



## On Carbon Capture and Conversion (or C<sup>3</sup>): The Power of Cubed

**E**nergy production from the combustion of fossil fuels results in greenhouse gas emissions (GGEs), a chief contributor among them being CO<sub>2</sub>. Public awareness and legislation continue to drive a policy of reducing GGEs in many countries although some may argue that not enough is being done. Much discussion and R&D have also centered on displacing fossil fuels with renewable energy sources. However, at least three factors will make this shift gradual rather than abrupt: (a) new discoveries of significant petroleum reserves and the current glut in natural gas supplies; (b) the inability of renewable energy to compete with fossil fuels in terms of utility costs (the so-called grid parity); and (c) the intermittency of renewable energy sources that demand new storage technologies to enable their electric power grid integration. Thus the immediate-to-intermediate energy demand is likely to be met by conventional fossil fuel combustion with increasing levels of emissions control as dictated by environmental regulations.

Of all the strategies for reducing GGEs from fossil fuel combustion systems, those based on carbon capture are likely to have the most impact. On the other hand, the so-called carbon capture and storage (CCS), based either on the use of sorbent materials or sequestration in underground and marine reservoirs, is largely a passive approach. Chemical sorption based on the use of materials such as CaO suffers from the fact it relies on an equilibrium process and thus requires the use of process temperatures, significantly above the ambient. Deposition in either ground or marine reservoirs may have unforeseen (and drastic) consequences related to salinity changes, impact on aquatic life, etc. Injecting CO<sub>2</sub> into depleted oil or gas-bearing fields for enhanced oil or natural gas recovery does have the virtue of putting a waste chemical to good end use. This approach obviously is less passive than simple burial or chemical conversion to an insoluble carbonate mineral.

We can go one step further and consider carbon capture coupled with its conversion to liquid fuel, what I refer to above as Carbon Capture and Conversion or C<sup>3</sup> group of technologies. There are many variants on this theme and conversion is the key, not to an inert product with low economic value (such as a carbonate mineral) but to a value-added product. For example, there is widespread interest in coupling the CO<sub>2</sub> captured (for example on a microporous polymer) with epoxides to form cyclic carbonate with applicability in the pharmaceutical or fine chemical industry sectors. Conversion to a liquid fuel has the most appeal (at least to me), and this strategy has the added virtue of being a closed, sustainable loop. For example, burning methanol generates CO<sub>2</sub> and water; recombining CO<sub>2</sub> and water to regenerate methanol closes the loop. This approach is akin to the much-discussed water splitting energy scheme (for example, see articles featured in the summer 2013 issue of this magazine) but unlike hydrogen, liquid fuels such as methanol do not pose problems associated with volumetric energy density, storage, and distribution infrastructure issues.

There are many approaches for converting CO<sub>2</sub> to liquid fuels, but I am in favor of those based on the use of sunlight and an inorganic semiconductor (such as Cu<sub>x</sub>O, derived from earth-abundant elements). Electrochemical conversion (reduction) of CO<sub>2</sub> to products such as methanol has been intensely researched, but where is the electricity to come from? If it is fossil-derived, then the approach would have less appeal relative to a solar-based approach, from a lifecycle (“well-to-wheels”) analysis perspective. One can always couple a solar photovoltaic panel to a CO<sub>2</sub> conversion reactor but an integrated system such as the solar photoelectrochemical approach based on a semiconductor electrode has several redeeming features. Nonetheless, process efficiencies and material stability issues have to be further improved before implementation of C<sup>3</sup> technologies on the scale needed to make real impact becomes viable. Stay tuned.

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