Editorial overview Innovative methods in CO2 conversion: A breath of fresh air?

Liangnian He, Thibault Cantat

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Innovative methods in CO_2 conversion: A breath of fresh air?

In December 2015, the United Nations conference on climate change (COP21) has brought public awareness on the steps required to slow down global warming. It has also set a framework to mitigate climate change by agreeing on 17 Sustainable development goals, including goal 13: "Take urgent action to combat climate change and its impacts". As this editorial is being written, major countries are ratifying the Agreement.

Anthropogenic emissions of carbon dioxide have increased by almost 50 per cent since 1990 and human activities today release 34 Gt CO_2 per year in the biosphere, with half of them accumulating in the atmosphere. While this abundance of CO_2 can be seen as an opportunity for production of carbon-based materials and chemicals, the thermodynamic and kinetic stability of this waste compound represents a tremendous hurdle in its transformation.

Whereas CO_2 Capture and Storage (CCS) could provide a meaningful way to reduce CO_2 emissions in the atmosphere, this strategy is not economically sustainable, in the absence of strong and reliable political incentives and subsidies. In contrast, the recycling of CO_2 in the form of valuable compounds (namely CCU – CO_2 Capture and Utilization) today represents the first approach implemented in the industry. Indeed, ca. 200 Mt/yr CO_2 are currently utilized to produce urea (Bosch-Meiser process), cyclic and polymeric carbonates and salicylic acid (Kolbe-Schmitt process), corresponding to only 0.6 % CO_2 being recycled. Much efforts are being focused by chemists worldwide, both in the academy and in the industry, to increase this tiny contribution and, in this issue, we have brought together some of the latest research on the best ways to capture and use waste CO_2.

Large-scale production using CO_2 in the industry would be a fascinating dream for synthetic chemists and the realization of such an objective necessitates the design of efficacious catalysts able to promote the activation and cleavage of the strong C–O bonds in CO_2. In this respect, mechanistic insights at the molecular level and efficient system and process models are invaluable. As a cost-efficient, non-toxic and sustainable carbon feedstock, CO_2 is an attractive raw material as a C1-building block for chemicals and materials but also as an energy vector.

The reduction of CO_2 to energetic compounds, such as CO, formic acid, methanol and light hydrocarbons, is of paramount importance to reduce our dependence to fossil fuels. This goal strongly depends on the elaboration of active and stable electro- and/or photo-catalysts, able to convert renewable energies into chemical energy, for example by mimicking photosynthesis. It could be achieved by using solar energy, wind energy, biomass-based energy, and development of advanced technologies using water or biomass as a hydrogen source.

If a source of low carbon energy is available, CO_2 reduction can be explored and **Guoxiong Wang** and **co-workers** consider its transformation by electrolysis using nanostructured heterogeneous catalysts. Like several of the other methods described, this research is still in

its early stages and is not yet a viable method for CO_2 use. For those wanting to avoid the use of metals, **Frédéric-Georges Fontaine** and **Douglas Stephan** offer an overview of CO_2 activation and reduction methods under metal-free conditions, to convert CO_2 to C1 synthons. **Bryony Ashford** and **Xin Tu** discuss another option: non-thermal plasma techniques. Although depending on electricity, plasma shows great potential. Even without high temperatures and/or pressure the dissociation of CO_2 can be promoted to obtain reduced products.

Before it can be used as a raw material, carbon dioxide has to be captured. **Xiaoyan Luo and Congmin Wang** describe a method of carbon dioxide capture using ionic liquids, an alternative to the better known use of an aqueous solution of amine. **Huanfeng Jiang and co-workers** discuss some of the products that can be made using a C1 synthon. **Shunjie Liu** and **Xianhong Wang** detail some polymers that can be produced using CO_2.

Cyclic carbonates are a starting chemical for polymers and are a promising use for CO_2. **Saptal** and **Bhanage** describe the heterogeneous catalysts being developed to convert CO_2 to cyclic carbonates**. José Enrique Gómez** and **Arjan Kleij** elaborate on the synthesis of cyclic carbonates using stereochemistry. **Bo Zou** and **Changwen Hu** look at alternative, green methods to produce these chemicals that are free of halogens. Beyond the formation of carbonates, **Hisanori Senboku** and **Asahi Katayama** describe electrochemical methods of producing carboxylic acids, while **Liang Zhang and Zhaomin Hou** consider the carboxylation of unsaturated substrates, such as alkenes, alkynes and allenes, using CO_2 and transition metal catalysts

This issue provides an insight into some of the areas being explored at the moment but there are definitely more discoveries to be made. The successful capture and utilization of CO_2 will rely on merging talents and efforts in a variety of research and engineering fields, including homogeneous and heterogeneous catalysis, (photo)electrochemistry, materials sciences, organic and inorganic chemistry and computational chemistry. We hope that you enjoy reading these reviews and, who knows, maybe they will encourage you to join the challenge of CO_2 recycling.

Liangnian He

Prof. He obtained a doctorate in Chemistry from Nankai University. Currently, Dr. He is a Professor of Chemistry at Nankai University, a Fellow of the Royal Society of Chemistry. Prof. He has authored over 190 scientific publications and held 21 patents. He edited 12 books and chapters, delivered more than 60 invited lectures at international conferences. Prof. He is also on the editorial board of dozens of international scientific journals. His research is centred on CO_2 chemistry, green synthetic chemistry, catalysis in green solvent and biomass conversion (castor-based energy), particularly catalytic transformation of CO_2 into fuels and

value-added chemicals as well as CO_2 capture and utilization, green technology related to desulfurization.

Thibault Cantat

Dr. Thibault Cantat is Senior Expert at the French Alternative Energies and Atomic Energy Commission (CEA). He did his undergraduate studies at the École Normale Supérieure de Paris and completed his Ph.D. at the École Polytechnique in 2007, working on the theoretical and experimental aspects of new organometallic complexes and their use in catalysis. Dr Cantat was then appointed a Director's Postdoctoral Fellow at Los Alamos National Laboratory (USA) to work in the groups of Dr. Jaqueline L. Kiplinger (experimental f-element chemistry) and Drs. P. Jeffrey Hay and Enrique R. Batista (theoretical chemistry). The general topic of his research is the development of novel catalytic reactions for the efficient reduction of CO_2 and biomass. His research interests therefore span organometallic chemistry of the transition metals and the *f*–elements to homogenous catalysis and computational chemistry.