



## **Company and Technology Overview**

**Hydrogen Technical Advisory Committee**

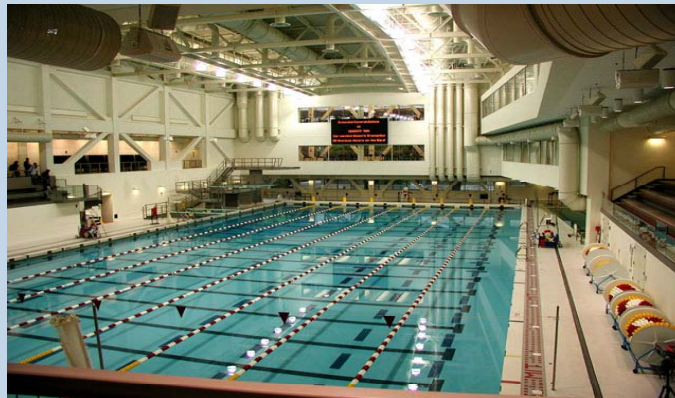
**14 October 2010**

# Transforming the Global Energy Paradigm

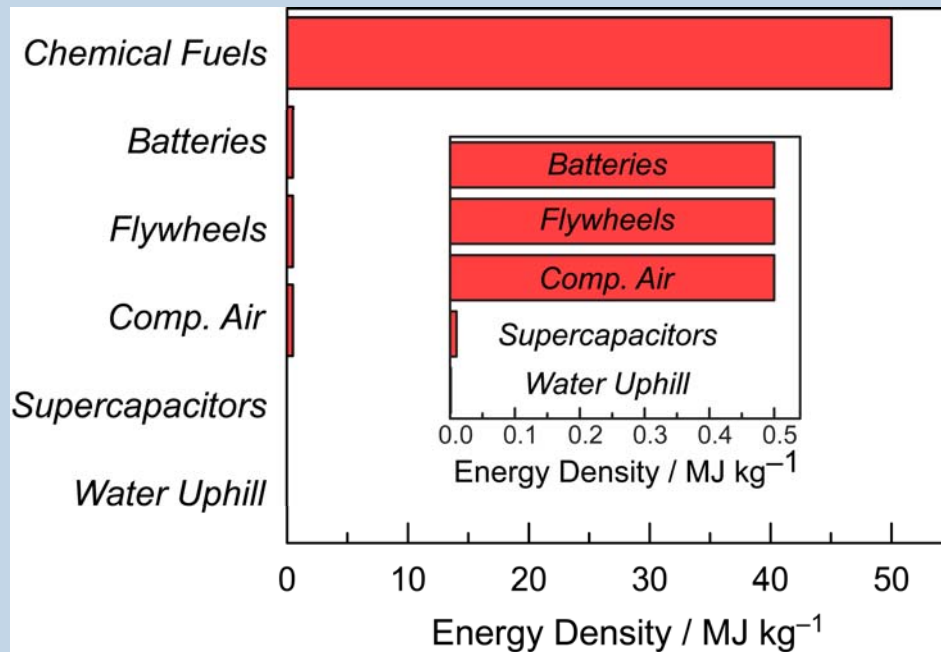
- **Vision: Sunlight + Water = Affordable, Accessible Energy**
  - *Sunlight*: Most Abundant Energy Source
  - *Water*: Most Abundant Liquid
  - *Sun Catalytix Technology*: Accessible and Inexpensive
- **Impact**
  - *Affordable Energy Storage*
  - *Distributed Fuel Production*
  - *Every Home and Community Becomes an Energy Production Center*
    - Personalized energy paradigm consistent with prior shifts
      - Land lines to cell phones
      - Mainframes to personal computers

# Sunlight + Water: Near Limitless Energy Supply

- Global energy usage likely to double to ~30TW by 2050
- $1.2 \times 10^5$  TW of Solar at Earth's surface; 800 TW practical
- Other renewables limited in scale
  - Biomass: 5-7 TW gross (with all arable land not used for food)
  - Wind: 2-4 TW total extractable
  - Geothermal: 12 TW gross over land small fraction recoverable
- *Volume of MIT pool  $\rightarrow H_2$  and  $O_2$  per second = 43 TW*

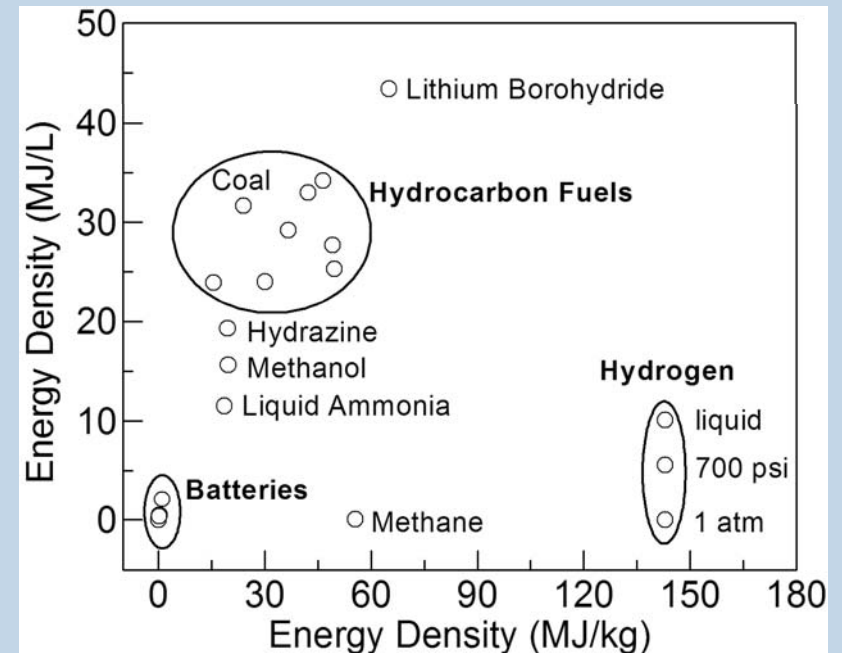


# Energy Storage in Chemical Fuels



Chemical fuels possess energy densities unmatched by any other storage means

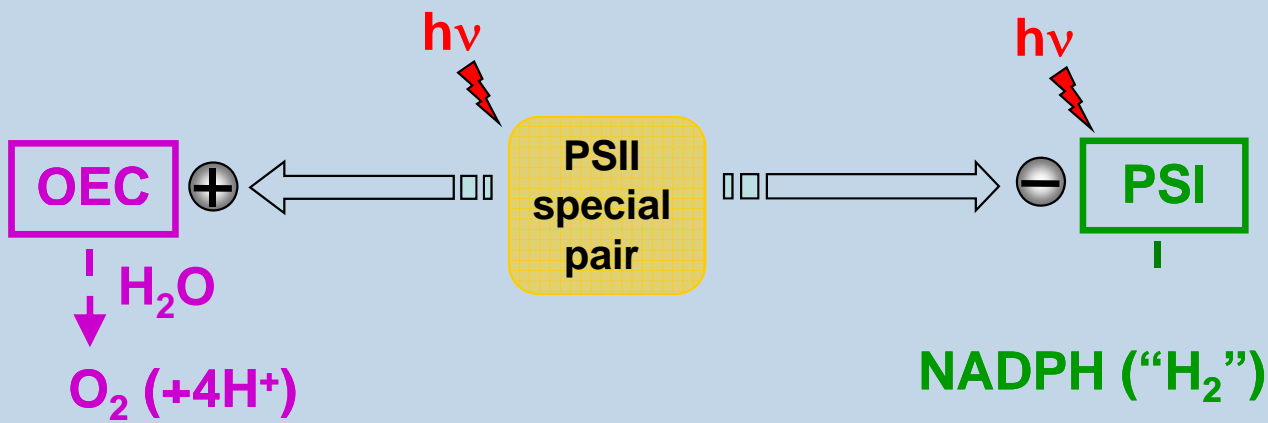
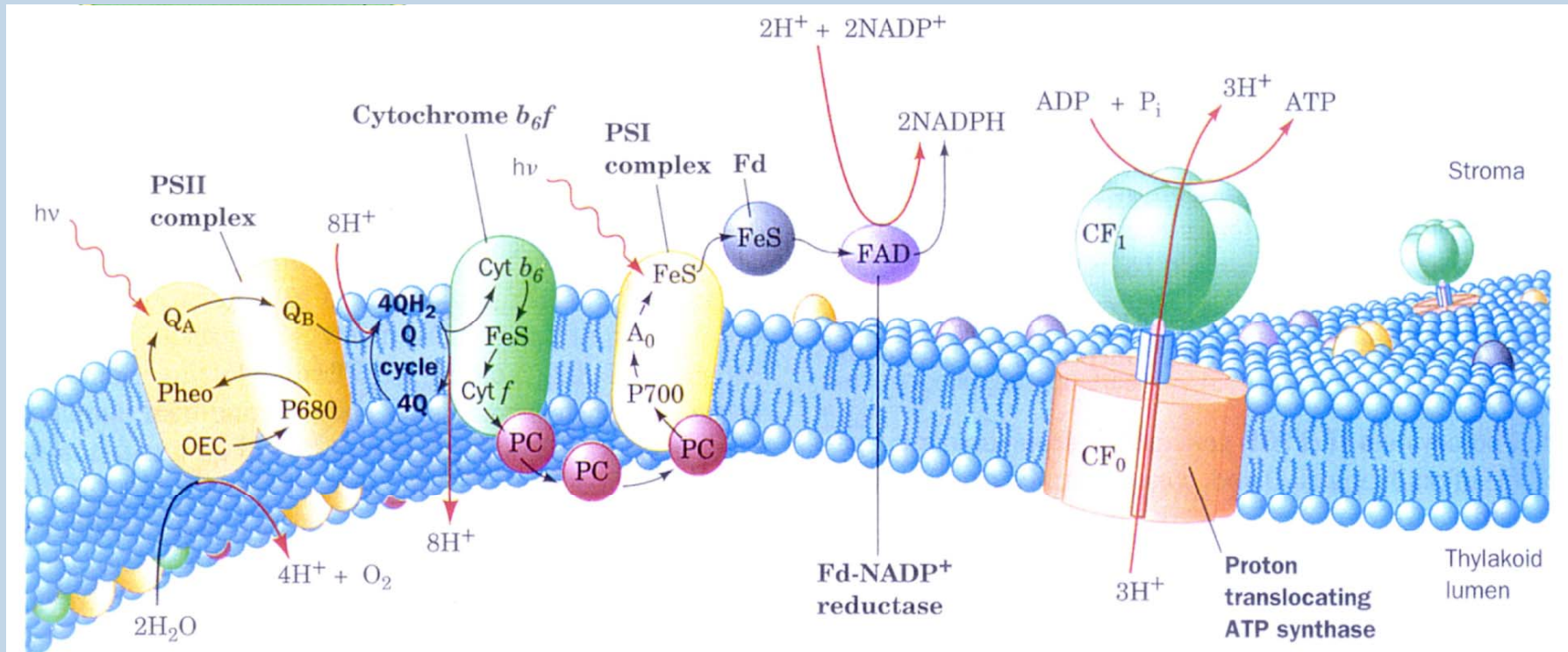
Hydrogen is the most energy dense fuel by mass



# Target Applications

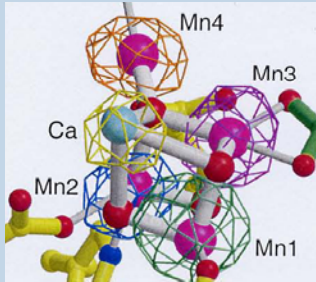
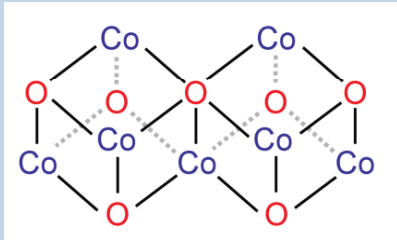
- **On-site industrial hydrogen**
  - For various applications: semiconductor fabrication, metal annealing, generator cooling, etc.
- **Energy storage**
  - Off grid power
  - On-grid storage
- **Fuels**
  - Automotive traction
  - Hydrogen as a fuel precursor (*e.g.*, renewable diesel)

# Natural Photosynthesis



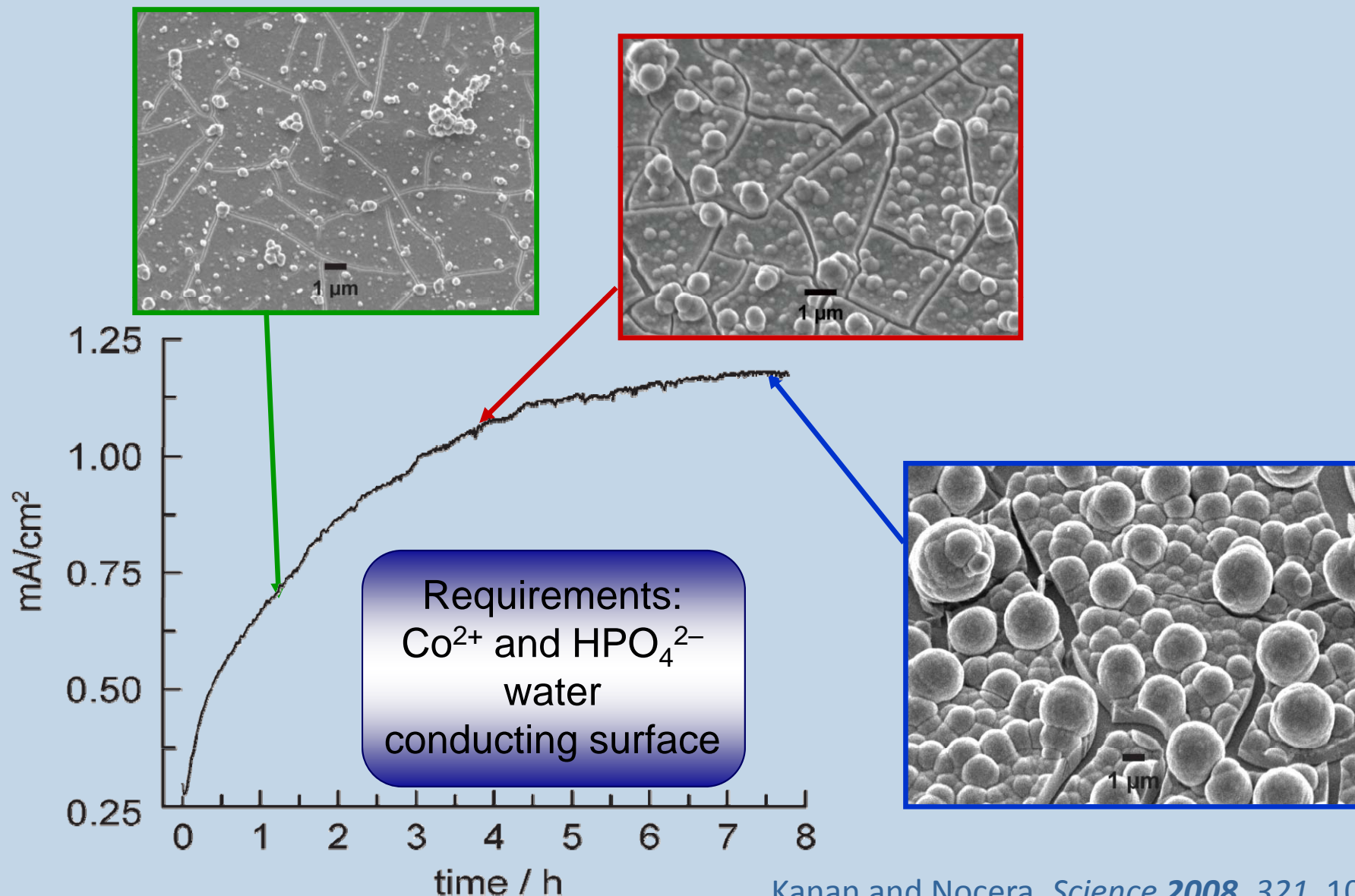
- (1) catalysis is performed under benign conditions at neutral pH
- (2) generation of OEC for water oxidation is key evolutionary step
- (3) photon sets up a (wireless) current within the leaf
- (4) separate light harvesting from energy storage

# Our Technology Mimics Nature's Processes

Design Criteria	Photo-system II	Cobalt-Phosphate
<i>Conditions of operation</i>	Neutral pH and STP Low over-potential	Neutral pH and STP Low over-potential
<i>Repair</i>	D1 protein	$\text{HPO}_4^{2-}/\text{Co}^{3+}$ equilibrium
<i>Water Supply</i>	Fresh or Salt	Fresh or Salt
<i>Stability</i>	Regenerative	Regenerative
<i>Abundant materials</i>	Manganese	Cobalt
<i>Structure</i>		



# In Situ Formation of an Oxygen-Evolving Catalyst

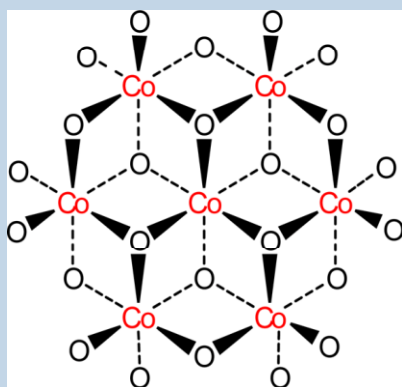
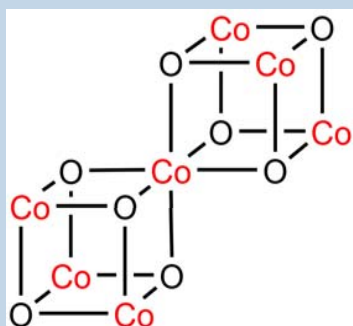
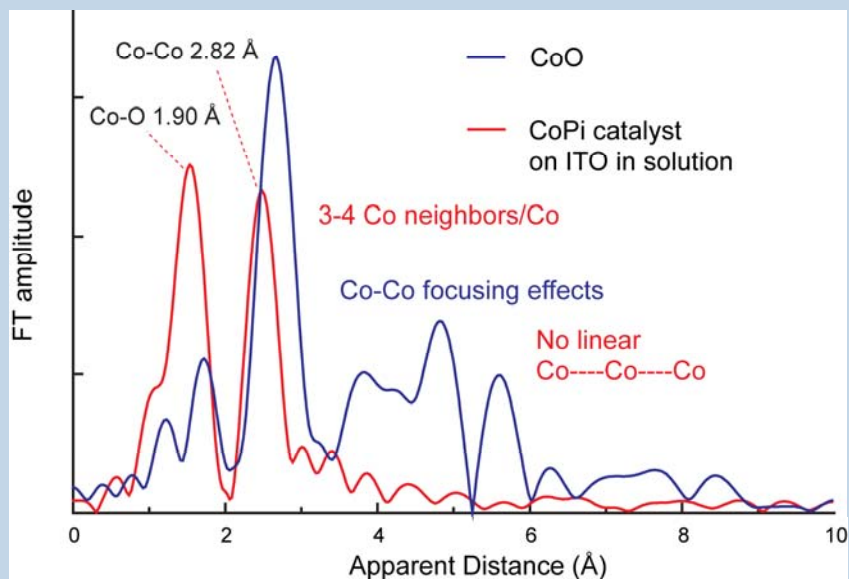


Kanan and Nocera, *Science* **2008**, 321, 1072.



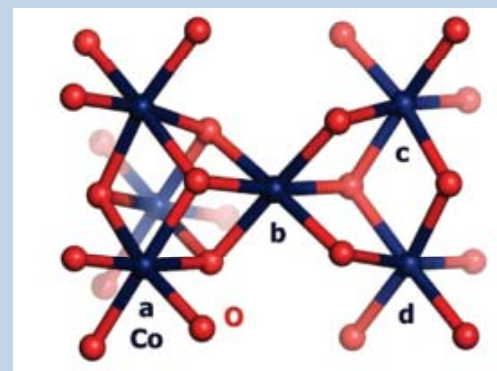
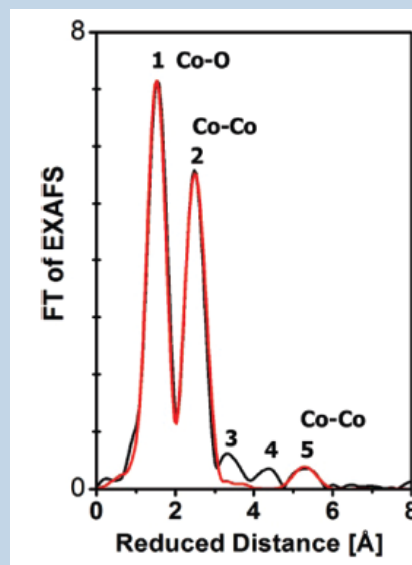
# Structural Insight from EXAFS

Not a typical Oxide material



With Junko Yano and Vittal Yachandra at LBNL

Confirmed by a German group

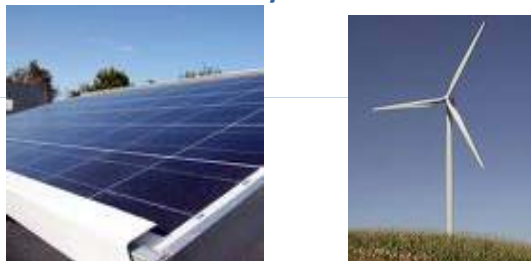


Dau and coworkers *JACS* **2009**, *131*, 6936

# Two Modalities for Sun Catalytix Technology

## 1. Electrolyzer Modality

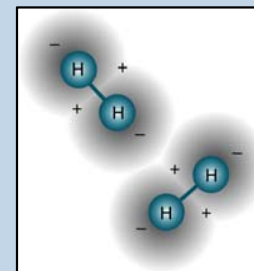
Solar, Wind or other  
electricity source



Sun Catalytix  
Electrolyzer

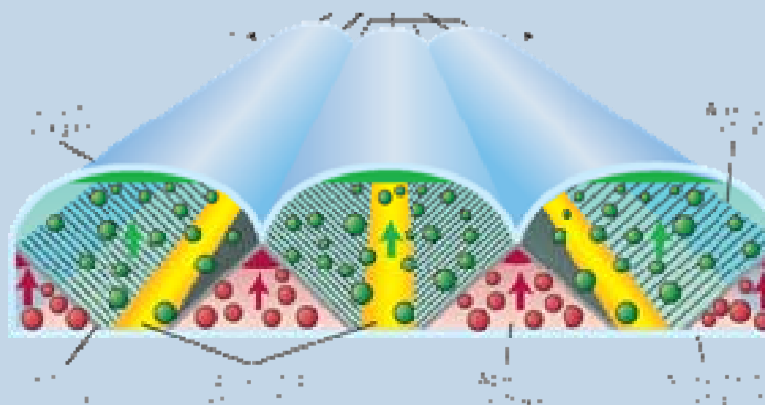
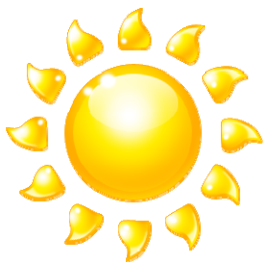


Hydrogen

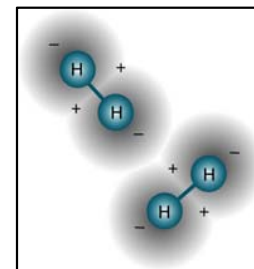


## 2. Photoelectrochemical (PEC) Modality

Sunlight

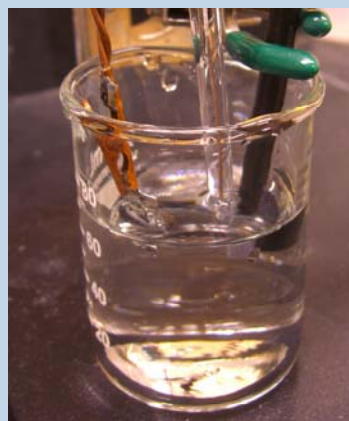


Hydrogen

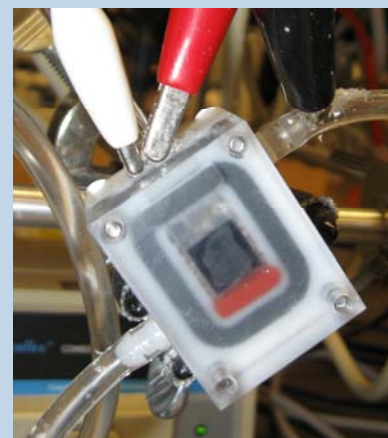


# Electrolyzer Technology Status

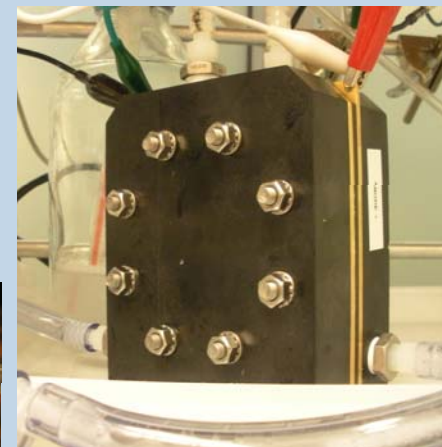
- Anode catalyst performance meets initial target
- Cathode catalyst performance meets initial target
- Membrane / separator criteria defined, initial materials selected
- Integration of cell components, electrode design, performance enhancement underway



**2008**



**2009**

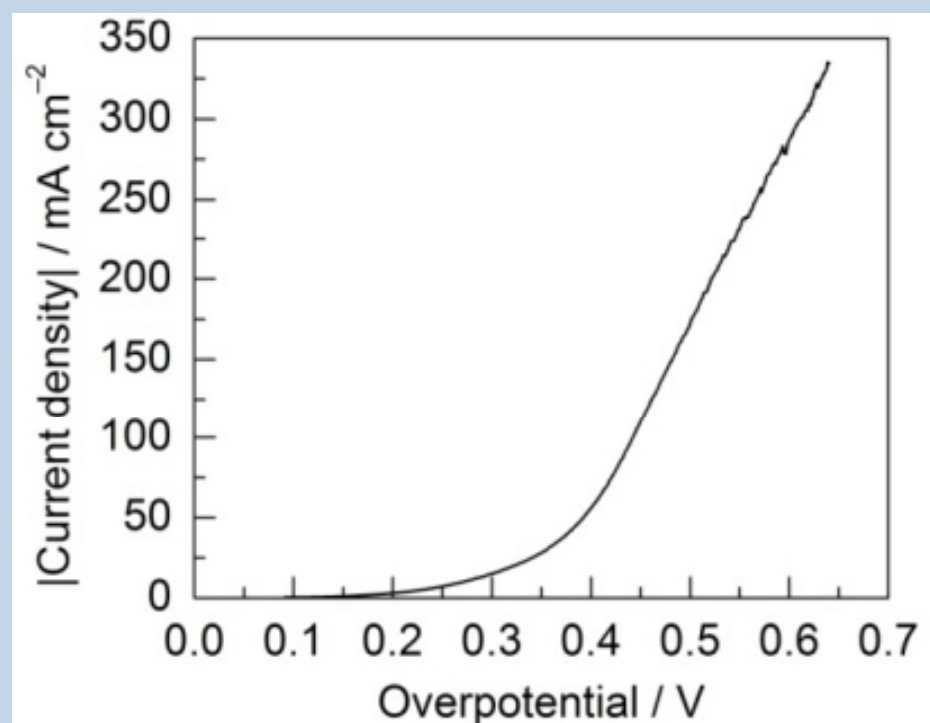
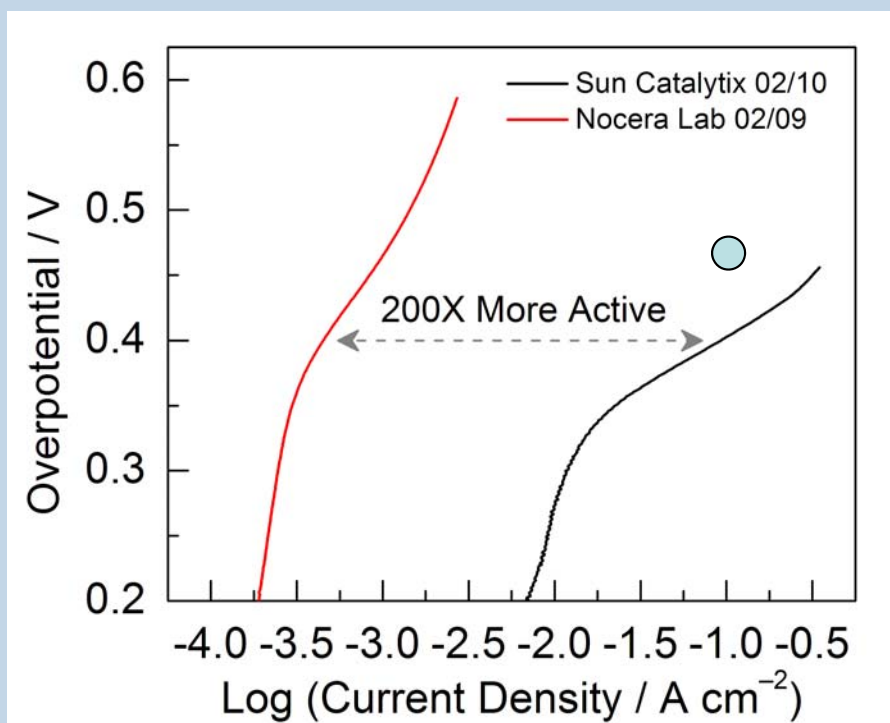


**2010**

# Electrolysis Performance Enhancement

Electrode design has enabled  $\sim 200\times$  current enhancement relative to results published in Kanan and Nocera, *Science* **2008**, 321, 1072.

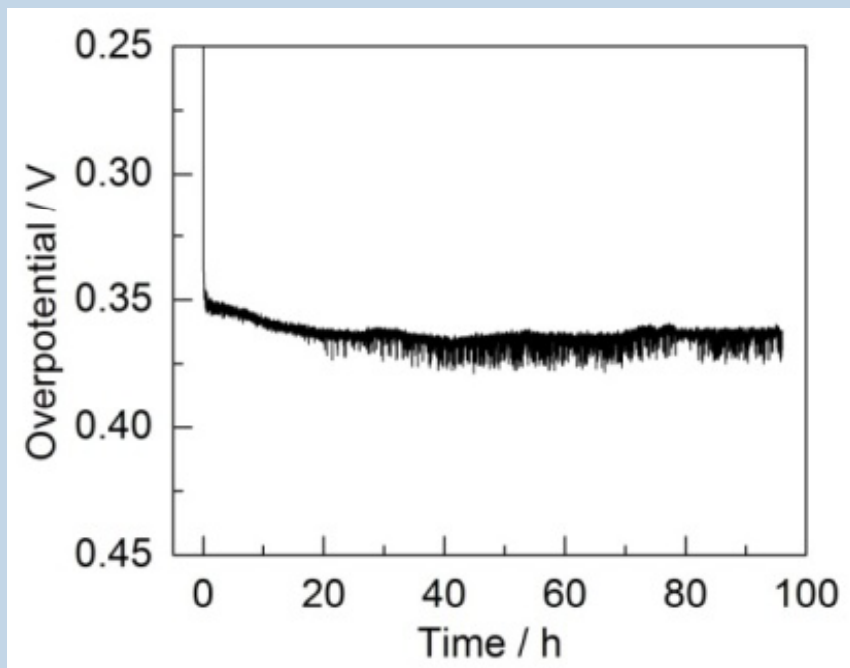
## Anode Activity Enhancement



Esswein et. al., Submitted to *Energy and Environmental Science*

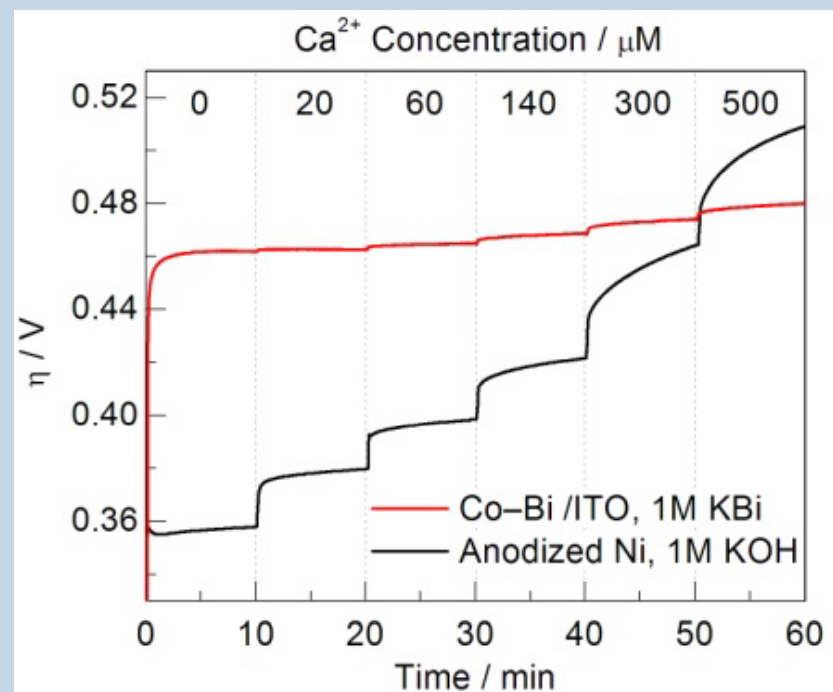
# Anode Catalyst Capability

## Anode Stability



Engineered Co-OEC catalysts exhibits high stability in untreated river water

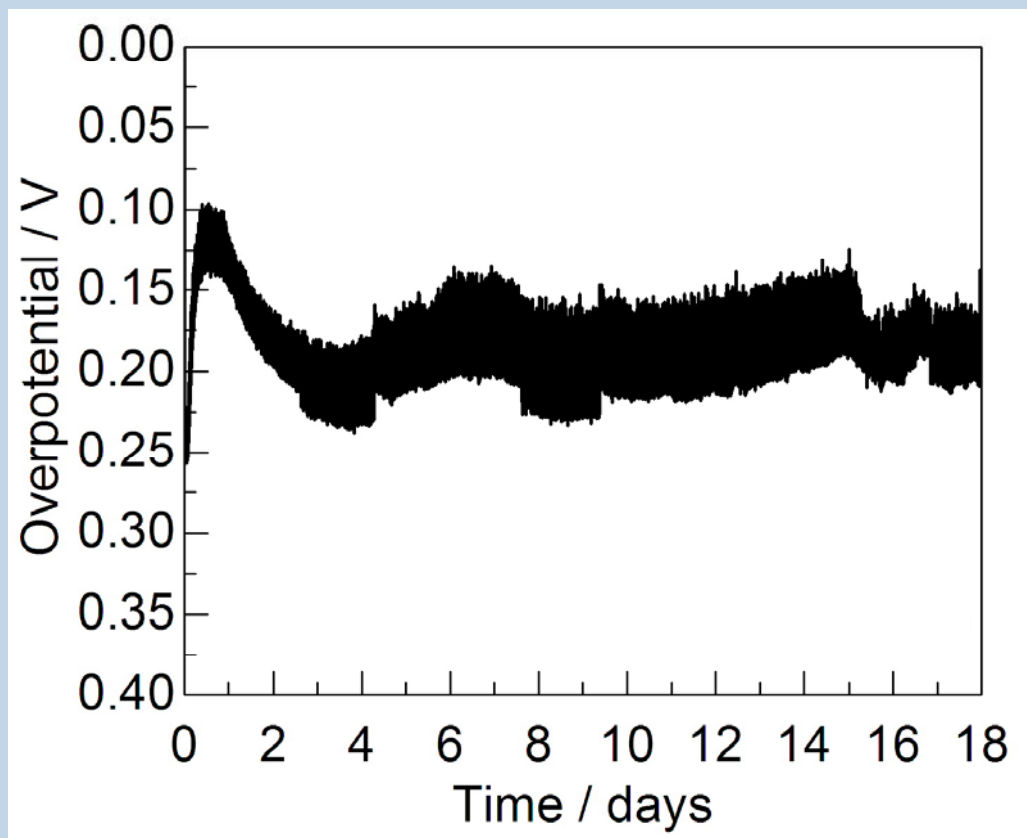
Esswein et. al., Submitted to *Energy and Environmental Science*



Engineered Co-OEC catalysts / conditions enable high resistance to poisoning

# Earth-Abundant Cathode Catalyst

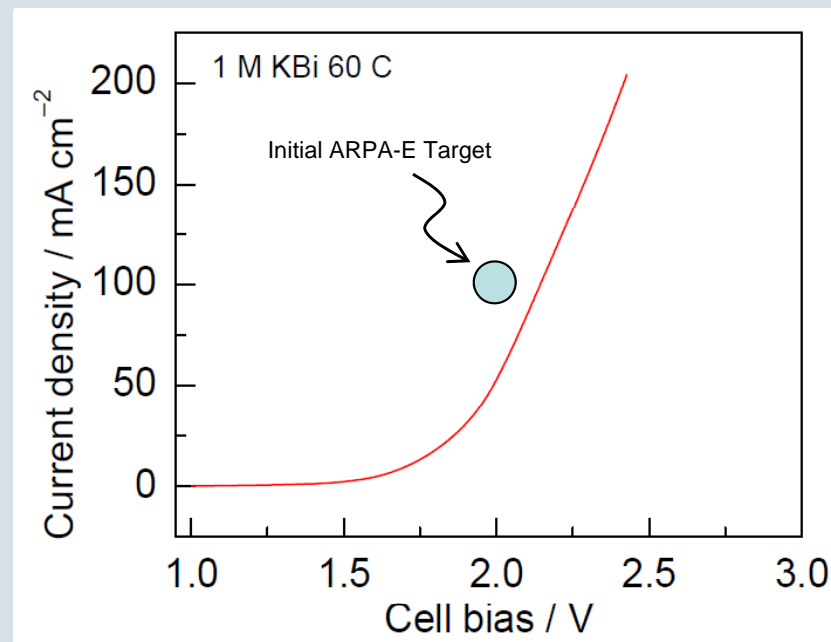
## Cathode Stability



Sun Catalytix discovery -- cathode catalyst made of earth-abundant elements that exhibits stability in untreated river water

# Full Cell Performance

- Initial results show progress toward ARPA-E goals (2V, 100 mA/cm<sup>2</sup>)
- Cells constructed using earth-abundant catalyst materials (anode is Co-OEC, cathode is proprietary)
- Ongoing efforts to improve performance by component engineering efforts





# Photo-Electrochemical Cells

- Benign conditions suitable for Sun Catalytix catalysts increase the number of PV cells that can be used
- Operational current densities are limited by collecting solar photons
- Excellent match of system requirements with Sun Catalytix materials characteristics
- Several alternative configurations being explored

## *Photoanode/PV*

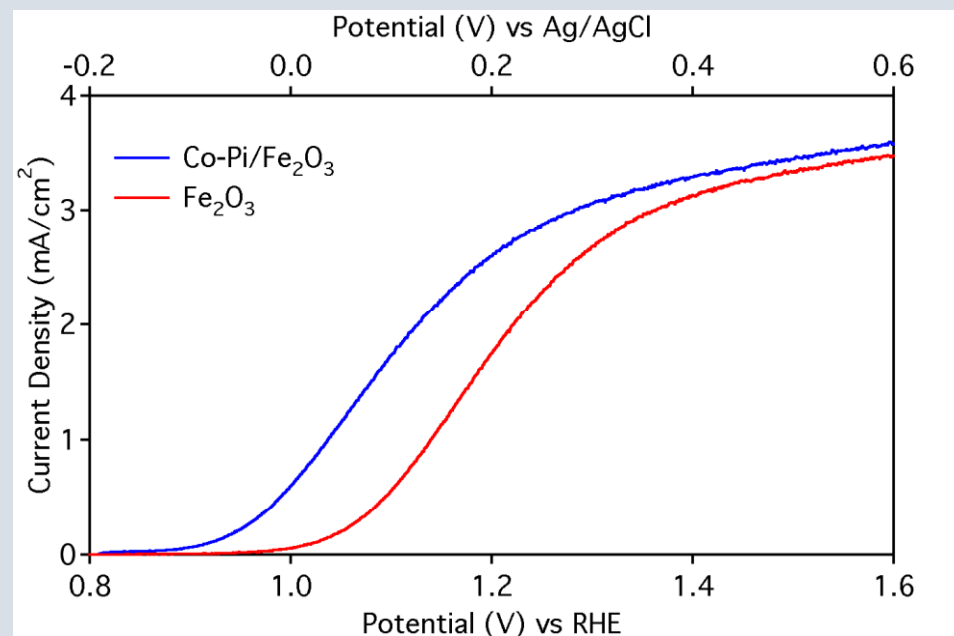
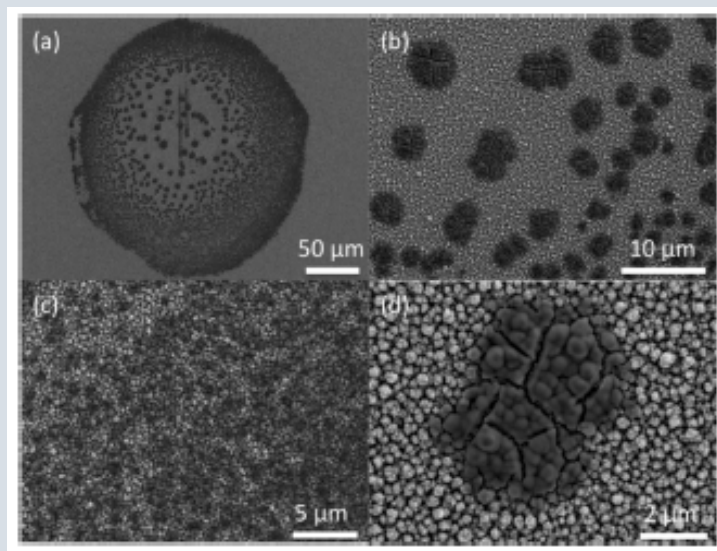
**Co-OEC Catalyst**

**Photoanode  
( $\text{Fe}_2\text{O}_3$ ,  $\text{WO}_3$ , etc)**

**PV (Si, CIGS, etc)**

**$\text{H}_2$  Catalyst**

# Photo-Anode Enhancement with Co-OEC



- Sun Catalytix catalysts shown to enhance photo current for Fe<sub>2</sub>O<sub>3</sub>
- Demonstrates proof of concept of enhanced activity via Co-OEC

Gamelin, D. R. and coworkers, Univ. of Wash.

# Scientific and Strategic Leadership

**Daniel Nocera**  
MIT  
*Founder*



**Art Goldstein**  
Ionics, Cabot, A123, MGH  
*Board Chairman*



**John Deutch**  
MIT, DOD, DOE, CIA, DARPA  
*SAB Chairman*



**Mark Wrighton**  
Washington U. – St Louis  
*SAB Member (Photo-catalytic chemistry)*



**Ken Smith**  
MIT  
*SAB Member  
(Chemical Engineering)*



**George Whitesides**  
University Professor, Harvard  
*SAB Member  
(Materials science / chemistry)*



**Henry White**  
University of Utah  
*SAB Member (Electrochemistry)*



# Management Team

**Amir Nashat**

Polaris Venture Partners, MIT

*Chief Executive Officer*



**Tom Jarvi**

United Technologies

*Chief Technology Officer*



**Mark Barnett**

CT Clean Energy Fund,  
Foley Hoag Energy Technology

*VP Business Development and  
General Counsel*



# Company Backing

- Polaris Venture Partners
  - Leading VC firm; >\$3B assets under management
  - Founding investor; equity investments in series A and B rounds
- Tata
  - Global, visionary company and investor; \$70B group revenue
  - Equity investment in B round
- ARPA-E
  - \$4.1 M grant awarded in highly-competitive initial round



**Contact:**

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