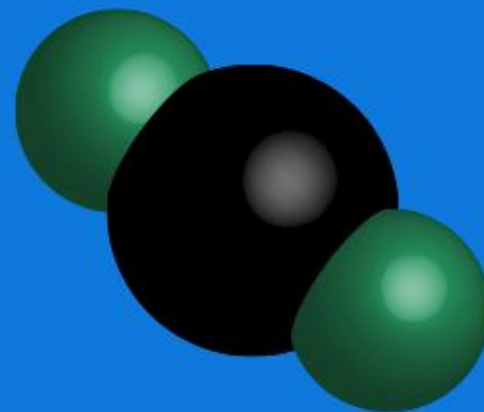


CO₂ Conversion to Fuels



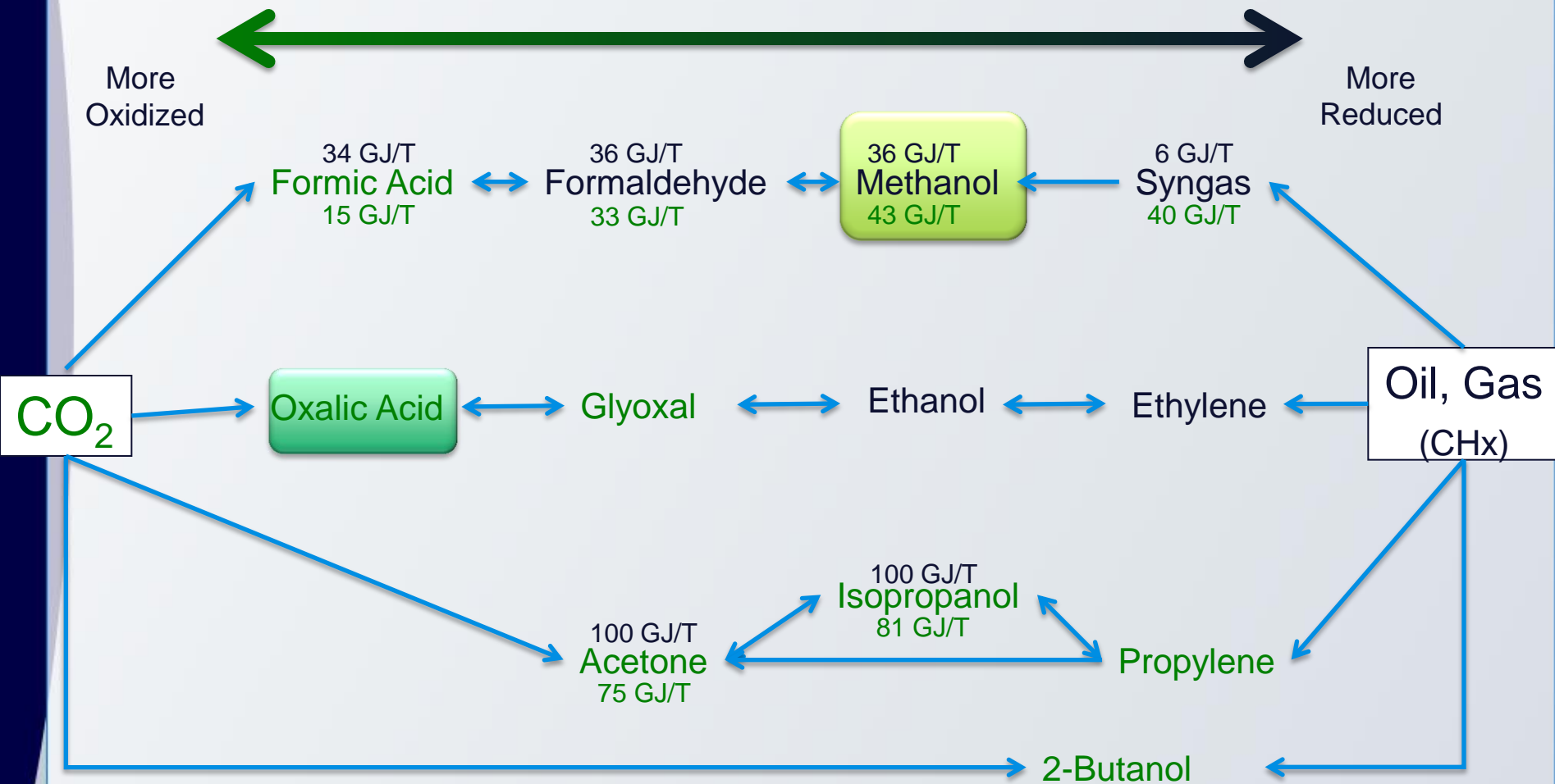
A Progress Report on Liquid Light Inc.

Andrew Bocarsly

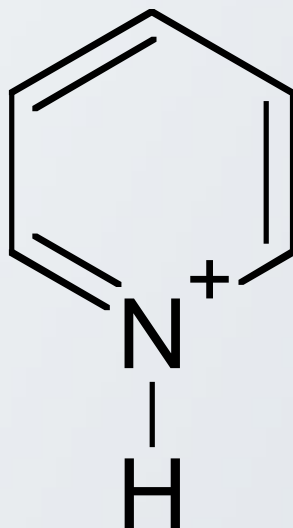
Princeton University Department of Chemistry | Frick Chemistry Laboratory

Columbia University, April 2014

Products and Energetics

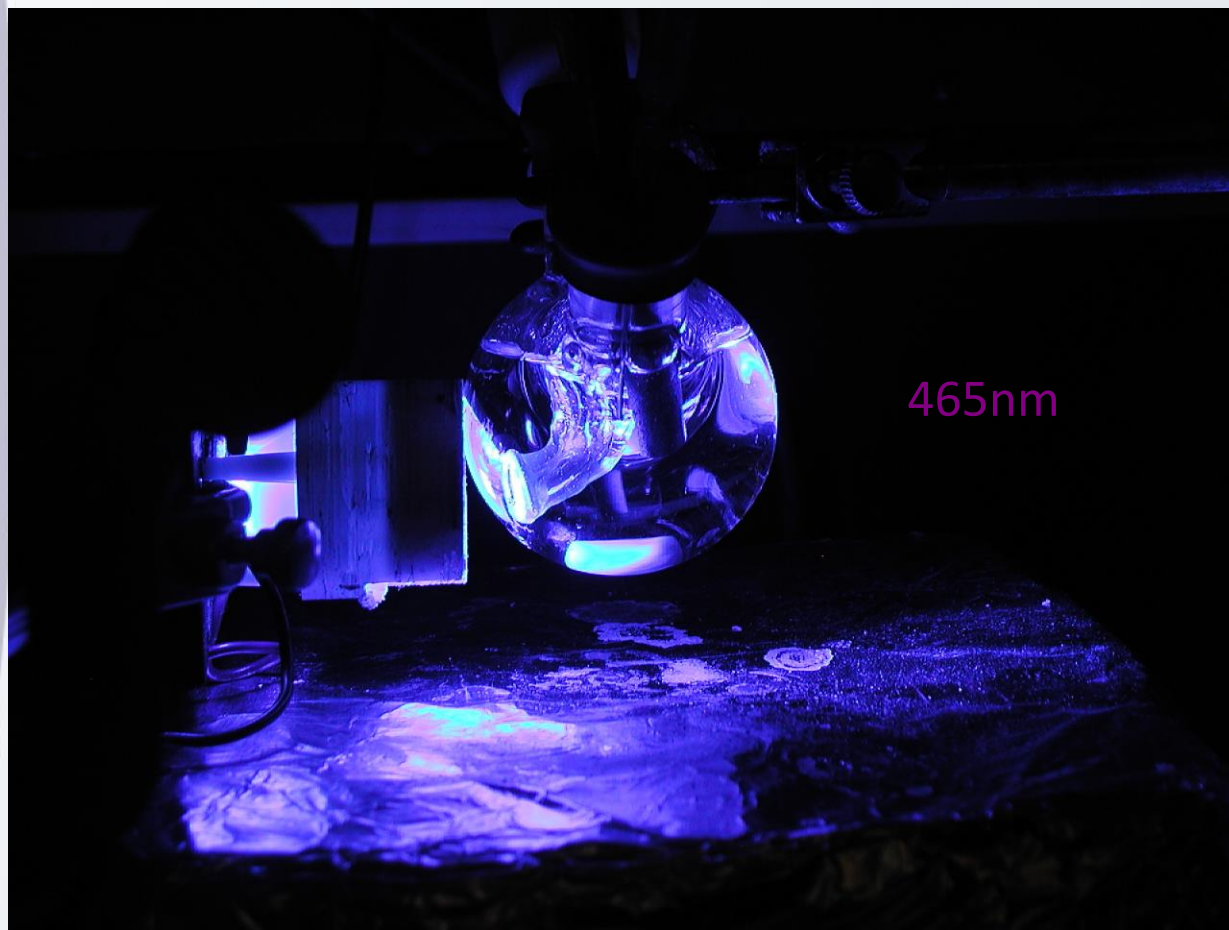
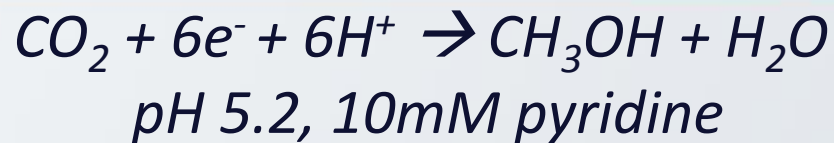


One Cannot Achieve the Electrochemical Energy Goals without an Efficient Catalyst

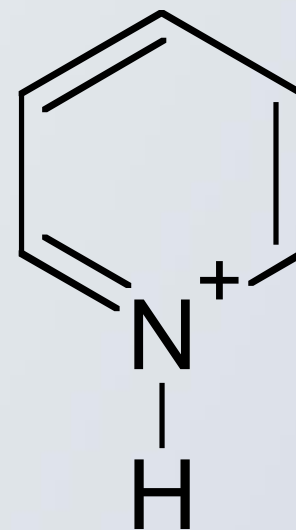


Aromatic Amines Drop the Activation
Overpotential to ~200mV

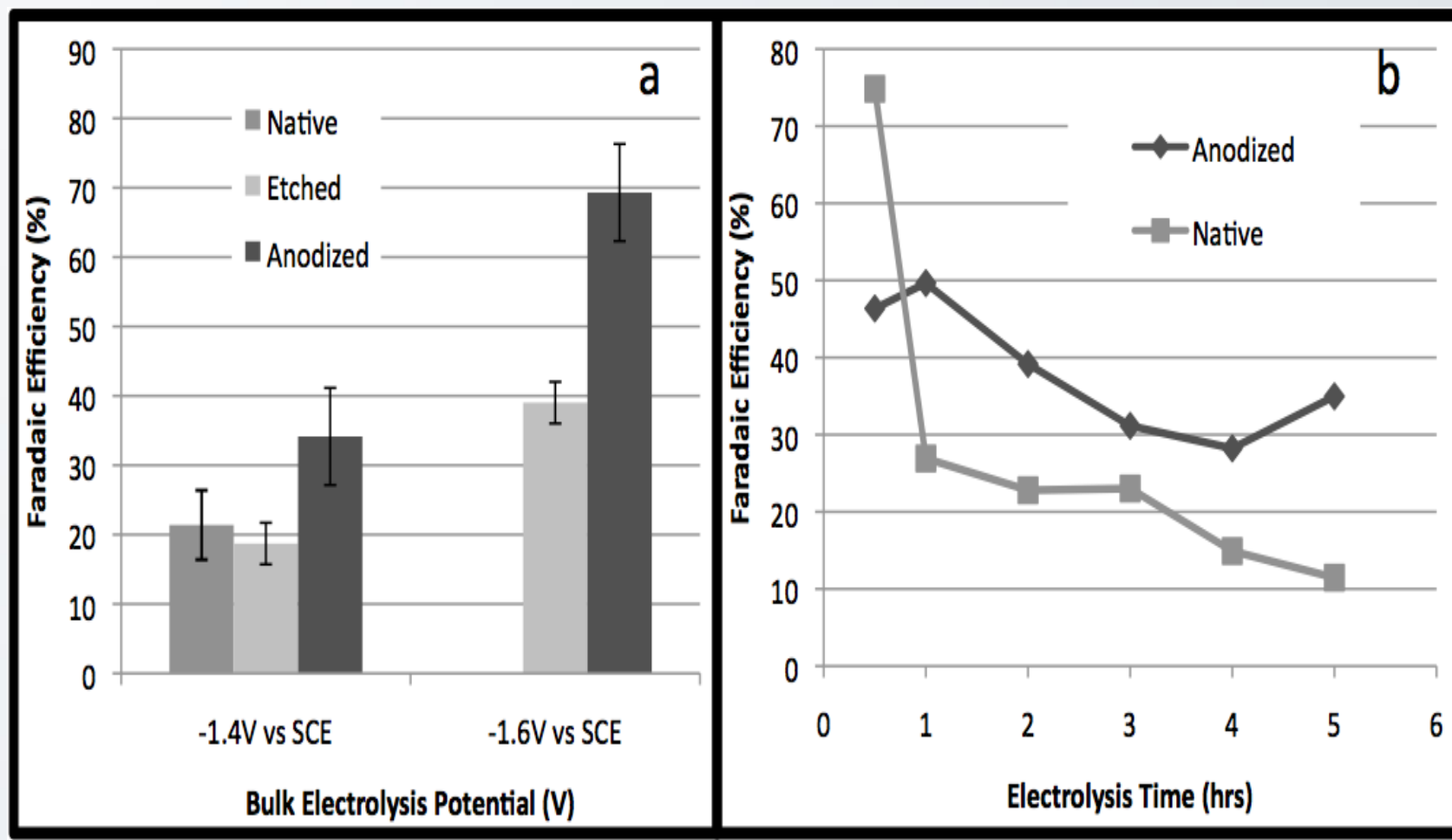
MeOH Evolving PEC Using p-GaP



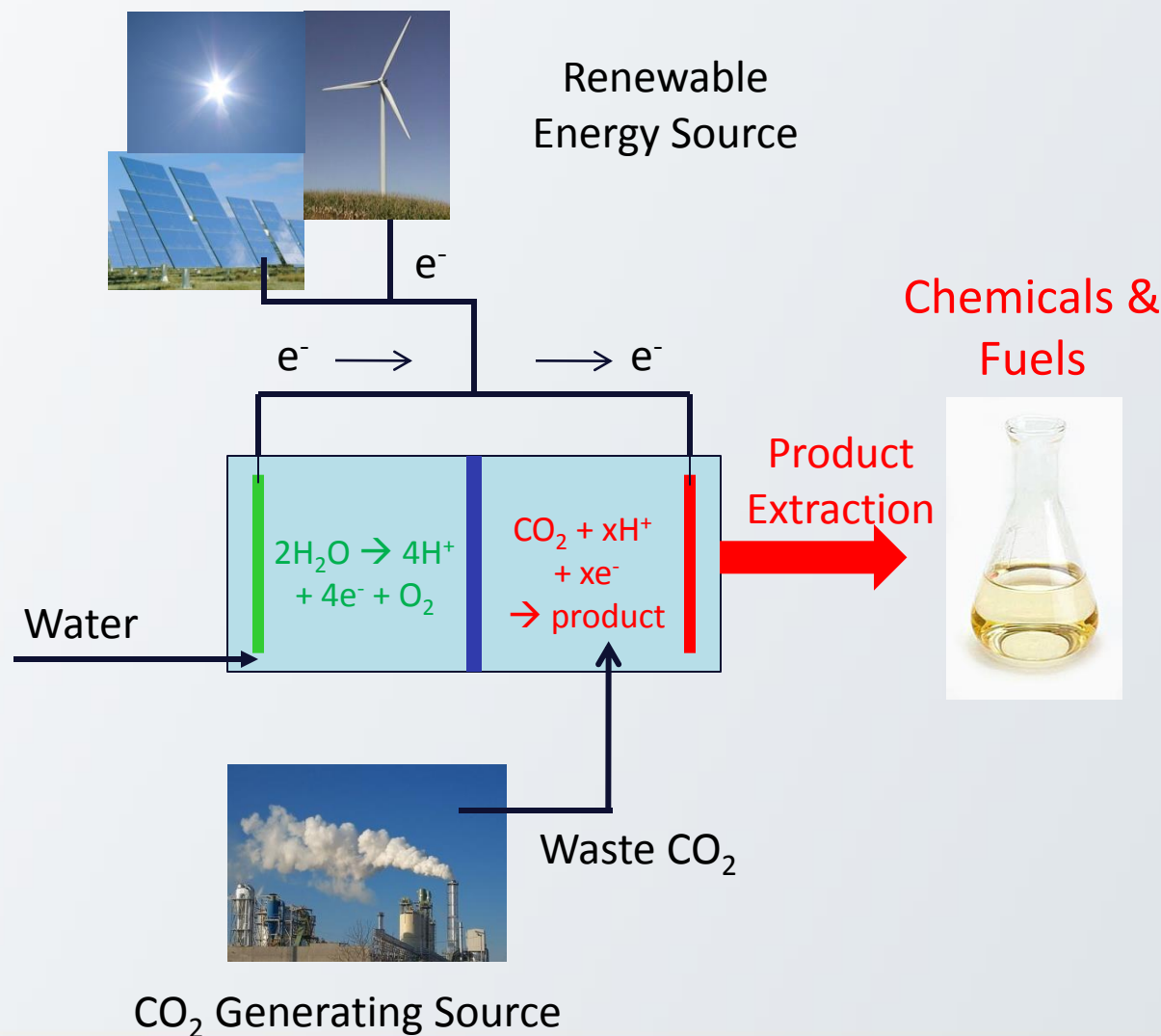
96% Faradaic Yield of
MeOH @ 200mV
UNDERpotential



CO₂ to Formate at an In Surface



The Liquid Light Process



Highlights

Abundant cathode materials

Efficient and selective catalysts

Low cell voltages (energy efficient)

Stability

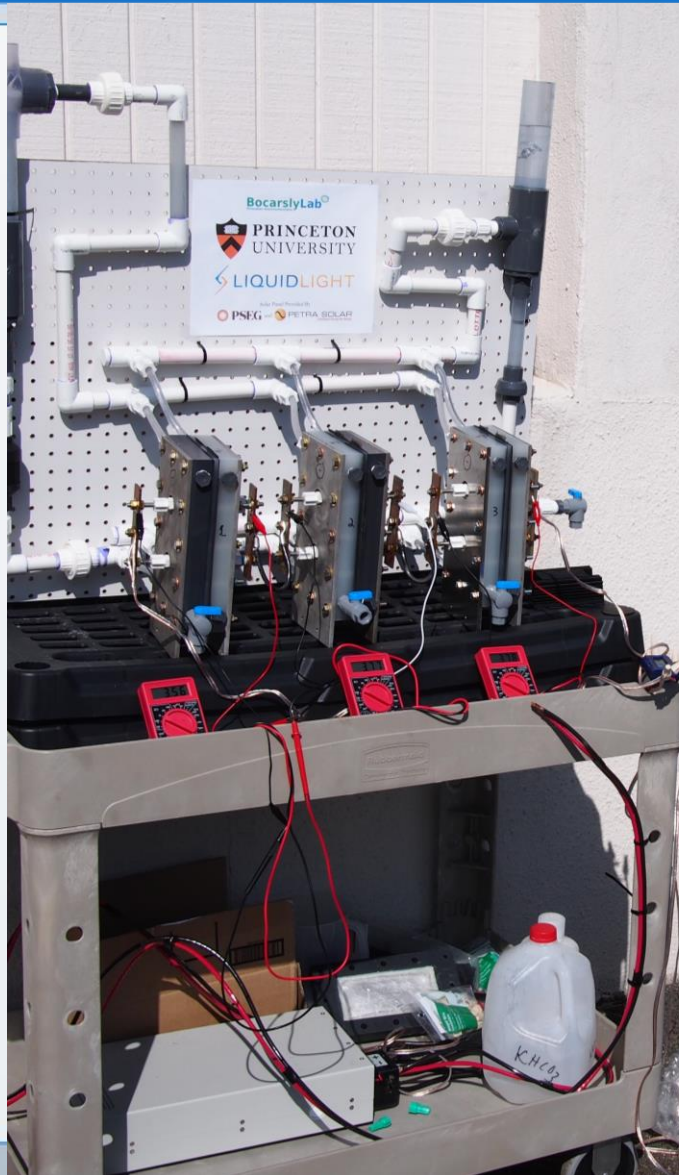
Solar Fuel is Here!



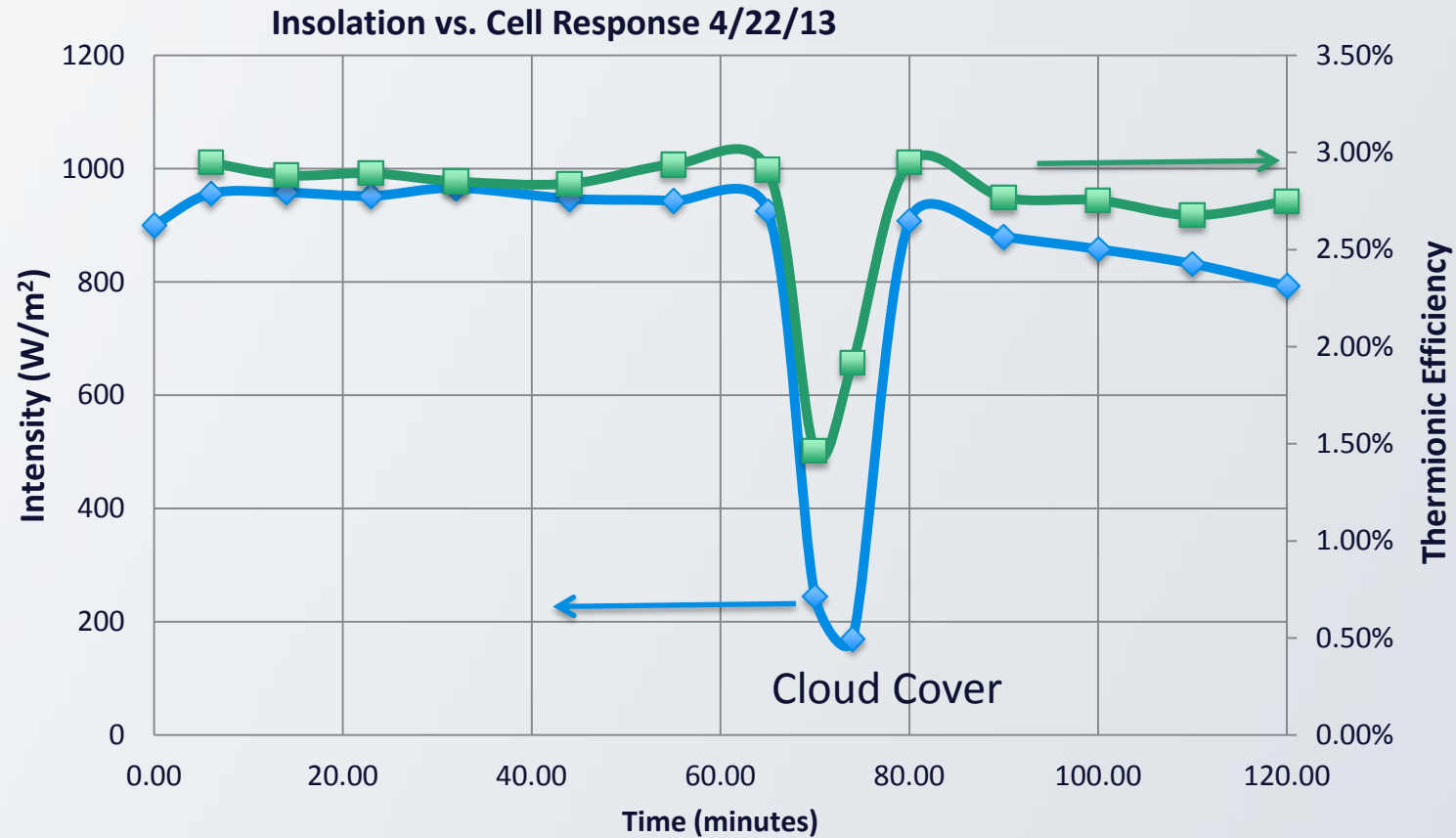
Solar Panel Provided By



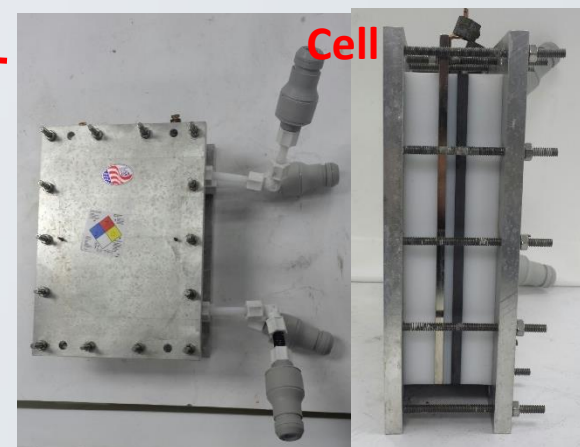
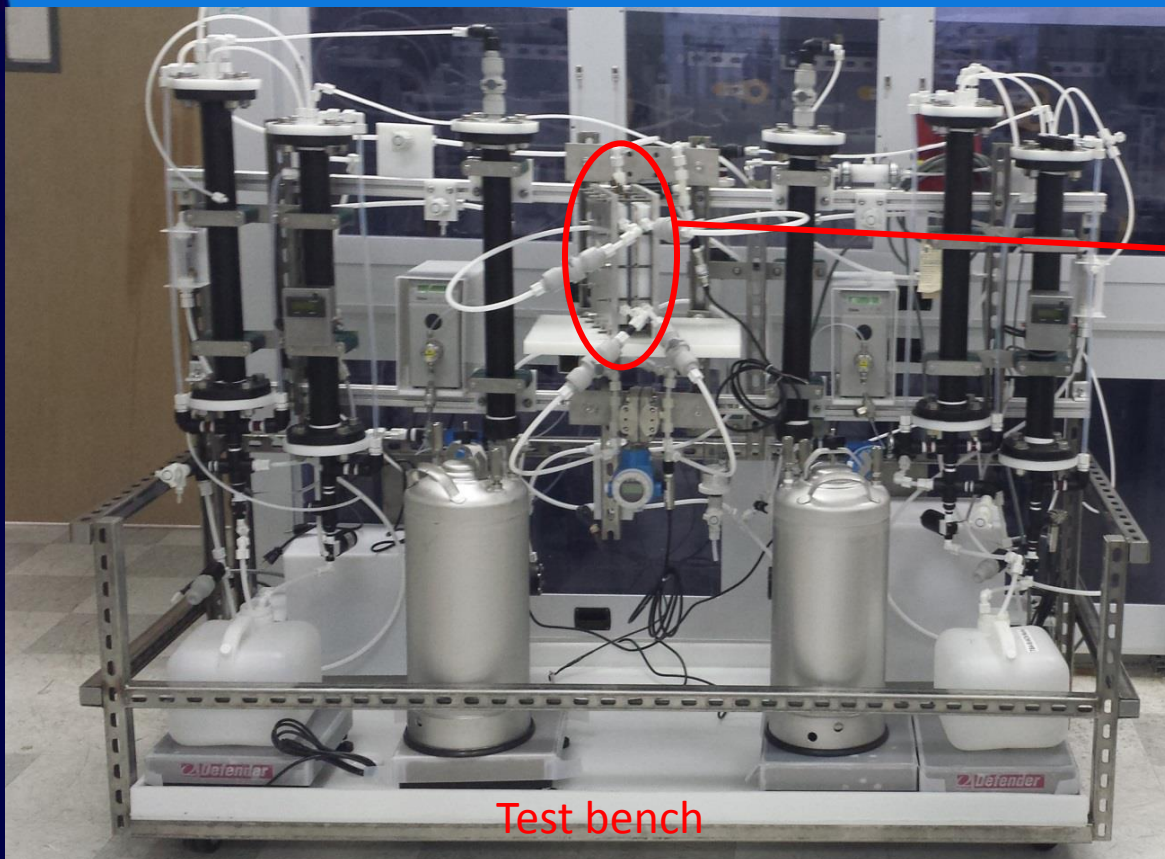
and



System Runs Utilize Real Sunlight (AM 1.5)



Liquid Light's 100cm² scale electrochemical cell test bench



Controls



Photo shows 100cm² active area electrochemical cell for conversion of CO₂ to multi-carbon product along with test bench used to operate and control electrochemical cell. System includes control of electrolyte feed and circulation and instrumentation for process monitoring and control.

They Did It!

Anyone want a good deal on Oxalate?

LIQUIDLIGHT

← ELECTROCHEMICAL PROCESS →

The diagram illustrates the electrochemical process for producing industrial chemicals. It starts with 'INDUSTRIAL ACTIVITY' (represented by smokestacks) which releases 'CO₂ (including low concentrations)'. This CO₂ is then combined with 'H₂O, NATURAL GAS, or WASTES (e.g. shale gas, process water, smokestack acids)' and a 'CLEAN ENERGY SOURCE (Baseload or intermittent)' (represented by a wind turbine and solar panels). The process results in 'INDUSTRIAL CHEMICALS (e.g. glycols, alcohols, olefins, organic acids)' (represented by a beaker).

Calcium Oxalate
 $\text{CaC}_2\text{O}_4 \cdot x\text{H}_2\text{O}$
CAS: 24804-31-7
97+%

The GHS hazard diamond for Calcium Oxalate shows a hazard of 1 for acute toxicity (blue) and 0 for other hazards (red, yellow, and white).

"I'm made from CO₂"

A small vial of Calcium Oxalate powder is shown. The label on the vial reads 'Calcium Oxalate' and 'not ingest'.

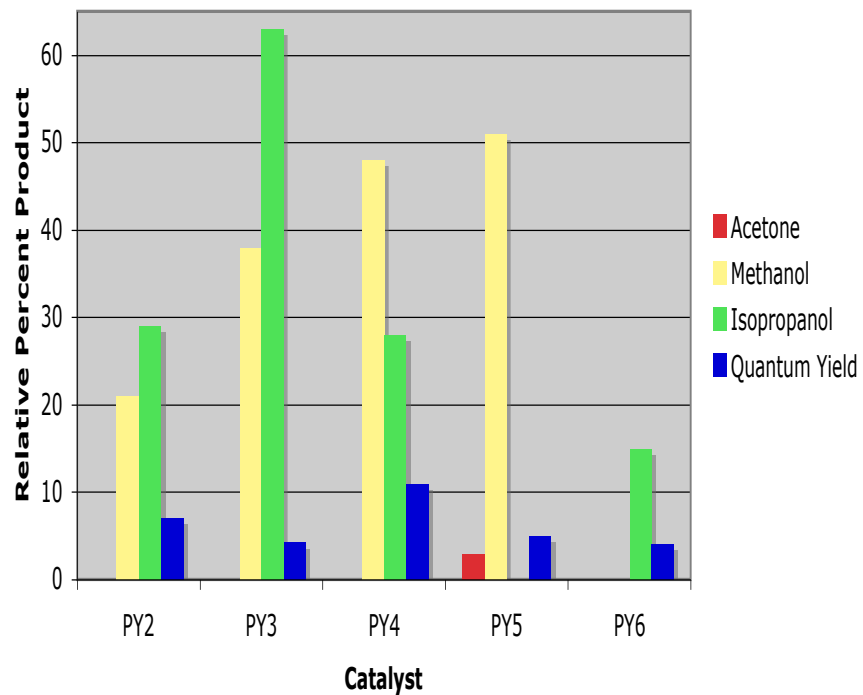
LLchemical.com

Acknowledgement

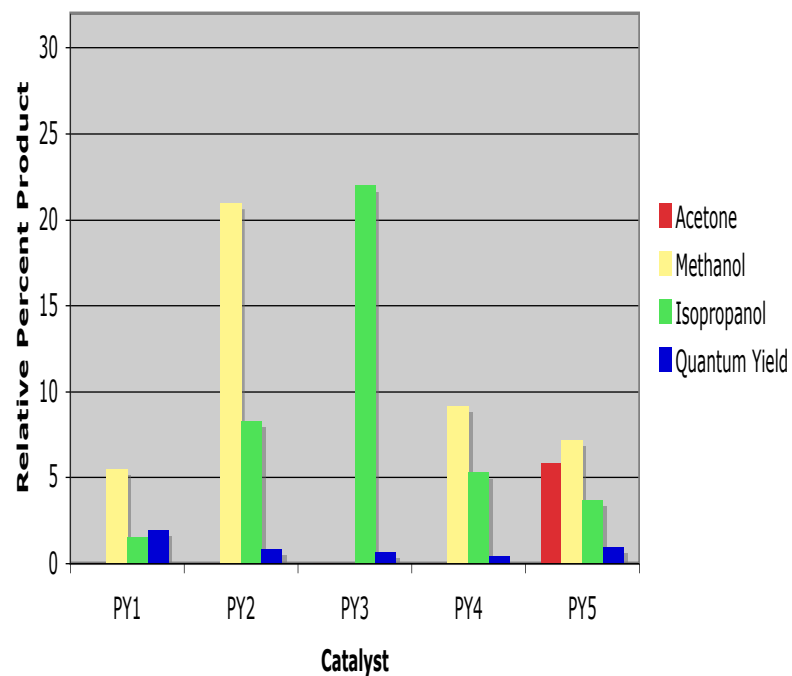


A Complex Synergy

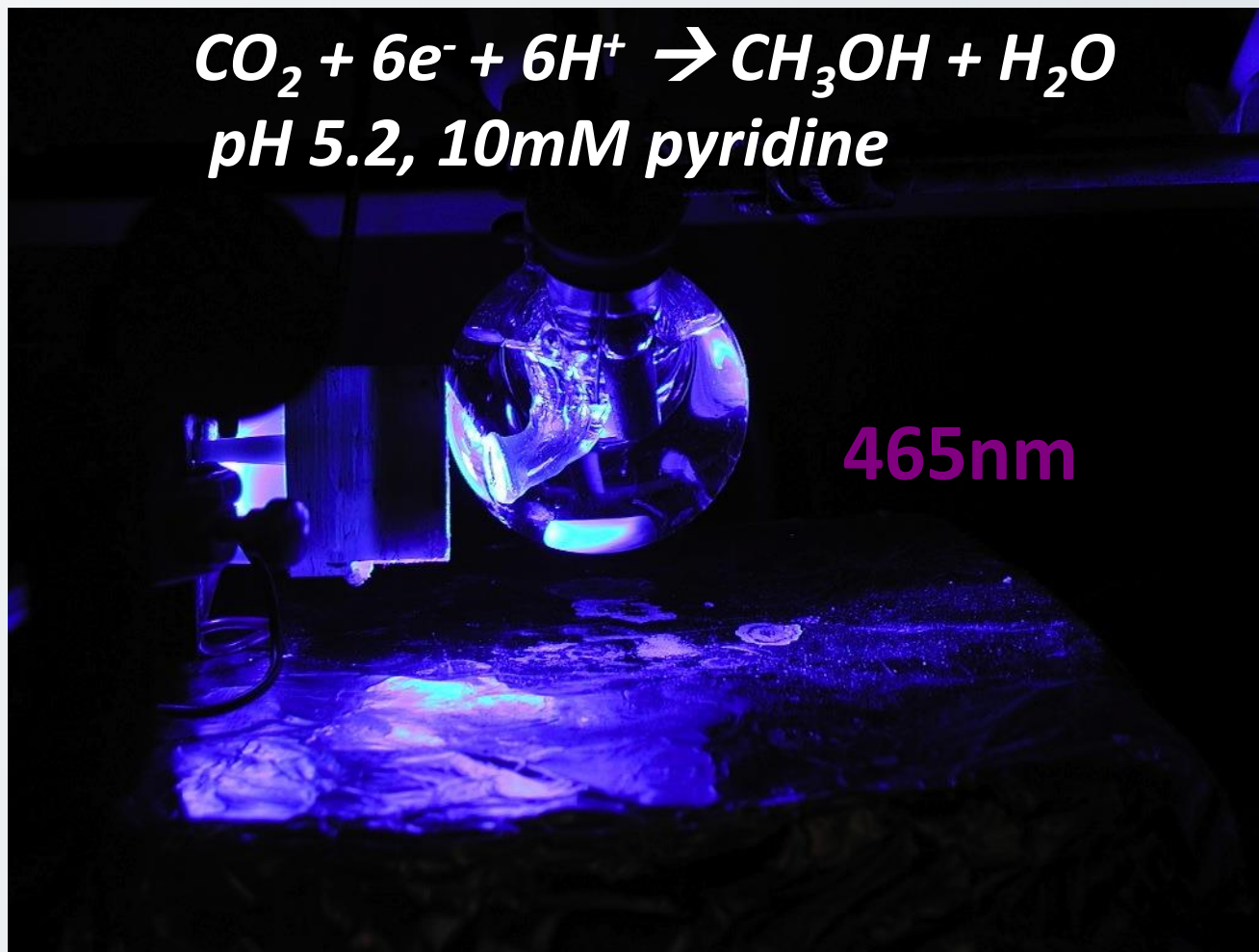
GaP @ 365nm



GaInP₂ @ 465nm



p-GaP MeOH Evolving Cell

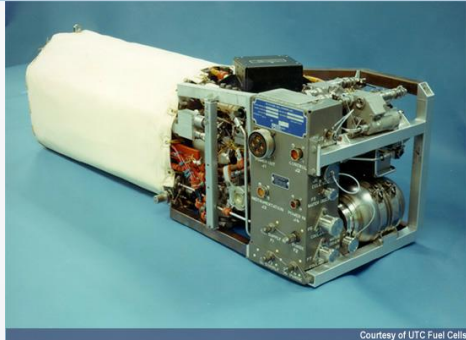


Formic Acid System Scale-Up

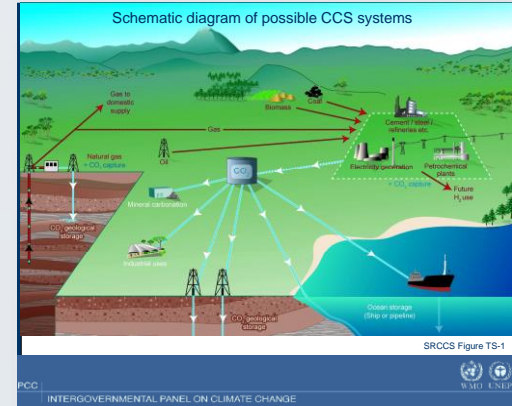


Currently producing target chemicals at grams/day with product concentration streams $\geq 3\%$ and $CD > 100 \text{ mA/cm}^2$ and 1000 hr stability testing, now scaling up to kg/day over the next year

What should we do with CO₂?



Sequestration



Fuels ← 93%

CO₂ Utilization



7%

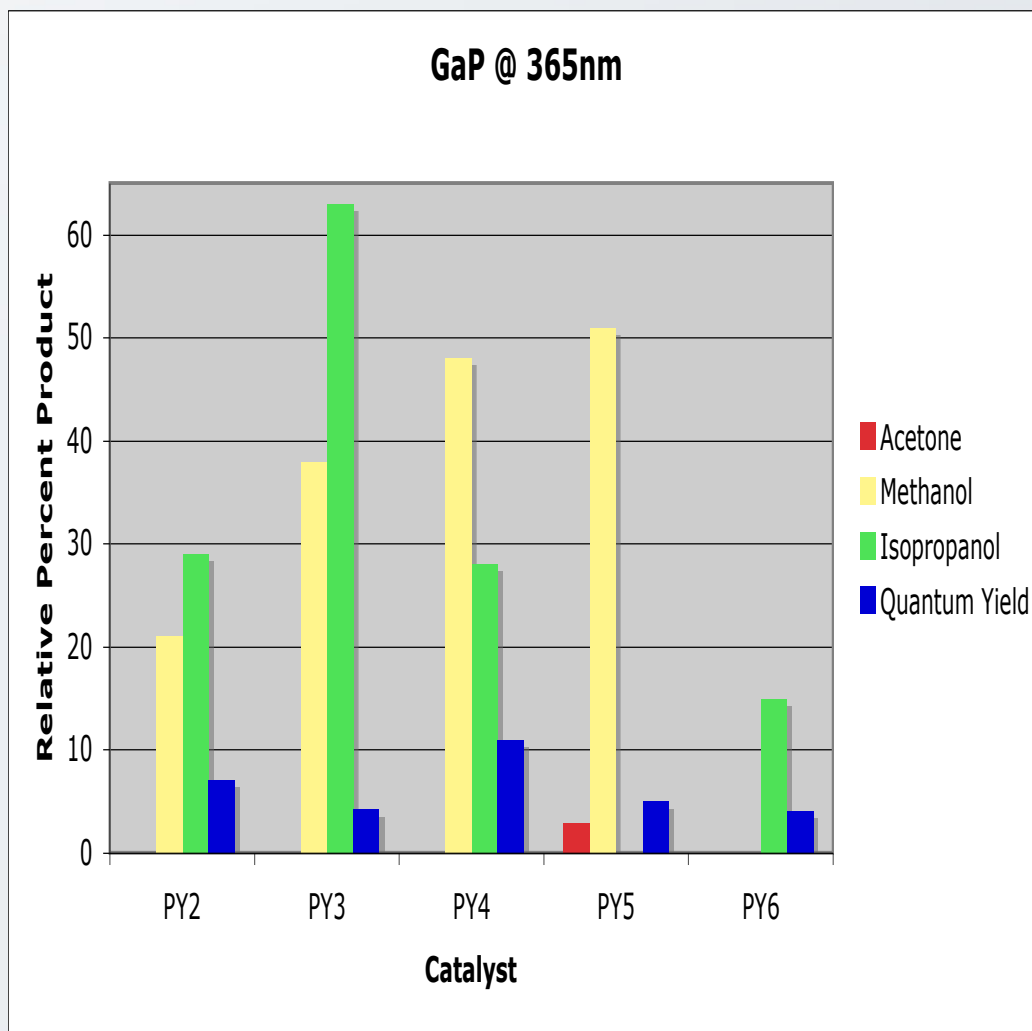
Utilization:

Polymers, Solid-State
Products

Carbon Dioxide as
Chemical Feedstock

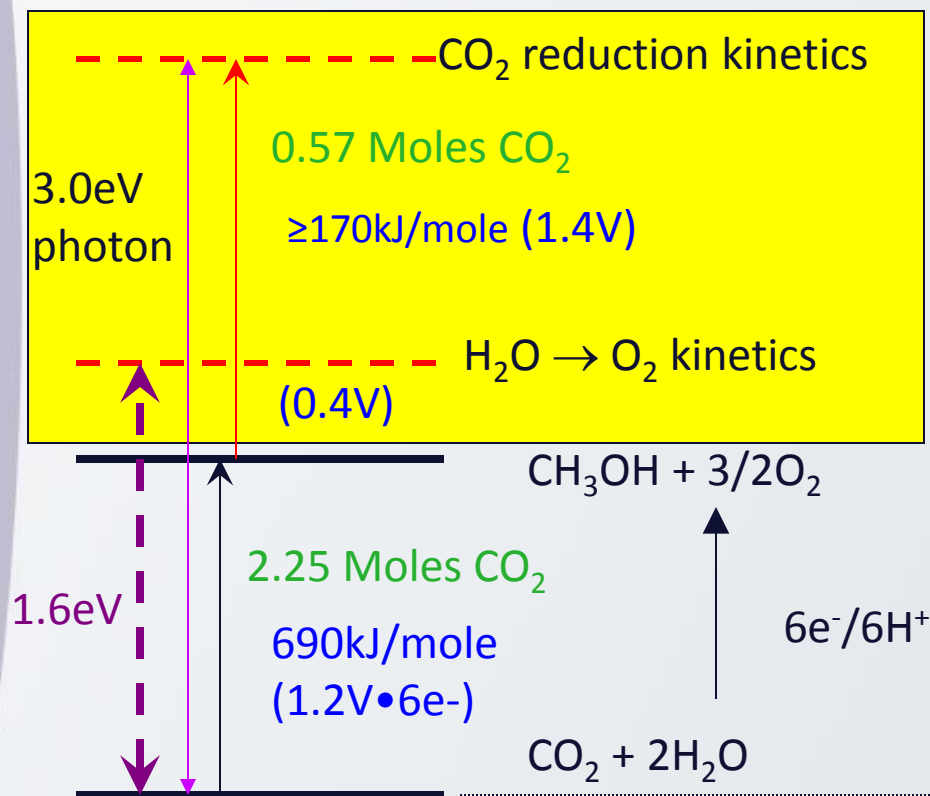


Carbon-Carbon Coupling is Possible!



Counting the Cost

If 1 Mole of CO_2 is converted:



According to the US DOE a gas fired power plant generates 1135 pounds of CO_2 /MWH

2.82 Moles CO_2
-1.00 Moles Consumed
1.82 Moles Net Formed!