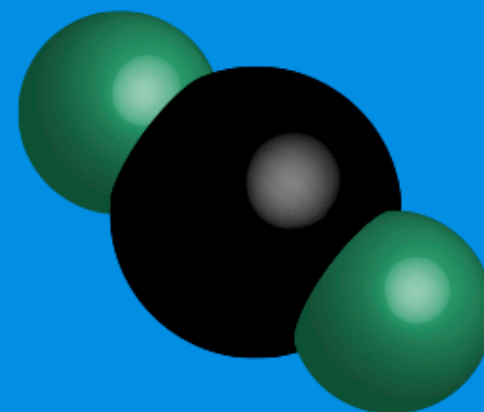


Carbon Dioxide a Problem and an Opportunity

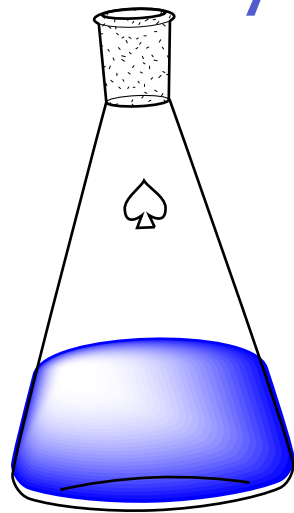


A Chemist's View on Interacting with God's Creation on Campus and in the Business World

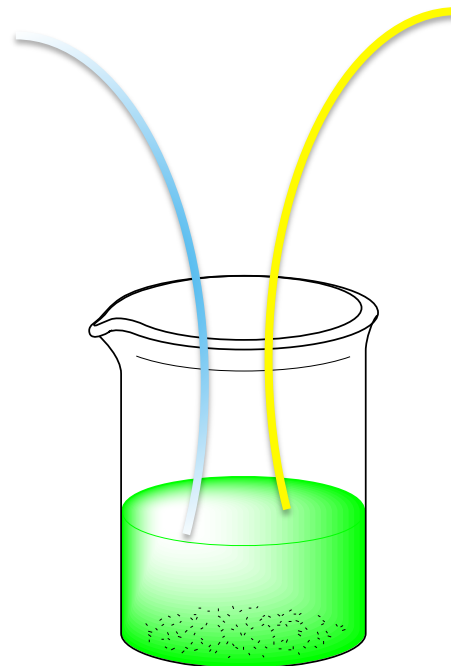
Andrew Bocarsly

Princeton University Department of Chemistry | Frick Chemistry Laboratory

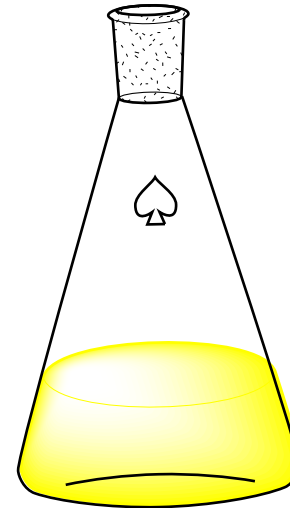
When most people have a solution they are done. But, when chemists have a solution they are all mixed up.



Faith



Me



Science



Westerly Road Church is a community focused on making disciples in Princeton and around the world. We are evangelical (we believe in the great news that Jesus came, died, and rose again so that we might be saved!), non-denominational, and moved by our love of God, one another, and our neighbor.



A Biblical Environmental Mandate

Therefore the Lord God sent him out from the garden of Eden to work the ground from which he was taken.
(Genesis 3:23)

For every kind of beast and bird, of reptile and sea creature, can be tamed and has been tamed by mankind... (James 3:7)

The Lord God took the man and put him in the garden of Eden to work it and keep it. (Genesis 2:15)

You have lived on the earth in luxury and in self-indulgence. You have fattened your hearts in a day of slaughter. (James 5:5)

...and for destroying the destroyers of the earth. (Rev 11:18)

Humanity's Top 10 Problems for next 50 years



1. ENERGY
2. WATER (= energy)
3. FOOD (= energy)
4. ENVIRONMENT
(= energy)
5. POVERTY (~ energy)

6. DISEASE
7. EDUCATION
8. TERRORISM & WAR
9. DEMOCRACY

10. POPULATION* 2003 2050

6.5 Billion People
8-10 Billion People



David Cahen WIS

Prof. Arrhenius in 1896

On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground

Svante Arrhenius

Philosophical Magazine and Journal of Science

Series 5, Volume 41, April 1896, pages 237-276.

This photocopy was prepared by Robert A. Rohde for Global Warming Art (<http://www.globalwarmingart.com/>) from original printed material that is now in the public domain.

Arrhenius's paper is the first to quantify the contribution of carbon dioxide to the greenhouse effect (Sections I-IV) and to speculate about whether variations in the atmospheric concentration of carbon dioxide have contributed to long-term variations in climate (Section V). Throughout this paper, Arrhenius refers to carbon dioxide as "carbonic acid" in accordance with the convention at the time he was writing.

Contrary to some misunderstandings, Arrhenius does not explicitly suggest in this paper that the burning of fossil fuels will cause global warming, though it is clear that he is aware that fossil fuels are a potentially significant source of carbon dioxide (page 270), and he does explicitly suggest this outcome in later work.

PHILOSOPHICAL MAGAZINE AND JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. Introduction : Observations of Langley on Atmospheric Absorption.

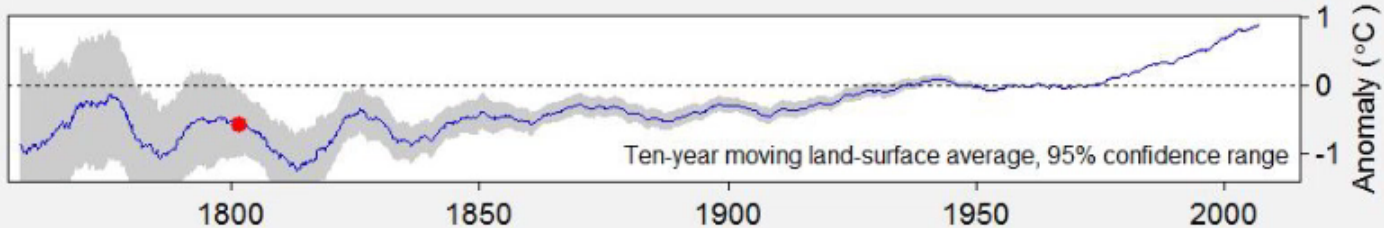
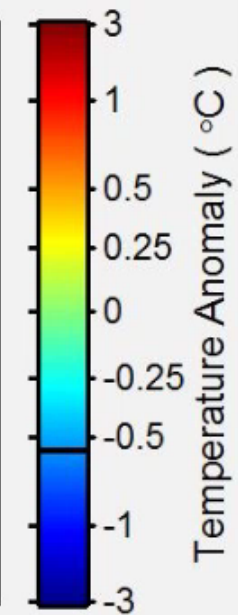
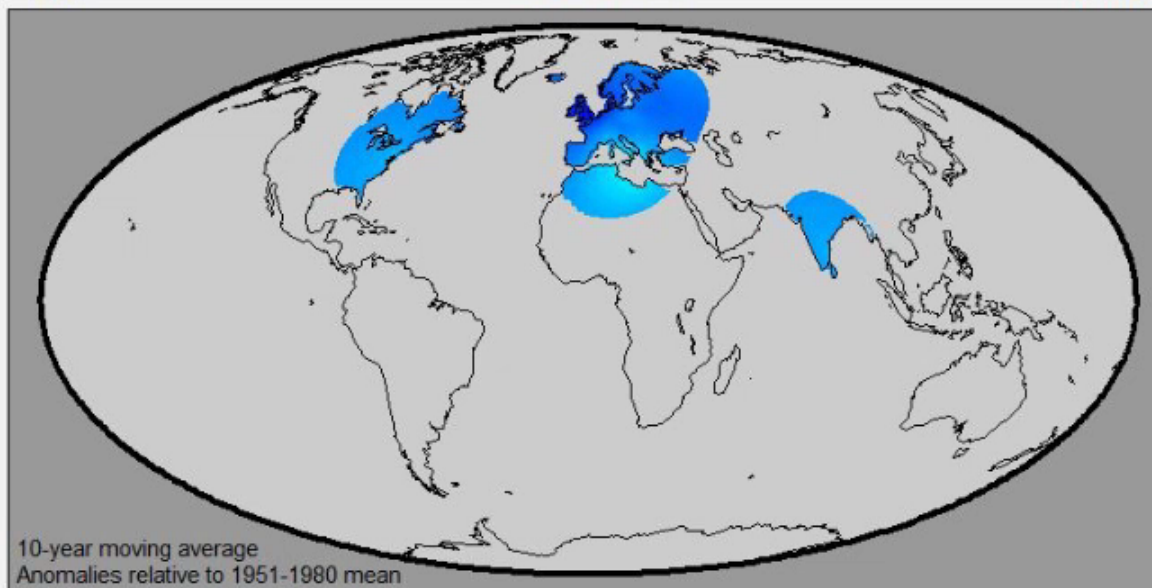
A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall† in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this : Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet§ ; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to -200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December 1895. Communicated by the Author.

Stations-Decades
46.0

1801.67

Land Coverage
10.1%



Berkeley Earth Surface Temperature

www.BerkeleyEarth.org

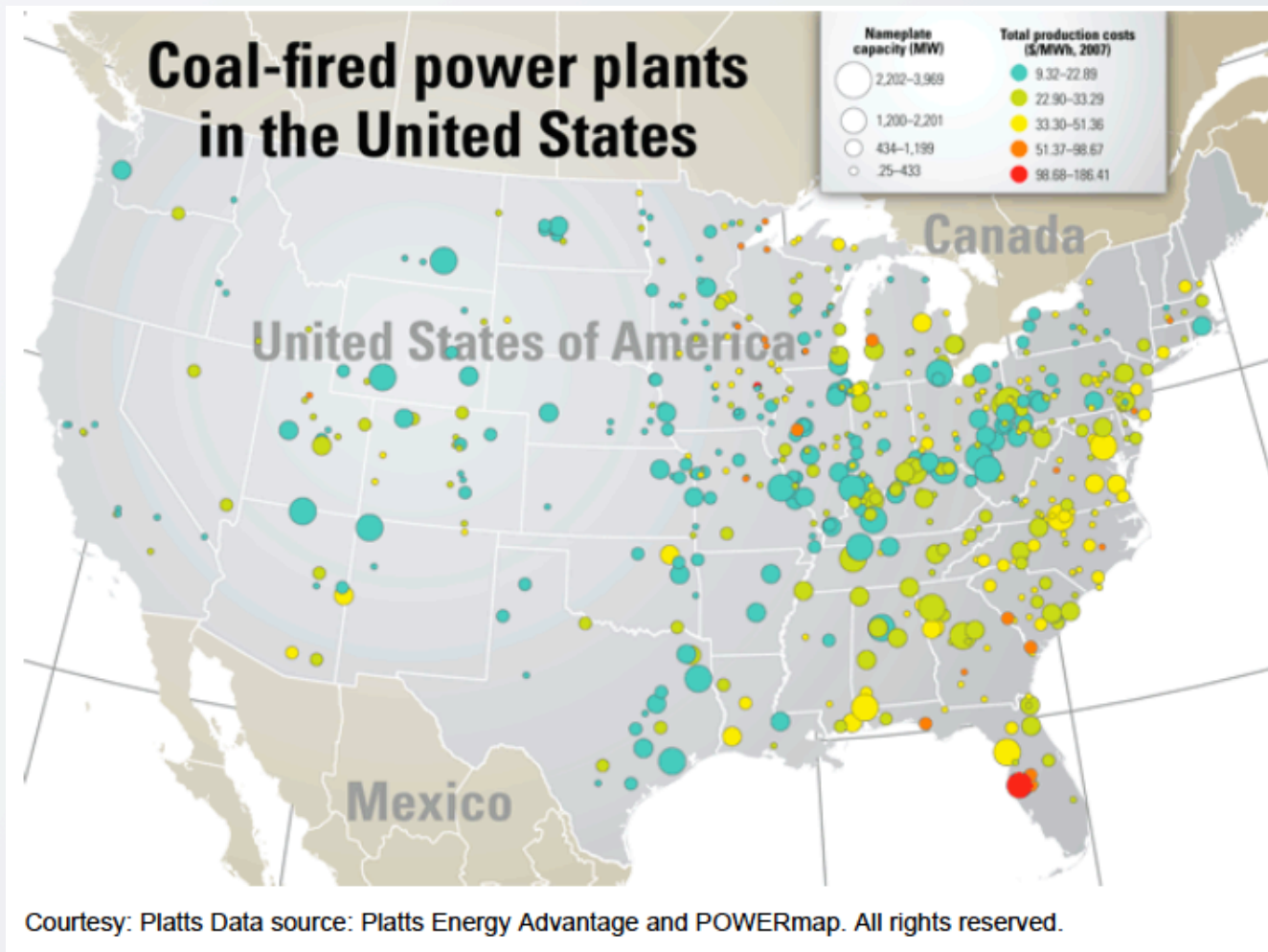
What is the problem?

A GigaWatt Coal Fired Power Plants ...



Generate 1000 lbs of CO₂ per SECOND!

And there is more than one such plant in the U.S.



Are we meeting the stewardship mandate?

And, if not, what can be done?

Does God Encourage us to “think
outside the box”?

The Parable of the Talents (Matthew 25)

¹⁴“For it will be like a man going on a journey, who called his servants and entrusted to them his property. ¹⁵To one he gave five talents, to another two, to another one, to each according to his ability. Then he went away. ¹⁶He who had received the five talents went at once and traded with them, and he made five talents more. ¹⁷So also he who had the two talents made two talents more. ¹⁸But he who had received the one talent went and dug in the ground and hid his master’s money. ¹⁹Now after a long time the master of those servants came and settled accounts with them. ²⁰And he who had received the five

¹⁶He who had received the five talents went at once and traded with them, and he made five talents more.

talents came forward, bringing five talents more, saying, ‘Master, you delivered to me five talents; here I have made five talents more.’ ²¹His master said to him, ‘Well done, good and faithful servant. You have been faithful over a little; I will set you over much. Enter into the joy of your master.’ ²²And he also who had the two talents came forward, saying, ‘Master, you delivered to me two talents; here I have made two talents more.’

²³His master said to him, ‘Well done, good and faithful servant. You have been faithful over a little; I will set you over much. Enter into the joy of your master.’ ²⁴He also who had received the one talent came forward, saying, ‘Master, I knew you to be a hard man, reaping where you did not sow, and gathering where you scattered no seed, ²⁵so I was afraid, and I went and hid your talent in the ground. Here you have what is yours.’ ²⁶But his master answered him, ‘You wicked and slothful servant! You knew that I reap where I have not sowed and gather where I scattered no seed? ²⁷Then you ought to have invested my money with the bankers, and at my coming I should have received what was my own with interest. ²⁸So take the talent from him and give it to him who has the ten talents. ²⁹For to everyone who has will more be given, and he will have an abundance. But from the one who has not, even what he has will be taken.

‘I went and hid your talent in the ground. Here you have what is yours,’ ²⁶But his master answered him, ‘You wicked and slothful servant!’

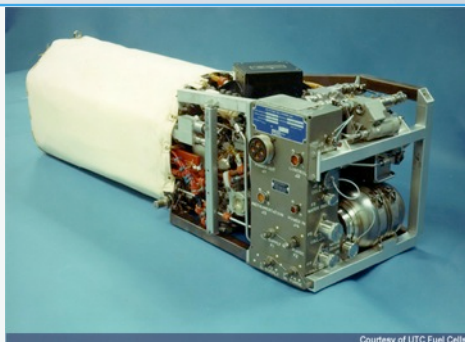
invested my money with the bankers, and at my coming I should have received what was my own with interest. ²⁸So take the talent from him and give it to him who has the ten talents. ²⁹For to everyone who has will more be given, and he will have an abundance. But from the one who has not, even what he has will be taken.

A Story of Three Princeton Undergrads (a.k.a. The Tupperware[®] Problem)

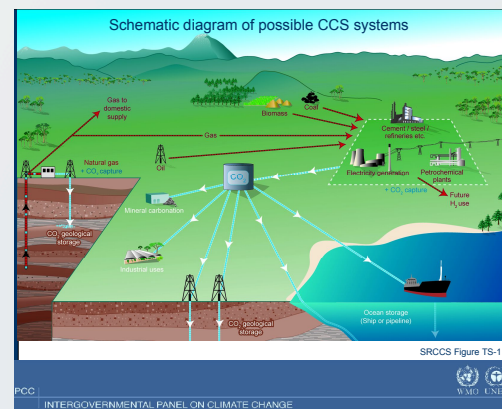
- **Student A:** Prof. Coates at Cornell has developed very interesting chemistry for reacting CO₂ with nature products found in lemon to make a polymer with excellent properties as a plastic. So we can make Tupperware from it!
- **Student B:** CO₂ can be reduced to elemental carbon (carbon black) and this is needed for making tires.
- **Student C:** We can do your chemistry Professor Bocarsly, and convert CO₂ into methanol, which is a fuel.

What is your answer to this problem A B or C?

On hearing this Student A responded, " No one can use that much Tupperware!"



Sequestration



Fuels ← 93%

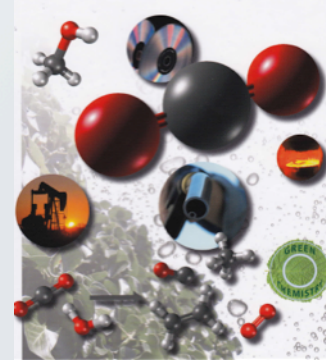
CO₂ Mitigation



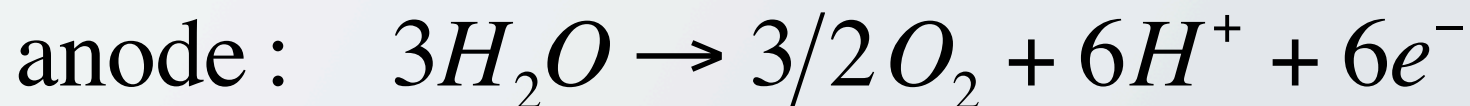
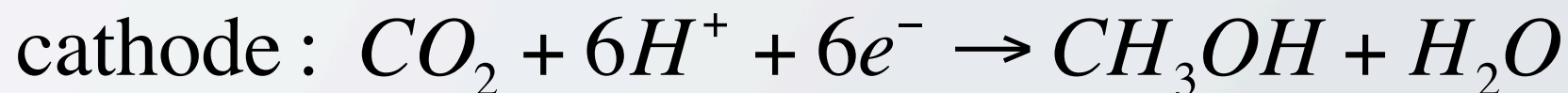
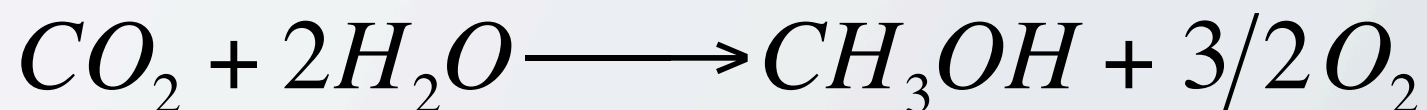
7%

Polymers, Solid-State Products

Carbon Dioxide as Chemical Feedstock

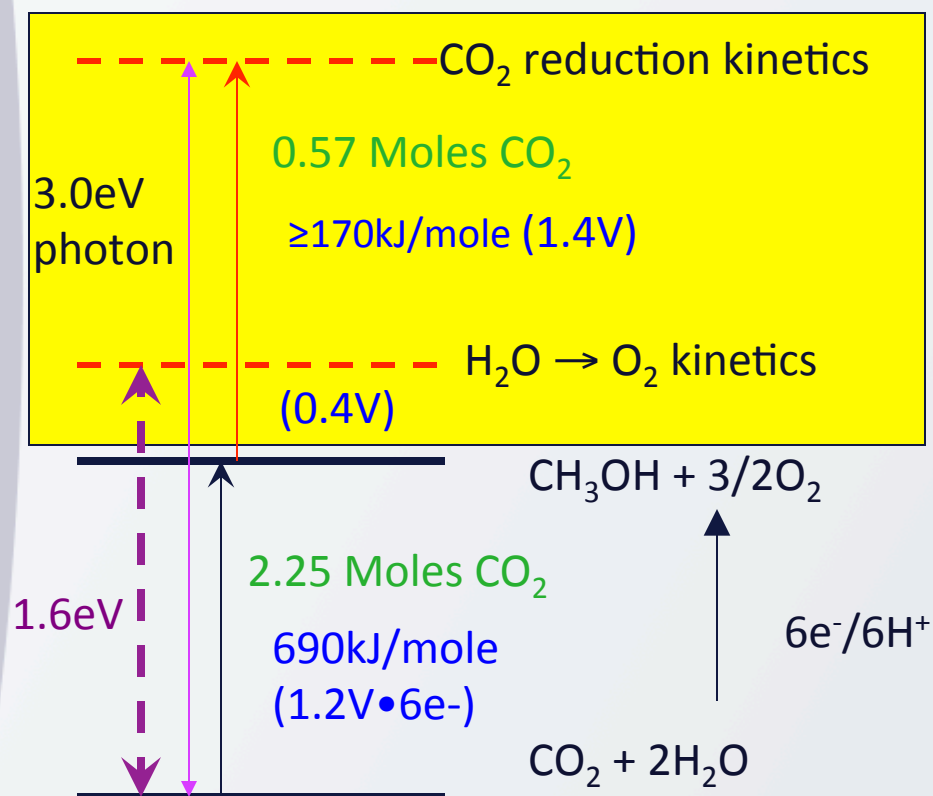


How About Electrochemical Conversion?



Counting the Cost

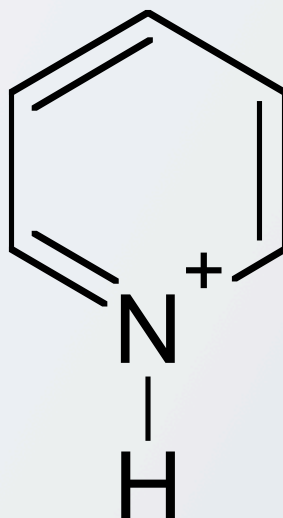
If 1 Mole of CO₂ is converted:



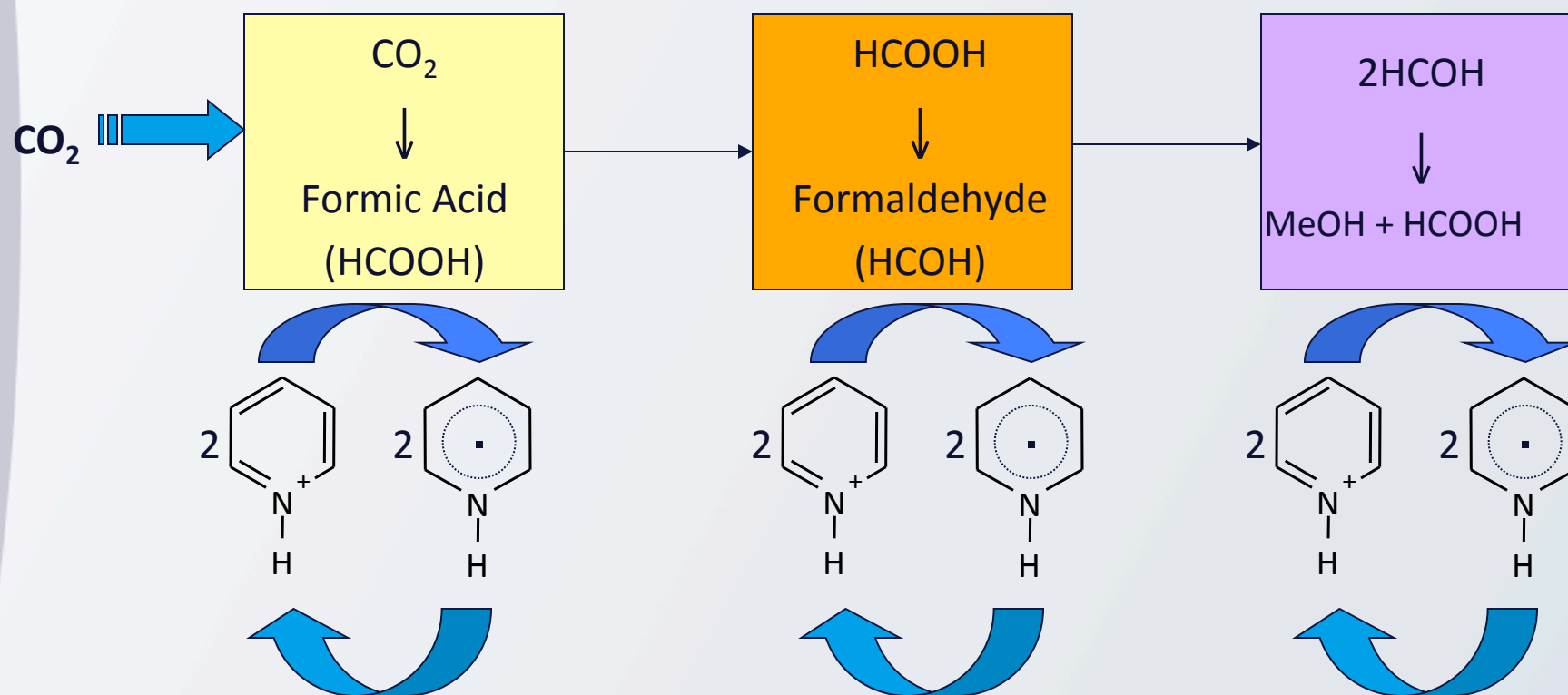
According to the US DOE a gas fired power plant generates 1135 pounds of CO₂/MWH

2.82 Moles CO₂
~~-1.00 Moles Consumed~~
 1.82 Moles Net Formed!

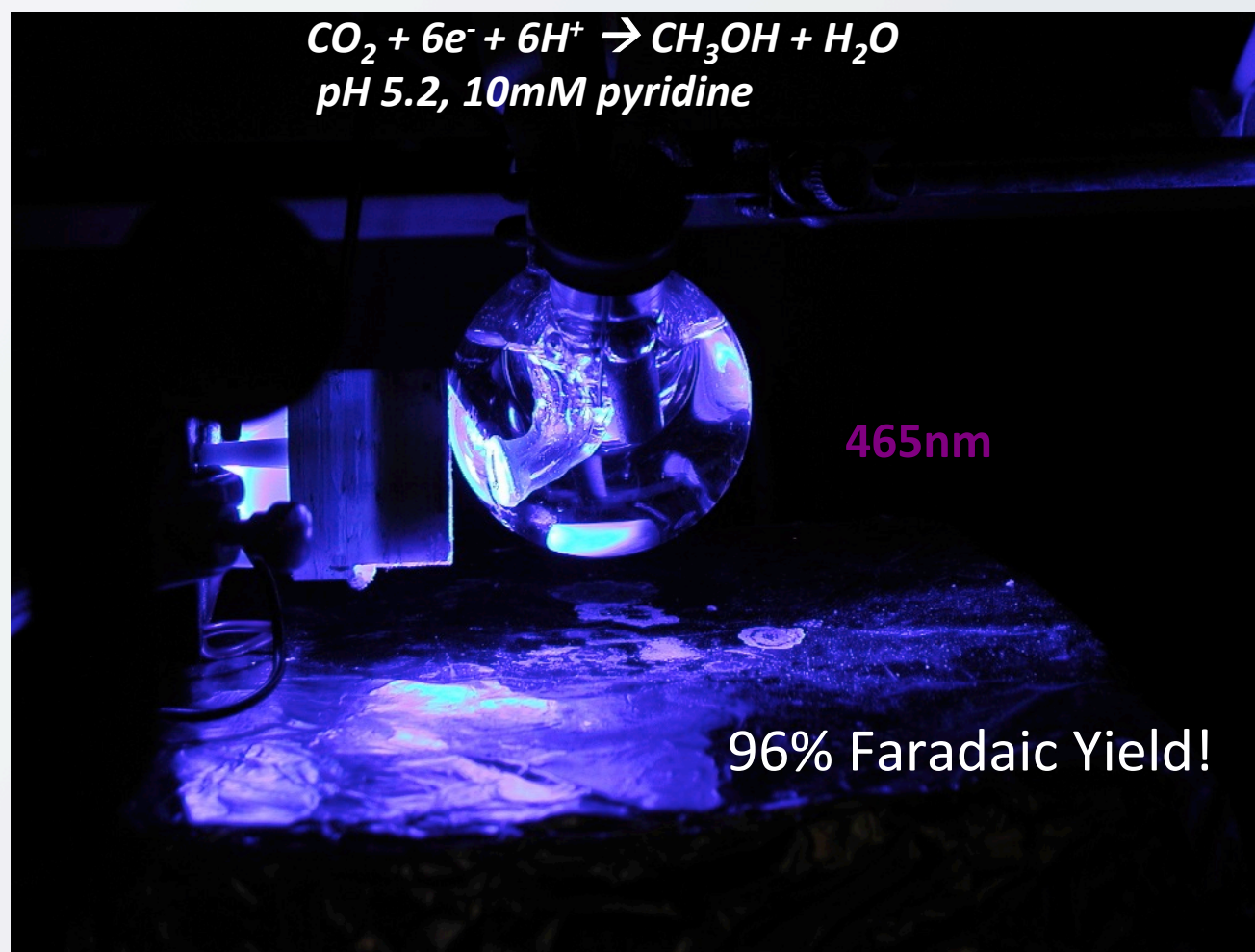
The Catalyst: Pyridinium



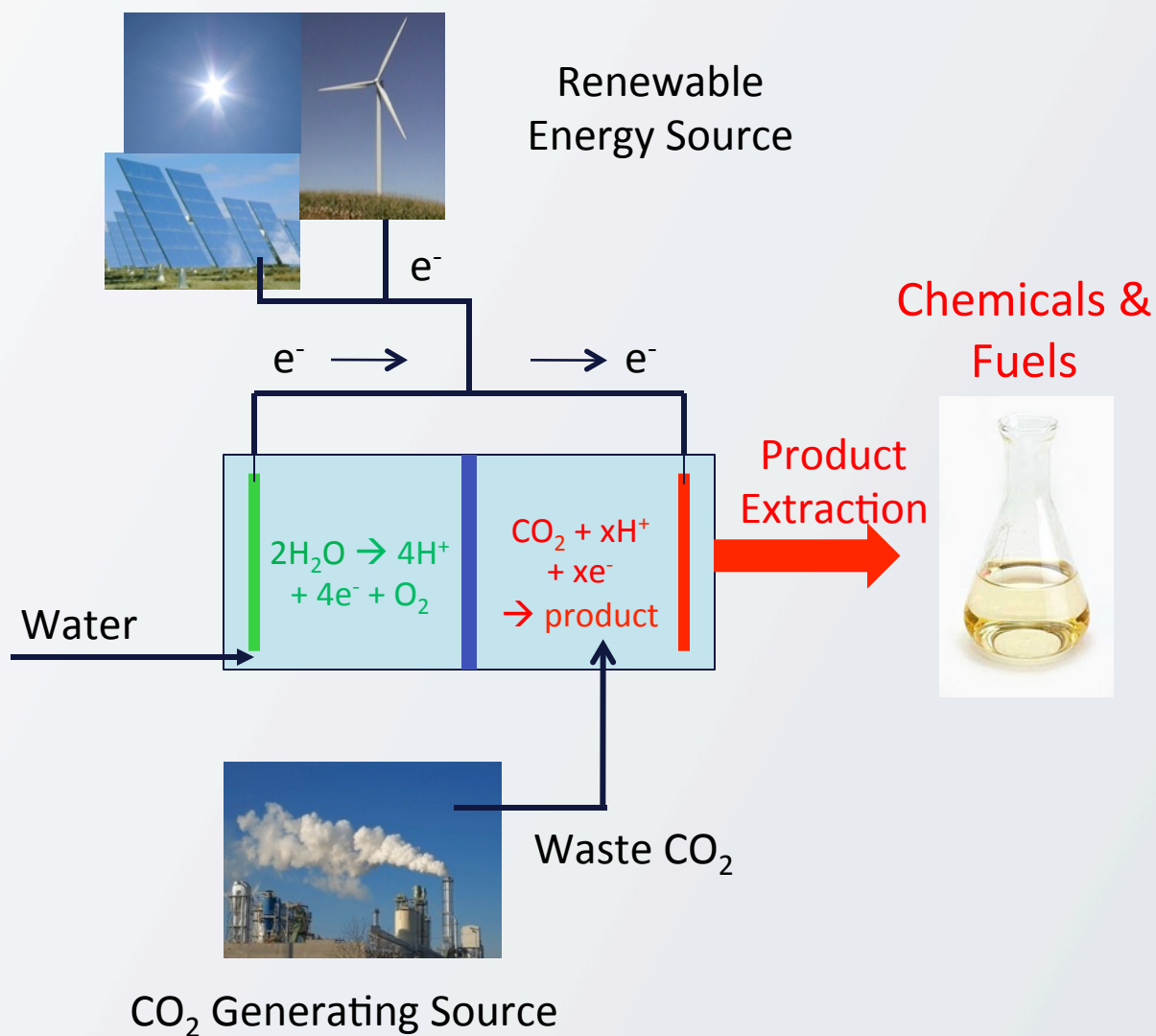
Overview of Mechanism



p-GaP MeOH Evolving Cell



The Liquid Light Process



Highlights

Abundant cathode materials

Efficient and selective catalysts

Low cell voltages (energy efficient)

Stability

PRUDENCE AND ITS COUNTERFEITS

-From Jeff Cornwall

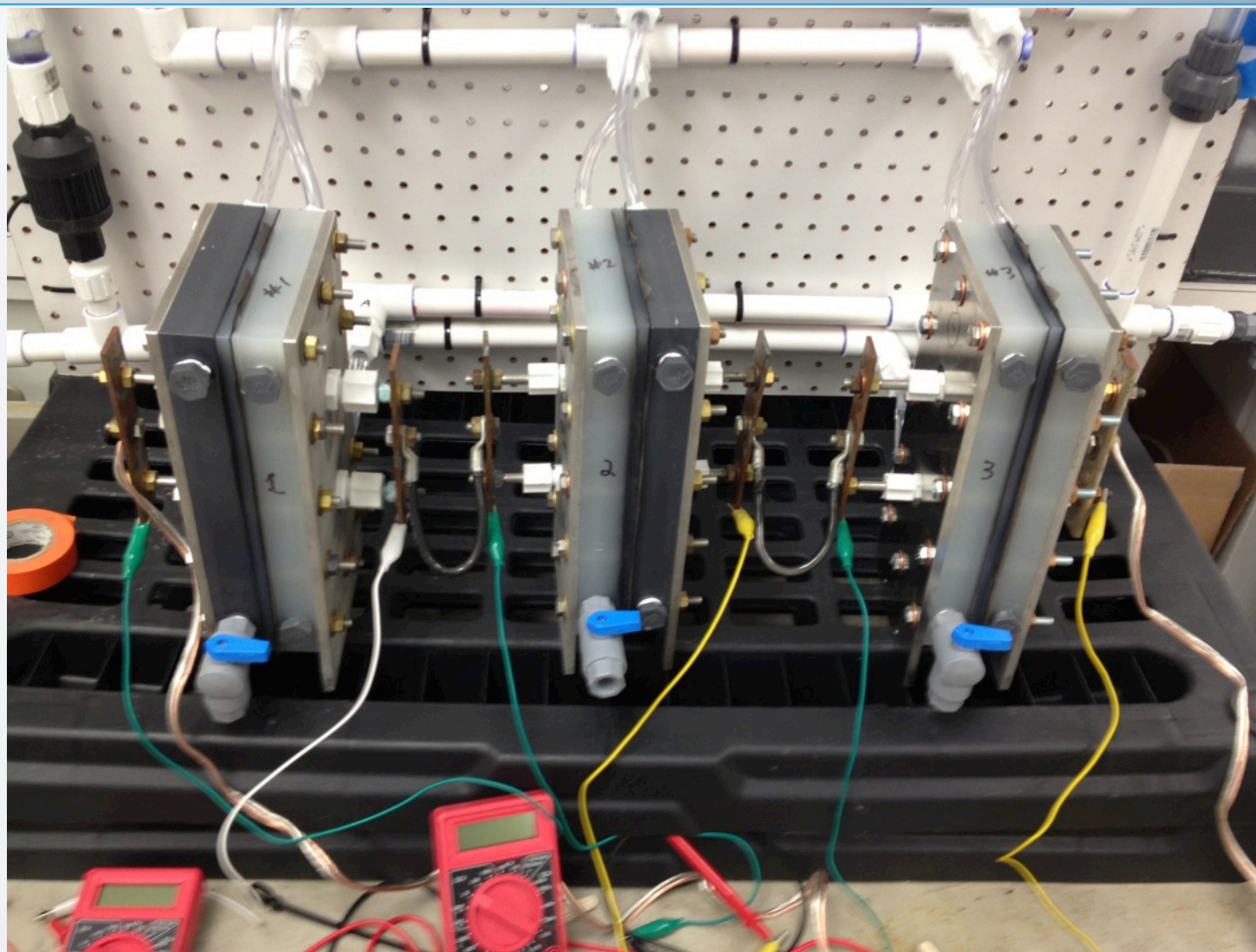
	Ineffective Means	Effective Means
Good Ends	Well-intentioned (moralistic)	Prudence (flourish)
Bad Ends	Incompetent (broke)	Cunning (survival)

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

A Three Cell Stack for Formate Production



Solar Fuel is Here!



Solar Panel Provided By



PSEG

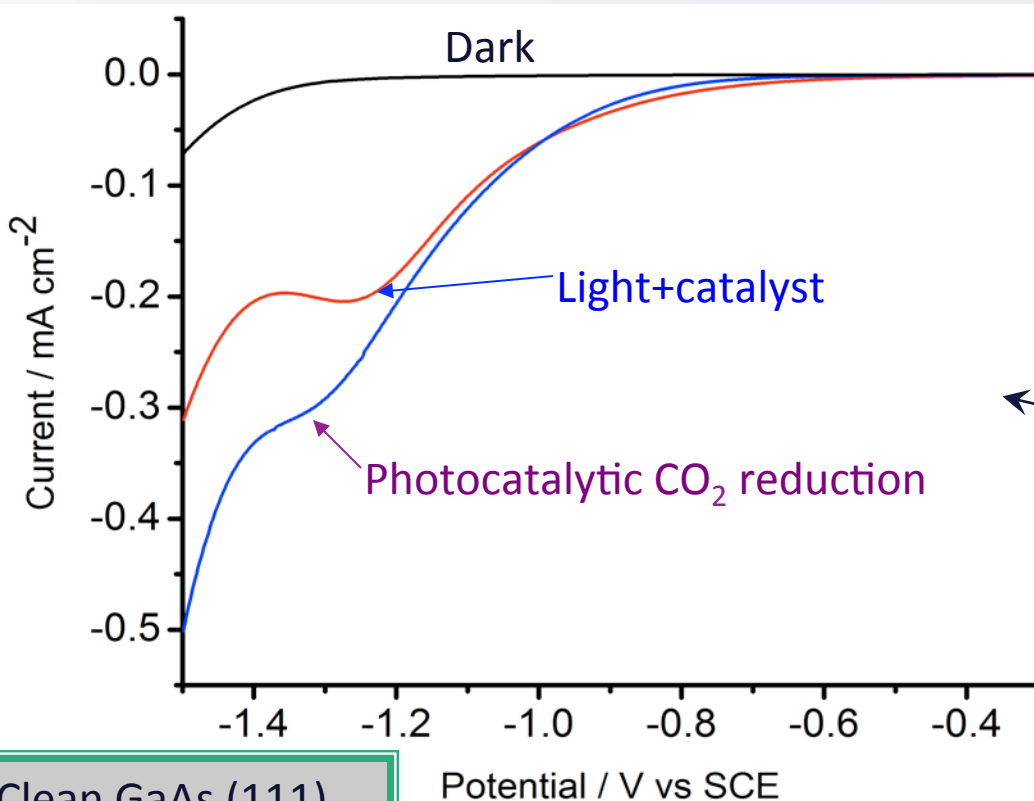
and



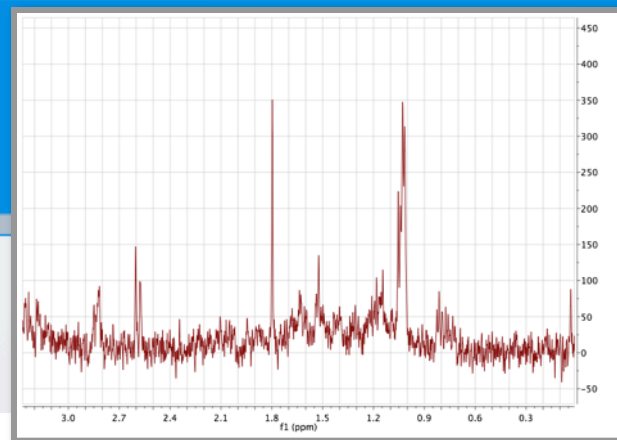
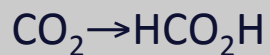
PETRA SOLAR
Intelligent Energy By Design



P-GaAs: The Surface Counts



Clean GaAs (111)



GaAs (111)
+
Pt particles
CO₂ → isopropanol

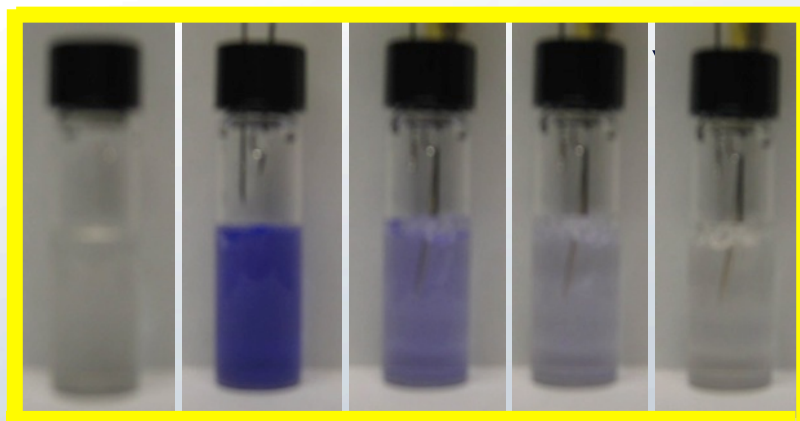
Pt/GaAs(111)

	Faradaic Efficiency, %					
Catalyst	Light source	Formic acid	Acetic acid	Acetone	2-Propanol	n-Butanol
Pyridinium	HgXe	14	10	7	50	~20

Acknowledgement



“See, I have set before you today life and good, death and evil. ...Therefore choose life, that you and your offspring may live, loving the Lord your God, obeying his voice and holding fast to him....” (Duet. 30:15 &20)



Start Reduction add CO₂ methanol
10mM pyr, under Ar and pyr.