



U.S. DEPARTMENT OF
ENERGY

Hydrogen Production

Rick Farmer

**2009 DOE Hydrogen Program & Vehicle
Technologies Program**

Merit Review and Peer Evaluation Meeting

May 19, 2009



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

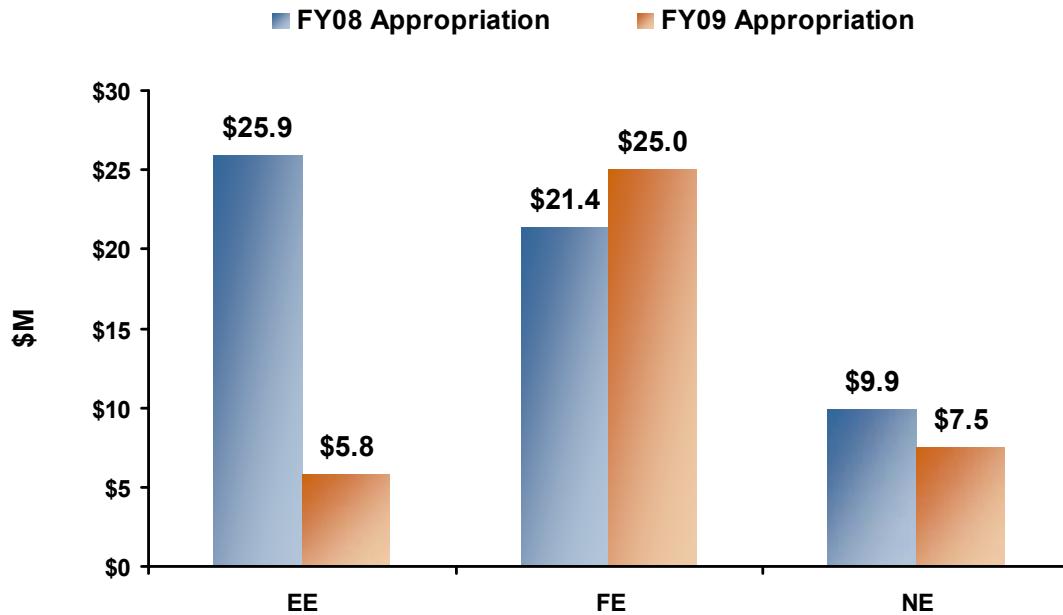
(large investment in delivery infrastructure needed)

- *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.



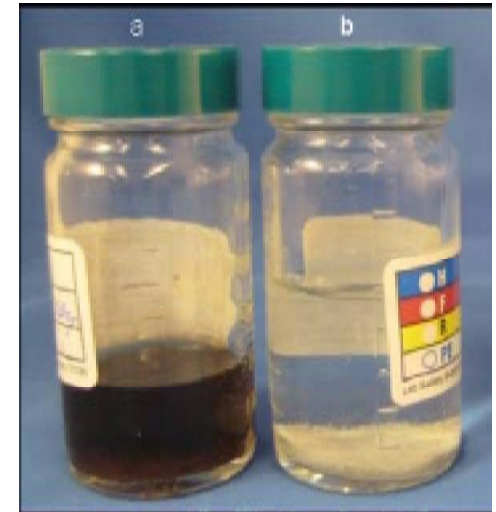
Hydrogen Production is Possible from Many Domestic Resources

- 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
 - H₂ 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



Biomass Processes

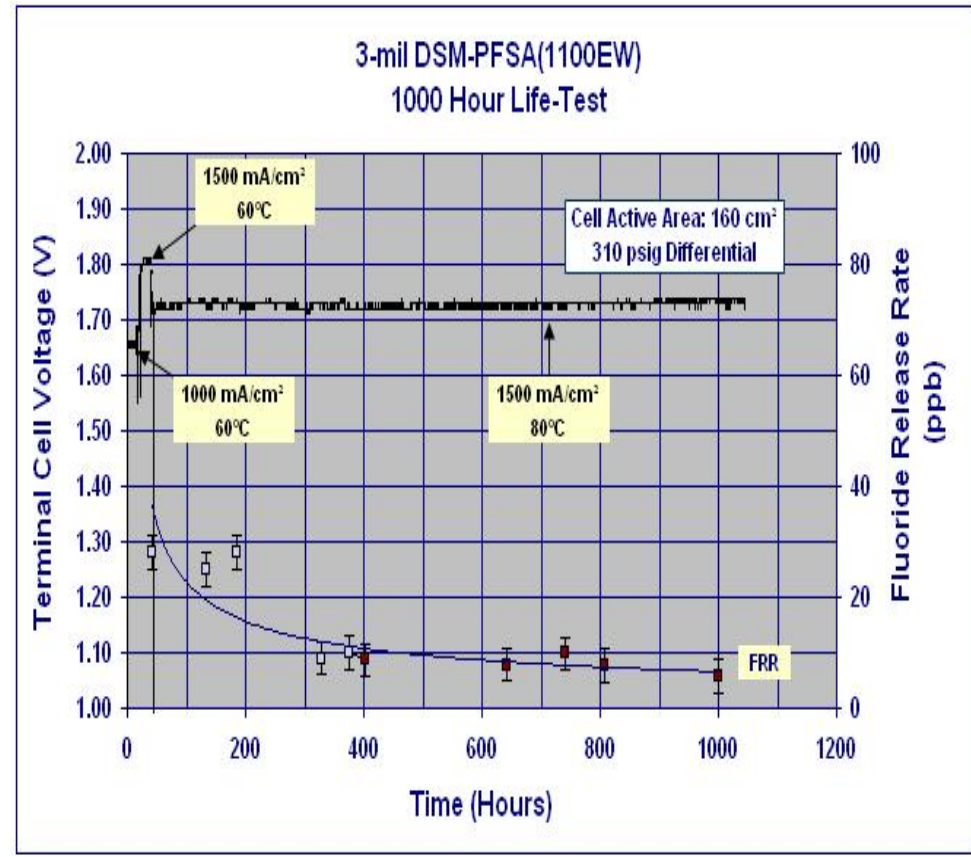
- Vapor phase reforming of ethanol (PNNL)
 - Increased H₂ yields >92% by optimizing catalyst formulation and reaction conditions
- Aqueous phase reforming (UTRC)
 - Exceeded 95% conversion of cellulosic biomass (yellow poplar) with 74% hydrogen selectivity
- Biomass gasification (NREL)
 - Completed pilot unit parametric studies and updated Aspen PlusTM gasification model which now predicts about 50% less char formation





Electrolysis

- Giner Electrochemical Systems, LLC
 - Demonstrated 1,000 hrs stability
 - Projects to 45,000-55,000 hr life at 80°C, 1,500 mA/cm², 300 psig differential, and ~70% efficiency
 - Developed new biphenyl sulfone (BPSH) membrane with >71% efficiency

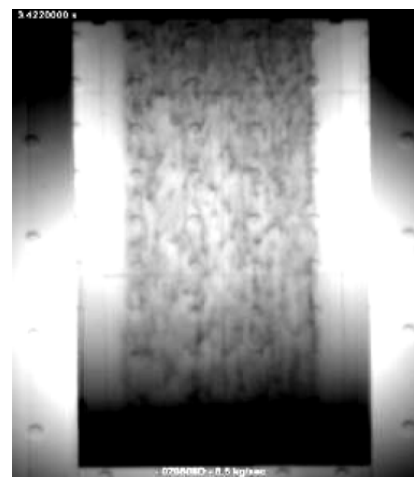
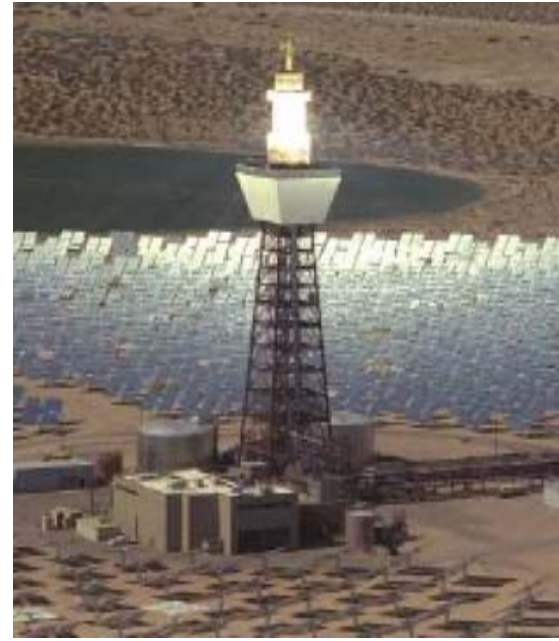


Solar Driven HT Thermochemical

- 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



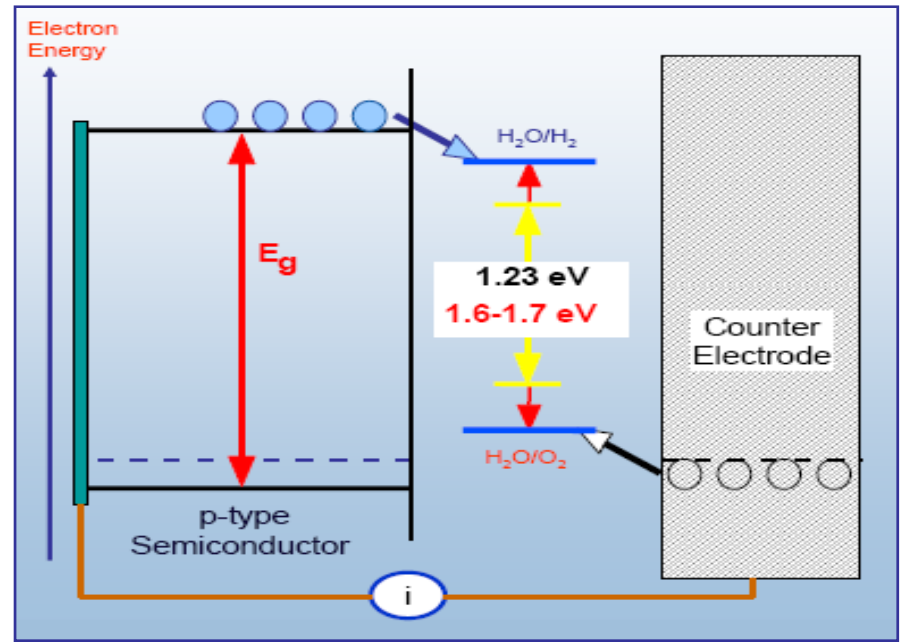
Particle Curtain on Sun



Photoelectrochemical

- Directed Technologies, Inc.
 - Completed boundary level techno-economic 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)





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 CO₂ capture compared to conventional technology





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





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)



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