## Reaction Chemistry & Engineering



## **EDITORIAL**

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Cite this: React. Chem. Eng., 2022, 7, 487

## Introduction to CO<sub>2</sub> capture, utilization and storage (CCUS)

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DOI: 10.1039/d2re90007f

rsc.li/reaction-engineering

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In recent years, great efforts have been devoted to limiting rising atmospheric carbon dioxide (CO2) concentrations while meeting increasing demand for energy. To prevent the detrimental impacts of climate change, CO<sub>2</sub> capture, utilization and storage (CCUS) technologies have to be implemented to reduce the cumulative amount of CO<sub>2</sub> in the atmosphere. CO<sub>2</sub> capture processes generally include adsorption, absorption, biochemical, and membrane technologies that can effectively separate CO2 from flue gases (post-combustion), industrial processes (pre-combustion), or even the atmosphere (DOI: 10.1039/d1re00233c). In addition, how to deal with the captured  $CO_2$  is another big issue. So far, we can convert it into useful chemicals, fuels, and polymers, or utilize it for oil extraction and alkaline industrial waste remediation, or inject it in geologic formations and oceans.

For CO<sub>2</sub> capture at relatively low temperatures, porous materials, such as metal-organic frameworks (MOFs), zeolite, carbon, and supported solid amines, have attracted great attention (DOI: 10.1039/d1re00214g). MOFs are a



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**Professor Qiang Wang** 

Professor Qiang Wang received his BSc (2003) and MSc (2005) from the Harbin Institute of Technology in China, and his PhD (2009) from POSTECH in South Korea. Between 2009-2011, he worked as a Research Fellow in the Institute of Chemical and Engineering Sciences under A\*STAR, Singapore. From 2011-2012, he worked as a Postdoctoral Associate in the Department of Chemistry, University of Oxford. From 2012, he has held a full

professor position in the College of Environmental Science and Engineering, Beijing Forestry University. He serves as the section editor (capture, storage, and chemical conversion of carbon dioxide) of the Journal of Energy Chemistry and is on the editorial boards of several scientific journals. His current research interests include environmental functional nanomaterials for air pollution control and  $CO_2$  capture and utilization (CCU).



Dr. Heriberto Pfeiffer

Dr. Heriberto Pfeiffer is a member Materials Research of the Universidad Institute Nacional Autónoma de México, at Mexico City. His research is focused on CO2 capture and its conversion to value added products. At the same time, he works on different catalytic processes (reforming processes, POM, NO<sub>x</sub> sorption-WGS, reduction, etc.) as well as on the oxidation-chemisorption process as a possible syngas

separation process. Finally, he is interested in biomass pyrolysis and decomposition for  $H_2$  production and he has several studies on ceramic membranes for gas separation. He has published more than 155 scientific articles and several book chapters.

relatively new class of porous materials with unique structural characteristics such as high surface areas, chemical tunability and stability, and have been extensively studied as promising CO2 capture materials. Cotlame-Salinas et al. (DOI: 10.1039/d0re00410c) studied the enhancement of CO2 capture in MOFs molecular confinement. They critically reviewed the most significant advances on the enhanced CO2 uptake performance of selected MOFs with preadsorbed polar (water, alcohols, and amines) and non-polar (toluene and benzene) molecules, as well as some findings from interesting robust computational calculations. In addition, the preferential CO2 adsorption sites, water stability, CO<sub>2</sub>-MOF complex configuration, adsorption  $CO_2$ dynamics, bonding angle, decomposition mechanism, and swing effects are also of great research interest for MOF-based CO2 capture materials (DOI: 10.1039/d1re00090j). Paudel et al. (DOI: 10.1039/d0re00416b) reported that the gas interactions and diffusion mechanisms of CO2 and CH4 in ZIF-8 can be computationally investigated density functional using theory. Gandara-Loe et al. (DOI: 10.1039/ d1re00034a) pointed out that MOFs are

not only promising for CO2 capture, but also offer opportunities as advanced catalysts for gas-phase CO2 conversion.

For  $CO_2$ at capture high various sorbents, temperatures, including Li<sub>4</sub>SiO<sub>4</sub>, KNaTiO<sub>3</sub> and CaO, have been intensively studied. In a recent work, Blanco et al. (DOI: 10.1039/ d1re00125f) provided a detailed study on the synthesis of Na<sub>2</sub>TiO<sub>3</sub> via a solidstate route starting from NaOH and TiO2. In situ experiments performed under different conditions revealed the occurrence of thermally-driven phase transitions derived from the structural instability of the material at high temperatures. These reactions could be differentiated from carbonation processes, allowing the proposal of a mechanism for CO2 sorption. The obtained results could explain the abnormal dynamic thermogram displayed by Na2TiO3 in the presence of CO<sub>2</sub> within a temperature range that is of interest for practical applications and serves as a basis for evaluating the feasibility of using this material in CO2 capture schemes. Within a similar context, Hernández-Castillo et al. (DOI: 10.1039/d1re00087j) reported a new approach to consecutive CO oxidation and CO2 chemisorption using Li2CuO2

modified with ceramics Na and K molten salts.

In a different CO<sub>2</sub> separation conceptualization, dense ceramiccarbonate dual-phase membranes have been recently proposed as an alternative for pre-combustion CO2 capture in the integrated gasification combined cycle (IGCC) process at high-temperature, where these membranes can work as reactors for H<sub>2</sub> production and CO<sub>2</sub> separation/capture. González-Varela al.(DOI: 10.1039/d0re00375a) investigated the high-temperature CO2 perm-selectivity of yttrium-doped SDC (Y-SDC) ceramic-carbonate dual-phase membranes, and revealed that the ionic conductivity of Y-SDC depends on the O<sub>2</sub> partial pressure and yttrium content. The CO<sub>2</sub> permeation flux is correlated to the ionic conductivity of Y-SDC and can be improved by tailoring the membrane microstructure.

In addition to CO2 capture or separation, CO2 utilization is also of great importance for carbon neutrality. To date, many technologies, including CO2 hydrogenation, electrochemical CO<sub>2</sub> reduction, photochemical CO2 reduction, bioelectrochemical CO<sub>2</sub> reduction, CO<sub>2</sub> conversion to polymers, etc., have been studied. Shah et al. (DOI: 10.1039/



**Professor Rose Amal** 

Professor Rose Amal is a Scientia Professor in the School of Chemical Engineering, UNSW Sydney. Her current research designing focuses on nanomaterials for solar to energy chemical conversion applications (including photo and electrocatalysis for water purification, and air water splitting and CO2 reduction) and engineering systems for solar induced processes. Prof. Amal is a Fellow of the Australian

Academy of Technological Sciences and Engineering (FTSE) and a Fellow of the Australian Academy of Science (FAA). She received the nation's top civilian honour - the Companion of the Order of Australia - as part of the 2018 Queen's Birthday Honours for her eminent service to chemical engineering, and was named 2019 NSW Scientist of the Year.



Dermot O'Hare

Dermot O'Hare is a Professor of Organometallic and Materials Chemistry in the Department of Chemistry at the University of Oxford. In addition, he is currently the Director of the SCG-Oxford Centre of Excellence for Chemistry and Associate Head for Business & Innovation in the Mathematics, Physical and Life Sciences Division. Professor O'Hare leads a multidisciplinary research team that works across broad areas of catalysis and

nanomaterials. O'Hare's research is specifically targeted at finding solutions to global issues relating to energy, zero carbon and the circular economy. He has been awarded numerous awards and prizes for his creative and ground-breaking work in Inorganic Chemistry, including the Royal Society Chemistry Ludwig Mond Prize, the Royal Society Chemistry Tilden Medal and Royal Society of Chemistry Academia-Industry Prize.

d1re00150g) investigated the enhanced conversion of methane using Ni-doped Ca<sub>2</sub>Fe<sub>2</sub>O<sub>5</sub> oxygen carriers in chemical looping partial oxidation systems with CO2 utilization. This work revealed that the addition of Ni as a dopant can lower the oxygen vacancy formation energy and increase the CO2 adsorption energy, which is favorable for CO2 activation and splitting. Jeng et al. (DOI: 10.1039/ d0re00261e) studied the potential impacts of current densities, CO2 feeding rates, and reaction temperatures on the single-pass conversion of CO2 in a typical CO2 flow electrolyzer. Fu et al. (DOI: 10.1039/d1re00001b) pointed out that the direct reduction of CO2 to multi-carbon (C2+) products suffers from low activity in non-alkaline electrolyte or problems with electrolyte degradation caused carbonate formation in alkaline electrolyte. They reviewed the potential a two-step process for CO<sub>2</sub>

electroreduction circumventing such problems by converting CO2 to CO (the first step) in the non-alkaline electrolyte and promoting the rate of carbon-carbon coupling for CO-to-C2+ conversion (the second step) in alkaline electrolytes. Metal halide perovskite materials have emerged as one of the leading candidates for CO2 photoreduction due to their exceptional optoelectronic properties. Méndez-Galván et al. (DOI: 10.1039/ d1re00039j) found that it is possible to create, modify, improve, and finally enhance the photocatalytic activity of metal halide perovskites to reduce atmospheric CO2 concentrations. Some challenges must be addressed to develop technology further, such as identifying and quantifying the other reaction products, the influence of the process parameters, and kinetics. Mo<sub>2</sub>C/ TiO<sub>2</sub> represents another promising catalyst with enhanced visible-light photoreduction of  $CO_2$  to methanol (DOI: 10.1039/d0re00376j). Thatikayala *et al.* (DOI: 10.1039/d1re00166c) revealed that  $CO_2$  can be converted into volatile fatty acids through microbial electrosynthesis (MES) in a single chamber reactor. Ozorio *et al.* (DOI: 10.1039/d1re00036e) reported that  $CO_2$  could react with styrene oxide to cyclic organic carbonates over appropriate catalysts.

In this themed collection, we showcase the global efforts on CCUS as an issue of worldwide concern, the diverse chemistry engineering approaches that are being used. Herein, we would like to thank all the contributors for their nice submissions to this themed collection. We hope this successful themed collection will encourage the future expansion of this impactful research area and eventually make an impact on the goal of carbon neutrality.