Energy and Resources
Solar Energy

Sunshine to Petrol

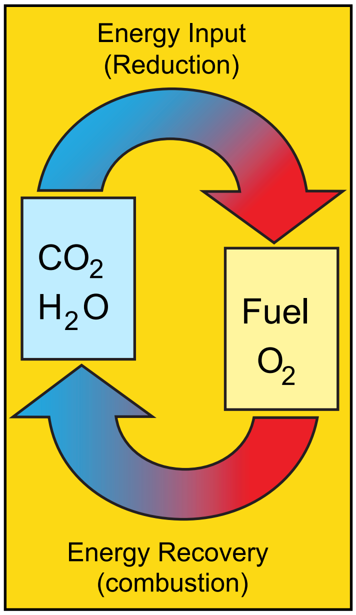

Figure 1: The S2P process incorporates CO_2 into the vision for the Hydrogen Economy powered by the sun.

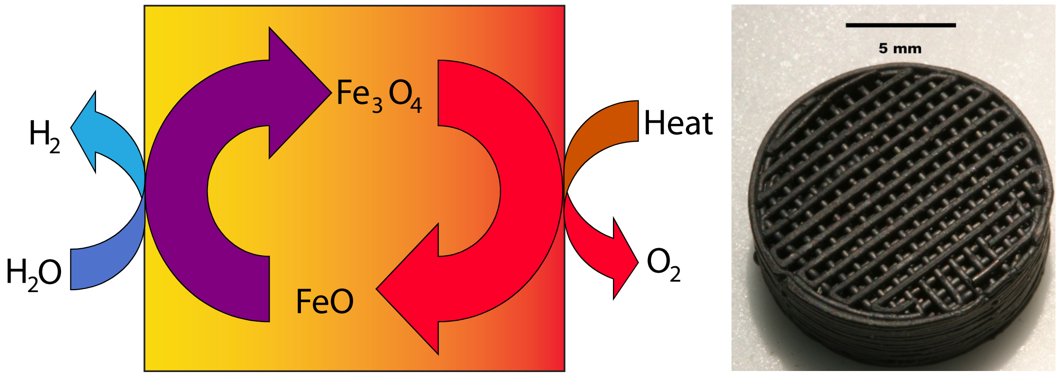

Figure 2: Left: The iron oxide or ferrite cycle is the archetype of metal-oxide thermochemical cycles. The CR5 prototype employs mixed-metal cobalt ferrites supported in a zirconia matrix. In one chamber concentrated solar irradiation heats the ferrite to high temperature driving off oxygen. In the opposite chamber the oxygen deficient ferrite is exposed to CO_2 or H_2O at a lower temperature to produce CO or H_2. Heat is recuperated between the two reaction chambers by driving neighboring reactive rings countercurrent to one another. Right: Monolithic laboratory test sample fabricated directly from a cobalt ferrite/YSZ composite. Lattice structure provides high geometric surface area area. (Scale bar = 5mm)

High efficiency thermochemical heat engine for production of synthetic fuels

Solar irradiation is the only sustainable energy source of a magnitude sufficient to meet projections for global energy demand. Solar fuels (i.e., fuels created from sunlight, carbon dioxide, and water) are especially attractive as they impact not only energy production and climate change, but also energy storage and energy security. Applying a solar energy source to chemically "reverse combustion" and produce liquid hydrocarbon fuels that are compatible with our current infrastructure from CO_2 and H_2O (Figure 1) is an extension of the hydrogen economy that is analogous to the process of photosynthesis. However, by directly applying concentrating solar power to the problem of splitting CO_2 and H_2O to produce CO and H_2, the basic energy-rich building blocks of synthetic liquid fuels, Sandia researchers are optimistic that sunlight-to-fuel efficiencies will be significantly improved. The researchers call this unique approach of re-imagining the transportation fuel paradigm "Sunshine to Petrol" or S2P.

The heart of the S2P process is a unique metal-oxide-based thermochemical heat engine, the Counter-Rotating-Ring Receiver Reactor Recuperator, or CR5. Within the engine, rings of a reactive solid are thermally and chemically cycled to produce O_2 and CO or H_2 from CO_2 or H_2O in separate and isolated steps (Figure 2). These steps require high temperatures (ca. 1500 °C) that are achieved by concentrating solar power. The CR5 is a thermochemical analog to Stirling and Ericsson cycle heat engines and provides a framework for maximizing efficiency. Thus a key feature of the CR5 is the counter-current recuperation of heat between the high temperature O_2-generating thermal reduction of the metal oxide and the lower temperature H_2- or CO-producing oxidation of the metal oxide that improves the overall efficiency of the thermochemical process.

This CR5 is very demanding from a materials point of view. The active rings must maintain structural integrity and high reactivity after extensive thermal cycling.

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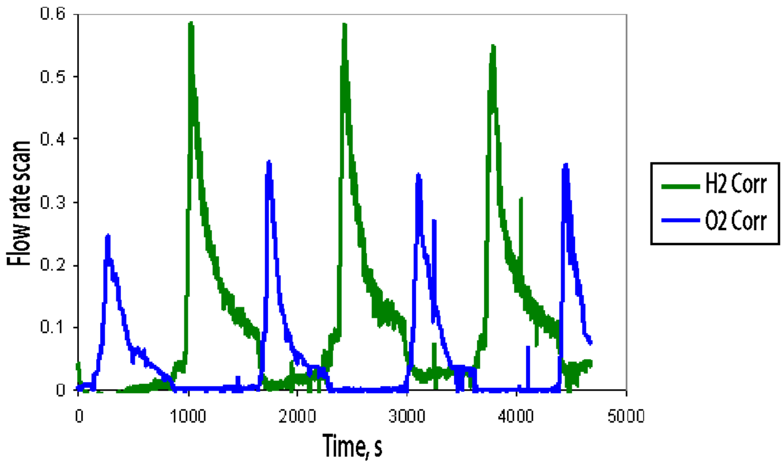

Figure 3: Hydrogen and oxygen are produced over successive cycles in a 2:1 ratio in a solar furnace evaluation of a cobalt ferrite/YSZ monolith (thermal reduction at 1580 °C, water oxidation at 1050 °C).

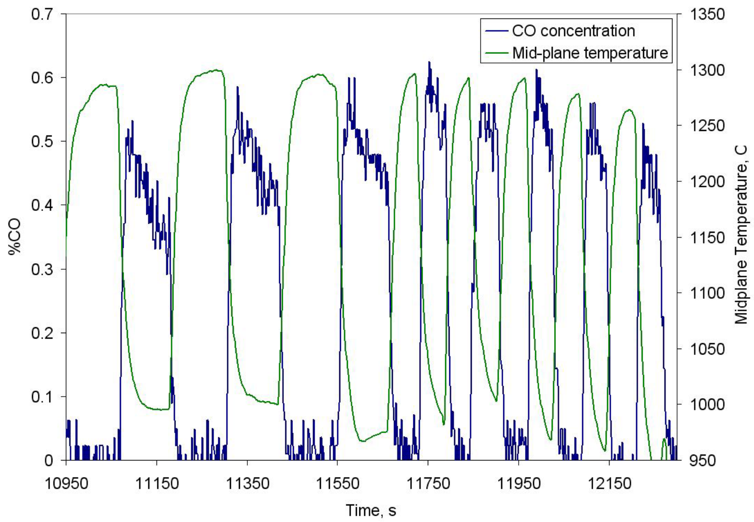

Figure 4: CO produced over a cobalt ferrite/YSZ monolith in a solar furnace evaluation. The data demonstrates that reduction times as brief as one minute are sufficient to yield CO when the monolith is subsequently contacted with CO_2.

In addition, the monolithic ring structures must have high geometric surface area for gas-solid contact and for adsorption of incident solar radiation. It was found that directly fabricating structures from the active components of cobalt ferrite and yttria-stabilized zirconia yields robust and active monolithic parts (Figure 2) that maintain productivity over tens of cycles of laboratory and solar testing (Figure 3). Furthermore, it has been demonstrated for the first time that CO_2 splitting to CO and O_2 can be conducted with both iron- and cerium-based materials in a cyclic manner (Figure 4). Testing of the CR5 prototype containing over 5kg of active materials will commence during the summer of 2008.

Reference:

James E. Miller, Mark D. Allendorf, Richard B. Diver, Lindsey R. Evans, Nathan P. Siegel, and John N. Stuecker "Metal Oxide Composites and Structures for Ultra-High Temperature Solar Thermochemical Cycles" J. Mater. Sci. (2008) 43:4714–4728.

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