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Perspective

You can't have an Energy Revolution without Transforming Advances in Materials, Chemistry and Catalysis into Policy Change and Action

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Broader Context Box

A very enticing renewable energy technology of the future involves the transformation of CO_2-to-Fuel. If the science underpinning this technology can be reduced to practice at an industrial scale and proven to be cost competitive with fossil fuel resources, it will help relieve the energy-hungry global dilemma for clean fuels, ameliorate the greenhouse gas climate concerns facing humanity, and bring forth an much desired energy revolution. Undoubtedly, whatever approach is adopted to enable a viable CO2-to-Fuel technology, exemplified by solar thermal, photothermal, photocatalysis, electrocatalysis, photoelectrochemistry methodologies, groundbreaking advances in fundamental and applied materials, chemistry and catalysis will be the key scientific drivers responsible for accelerating improvements in mass and energy efficiency and economic flows in the process. However, for an envisioned CO2-to-Fuel energy revolution these groundbreaking advances will have to be transformed into policy change and action to help solve what currently looks like an insolvable global problem.

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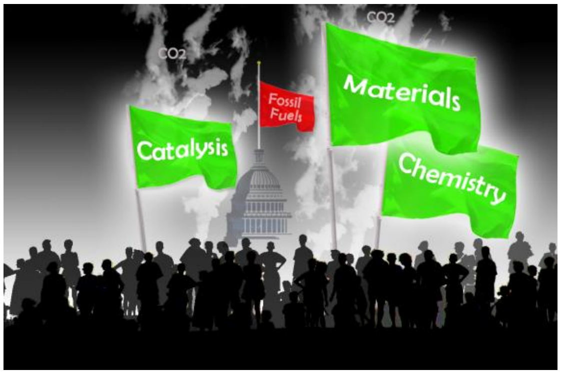

CO2-to-Fuel, an emerging area of renewable energy research, will require radical policy change and action to enable its implementation globally.

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You can’t have an Energy Revolution without Materials, Chemistry and Catalysis, Policy Change and Action; Graphic image courtesy of Chenxi Qian.

Abstract The central postulate of this Perspective is that CO_2 is not to be regarded as a combustion waste product of fossil fuel but rather to be considered as a chemical resource to be harvested and recycled to a renewable fuel using the power of the sun and the assistance of a catalyst. This vision reminds me of a prescient quote in a Life Magazine interview by Richard Buckminster Fuller, American philosopher, systems theorist, architect and inventor, who said: “***Pollution is nothing but resources we're not harvesting. We allow them to disperse because we've been ignorant of their value. But if we got onto a planning basis, the government could trap pollutants in the stacks and spillages and get back more money than this would cost out of the stockpiled chemistries they'd be collecting***” [1].In this context I have been pondering how the grand challenge faced by the materials research community of creating the science and technology to enable the transformation of CO_2-to-fuel at a globally significant rate, efficiency and scale, necessary to help solve what looks like an insolvable global problem, is related to policy change and action?

Because CO_2 is the thermodynamic product of all fossil combustion processes, its efficient conversion back to an energy-rich fuel by thermochemical, electrochemical, photoelectrochemical or photochemical means, requires the use of a catalyst. Synthesis of a champion CO_2-to-fuels catalyst requires an in-depth understanding of how the structure, properties and activity relate to each other to make it work efficiently.

Catalysts are an essential part of our modern society forming the bedrock for manufacturing a myriad of industrial chemicals and products. Catalyzed chemical reactions are also ubiquitous in nature driving many important biochemical processes and have been widely applied in the chemical industry. By definition, a catalyst accelerates the rate of a chemical reaction by reducing its activation energy without being consumed in the process.

While catalysis can be traced to the rise of civilization with the fermentation of alcohol, it rose to prominence with the seminal work of Sabatier in 1890-1920 on hydrogenation catalysis, which set the ground-work for the evolution of both heterogeneous and homogeneous catalysis that we now depend on today.

A deeper understanding of the physicochemical principles of catalysis began to take shape in the 20th century, emerging with the industrial scale production of bulk chemicals, notably ammonia for fertilizers and explosives, synthetic hydrocarbons for fuels, and methanol for the manufacture of a myriad of base chemicals. It was only when the need for explosives receded at the end of the First World War that industry turned its attention to the catalytic production of synthetic chemicals and fuels which powered the Second World War.

After the Second World War ended many new catalyst materials were being invented and catalytic processes developed, exemplified by the petrochemical industry for the high volume production of chemicals, fuels and polymers, by the pharmaceutical industry where catalysis was employed to make fine chemicals for medical applications, by the automobile industry for manufacturing exhaust gas catalysts for catalytic converters, and recently by the use of enzymatic bio-catalysis, for example in the bio-fuel, detergent, food, dairy, brewing and paper industries.

This brief backdrop on the history of chemistry and catalysis from ancient to modern times provides a preview to the next era of catalysis that marks the revolutionary vision for a sustainable-fuel future in the 21st century based on a CO_2 economy. We are now well aware of the deleterious effects of the continuous emission of CO_2 on our climate from burning fossil fuels to power our industries, energize our commercial sectors, run our transportation and heat our homes. Through catalysis of CO_2 reactions we can now envision an economically viable and secure energy supply, where CO_2 is treated not as a waste product, but rather as a valuable and bountiful chemical feedstock for making renewable fuels in a CO_2-to-fuel carbon neutral catalytic cycle.

Ideas and practice on CO_2-to-fuel catalysis have been published in detail earlier and will not be further elaborated upon in this article but rather the remaining discussion will be focused on the challenging transformation of the basic science of CO_2-to-fuels to policy and industry implementation [2,3].

Seen in this new light, the CO_2 molecule is also, critically, the key driver of a clean-tech energy-innovation sector with goals that have been set out in renewed Science, Technology & Innovation Strategies of many countries. For fossil-rich countries this strategy stresses a gradual shift away from dependency on its unsustainable fossil resource economy with its growing greenhouse gas emissions, which points to the validity and currency of developing a sustainable CO_2-to-fuel conversion strategy as an alternative to continuing the current practice.

The leading scientists and institutions of many countries increasingly recognize that renewable-energy systems do not represent a single-pronged approach, depending solely, for example, on feeding renewable sources of electrical energy into the grid. Most importantly, they recognize the urgency of reducing greenhouse gases. However, they're uncertain about the most effective and efficient way to implement the reduction. These challenges are heightened by the fact that developing economic and environmental solutions are not confined to discrete countries but, rather, are the concerns of all countries.

These countries are seeking bold but pragmatic solutions with the greatest short-term and long-term impact, despite the complexity of this research concept.

The whole enterprise includes putting forward to politicians and governments this CO_2-to-fuel conversion strategy and persuading them to adopt it as a goal. At the same time, the public should be informed and educated that this strategy is a viable economic and environmental solution to reduce greenhouse gases.

Many stakeholders have their sights on a "solar refinery" as one potential central energy strategy. This refinery system would offer "platform molecules" such as CO, CH_4 and CH_3OH, to store renewable solar energy in the form of chemical bonds, using CO_2 as a carbon source [4]. These ambitions are at the conceptual stage globally. Nevertheless they come with feasible strategic plans for implementing these CO_2 refineries, for example in the case of Germany [5], which aims to demonstrate this new refinery system.

Fortunately, forward-looking teams of scientists and engineers internationally sense the importance of such a breakthrough that builds on technologically significant CO_2 conversion efficiencies. Their collective vision continues to inspire and forge essential global research collaborations committed to moving mutually beneficial discoveries forward to enable a sustainable CO_2-neutral renewable-fuels economy.

Further, in a recent study the Global Carbon Capture and Storage Institute concluded that once the economic and technical feasibility of producing hydrocarbon fuels from CO_2 is demonstrated, this could well accelerate the growth of carbon capture and sequestration and catalyze its mature commercial exploitation in the production of energy rich fuels [6].

Teams of academic and industry collaborators around the world are devoting considerable time and expertise to realize the dream of a CO_2 economy. They envision the intersection of materials, chemistry and catalysis with process engineering and systems research for these large-scale types of projects. It is becoming increasingly apparent that the solar refinery of the future cannot be limited to the historical approach of aqueous-phase biomimetics, which is often characterized by low CO_2-to-fuels conversion efficiencies [7]. A shift to gas-phase heterogeneous catalysis is occurring and looks promising in terms of its ability to deliver high CO_2-to-fuel conversion efficiencies with the added advantage of being able to interface seamlessly with existing chemical and petrochemical industrial infrastructure [2,3].

In order to benefit from this necessary global enterprise, new working relationships between academic and industrial collaborators and competitors will need to be developed and implemented. This can be achieved through joint research projects, co-publication and knowledge dissemination, which involve elevating key international players' profiles in the paradigm shift. Through shared IP agreements with academic and, later, industrial collaborators and trustworthy licensees who share similar codes of ethics, all of this can be accomplished rapidly, further actualizing this paradigm shift.

Knowledge dissemination also includes making the global CO_2-to-fuel paradigm known to politicians and the public. The most effective way to catch their attention would be by demonstrating a working pilot solar refinery that shows it has the potential to ultimately be economically viable.

This "pipeline" for CO_2-to-fuels knowledge dissemination should greatly increase the capacity to inform policy in individual countries, validated by basic and translational science across countries. As such, CO_2-to-fuels teams around the world will become key players who enable a future strategic global economy in the new paradigm, both in research and development, and in the advanced training of a world-leading talent pool to enable a CO_2-to-fuels economy.

Currently this "pipeline" seems to be extremely scattered in its aim and there needs to be more coordination. However, teams pursuing the "holy grail" of CO_2-to-fuels conversion efficiency do not want to miss out on the prestige of being the one that succeeds and therefore at the moment no one really wants to coordinate in knowledge dissemination if that means another teams unfairly gets the glory.

This renewable energy revolution will not however be possible without chemistry, materials and catalysis research. These are the science and engineering disciplines that underpin the discovery of catalytically active materials and facilitate the chemical transformation of CO_2 to stored energy in the chemical bonds of CH_4 and CH_3OH at rates, efficiencies and scales required for large volume production of fuel from CO_2.

Consider a historical perspective on some energy related world-changing breakthroughs: the first practical solar cell is only a 60-year-old story; the first practical light-emitting diode (LED) is 50 years old; the past 40 years has seen aqueous-based photocatalysis to convert light and/or electricity into an energy-rich fuel.

None of these problems has been simple, and all of these breakthroughs have relied on the unique physical and chemical properties of semiconductors. In fact, nanostructured forms of semiconductors are precisely what a materials solution for the CO_2 economy will depend upon. It will likely be predicated upon a gas-phase conversion of a CO_2-to-fuel system rooted in existing combustion driven, heterogeneous catalytic processes that, together with the renewable power of light and/or heat, will now outperform nature's leaf in accommodating the sheer volume of CO_2 available to be exploited.

Recently several promising candidate materials and thermocatalytic, electrocatalytic and photocatalytic processes have been discovered for the move forward to the energy revolution that will identify the winning nanoscale materials and catalytic reactors as the key to CO_2 conversion efficiency success and overall process cost [2,3,7-11].

One overarching fact that can spur this revolution fast forward: the world is currently consuming about 400 Quads per year of energy from all fossil fuels sources (1 Quad = 1.1×10^6 TJ = 0.033 TW-year = 1×10^9 MBTU = 172MBOE). This is equivalent to about 70 billion barrels of oil which translates into about 20 billion ton equivalents of CO_2 emitted into the atmosphere per year.

The world's energy needs are projected to double by 2030. If one is to stabilize the expected level of CO_2 in our atmosphere in the next couple of decades then the sum total of all kinds of CO_2 refineries around the globe will have to cope with CO_2-to-fuel conversion rates of 20-40 billions of tons per year.

The opportunity for a revolutionary change could be made to happen in practice however research efforts on converting CO_2-to-fuel are currently scattered amongst isolated groups around the world, and information and education about these research projects are not targeted at policy makers and the public in an effective way, which is unnecessarily delaying the transition. A global CO_2-to-fuel initiative is needed to solve this global challenge. Clearly reducing this vision to practice would represent an energy revolution, which is not likely to occur without materials, chemistry and catalysis, policy change and action!

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