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# **U.S. Department of Energy Hydrogen Program**

## ***Hydrogen Production & Delivery***

**Rick Farmer**

**2008 DOE Hydrogen Program  
Merit Review and Peer Evaluation Meeting**

**June 9, 2008**





# Goal and Objectives

***GOAL: Research and develop low-cost, clean, highly efficient hydrogen production technologies from diverse domestic resources, including fossil, nuclear, and renewable sources***

- Reduce the cost of hydrogen to \$2.00 - \$3.00/gge (Untaxed & Delivered)

## **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)*

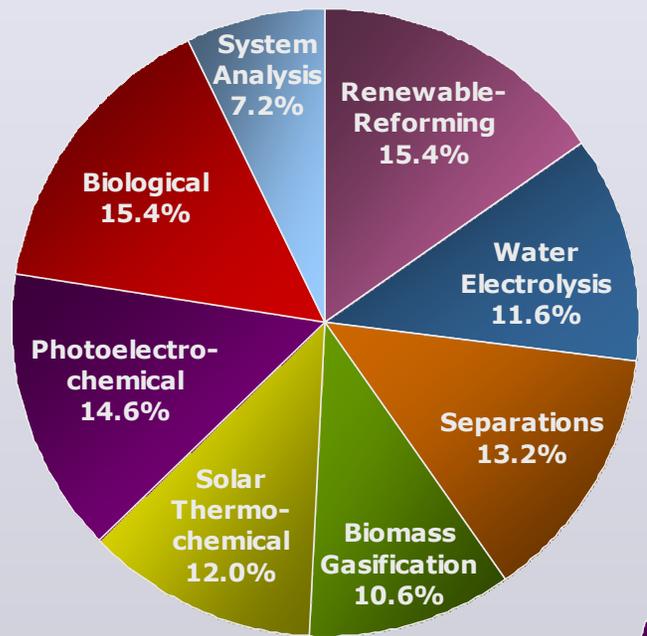
- *Biomass gasification*
- *Coal with sequestration*
- *Wind, solar, and nuclear-driven electrolysis*
- *Solar/nuclear high-temperature thermochemical water splitting*
- *Photoelectrochemical, biological production*

- Reduce total hydrogen delivery cost to < \$1.00/gge

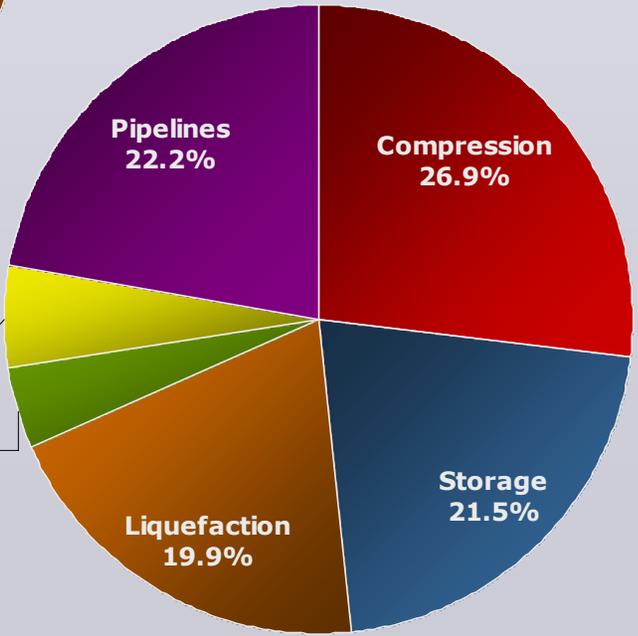


# EERE H<sub>2</sub> Production and Delivery Budget

**FY2008 Budget = \$39.6 M**



**Production FY 2008 (\$28.9M)**



**Delivery FY 2008 (\$10.7M)**

- ### FY2008 Emphasis
- Initiate 8 new projects
    - Electrolysis
    - Compression
    - Off-board storage
    - Liquefaction
  - Identify renewable reforming pathways to achieve <\$3.80/gge by 2012
  - Complete solar thermochemical down selection to 1-2 cycles



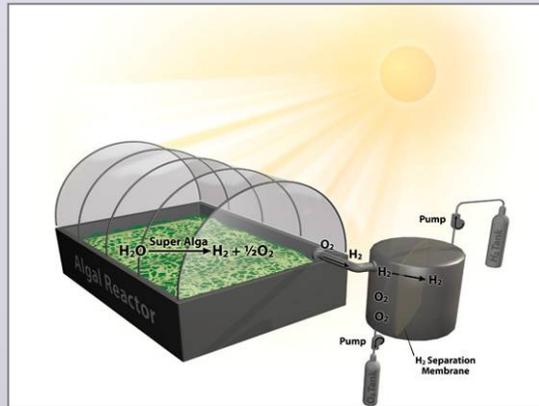
# Challenges – H<sub>2</sub> Production & Delivery



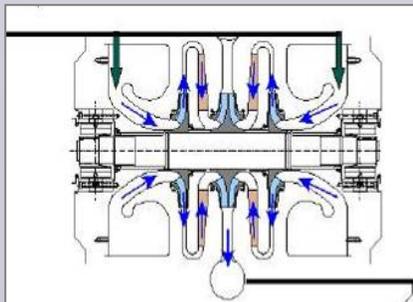
**Biomass Gasifier**

## Production

- Biomass Based Processes
  - Catalyst efficiency and durability
  - Capital equipment cost
  - Feedstock cost and handling
- Electrolysis
  - Capital equipment cost
  - Integration with renewable electricity
- Biological, PEC, Solar Thermochemical
  - H<sub>2</sub> production rate
  - Materials efficiency
  - Reactors and process development



**Biohydrogen**



**Compressors**

## Delivery

- Capital cost
- Materials
- Energy efficiency



# 2008 Production Accomplishments



## **Demonstrated significant improvements in electrolyzer performance**

- Achieved 67% stack efficiency
  - Verified by NREL
- Produced H<sub>2</sub> at 1200 psig
- Demonstrated an advanced high efficiency membrane
- Developed lower cost fabrication methods for two key cell components

*(Giner Electrochemical Systems, LLC)*



# 2008 Production Accomplishments

## Continued to Improve Aqueous Phase Reforming of Bio-derived Liquids

- Cost of H<sub>2</sub> reduced 10X since 2005
- Catalyst lifetimes now exceeding 1 year
- Increased hydrogen productivity by 50% through chemical control of feedstock and catalyst improvement

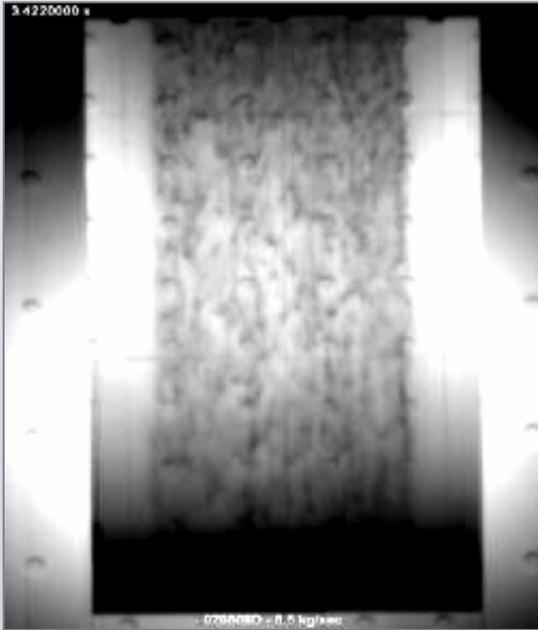
*(PNNL and Virent)*



**10 kg/day H<sub>2</sub>  
Pilot Plant**



# 2008 Production Accomplishments



**Demonstrated falling particle receiver/heat transfer system**

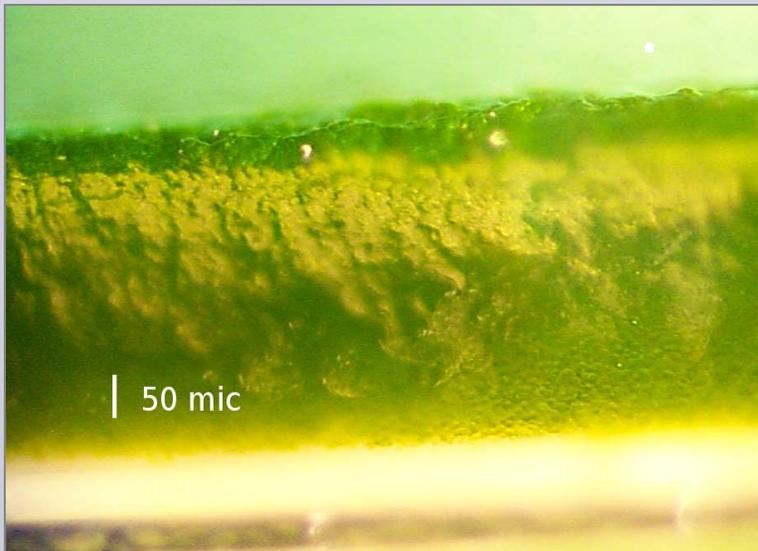
*(Sandia National Lab)*

**Completed first experimental determination of the electronic surface structure of a PEC material ( $\text{WO}_3$ )**

*(UNLV and U. of Hawaii)*

**Cloned a novel hydrogenase using environmental DNA samples and expressed a functional hydrogenase in an organism**

*(J. Craig Venter)*





# 2008 Delivery Accomplishments



**Electrochemical  
Hydrogen Compressor  
(EHC)**

## **Developed Prototype Electrochemical Hydrogen Compressor**

- Peak compression of 4000 psi
- Continuous operation for 1500 hours
- No seal leakage

*(FuelCell Energy)*

## **Identified APCI Liquid Hydrocarbon as a Promising Carrier**

- Developed novel carrier evaluation and down select tool
- Planned integration into H2A V.3

*(TIAX, LLC)*





# 2008 Delivery Accomplishments

## Identified Low Cost & Low Permeability Fiber Reinforced Polymer

- 1 psi per day or
  - o  $\ll 0.1\%$  hydrogen per day
- Developed & verified test bed for ASME compliance testing

(Oak Ridge and Savannah River)

Photo courtesy of Fiberspar, LLC





# Summary

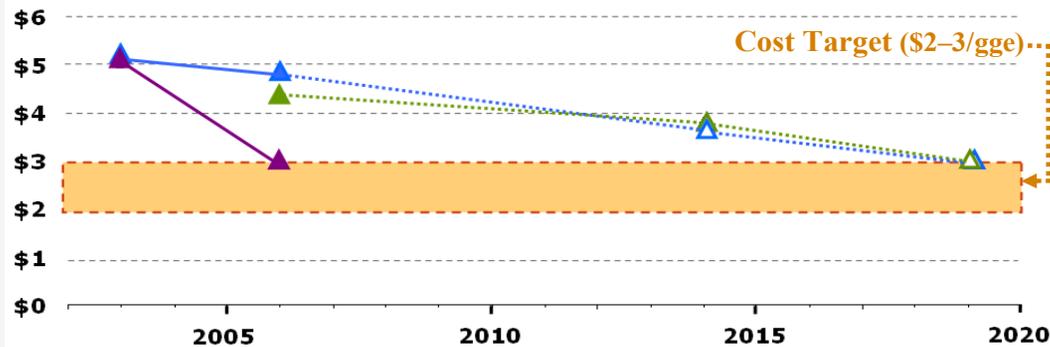
**The Program has reduced the cost of producing hydrogen from multiple pathways.**

## Cost of Hydrogen (Delivered) – Status & Targets (in \$/gallon gasoline equivalent (gge), untaxed)

### NEAR TERM: Distributed Production

→ Hydrogen is produced at station to enable low-cost delivery

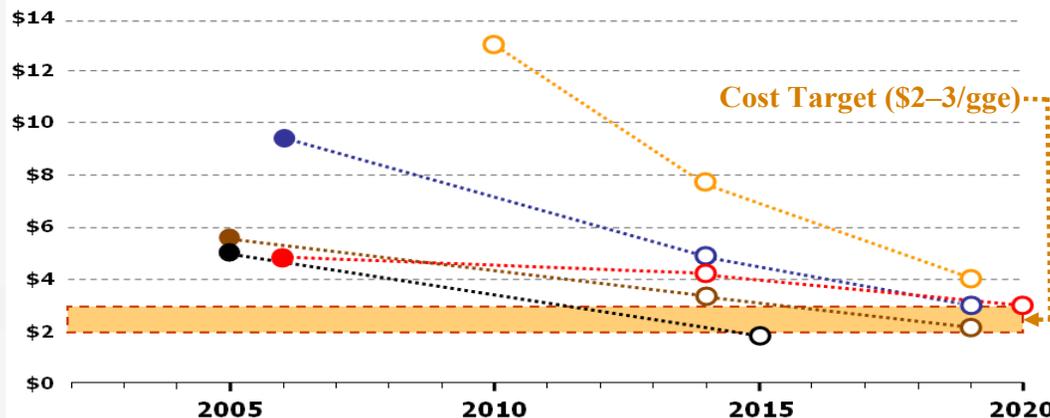
- ▲ Distributed Natural Gas
- ▲ Distributed Electrolysis
- ▲ Distributed Bio-Derived Renewable Liquids



### LONGER TERM: Centralized Production

→ Large investment in delivery infrastructure needed

- Biomass Gasification
- Central Wind Electrolysis
- Coal Gasification with Sequestration
- Nuclear
- Solar High-Temperature Thermochemical Cycle





# For More Information

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