



Editorial: Beyond Current Research Trends in CO₂ Utilization

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Editorial on the Research Topic

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The Carbon Circular Economy-CCE is a key component of the strategy for sustainable, climate-neutral growth of our society. CCE encompasses carbon management in all its forms and fields of application (energy sector, all manufacturing sectors including the chemical industry, agriculture and related practices, civil life) for an efficient reduction strategy that minimizes the emission of greenhouse gases (GHGs), and CO₂ in particular, in all anthropic activities.

Carbon Dioxide emissions reduction is under particular pressure these days as CO₂ is considered the origin of climate change. In our opinion, the protagonist of the extreme events we are observing of late (tornados, floodings and fires, desertification, and rising oceans) is the inefficient use we make of fossil-C that causes over 65% of the energy to be released in the form of heat to the atmosphere, in addition to too high emissions of all GHGs, including water vapor.

The reduction of CO₂ emissions can be achieved primarily by reducing the consumption of fossil-C, and by changing primary energy sources or adopting a Nature-like strategy: the recycling of carbon.

The use of Renewable Carbon is a major attitude shift, and this stopping the linear model of taking fossil-C (formed over millions of years) and releasing CO₂ (a spent form of carbon). Human intelligence must discover ways to develop a man-made Carbon Cycle, that can complement the natural one, one even more efficient in terms of rate and selectivity of processes. Vegetal plants make what they need, and a man-made carbon cycle can make what humans need: energy products, or alternatively molecular compounds necessary for everyday life, or else other materials. Nature uses the sun to power the synthetic processes; we can use sun, wind, hydropower, geothermal energy-SWHG, all C-free, perennial sources, to power synthetic processes. We call SWHG sources perennial as have always existed and will continue to exist in the future for as long as our planet does. We prefer to reserve the term *renewable* for biomass.

The cost of the change is high, as all technologies based on C-free perennial energy sources and even on renewable energy sources (biomass) are more costly than technologies based on fossil-C, and less efficient. Over two hundred years of Chemical Industry based on fossil-C has developed efficient syntheses for a single target product. Technologies based on perennial energies are much younger and need to develop and mature.

However, carbon recycling can be performed by Nature-based systems (growing any kind of biomass) or by man-made systems, e.g., by converting CO₂ into chemicals, materials, and fuels. Biomass-based products are already on the market, CO₂ based products must be developed in a legal frame and become accepted by the public. This will take time and education.

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Nevertheless, it is time to implement CO₂ utilization if we wish to reduce the use of fossil-C. Biomass alone cannot satisfy the needs of human beings (being limited by growth rate and amount). Complementing biomass with industrial processes may help to find a valid solution.

This Research Topic is devoted to making the point on what we do with CO₂ and what we could do if perennial energy sources were available at a low cost. Most likely, by 2050 innovative synthetic strategies based on CO₂ will be performing at high efficiency.

In Chapter 1 (Aresta and Dibenedetto), a perspective on future utilization of CO₂ is outlined, highlighting barriers and ways to get around them. Any use of CO₂ requires its availability: therefore, Chapter 2 (Wang and Song) makes the point on established techniques for CO₂-capture and discusses the capture from air, where CO₂ is present at a low concentration (410 ppm at present), but will guarantee its availability forever (fossil-C availability is finite). Chapter 3 (Bacocchi and Costa) presents a way to fix CO₂ into materials that have a long lifetime: such materials are like natural rocks that sequester CO₂, and the technology does not integrate into the circular economy: it is more functional to the linear economy for carbon dioxide sequestration. Chapter 4 (Zhang et al.) discusses the conversion of CO₂ into methanol, a chemical with rich chemistry and an energy product at the same time (usable if fuel cells and mixed with gasoline in cars). Chapter 5 (Centi et al.) is a complementary aspect of methanol synthesis as it makes a point on the economics of methanol production. As mentioned above, fossil-C substitution will raise costs issues as today fossil-C is a cheap source of raw materials and processes are optimized for both investment and operational costs, CAPEX and OPEX, respectively. Chapter 6 (Bogaerts and Centi) presents plasma technology for CO₂ conversion, highlighting how fluctuating renewable energy can be used and stored as chemical energy. Chapter 7 (Tomishige et al.) exemplifies the use of CO₂ in the production of large market chemicals, namely organic carbonates that may find application in several sectors such as solvents, raw materials, monomers for polymers, a medium in

lithium batteries, etc. Chapter 8 (Kondaveeti et al.) introduces new systems for CO₂ conversion, e.g., biosystems coupled to electricity. This is an attractive new area that can contribute to CO₂ utilization on a large scale making a variety of products according to the bio-system (microorganism) used. Chapter 9 (Gerotto et al.) makes light on the organisms in Nature which convert CO₂ the fastest: microalgae, a fascinating world that has a great potential for application in the synthesis of fuels or chemicals or materials. Finally, Chapter 10 (Kumar et al.) opens a window on the use of biomass highlighting problems that are around when one wishes to use such raw materials as a source of chemicals or energy.

All together, this book presents interesting aspects of the potential of carbon recycling, and the difficulties that one encounters when facing such stimulating and innovative technology, barriers to full exploitation of the strategy, and how to go around them.

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The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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