



ENI AWARD 2024

Energy Transition

Marc Fontecave

Winner

Utilization of CO₂ and CO: Catalysts and Devices for Production of Hydrocarbons and Alcohols

Research Description

Carbon dioxide (CO₂), captured from point sources (power plants, cementeries, steel factories) or from the atmosphere, is one promising alternative to fossil carbon sources. Such a scenario depends on the development of cheap and efficient technologies for the conversion of CO₂ into energy-dense carbon compounds, notably hydrocarbons and alcohols, useful for industry, transport, heat generation, etc... Interestingly, these products may be considered as carbon-neutral since their combustion emits CO₂ previously diverted from the atmosphere. Among these technologies, direct electrolysis of CO₂, and of its derivative carbon monoxide (CO), is the matter of intense research in academic and industrial laboratories. It consists into the reduction of CO₂ (or CO) into hydrocarbons, such as ethylene, or alcohols, such as ethanol and propanol, at the cathode of the electrolyzer and the oxidation of water into oxygen at the anode. The requested energy is provided by electrical sources, ideally low-carbon (for example solar energy, via coupling solar panels to the electrolyser). Since these reactions are kinetically limited, catalysts are absolutely needed both at the cathode and the anode. Marc Fontecave research has led to major achievements in the development of catalysts with exquisite performances (efficiency, selectivity, stability) and optimized electrolyzers with the highest energy efficiencies. This was operated via an original, multidisciplinary, both fundamental and technological, approach. On the catalysis front, both original bioinspired molecular complexes and heterogeneous materials have been discovered, while on the electrolyzer front, various cell configurations (liquid vs gas phase; H-cells, flow cells with gas diffusion electrodes, membrane electrode assemblies, pressure cells) and reaction conditions (membranes, electrolytes, pressure) have been explored. Fontecave laboratory has managed the whole chain from synthesis (molecules and materials), cell engineering to functional characterization. One can mention: (i) the

first active bioinspired molecular catalysts, namely dithiolene-metal complexes mimicking the active sites of formate- and CO-dehydrogenases; (ii) the discovery of single atom catalysts for ethanol production; (iii) molecularly modified Cu surfaces for improving selectivity; (iv) selective copper nitride-derived catalysts for CO reduction to ethylene and propanol; (v) photovoltaics/electrolyzer systems for solar hydrocarbon production with a record efficiency; (vi) acidic CO₂ electrolysis with high (> 85%) utilization of CO₂; (vii) water oxidation catalysts for the anode with record performances. Such achievements are seen as being at the forefront of innovation in catalysis. Industrial applicability is one of the objectives of the above-mentioned highly patented discoveries. The development of industrially-relevant electrolyzers is carried out in collaboration with a number of industrial partners (in particular TotalEnergies and Veolia). Marc Fontecave's innovation in new catalysts (non noble metals) and devices (high current densities and low voltages) for CO₂/CO utilization is essential to sustainably defossilize the society via the production of key precursors for the chemical industry at low cost and low carbon footprint, thus arousing enthusiastic industrial interest.