Reimagining Liquid Transportation Fuels: Sunshine to Petrol

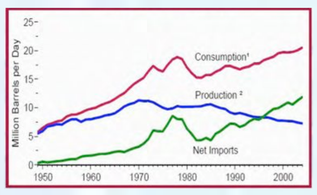
Sandia National Laboratories

James E. Miller, Ellen B. Stechel, Andrea Ambrosini, Eric N. Coker, Mark A. Rodriguez, Gary L Kellogg, Ivan Ermanoski, Mark D. Allendorf, Anthony H. McDaniel, Terry J. Garino, Stephanie Livers, Richard B. Diver, Nathan P. Siegel, Roy E. Hogan, Ken S. Chen, Daniel E. Dedrick, Terry A. Johnson, Gregory H. Evans, Chad L. Staiger

Problem

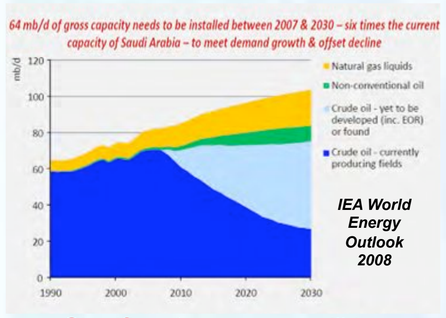
Two intertwined Problems: Energy Security and Climate Change

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



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

Costs include economic and strategic vulnerability, transfer of wealth, loss of opportunity



IEA World Energy Outlook 2008

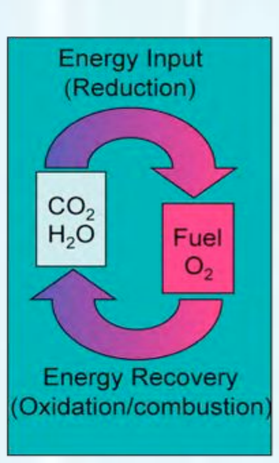
Significant resources will be expended even if we choose only to maintain the petroleum economy

Global energy consumption is currently about 14 TW. Accounting for growth, a similar level of carbon-neutral energy will need to be brought online by 2050 to "stabilize" CO_2 levels.

Lewis and Nocera, PNAS 103(43) 15729 (2006).

Approach

Recycling CO_2 into Fuel



A Hydrogen Economy driven by persistent sources of energy (sunlight) is one potential solution. But, by most measures H_2 is inferior to liquid hydrocarbon fuels. Incorporating CO_2 recycle into the Hydrogen Economy offers the benefits of the both the Hydrogen and Hydrocarbon Economies.

Applying solar energy directly to "re-energize" CO_2 and H_2O back into hydrocarbon form (via a syngas intermediate) is analogous to photosynthetic processes, but potentially more efficient.

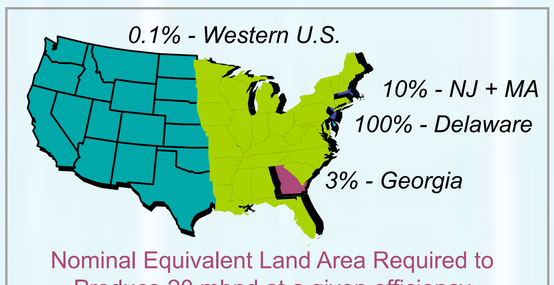
Capitalize on decades of Synfuel technology.

Sunlight + CO_2 + H_2O → CO + H_2 (+O_2) → Fuel (+ O_2)

Focus on the critical energy intensive conversions:

$4H_2O$ + energy → $4H_2$ + $2O_2$ (water splitting)
$2CO_2$ + energy → 2CO + O_2 (carbon dioxide splitting)
$2CO_2$ + $4H_2O$ + energy → 2CO + $4H_2$ + $3O_2$

And integrating in these into a efficient system powered by a diffuse energy source.



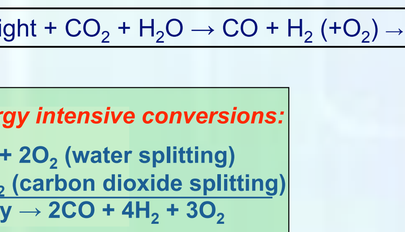
Nominal Equivalent Land Area Required to Produce 20 mbpd at a given efficiency

Sunlight to fuel efficiency assuming solar resource equivalent to Albuquerque – 2600 kWh/m²/yr.
U.S. Petroleum consumption - 20 million bbls/day

The magnitude of fuel consumption in developed economies mandates high efficiency for renewable fuel alternatives.

Thermochemical Conversion is the Heart of the S2P concept

Thermodynamically unfavorable reactions divided into two more favorable thermally driven reactions.



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

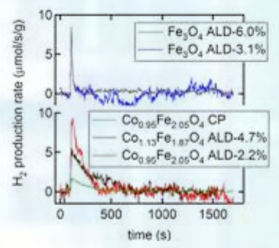
Efficiency gains over electrolysis for example are possible as intermediate conversion to mechanical work and/or electricity are avoided.

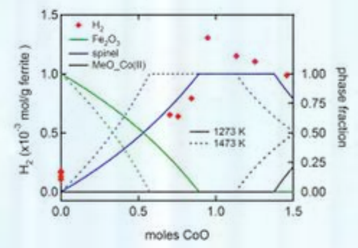
Energy management is essential.

Results

Sampling of Materials Accomplishments

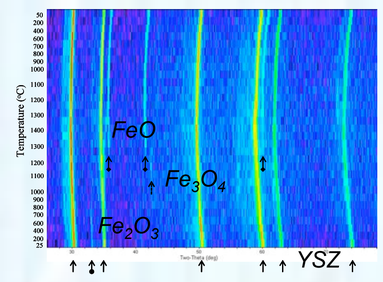
Developed procedures for producing model materials in planar, thin film, powder, and bulk geometries. Experimental results correlate with thermodynamic models.





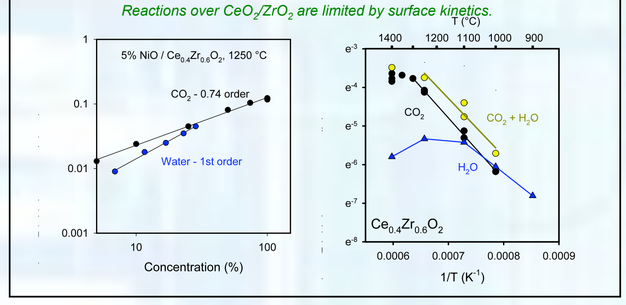
Characterized thermal reduction and CO_2 oxidation of active Fe/YSZ composites for the first time *in-situ*.

3-D XRD plot shows stages of reduction:
Fe_2O_3 → Fe_3O_4 → FeO
Dissolved Fe leaves the YSZ phase as it is reduced.

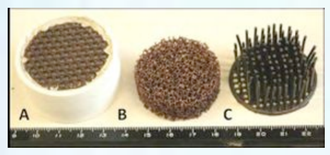


Determined kinetics of oxidation reactions over iron- and ceria-based monolithic materials.

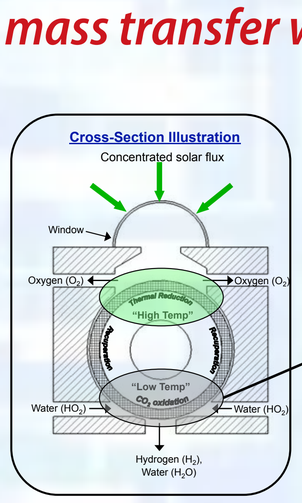
Reactions over CeO_2/ZrO_2 are limited by surface kinetics.

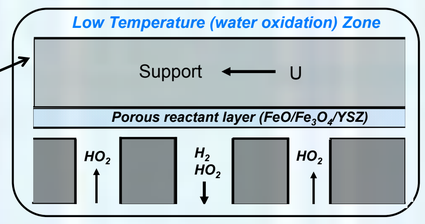


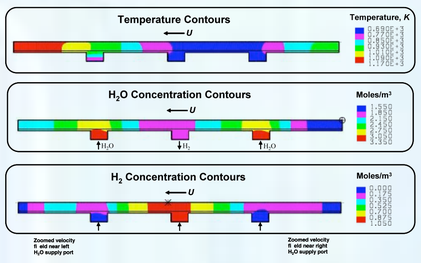
Developed advanced monolith structures for CR5 and associated qualification/ageing apparatus.



Advanced engineering models couple heat and mass transfer with chemistry.







Significance

Quantitative Systems Models Illuminate Paths to Maximum Efficiency

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.

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