U.S. DEPARTMENT OF ENERGY

Hydrogen Production

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2009 DOE Hydrogen Program & Vehicle Technologies Program

Merit Review and Peer Evaluation Meeting

May 19, 2009

Goal and Objectives

Goal: Reduce the cost of hydrogen to $2.00 - $3.00/gge (gallon gasoline equivalent) untaxed at the pump.

Near-term: Distributed Production

(produced at station to enable low-cost delivery)

- *Natural gas reforming*
- *Renewable liquid reforming*
- *Electrolysis*

Longer-term: Centralized Production

(large investment in delivery infrastructure needed)

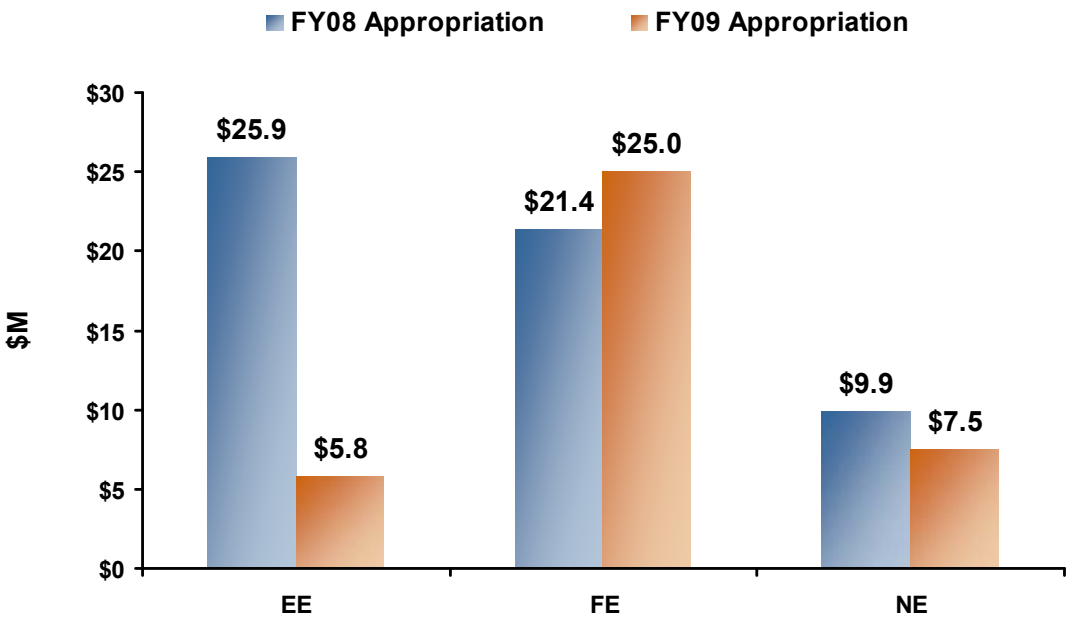
- *Biomass gasification*
- *Coal with sequestration*
- *Wind- and solar-driven electrolysis*
- *Solar/nuclear high-temperature thermochemical water splitting*
- *Photoelectrochemical, biological production*

In the United States, about 9 million tons of hydrogen are produced annually for industrial purposes, and there are about 1,200 miles of hydrogen pipelines.

Begin to focus budget on key technologies

FY 2009 Appropriation = $38.3M

FY 2008 Appropriation = $57.2M



EMPHASIS

- Focus biomass based processes to achieve $3.00/gge delivered hydrogen cost in 2019.
- Reduce hydrogen cost from distributed water electrolysis to achieve $3.70/gge in 2014.
- Continue research on longer-term renewable technologies.
- Select a single nuclear hydrogen production technology.
- Develop laboratory scale hydrogen separation and purification from coal-derived syngas streams and explore potential for limited scale-up of technology.

Challenges

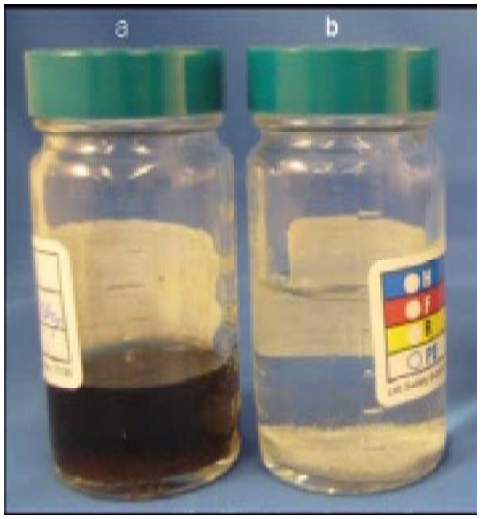
Hydrogen Production is Possible from Many Domestic Resources

- Biomass Based Processes
  - Catalyst efficiency and durability
  - Capital equipment cost
  - Feedstock cost and handling
- Electrolysis
  - Capital equipment cost
  - Integration with renewable electricity generation
- Biological, Photoelectrochemical, Solar Thermochemical
  - H_2 production rate
  - Materials efficiency
  - Reactors and process development
- Nuclear Driven Processes
  - Durability of high temperature electrolysis cells
  - Catalyst and process equipment durability for thermochemical cycles
- Coal-based Processes
  - Capital equipment cost
  - Capture and sequester carbon

2009 Progress & Accomplishments

Biomass Processes

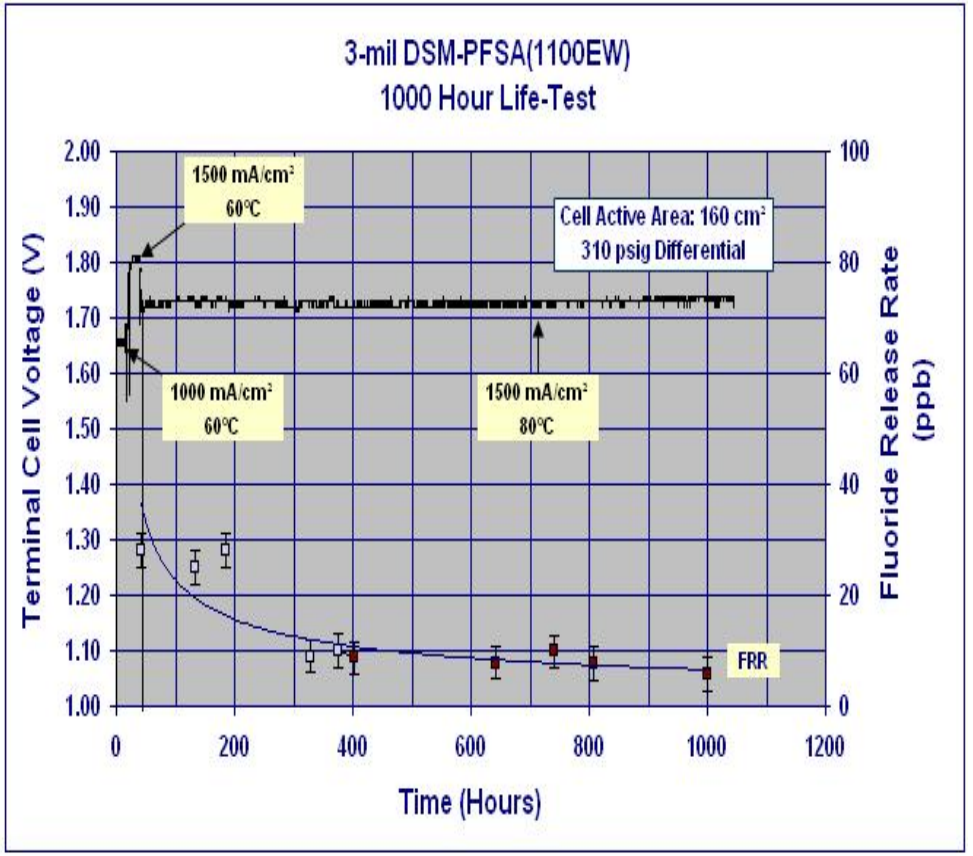
- Vapor phase reforming of ethanol (PNNL)
  - Increased H_2 yields >92% by optimizing catalyst formulation and reaction conditions
- Aqueous phase reforming (UTRC)
  - Exceeded 95% conversion of cellulosic biomass (yellow poplar) with 74% hydrogen selectivity
- Biomass gasification (NREL)
  - Completed pilot unit parametric studies and updated Aspen Plus™ gasification model which now predicts about 50% less char formation



2009 Progress & Accomplishments

Electrolysis

- Giner Electrochemical Systems, LLC
  - Demonstrated 1,000 hrs stability
    - Projects to 45,000-55,000 hr life at 80°C, 1,500 mA/cm^2, 300 psig differential, and ~70% efficiency
  - Developed new biphenyl sulfone (BPSH) membrane with >71% efficiency

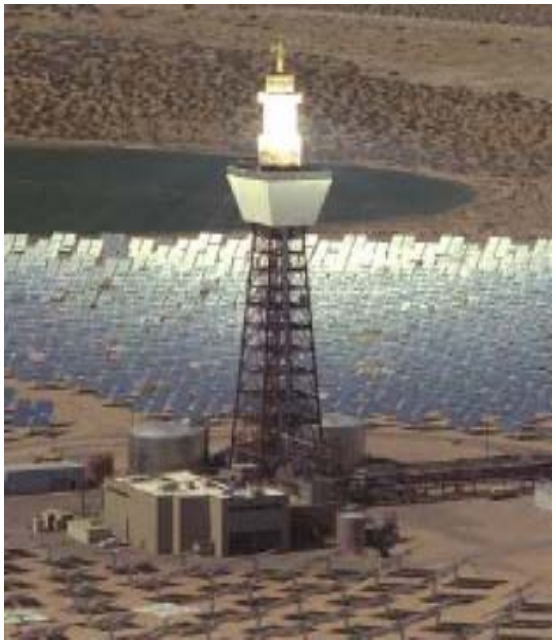


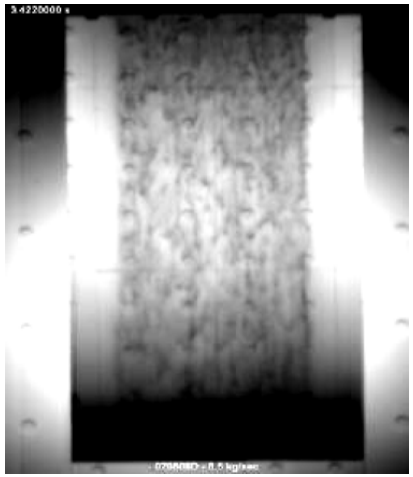
2009 Progress & Accomplishments

Solar Driven HT Thermochemical

- Tested prototype aerosol reactor on-sun (NREL & U. of Colorado)
- Decreased water splitting temperature by 200°C using atomic layer deposition CoFe ferrite on alumina (U. of Colorado)
- Down selected ZnO cycle and identified critical tasks for other cycles to address

Aerosol Reactor



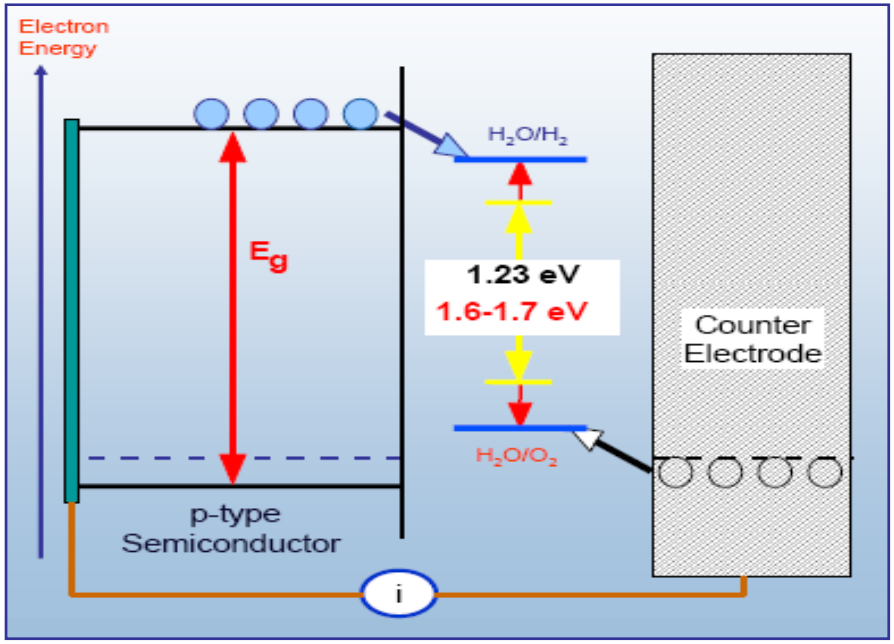


Particle Curtain on Sun

2009 Progress & Accomplishments

Photoelectrochemical

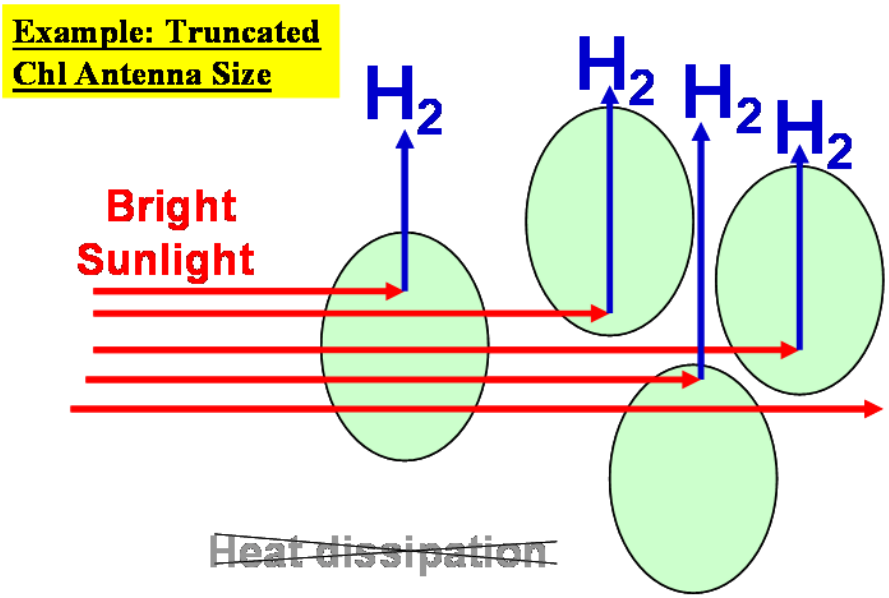
- Directed Technologies, Inc.
  - Completed boundary level technoeconomic analysis
  - Determined PEC hydrogen production has the potential to be cost effective in the long-term ($4 - 10/gge)
- PEC Working Group
  - Developed standardized test protocols for PEC material characterization (currently in peer review for publication)



2009 Progress & Accomplishments

Biological

- UC Berkeley
  - Cloned the previously reported Tla2 gene
    - Enables a 15% solar-to-chemical energy conversion efficiency in microalgae.
    - Brings the effort midway from the 3% solar-to-chemical energy conversion efficiency in wild type microalgae, to the 30% theoretical maximum of photosynthesis
- Directed Technologies, Inc.
  - Completed boundary level technoeconomic analysis and provided a preliminary estimate of $3 - 12/gge for hydrogen production cost using biological processes



Truncated Chl antenna cells permit greater transmittance of light and overall better solar utilization by the culture.

2009 Progress & Accomplishments

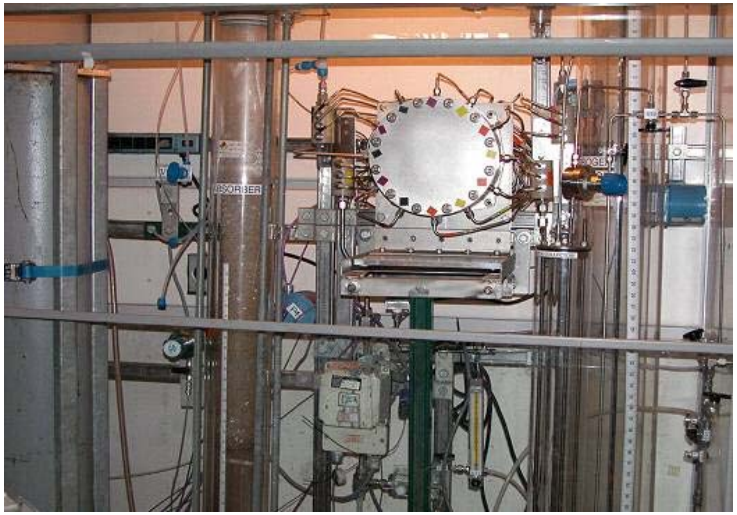
Hydrogen from Coal

- Membrane Separations
  - Implemented standardized testing protocol for membrane separations
  - Showed in the lab that some membrane technologies (Eltron, SWRI®) capable of achieving 2010 targets
  - Evaluation of ternary alloy membranes in progress
  - Preliminary process economic studies show potential for lowered cost of electricity, higher thermal efficiency, and improved CO_2 capture compared to conventional technology

2009 Progress & Accomplishments

Nuclear Hydrogen Initiative

- High Temperature Electrolysis
  - Integrated laboratory-scale experiment operated 45 days
  - Peak output 5,650 liters per hour at 15kWe input, but with significant cell degradation evident over the test duration
- Hybrid Sulfur Thermochemical
  - Developed new HyS electrolyzer operating method to eliminate sulfur build-up
  - Identified and tested advanced proton exchange membranes allowing higher temperature operation (up to 120°C) with lower cell voltage



Summary

Hydrogen Production Progress in FY 2009.

- Significant progress was achieved in all production pathways (EE)
- Continue lab-scale development of separations/process intensification and proceed with engineering scale development of advanced hydrogen separations (FE)
- Select a single nuclear hydrogen production technology for use with high temperature gas reactors (NE)

For More Information

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