Direct Approaches for Recycling Carbon Dioxide into Synthetic Fuel

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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Two Intertwined Problems:

Energy Security and Climate Change

Petroleum in the U.S. - DOE/EIA-0384 (2004)

Leading Petroleum Importers in 2003 (mbpd*)	
United States	11.2
Japan	5.5
Germany	2.5
China	2.0

Leading Exporters	
Persian Gulf	18.7
Russia	5.5
Norway	3.3
Venezuela	2.2

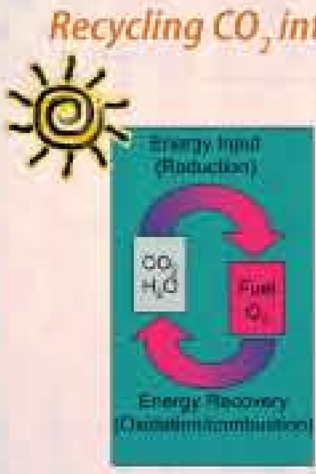
*millions of barrels per day

Roger Doyle, Scientific American, Sept. 2004

U.S. Petroleum imports are roughly equivalent to that consumed by the transportation sector.

More than 10 TW of clean energy worldwide are needed by 2050 to "stabilize" CO_2 levels.

Recycling CO_2 into Fuel



A Hydrogen Economy driven by persistent sources of energy (sunlight) offers a way out. But, by most measures, H_2 is inferior to liquid hydrocarbon fuels. Incorporating CO_2 recycle into the Hydrogen Economy preserves the Hydrocarbon Economy.

"Re-energizing" CO_2 and H_2O back into hydrocarbon form is equivalent to reversing combustion but is analogous to the photosynthetic processes that produce bio- and fossil-fuels.

$$\text{Sunlight} + CO_2 + H_2O \rightarrow \text{Fuel} + O_2$$

Approach

Path to Achieving Vision

Energy Efficiency (sunlight to fuel) is the key consideration

Nominal Equivalent Land Area Required to Produce 20 mbpd at a given efficiency

Sunlight to fuel efficiency assuming solar resource equivalent to Albuquerque ~ 2800 kWh/m²/yr

U.S. Petroleum consumption - 20 million bbls/day

Capitalize on Decades of Syngas ($CO + H_2$) Chemistry.

Key step is production of CO from CO_2 and H_2 from H_2O.

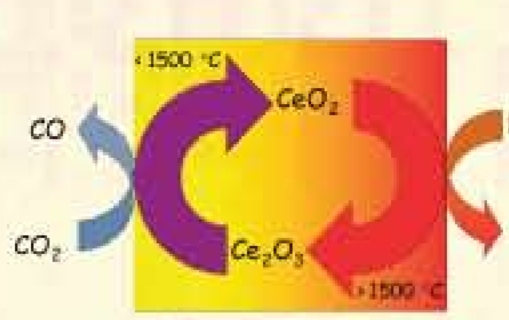
Thermochemistry avoids solar to electric conversion potentially boosting efficiency above electrolysis.

Solar-driven water electrolysis followed by reaction of H_2 with CO_2 sets the standard at ~ 5% efficiency.

Bioethanol routes currently < 1%.

Thermochemistry: Using Heat to Split CO_2

Unfavorable reaction split into two or more favorable reactions.



$CeO_2 \rightarrow Ce_2O_3 + O_2$
$Ce_2O_3 + CO_2 \rightarrow 2CeO_2 + CO$

A thermochemical cycle is essentially a heat engine that converts heat into work in the form of stored chemical energy.

In our case, the "working fluid" is a metal oxide compound.

High-end temperatures of ~1500 °C couple best with CSP.

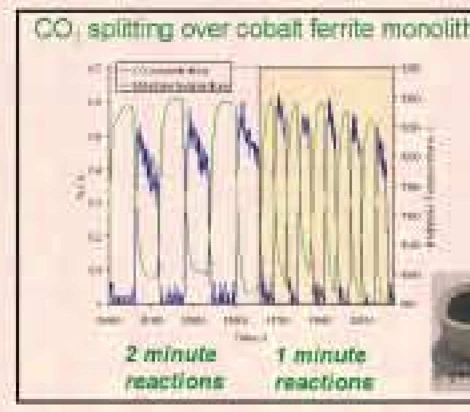
Efficiency gains are possible as conversion to mechanical work and electricity are avoided.

CO_2 splitting appears favorable relative to water.

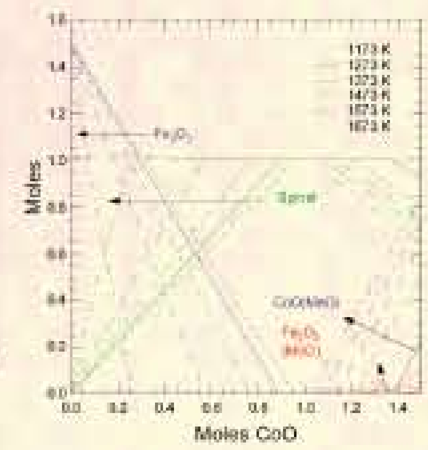
Results

Key Accomplishments

CO_2 splitting over cobalt ferrite monolith

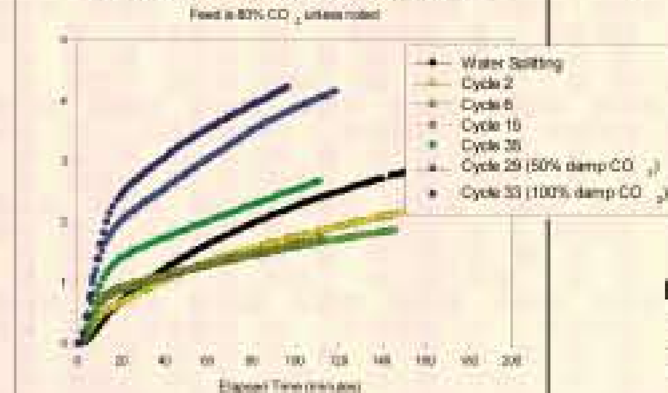


Demonstrated, for the first time, the cyclic re-energizing CO_2 splitting reaction via iron- and ceria-based thermochemical processes.



Applied thermodynamics to link the improvement in thermal reduction with metal substitution to the formation of mixed phases and to understand the effect of composition and temperature on phases.

Linked reaction of Fe and YSZ to improving performance over time (but not total yield) and established that combination of H_2O splitting and CO_2 splitting is superior to either alone.



Reaction of H_2O and CO_2 over reduced 5% Fe_2O_3/YSZ monolith.

CO production for different monolith configurations

Established that direct solar illumination is a path to high materials utilization.

CO_2 splitting will be demonstrated on-sun at the 9kW level in unique Counter-Rotating-Ring Receiver/Reactor/Recuperator designed for continuous and efficient operation.

Significance

Energy security and climate change will be the defining issues for the national laboratories, the nation, and the global community for the remainder of this century. The availability and price of transportation fuels is closely linked to our economic and national security. Addressing the challenge of creating a breakthrough technology for the production of transportation fuels is a task ideally suited for a multi-mission national laboratory with expertise in science, engineering, and systems analysis.

The application of sunlight to re-energize CO_2 is a key challenge that must be surmounted to solve the intertwined problems of accelerating energy demand and climate change. Thermochemical CO_2 splitting, a key step in CO_2 utilization, has been demonstrated, laying the foundation for the eventual efficient and sustainable production of transportation fuel from sunlight, carbon dioxide, and water.

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NNSA National Nuclear Security Administration

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