Taking charge of carbon capture: electrochemical strategies for reduction of greenhouse gas emissions

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Anthropogenic carbon dioxide (CO₂) in the Earth’s atmosphere has been cited as a primary cause of global climate change and threatens global public health and welfare. Carbon Capture and Sequestration (CCS) is an effective and important part of CO₂ emission abatement strategies, with the major CCS efforts to date focusing on the removal of CO₂ directly from large-scale carbon emitters and storing it in secure geologic reservoirs. Thermal-swing operations using aqueous base scrubbing followed by stripping at elevated temperature have been the chemical sorption processes most investigated over the past two decades for CO₂ capture. Considerable quantities of steam and heat are required to release the CO₂ after capture at low temperatures, and substantial parasitic energy losses result from the need to use excess steam and heat in order to meet the kinetic requirements of the process.

Electrochemically mediated separations offer a nearly isothermal alternative to the thermal-swing separation strategies typically used for CO₂ capture. The driving force in these systems is supplied by changes in electrochemical potential to modulate the redox state of an active species and thereby mediate the complexation of the sorbents with CO₂. These potential swings can be controlled precisely to reduce energy losses. We will discuss the operational concepts of three different strategies that exploit the isothermal electrochemical switching of separation conditions, covering adsorption, absorption and membrane processes for the capture and release of CO₂ from flue gas and other emissions. The underlying physicochemical thermodynamic and transport behavior of these systems will be discussed, and an overall assessment of their potential for use in large-scale applications given.