matrix Stem Cells) in the cellulose/alginate-based bioinks showed cell viabilities equal to, respectively, 95% and 85%. Their results led to a double benefit. The usage of commercial and costless devices for the production of scaffolds, allows to contain the emissions associated to the process. Moreover, it makes this research more accessible, thus lowering the time expected prior to achieve the expected targets.

Large agglomerations of city housing and commercial/industrial areas, lead to the formation of "hot islands" where, especially during summertime, the temperatures are often higher than the corresponding in the surrounding areas. This phenomenon is commonly referred ad Urban Heat Island (UHI).

With the main goal of reducing as much as possible the Urban Heat Island effect, in the last decades the construction sector has developed numerous solutions to keep the local temperatures within acceptable ranges. The usage of high-reflective surface represents a promising strategy in this sense [14,15]. Rossi and colleagues [16] explored the global warming mitigation via terrestrial albedo increase. They found that the methodologies relate carbon dioxide compensation to albedo increase via the concept of Radiative Forcing (RF). In the present manuscript, they explained in detail how the RF variation, which may depend on local and temporal phenomena, may lead to relevant variations in terms of compensated kg CO_{2eq}/m^2.

Finally, gas hydrates represent a double opportunity in this context. Natural gas hydrates reservoirs are considered a potential unvaluable energy source [17,18]. Since 1980, the proposal and experimental validation of methane recovery via contemporary carbon dioxide enclathration, allowed to obtain a carbon neutral energy source. The replacement processes can be considered the first opportunity to exploit gas hydrates for CCUS. Unfortunately, the process efficiency needs to be further enhanced to make such a strategy really attractive and economically competitive [19]. The second opportunity consists of directly forming new CO_2 hydrate structures to perform the permanent disposal of this green house species. Despite the still present limitations related to its costs, this technique is gaining a growing interest from researchers and industrialists [20]. The reading of the articles collection proposed in the present Special Issue, can be concluded with the experimental study of Li and co-workers [21]. The study aimed to describe the formation of carbon dioxide hydrates into an aqueous mixture containing Sodium Dodecyl Sulfate (SDS) and micron Cu particles. It was confirmed that SDS acts as kinetic promoter for the formation process. Conversely, the addition of Cu inhibited the consumption of CO_2. Altogether, the mixture showed a faint kinetic inhibiting effect and the reason was mainly attributed to the Brownian motion restriction due to the specific mixture.

This brief collection of articles proves once again that the theme of CCUS is multidisciplinary and can be addressed in innumerable ways. By itself, the lowering of CO_2 production cannot be considered resolutive and must be accompanied by storage and/or reusage strategies, as the ones proposed in this Special Issue.

Conflicts of Interest: The author declares no conflict of interest.

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