

# Sunshine to Petrol: Reimagining Transportation Fuels

## ExxonMobil Executive Visit 11 JANUARY 2011

Sara Ortwein, President, Upstream Research Company

Carlos Dengo, Vice President, Geoscience, Upstream Research Co.

Marco Rasi, Vice President, Engineering, Upstream Research Co.

Emil Jacobs, Vice President, Research & Development, Research & Engineering Co.

Sam Perkins, Planning Manager, Upstream Research Co.

Ellen B, Stechel, Presenting  
Concentrating Solar Technologies Dept, Manager  
Sunshine to Petrol, Program Manager

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

# Global Context



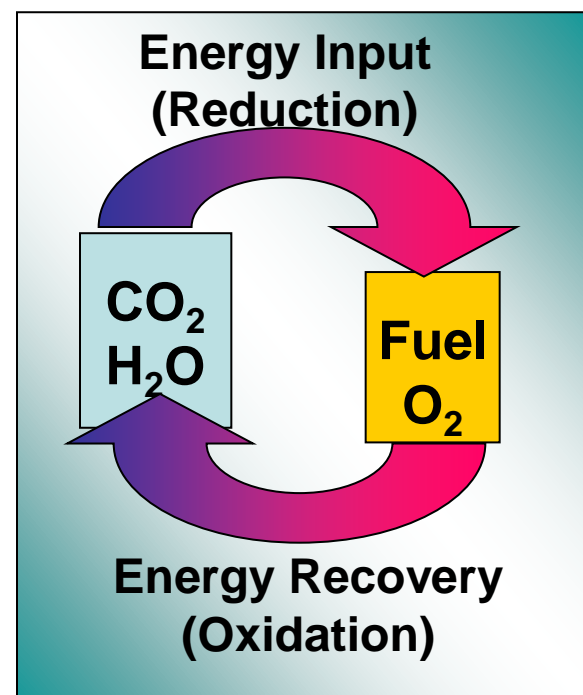
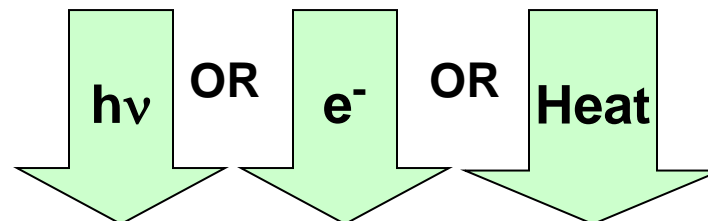
- Energy consumption will continue to grow with development gains and population growth
- Fossil fuels dominate energy picture and drive GHG emissions from energy sector
- U.S. deeply dependent on foreign supplies of petroleum in the transportation sector
- Energy and climate security are now a clear global priority

# Motivated to "Recycle" CO<sub>2</sub> into Fuels

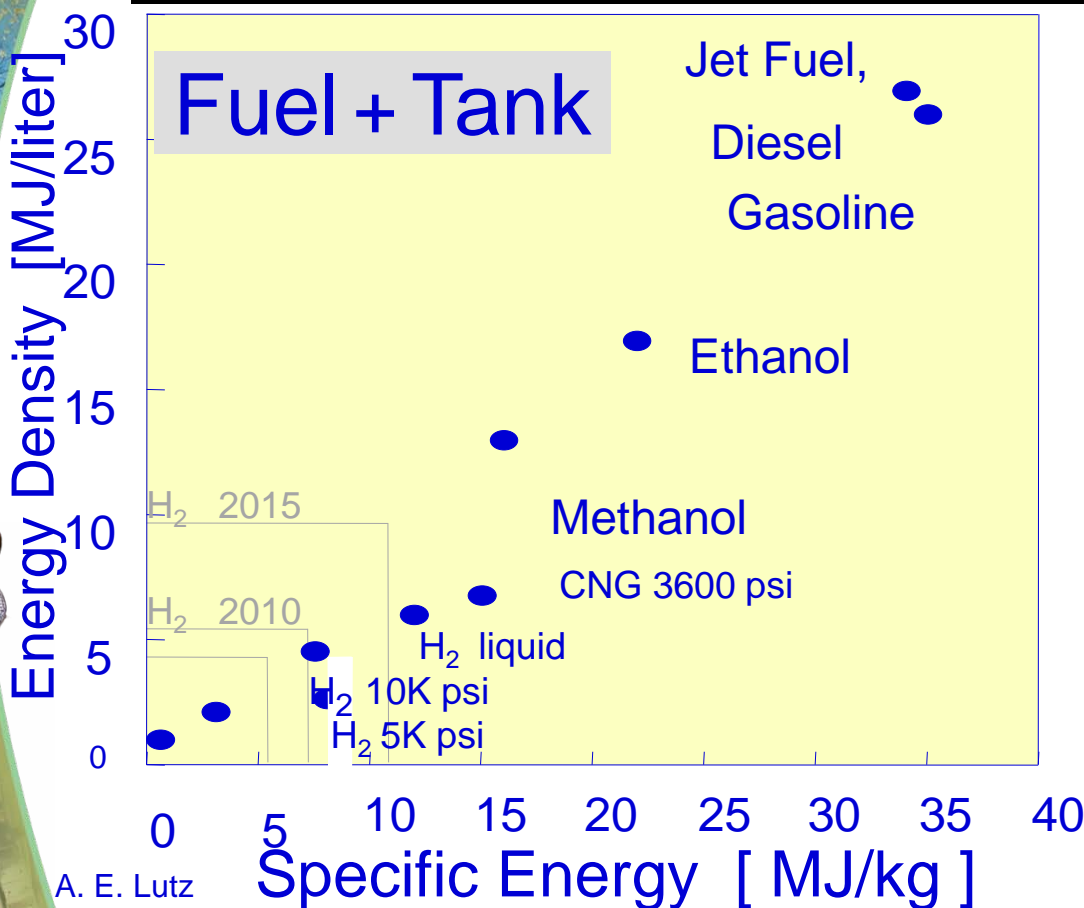


- **To Assure Energy Security**
  - Decrease the **Strategic Importance** of Petroleum and vulnerability to Supply Disruptions
  - **Diversify** Supply and to use geographically and domestically available dispersed resources
  - Develop Infrastructure Compatible: Scalable & Fungible, **Drop-In** Fuels
- **To Mitigate Climate Change Risk**
  - Increase uses for and create value from CO<sub>2</sub>
  - Decrease net CO<sub>2</sub> emissions significantly
- **To Enhance Prosperity & Economic Competitiveness**
  - Avoid trading one dependence for another
  - Create wealth at scale

## Scalable Carbon Neutral Energy



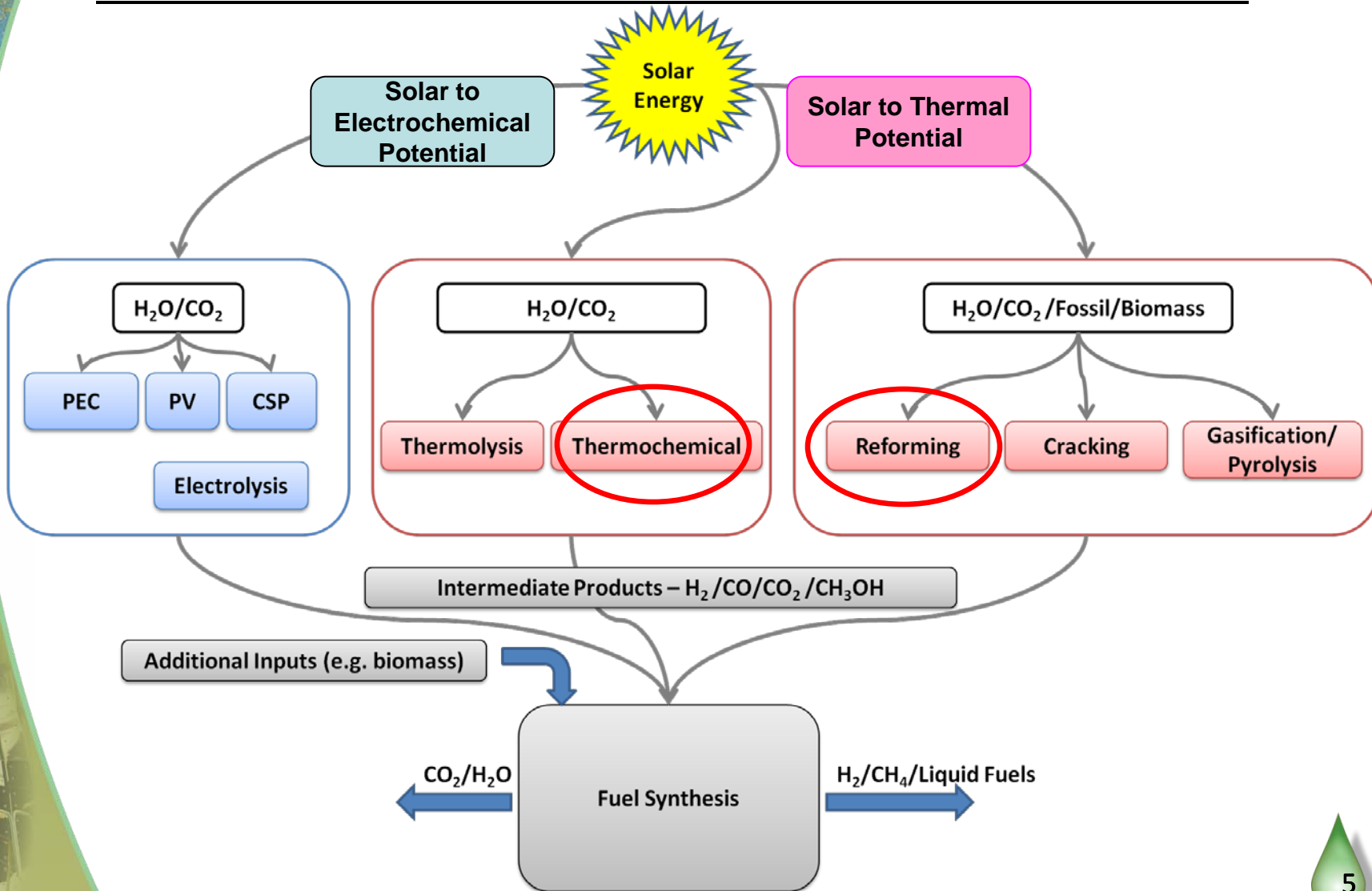
# Liquid Hydrocarbon Fuels: Remain the Gold Standard



- Energy Density
- Infrastructure
- Fueling Rate
- Airplanes
- Heavy Duty Vehicles
- Fungible Alternative Attractive

Fuel	Energy/ Mass	Energy/ Volume
Gasoline	1	1
Li Ion Battery	0.019	0.035

# Solar Fuels Grand Vision



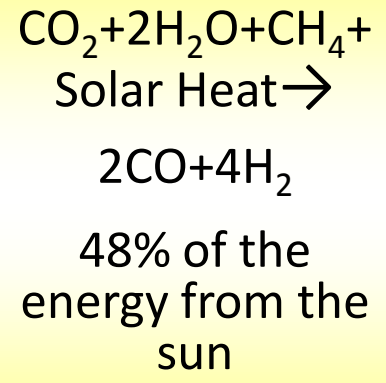
# Near Term Opportunity: Solar Reforming



Solar Reforming Reactor

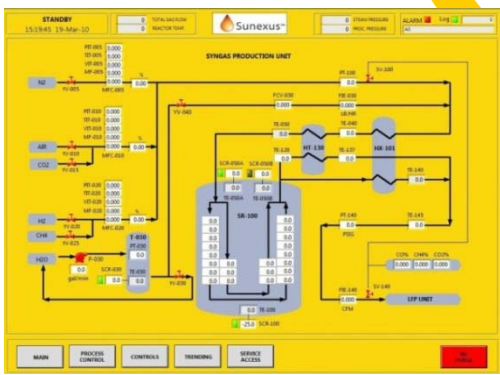


Sunexus Solar Catalyst



System Designs

Adaptive Control Software Systems



# Demonstration Unit



# From the Grand Vision to Sunshine to Petrol



- **Grand Vision** – Catalyze the creation of a **Solar Chemical Industry**
  - Needs on order ~\$100M/year sustained for at least 10 years
  - Intend to launch a new not for profit Enterprise – will be seeking investors and sponsors
- **Solar ThermoChemical Vision** – Foundations for Solar ThermoChemical conversion of  $\text{CO}_2/\text{H}_2\text{O}/\text{CH}_4$ 
  - Relatively near term opportunity exists in solar reforming, which is not all new
- **Sustainable and Secure Fuels from  $\text{CO}_2/\text{H}_2\text{O}$  and all energy from Sunlight**
  - Will take multiple generations of both the core components & system design
- **S2P Grand Challenge: Started Oct 2008 and concludes Sept 2011**
  - Introduced this to ExxonMobil (Carlos Dengo on November 2008)
  - 1<sup>st</sup> generation materials & reactor to realize Solar ThermoChemical conversion of  $\text{CO}_2/\text{H}_2\text{O}$  to syngas
  - Materials + Reactor + System  $\equiv$  Sunshine to Petrol.
  - Timeline to Commercial Deployment – Decade + with adequate resources

# Project Team



Principal Investigator – **James E. Miller**  
Program Manager - **Ellen B. Stechel**  
ECIS Program Champion – **Margie Tatro**  
LDRD Grand Challenge Champion – **Carol Adkins**  
ECIS VP – **Rick Stulen**; LDRD VP – **Steve Rottler**



## Systems

- Daniel Dedrick, Terry Johnson, Chad Staiger, Greg Evans, Christos Maravelias (U-WI), Carlos Henao (student,) Jiyong Kim (PD)

## Reactor

- Solar Reactor - Rich Diver (retired), Tim Moss, Scott Korey, Nathan Siegel
- Reactive Structures - Nathan Siegel, Terry Garino, Nelson Bell, Rich Diver, Brian Ehrhart
- Detailed Reactor Models - Roy Hogan, Ken Chen, Spencer Grange, Siri Khalsa, Darryl James (TTU,) Luke Mayer (student)

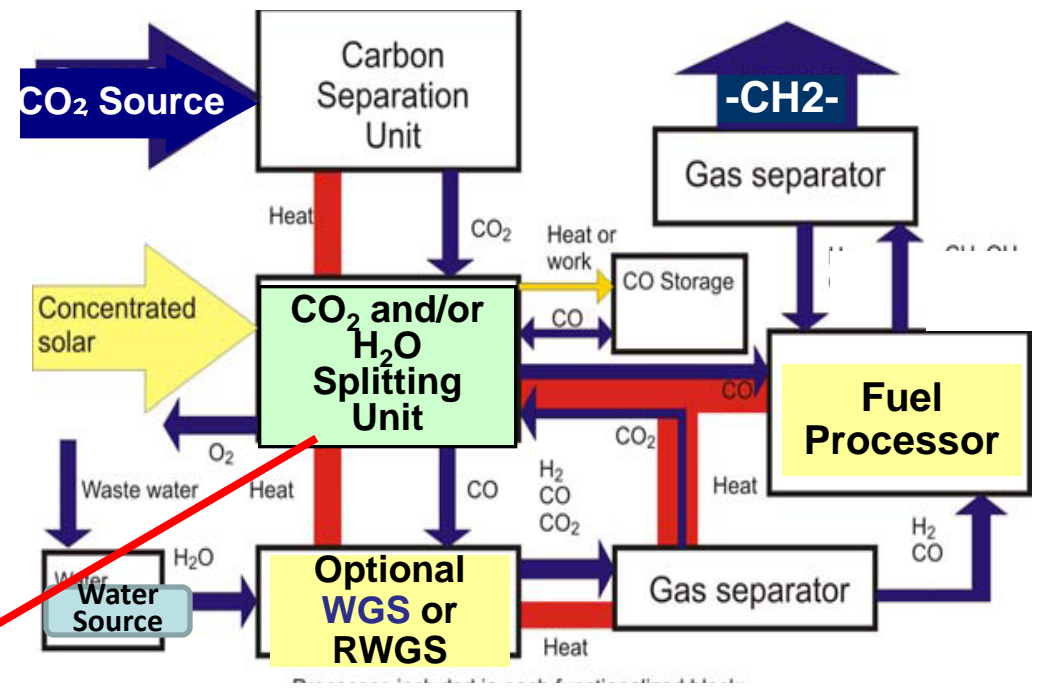
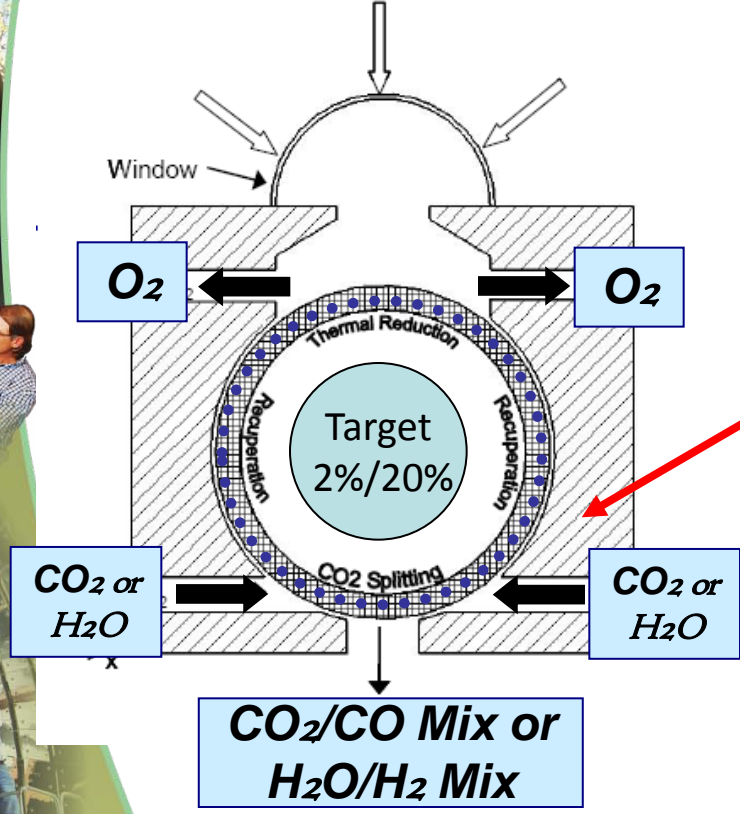
## Materials

- Reactive Materials Characterization & Development - Andrea Ambrosini, Eric Coker, Mark Rodriguez, Lindsey Evans, Stephanie Carroll, Tony Ohlhausen
- Bulk Transport & Surface Reactions - Gary Kellogg, Ivan Ermanoski, Taisuke Ohta, Randy Creighton
- Thermodynamics & Reaction Kinetics - Mark Allendorf, Tony McDaniel, Chris Wolverton (Northwestern University), Bryce Meredig (student), Heine Hansen (PD), Al Weimer (CU,) Jon Scheffe (student, thesis), William Cheuh (Truman Fellow)

# S2P System



**Concentrated Solar Flux**

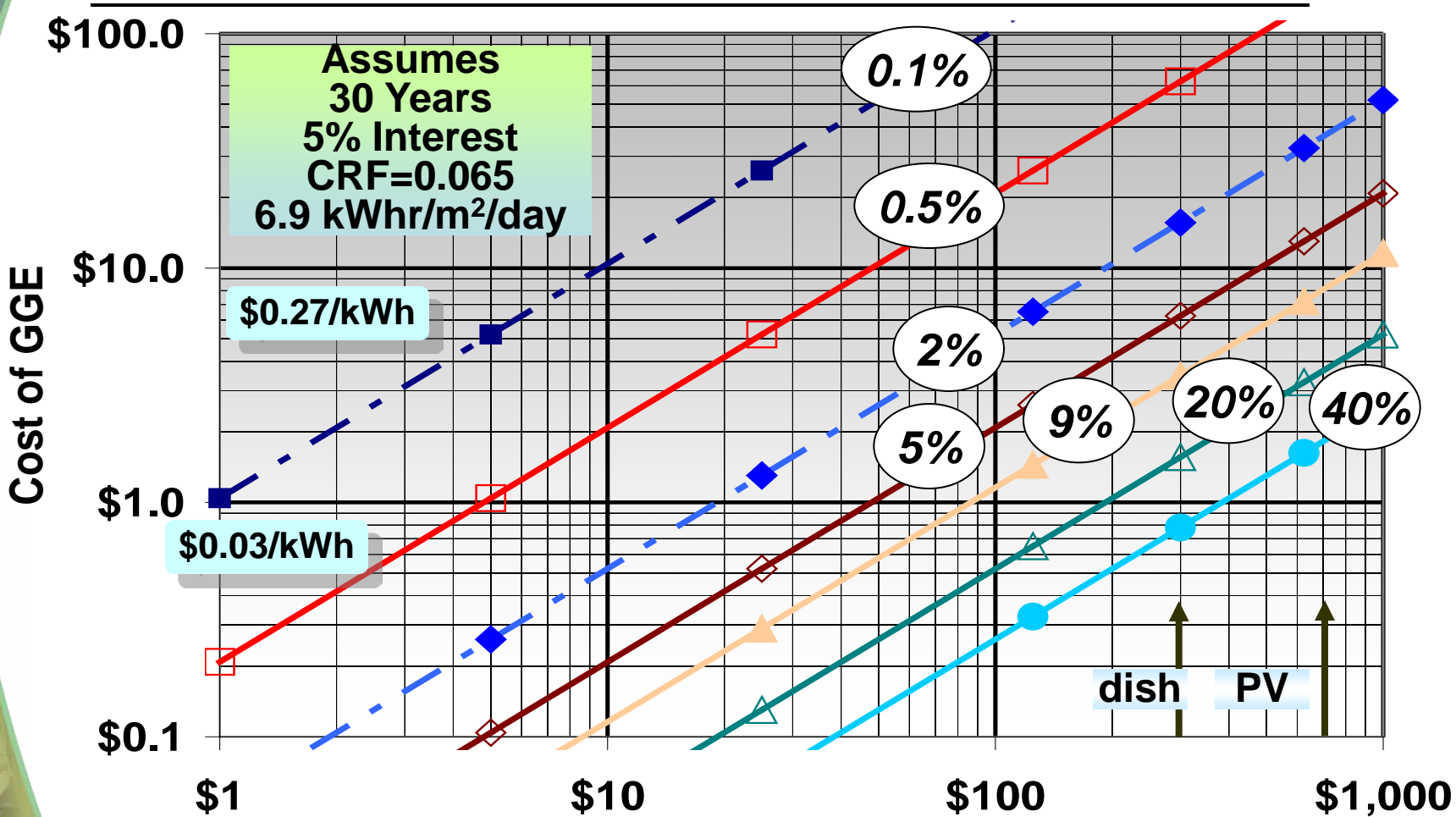


Baseline system – ~7% efficiency, ~\$10/GGE (BOP Energy 51% at purchased utility costs)

1<sup>st</sup> Gen System - ~16% efficiency ~\$7/GGE (BOP Energy 1%)

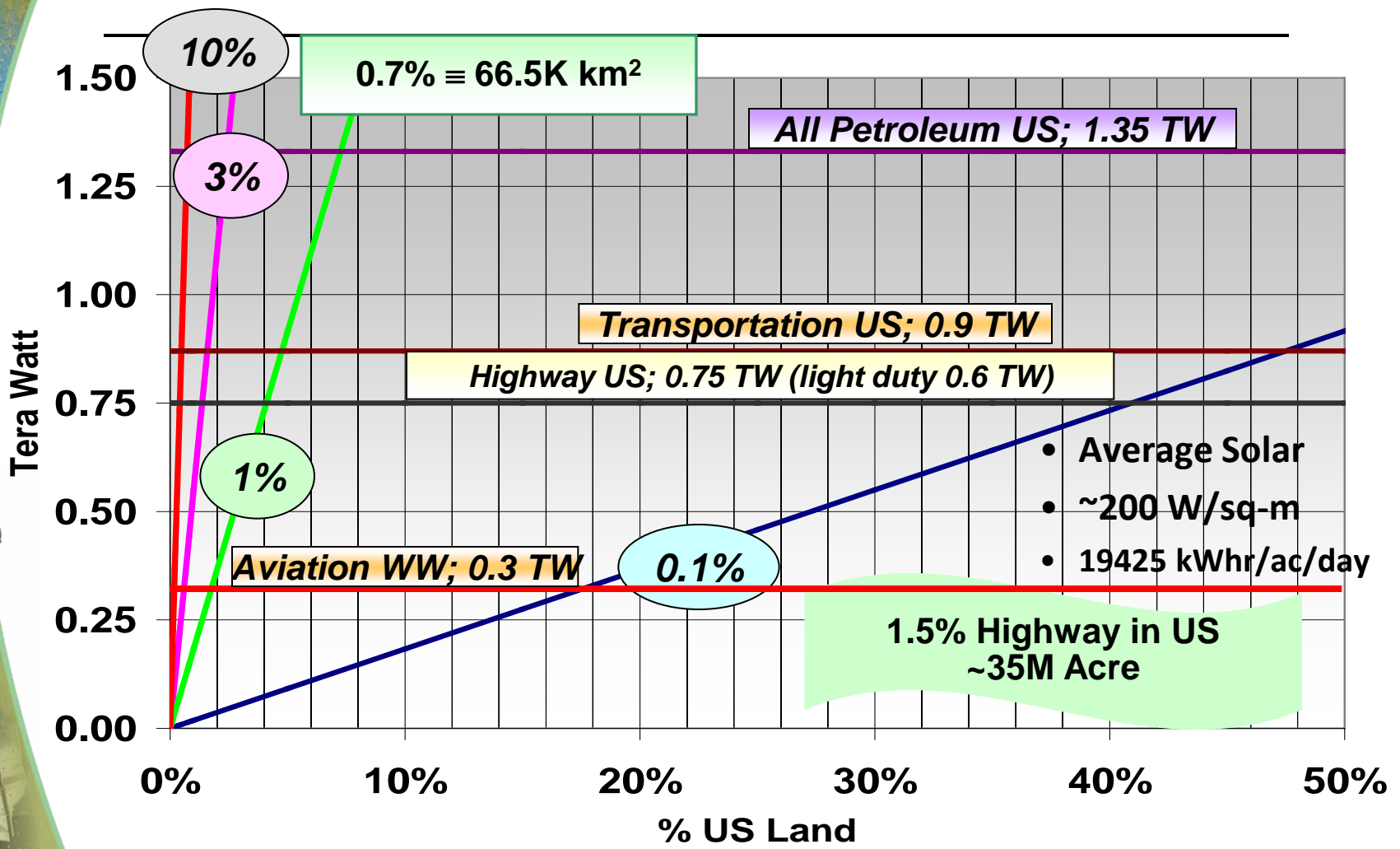
Target \$5/GGE, 13% Lifecycle Sunlight to Fuel

# Production Cost Highly Sensitive To Efficiency & CRF



**CRF: Capital Recovery Factor to get annualized cost**  
 30 years 15% CRF=0.152 (factor of 2.3)

# Solar to Fuel Efficiency Matters for Scalability

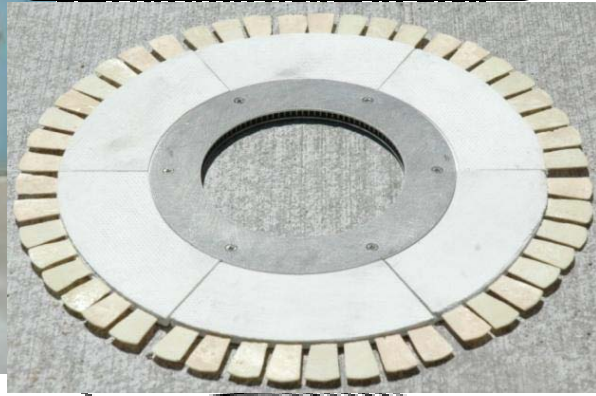


- Average Solar
- ~200 W/sq-m
- 19425 kWhr/ac/day

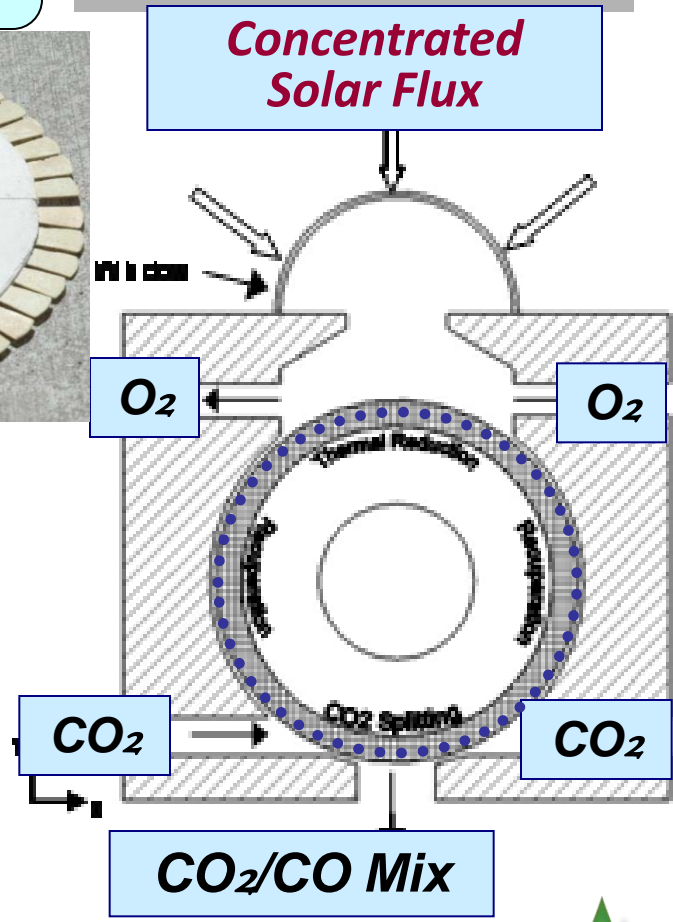
# What is the Enabling Innovation? A "ThermoChemical Heat Engine"



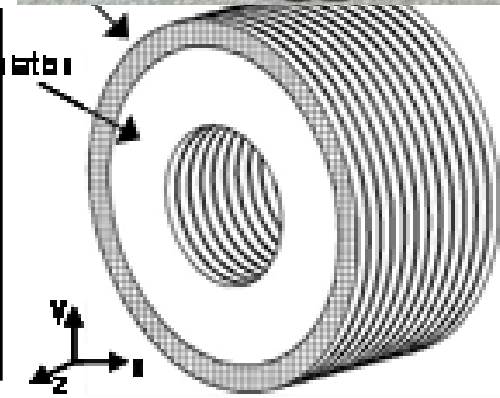
Monolithic Structures of Ferrite/YSZ & Ceria in the lab and on sun demonstrated



Cross-Section Illustration



Converts thermal energy to chemical work  
Analogous to mechanical heat engines  
Working "Fluid" – Metal Oxide

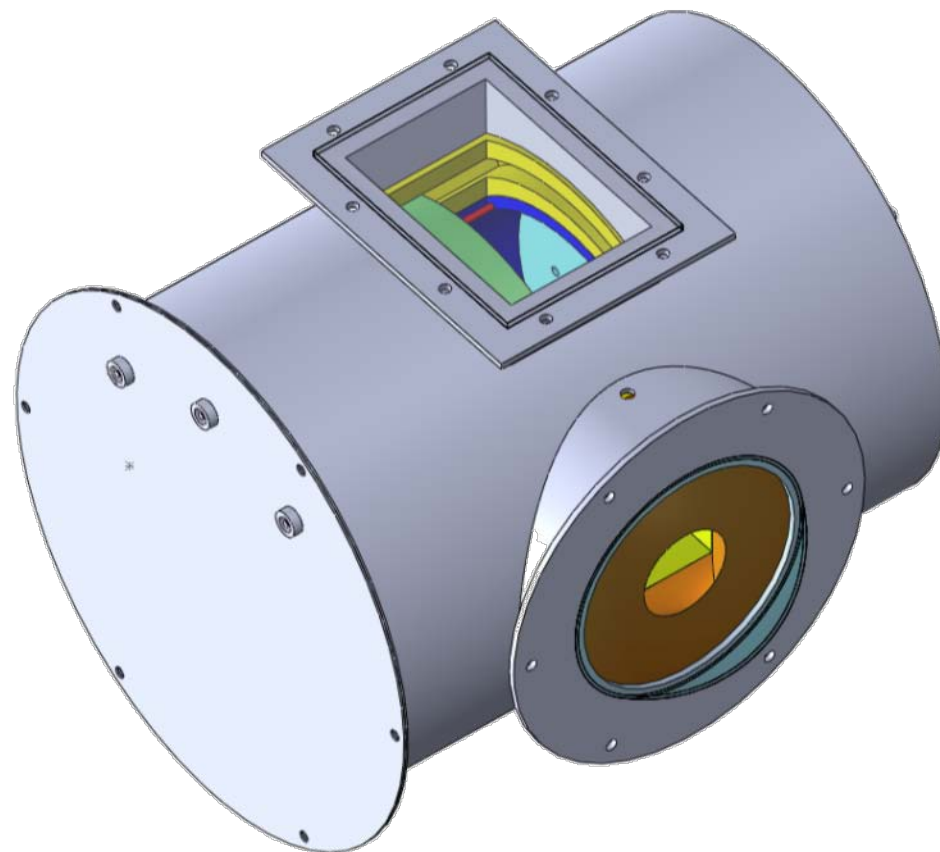


**Enabling Attributes:** Continuous flow, Spatial product separation, and Thermal recuperation

# Reactor Modeling: Model Validation

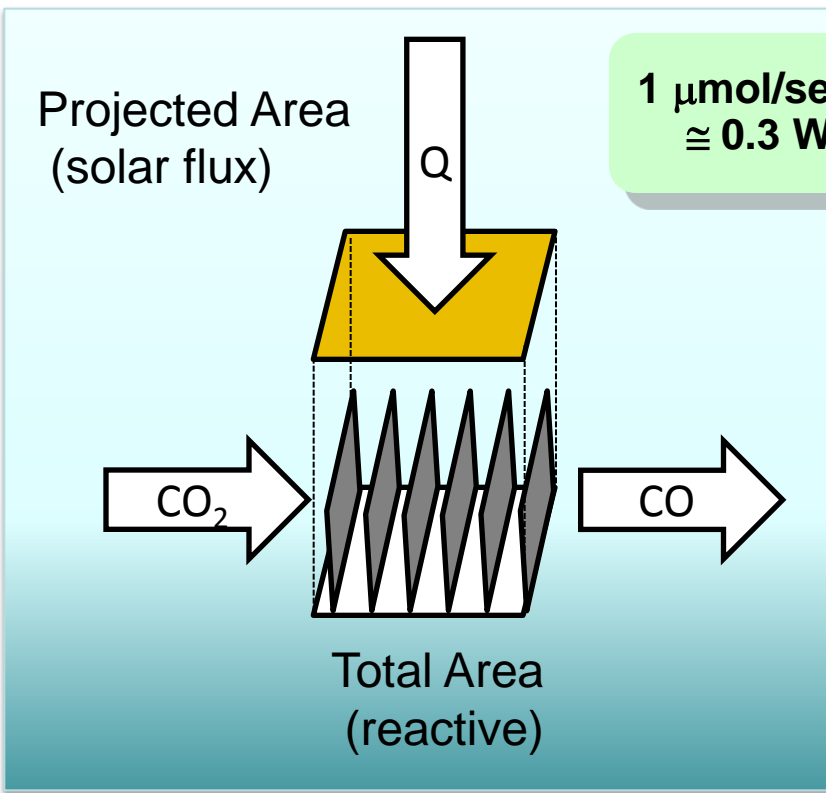
- A CR5 model validation reactor
  - Based on the design of the CR5 prototype housing
- Critical parameters :
  - Flow crossover
  - $T_R$  temperature distribution
  - Recuperation effectiveness

*Recuperator view port*

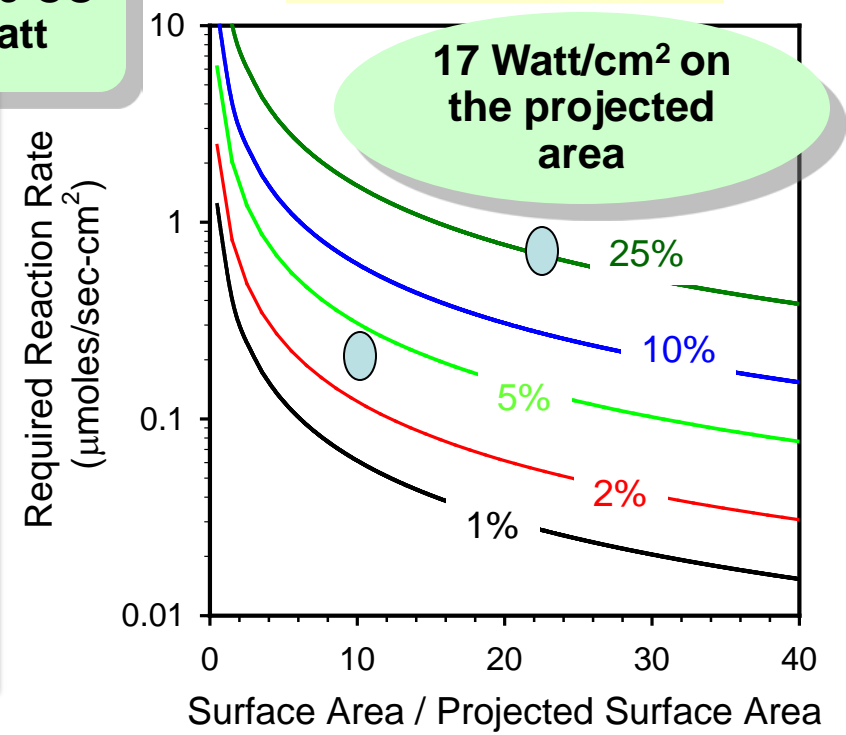
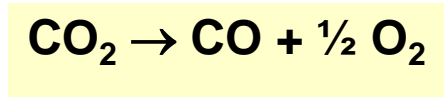


*The design drawing for the CR5 validation reactor*

# For a Defined Flux: Efficiency $\propto$ Reaction Rate



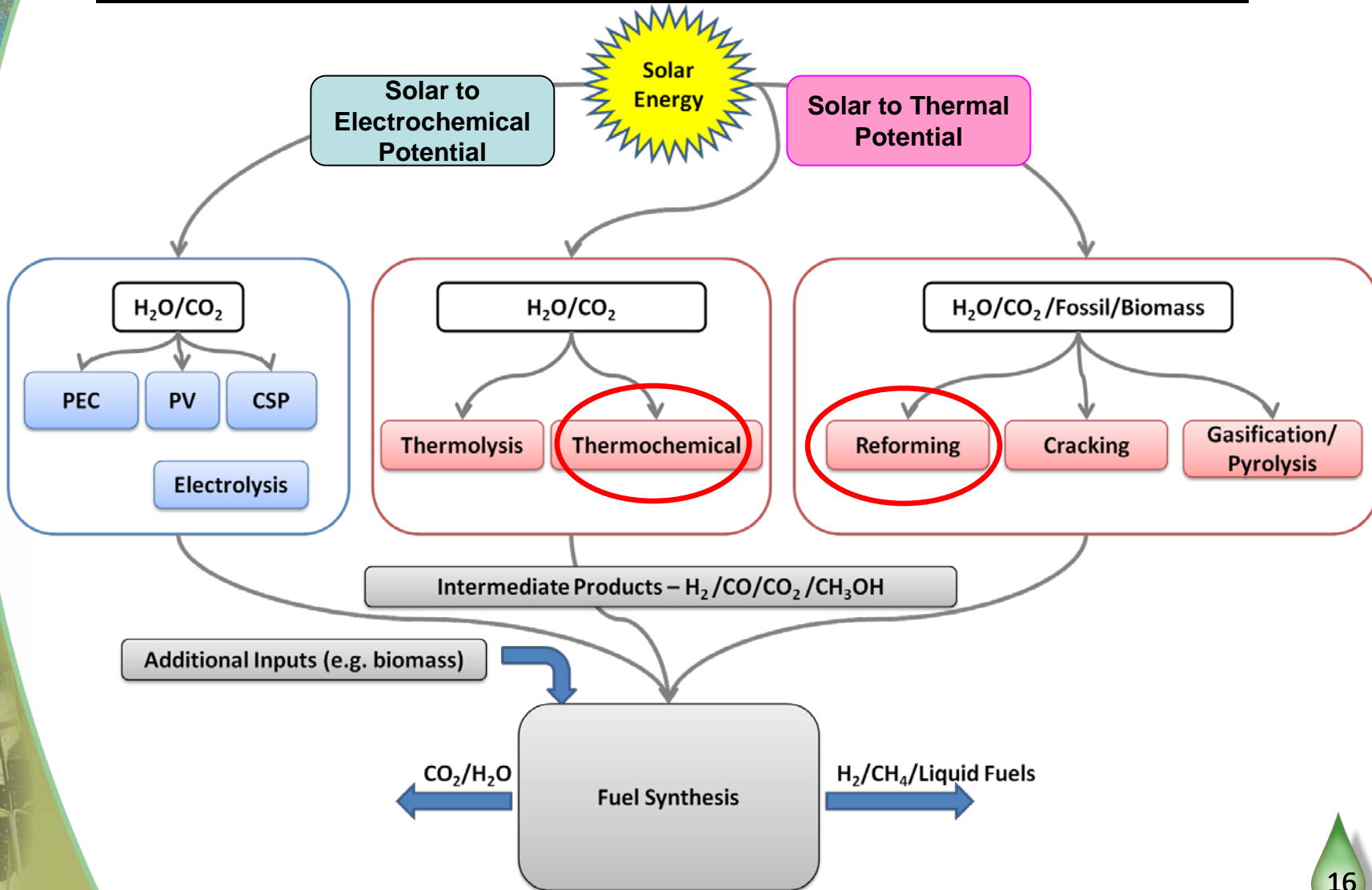
$1 \mu\text{mol/sec CO}$   
 $\cong 0.3 \text{ Watt}$



## To Improve Efficiency

- Improve Kinetics
- Increase Surface Area (Assuming Rates  $\propto$  Surface Area)
- Increase active (reducible metal) Loading (may have broader effects).

# Solar Fuels Grand Vision



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# Thank You For Your Attention

I Welcome Your Feedback and Questions