U.S. DEPARTMENT OF ENERGY

Hydrogen Production and Delivery Program Element (EERE)

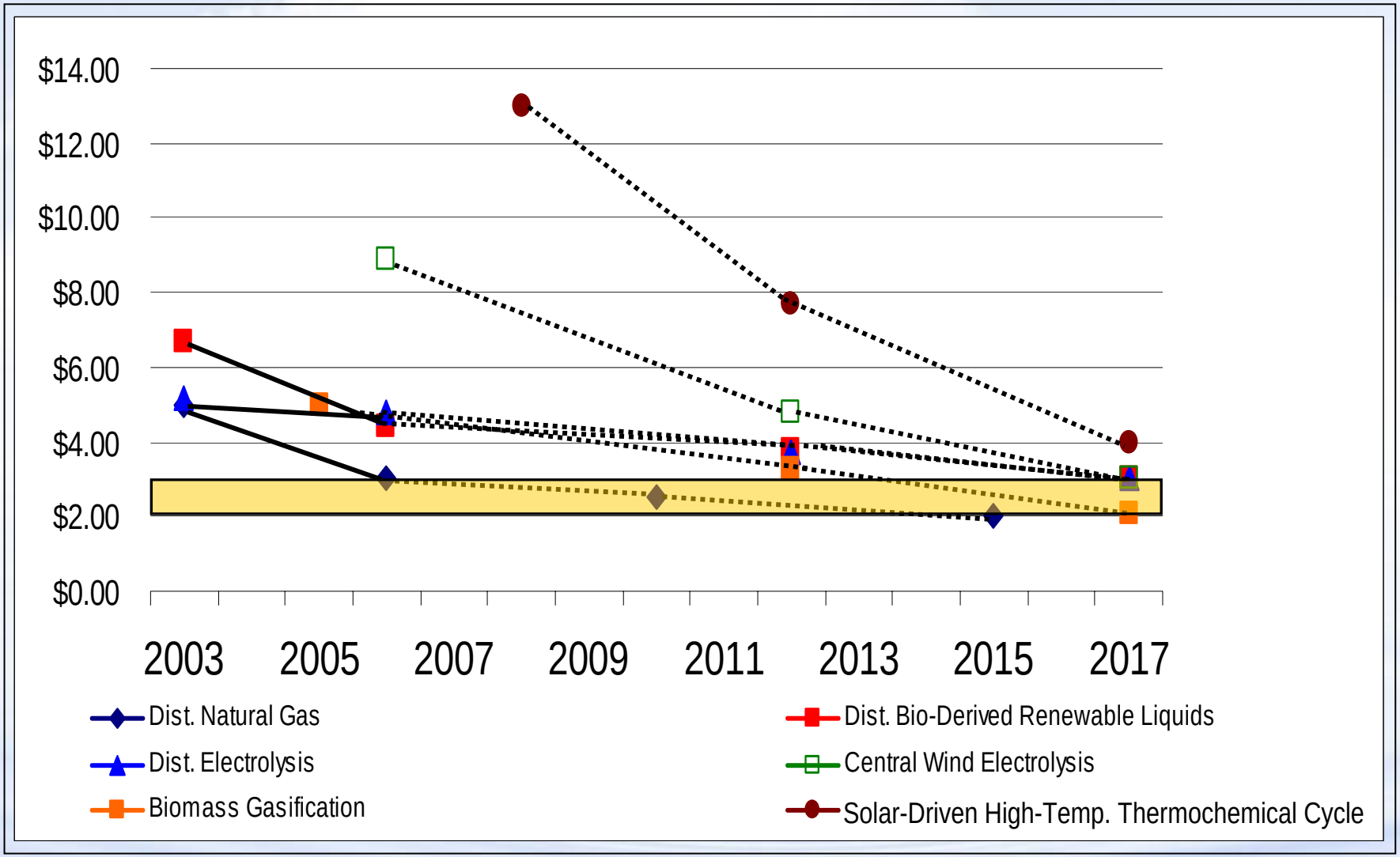
Mark Paster

2007 DOE Hydrogen Program

Merit Review and Peer Evaluation Meeting

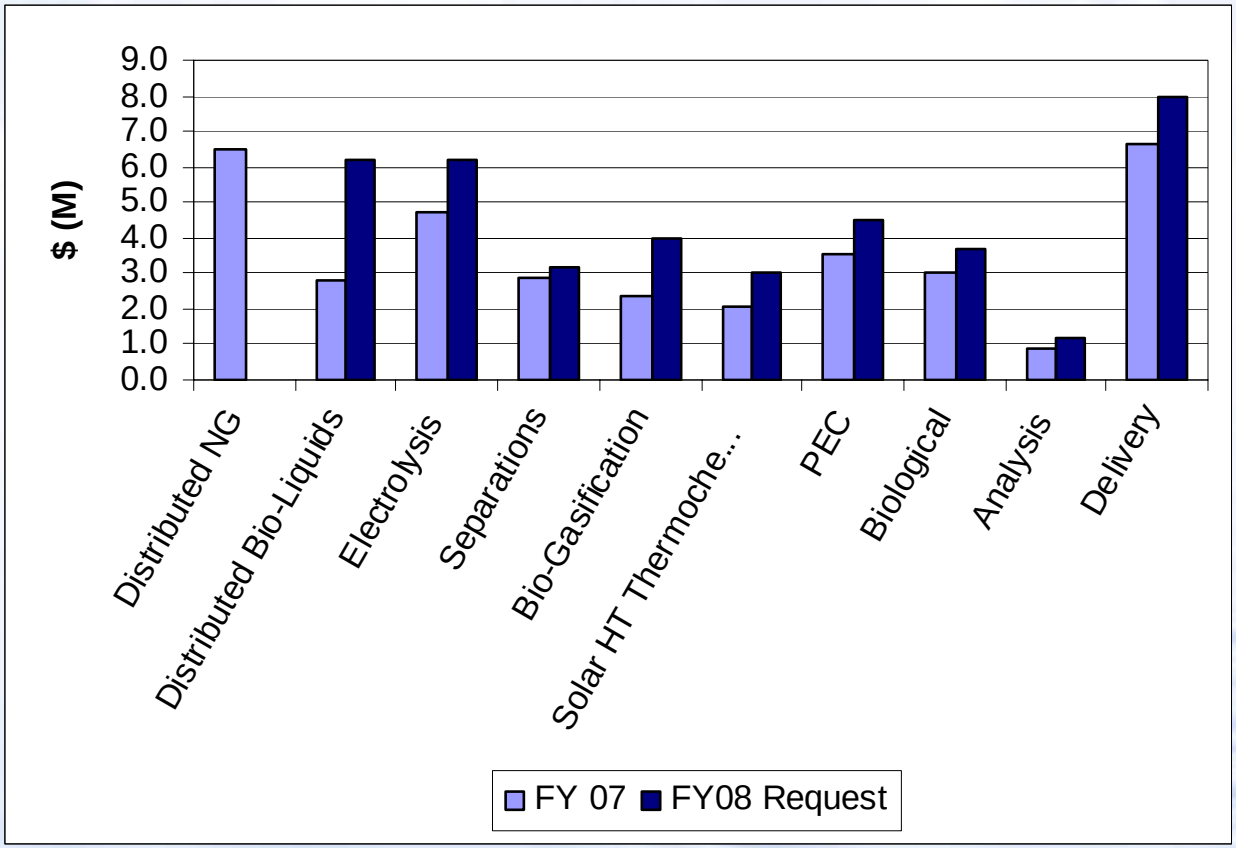
May 15, 2007

Production Pathways Status & Targets (EERE)



Hydrogen Production (EERE)

FY 2007 = $34.6M
FY 2008 Request = $40M



- **FY08 Emphasis:**
  - Shift from Distr. NG to Distr. Renewable Liquids Reforming focus ($3.00/gge delivered in 2017)
  - Continue focus on electrolyzer systems including integration with renewables ($3.00 delivered by 2017)
  - Continue research on longer-term renewable technologies and hydrogen delivery

- **FY08 Request**

Current Contracts	$16M
Lab Funding	$15M
New Awards	$9M

Distributed Bio-Derived Liquid Fuels

Reforming Challenges

- More difficult to reform than natural gas. Research is needed to identify better catalysts to improve yields and selectivity.

- Reducing the cost of ethanol and/or other biomass-derived liquid fuels (research conducted by DOE's Office of Energy Efficiency and Renewable Energy Biomass Program).

- Reducing capital equipment costs, as well as operation and maintenance costs, and improving process efficiency (similar to challenges of natural gas reforming).

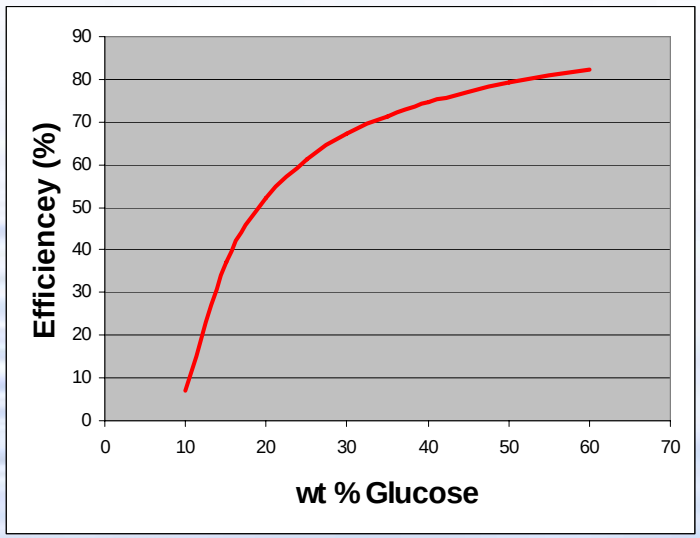
Distributed Reforming Accomplishments

- Validated an integrated natural gas reforming fueling system that achieves the 2006 targets for system efficiency, hydrogen purity and delivered hydrogen cost of $3/gge (when projected to 1500 kg/day scale and 500 units per year)

- Successfully developed a design and began construction of a proof-of-concept unit for producing high pressure, high-quality hydrogen from a single integrated natural gas reformer/separator with a metal hydride-based thermal compressor

- Achieved high hydrogen yields from initial bio-ethanol reforming tests using low-temperature (350-550 ^{0}C) non-precious metal catalysts

- Developed a new reactor system to enable aqueous phase reforming (APR) of bio-sugar in high concentrations and under conditions that minimizes side reactions and eliminates the need for subsequent water-gas-shift



Electrolysis Challenges

- Reducing capital cost and increasing system efficiency
  - *New capital cost targets in the R&D Plan are challenging and require innovative electrolysis concepts*

Table 3.1.4 Technical Targets: Distributed Electrolysis Hydrogen Production[a,b,c]

Characteristics	Units	2003 Status	2006[c] Status	2012 Target	2017 Target
Hydrogen Cost	$/gge	5.15	4.80	3.70	<3.00
Electrolyzer Capital Cost[d]	$/gge $/kW	N/A N/A	1.20 665	0.70 400	0.30 125
Electrolyzer Energy Efficiency[f]	% (LHV)	N/A	62	69	74

Table 3.1.5 Technical Targets: Central Wind Electrolysis[a,b]

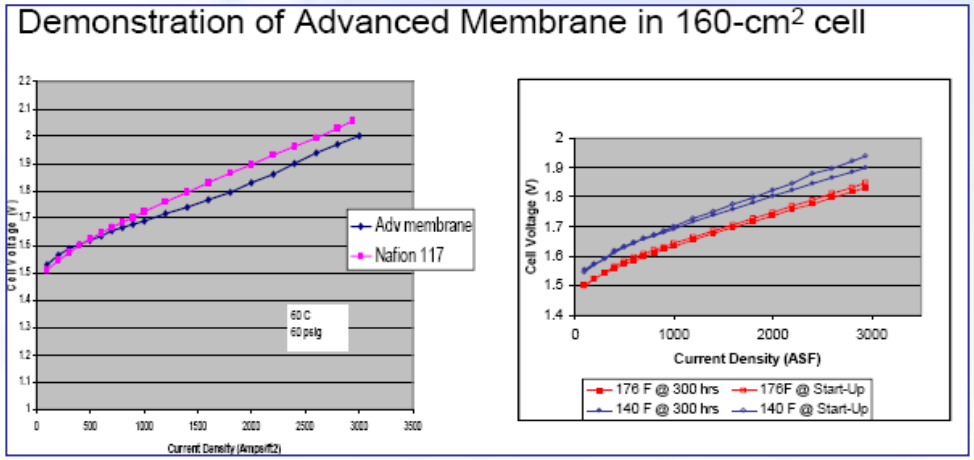
Characteristics	Units	2006[c] Status	2012 Target	2017 Target
Hydrogen Cost (Plant Gate)	$/gge H2	5.90	3.10	<2.00
Electrolyzer Capital Cost[b,d]	$/gge H2 $/kW	2.20 665	0.80 350	0.20 109
Electrolyzer Energy Efficiency[e]	% (LHV)	62	69	74

- Improving integration with renewable electricity generation capabilities (such as wind power)

Electrolysis Accomplishments

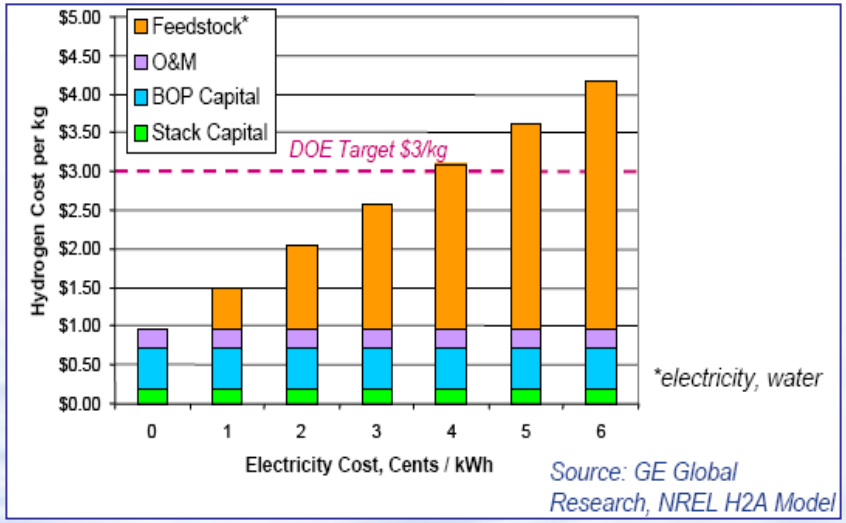
Giner Electrochemical Systems, LLC

- Demonstrated an advanced high-efficiency membrane and developed lower cost fabrication methods for two key cell components.



NREL Renewable Electrolysis Project

- Completing the installation and initial testing of the Wind2H2 Project between NREL and Xcel Energy integrating wind turbines with both PEM and alkaline electrolyzers.
- Completed testing and evaluation of the second generation power electronics interface for connecting a 10kW wind turbine to a 5kW electrolyzer.



Projected H2 Cost with GE Electrolyzer: 1000kg/day, 30 bar pressure.

Biomass Gasification Challenges

- Requires low cost biomass feedstock
- Many process steps: Need process intensification by combining or eliminating steps to reduce capital costs
- Lower than desired yields and selectivities: Need improved process designs and catalysts
- Feedstock storage, handling, drying, and feeding: Improvements will further reduce costs

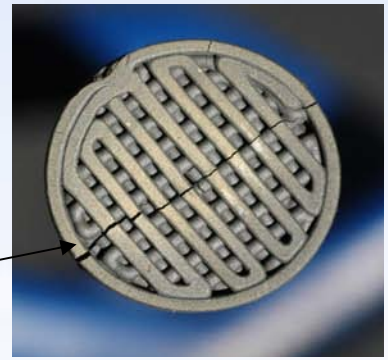
Research conducted by the DOE EERE Biomass Program is being leveraged on these issues.

Solar Driven HT Thermochemical Progress

Solar Ferrite Cycle Closure Demonstrated

$$Co_{0.67}Fe_{2.33}O_4 \xrightarrow{1400\,^{\circ}C} Co_{0.67}Fe_{2.33}O_{4-\delta} + \frac{\delta}{2}O_2$$

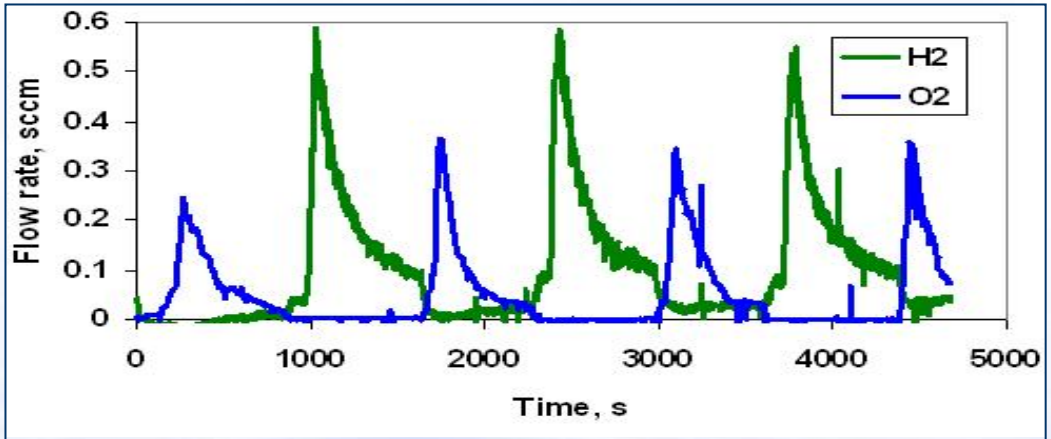
$$Co_{0.67}Fe_{2.33}O_{4-\delta} + \delta H_2O \xrightarrow{1000\,^{\circ}C} Co_{0.67}Fe_{2.33}O_4 + \delta H_2$$



Ferrite monoliths

CHALLENGES

- *Resolve the uncertainties of down-selected cycles and research and develop most promising cycles.*
- *Optimize system designs for temperatures and power requirements*
- *Develop and validate Reactor/Receivers and/or Falling Particle Receiver/heat transfer system*
- *Investigate materials challenges for solar reactor/receivers and other system components*
- *Reduce the cost of heliostats*

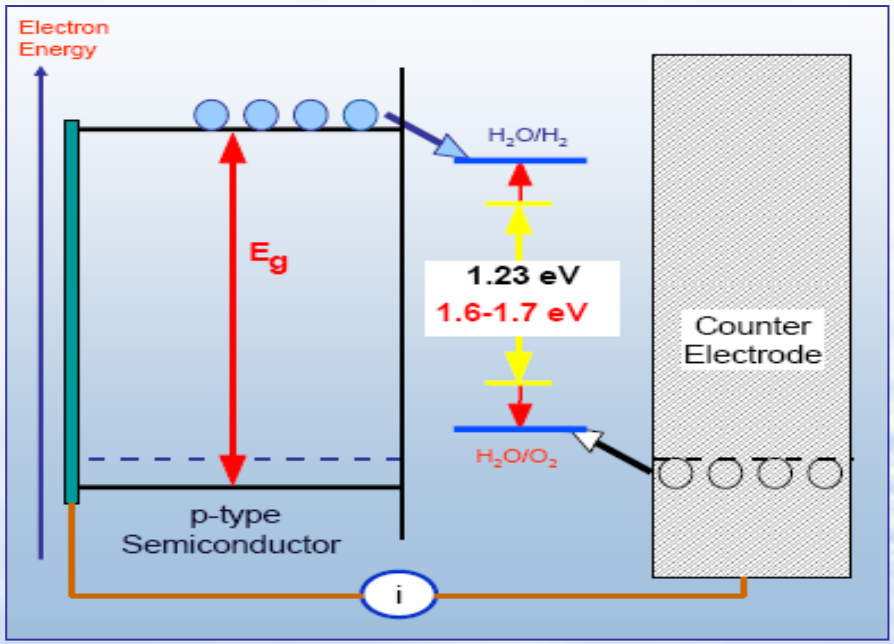


- ***On-sun reduction at 1550 °C, H2 production at 1100 °C***
- ***YSZ-stabilized ferrite shows stability, repeatability***
- ***First cycle closed "on-sun"***

Photoelectrochemical Pathway Progress

Challenges

- *Increase materials efficiency and durability*
- *Develop device and system configurations*



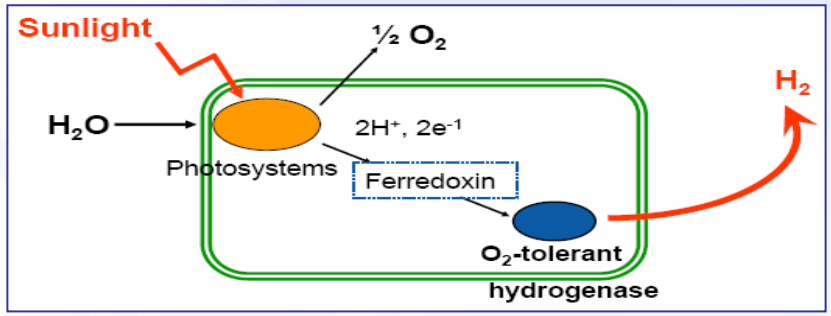
UNLV Team

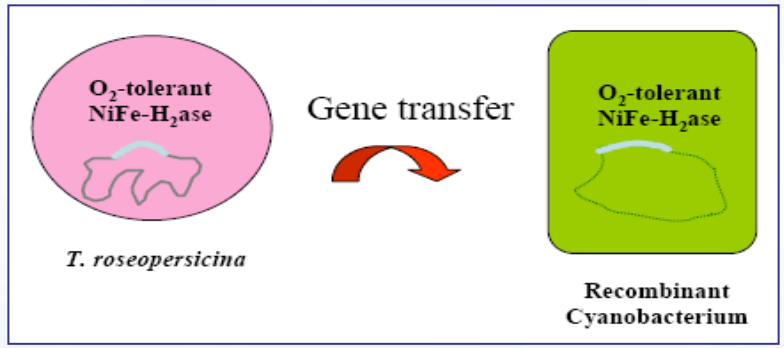
- **Collaborative Research Team Established:** *Combining materials theory, synthesis and characterizations*
- **Focus Materials Classes Established:** *Including Tungsten-, Zinc- Iron (oxide nanorods)-, Silicon- , and Copper-chalcopyrite-based thin film compounds*
- **Key Targets Met in Recent Focus Materials Experiments:**
  - *Photocurrents in excess of 6.5 mA/cm2 in Si- and chalcopyrite-based films*
  - *STH Device efficiencies in excess of 3% in WO3-based multi-junction structures (under 1-sun)*

Biological Pathway Progress

Challenges

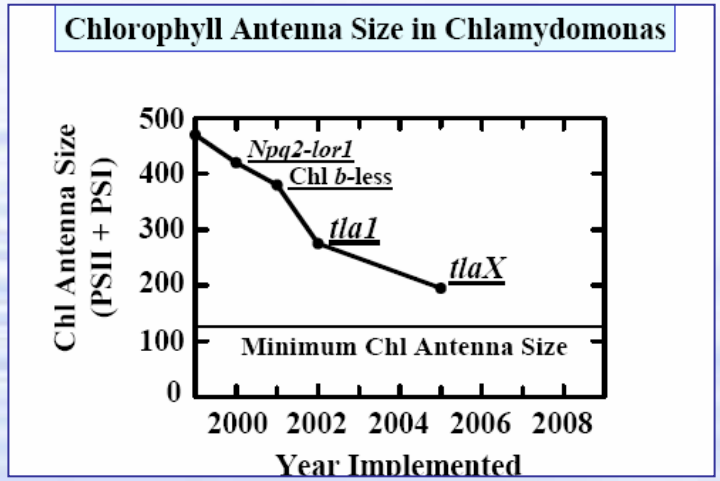
- *Increasing incident solar light to hydrogen efficiency*
- *Increase hydrogen production duration, rate, and molar yield*





NREL - Cloned O2-tolerant hydrogenase genes for expression in *E. coli*. towards increasing the continuity of H2 production utilizing cyanobacteria

UC Berkeley - First-time isolation of a gene (Tla1) that regulates the light-harvesting chlorophyll antenna size in photosynthesis, opening the way for improved solar conversion efficiency in hydrogen producing microalgae.



Future Plans

- Focus on distributed reforming of bio-derived liquids and electrolysis for near term market transformation
- Support biomass gasification leveraging the DOE EERE Biomass Program efforts
- Continue funding for longer term technologies
- Select and award new projects from FY07 SBIR and Program solicitations
- Next solicitation as early as the fall of 2007

Delivery Goals and Objectives

By 2017, develop technologies to reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/kg of hydrogen.

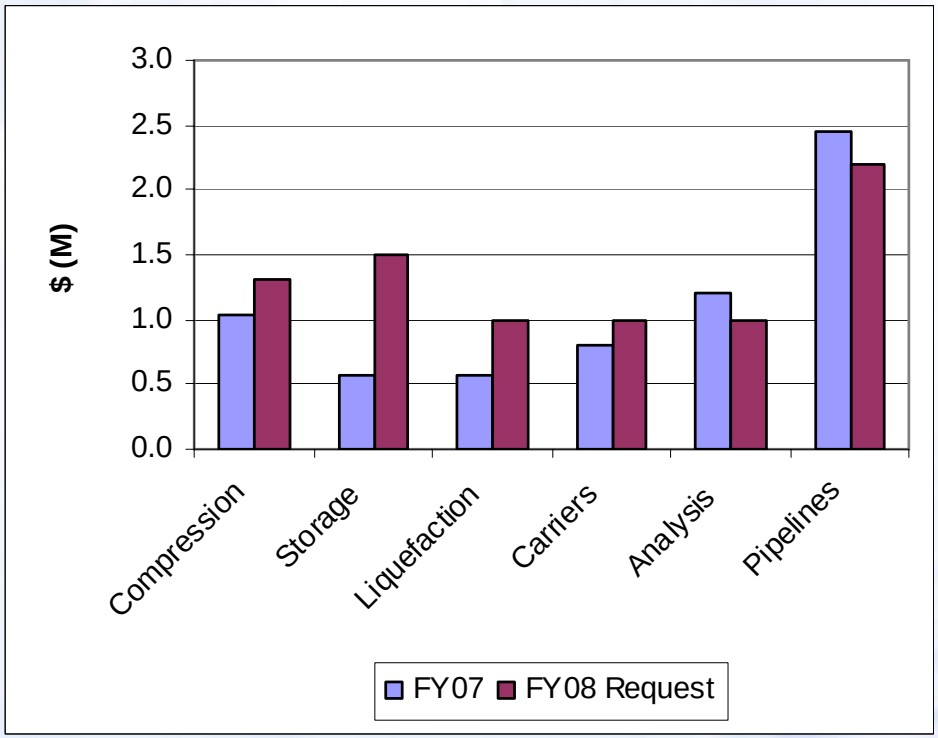
GH2 Pipelines, GH2 Tube Trailers, Liquefaction and Liquid Trucks, Novel Carriers

- By **2010**, develop technologies to reduce the cost of compression, storage, and dispensing at refueling stations and stationary power sites to ***<$0.80/kg*** of hydrogen. By **2015**, reduce this cost to ***<$0.40/kg.***
- By **2012**, develop technologies to reduce the cost of hydrogen delivery from central and semi-central production facilities to the gate of refueling stations and other end users to ***<$0.90/kg*** of hydrogen. By **2017**, reduce this cost to ***<$0.60/kg.***

Timing has been delayed by 2 years due to Congressional Earmarks and limited appropriations (except refueling site delivery).

Delivery Budget

FY2007 Funding = $6.6M
FY2008 Budget Request = $8.0M



Emphasis

- Continue to ramp up R&D on compression, off-board storage, and liquefaction for Technology Readiness by 2015.
- Complete analysis and modeling including novel carriers to confirm research is properly focused and prioritized.
- Maintain funding for pipelines for long term lowest cost option.

FY08 Request

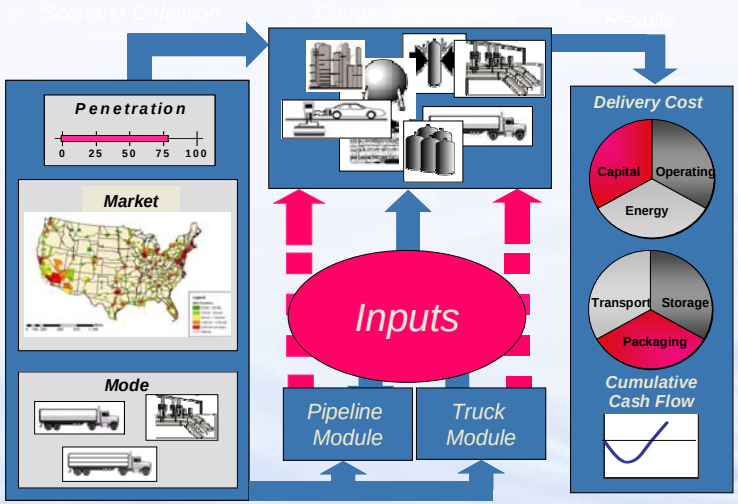
- Current Contracts $3.0M
- Lab Funding $3.0M
- New Awards $2.0M

Delivery Challenges

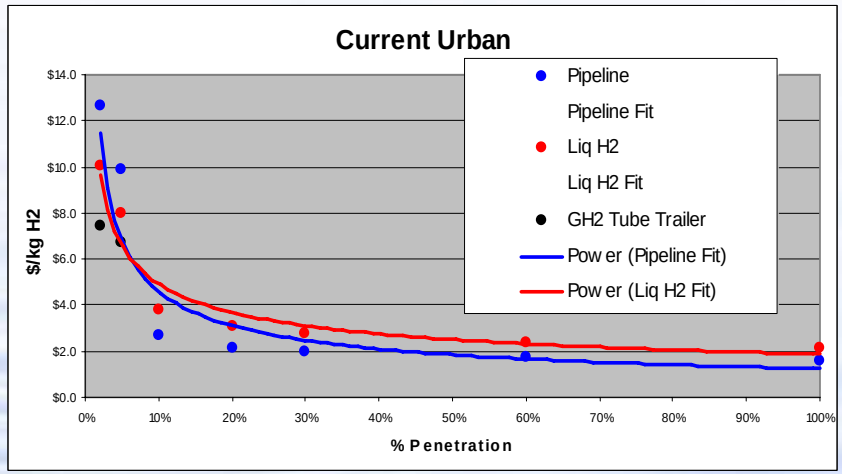
- **Pipelines:** hydrogen embrittlement, capital cost, urban distribution
- **Compression -Transmission and Refueling Stations**: reliability, capital cost, energy efficiency, new technologies
- **Liquefaction:** capital cost, energy efficiency
- **Off-Board Storage Vessels:** capital cost
- **Geologic Storage:** sufficient suitable sites and capacity?
- **Gaseous Tube Trailers**: cost - is 1000 kg capacity possible?
- **H2 Quality:** must meet stringent quality requirements for PEM FC
- **Carriers (Leverages the On-Board Storage Program)**
  - Liquid two-way carriers: low cost and efficient hydrogenation and dehydrogenation, high (~100%) yields and selectivity
  - Solid carriers: high volumetric and gravimetric hydrogen density, energy efficiency and cost

Accomplishments

- H2A Delivery Models
  - Components Model: Spreadsheet model on delivery system component cost contributions and performance:
  - Scenario Model: Urban and interstate scenarios that span major markets and demand levels.



Urban: 1 M people, Plant 100 km from city gate



Accomplishments

PIPELINE WORKING GROUP

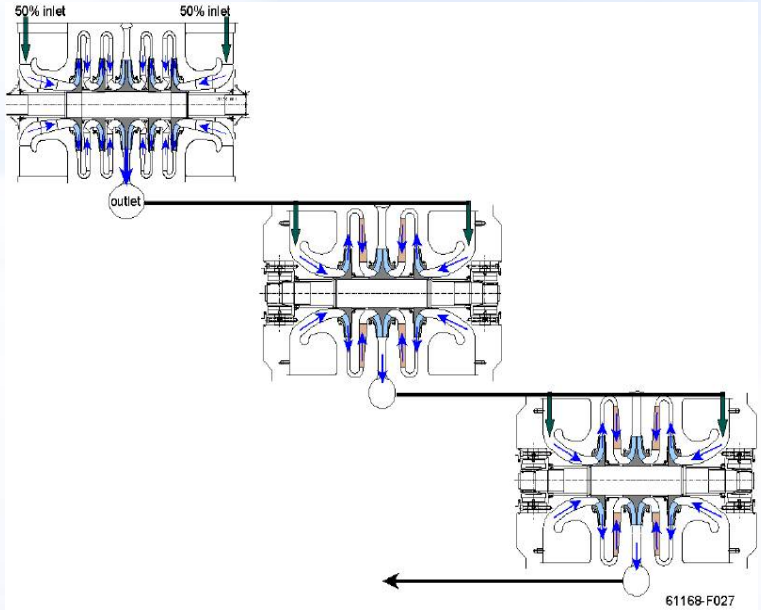
- **National Labs:** ORNL, SRNL, SNL
- **Industry:** CTC, APCi, RDC, SECAT, Chemical Composite Coatings Intl., Columbia Gas of KY, Oregon Steel Mills, Hatch Moss MacDonald, AME Stds., etc.
- **Universities:** University of Illinois

PROJECTS

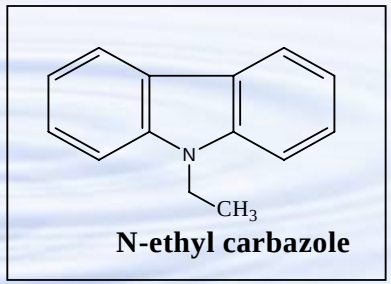
- Fundamental work on hydrogen embrittlement (U. of Illinois, SNL)
- Breakthrough composite pipe approach initiated
- Mini-Workshops including C&S community
- H2 permeability/diffusion measurements
- Steel pipeline R&D initiated (fatigue, and weld/HAZ focus)
- Interaction with EC Naturalhy Project

Accomplishments

- Compression (MITI)
  - Centrifugal pipeline compression: Feasible unit scoped and designed
  - Unique air foil bearings and seals are the key enabler (very high rotational speed)



- Carriers
  - Liquid hydrocarbon with 6 wt. % H_2 identified (Air Products)
  - Leveraging On-Board Storage R&D



Delivery Future Plans

- Complete analysis and modeling to confirm research is properly focused and prioritized
  - Novel carriers
  - 70 MPa refueling
  - Refueling site need for cooling or final purification
- Continue to ramp up R&D on compression, off-board storage, and liquefaction for Technology Readiness by 2015
  - Two solicitations issued in FY07 on these topics: Program and DOE SBIR
  - Next Solicitation as early as the fall of 2007
- Continue to explore alternatives for hydrogen delivery during market transformation
- Maintain funding for pipelines for long term lowest cost option
  - Increase effort on composite pipelines

For More Information

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