U.S. Department of Energy Energy Efficiency and Renewable Energy

Hydrogen Production & Storage R&D

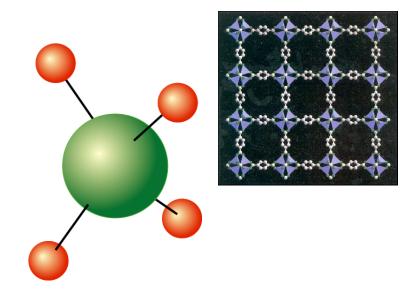
US Department of Energy Hydrogen, Fuel Cells & Infrastructure Technologies Program

Fuel Cell Seminar 2003 November 7, 2003

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Presented by Pete Devlin and Sunita Satyapal

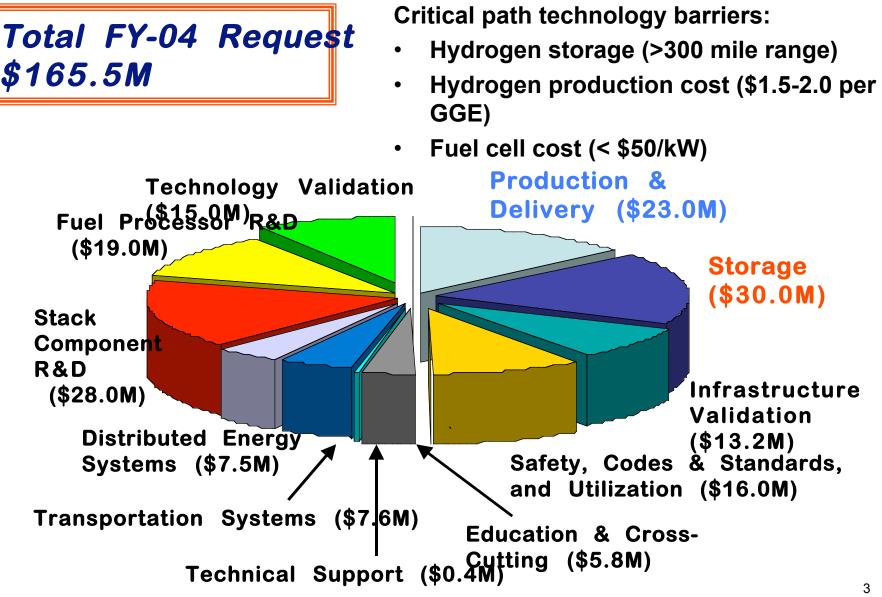




Outline

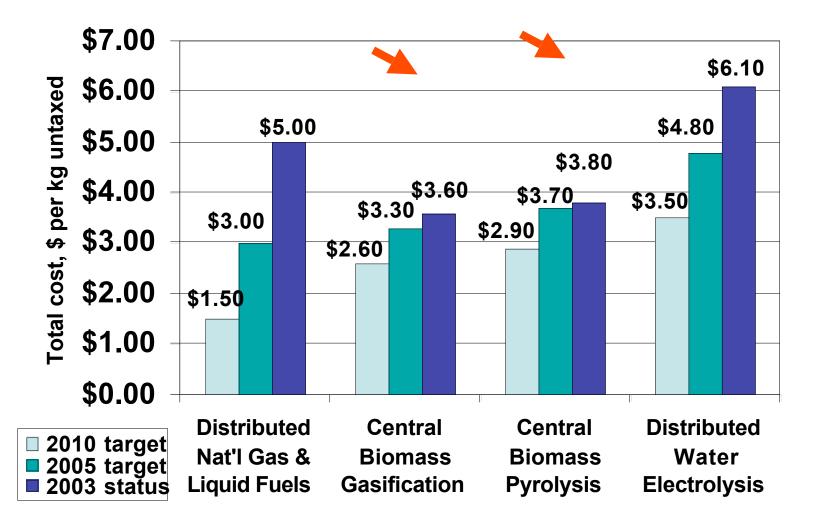
- Background: FY-04 Funding Request
- Hydrogen Production
 - Goals and Program Activities
 - Technical Status/Accomplishments
 - Future Plans
- Hydrogen Storage
 - Goals and Program Activities
 - Technical Status/Accomplishments
 - Future Plans
- Contact & Reference Information

FY-04 Funding Request Profile



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Goal : Research and develop low cost, highly efficient hydrogen production technologies from diverse, domestic sources, including fossil, nuclear, and renewable sources.



Distributed Reforming



Development Needs

Integration of reforming, shift and separation/purification into fewer/ one step operation(s)

- Hydrogen membrane technology
- Compact, DFM "appliances"
- Low maintenance, high reliability

Natural Gas

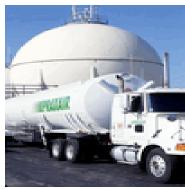
- Supply
 - 188 Quads proven reserves

Distributed Reforming

- Lowest potential cost for delivered hydrogen
- _ Very sensitive to NG price
- _ GHG emissions













Process Options

•Gasification \rightarrow Syngas \rightarrow Reforming-Shift •Pyrolysis \rightarrow Bio-Oil \rightarrow Reforming-Shift

Central Gasification/Pyrolysis Development Needs

- Lower cost delivered feedstocks
- Advanced and integrated gasification/pyrolysis, reforming, shift, separations/purification technologies

Supply

- 3 Quads/yr hydrogen possible
- Could be much more with biotech advancements



Distributed Water Electrolysis

Development Needs

- Lower capital equipment costs (\$750 kWe to 350 kWe)
- Higher energy efficiency (50% to 72%)

- Eliminates hydrogen delivery costs and infrastructure
- Essentially unlimited supply (water) Need purified water
- Non-GHG emitting clean power: wind, solar, geothermal, hydroelectric



By 2015

Develop technologies to produce H_2 using high temp heat sources (nuclear or solar) with a projected cost competitive with gasoline.

Process Options

- Direct water splitting chemical cycles (Sulfur Iodine)
 - High temp (500-1000 C) using nuclear heat source
 - Ultra-high temp (1000-3000 C) using solar concentrator

Investigate

Various Chemical Cycles

Materials Issues



By 2015 Develop photolytic hydrogen generation systems

Demonstrate:

- Engineering-scale biological system (\$10/kg plant-gate cost projection) Central Production Utilizing Photosynthetic Organisms (Algae)
- Direct photoelectrochemical water splitting (\$5/kg plant-gate cost projection) Central or Distributed Direct Photoelectrochemical Production

Requires breakthroughs in biotechnology and systems engineering





Distributed Reforming – Progress toward 2010 goal of \$1.50/kg:

- Completed first-of-a-kind hydrogen and electricity co-production facility
 - 99.95% purity, 5000 psi, up to 750 kg/day, \$3.60/kg (APCi NG SMR)
 - 50 kw PEM FC providing electricity to grid, (Plug Power)
- •Completed research and design for distributed NG reformer system to deliver
 - 99.95% purity, 5000 psi, up to 1000 kg/day, \$3.00/kg (GTI, GE, APCi)

Renewable based technologies:

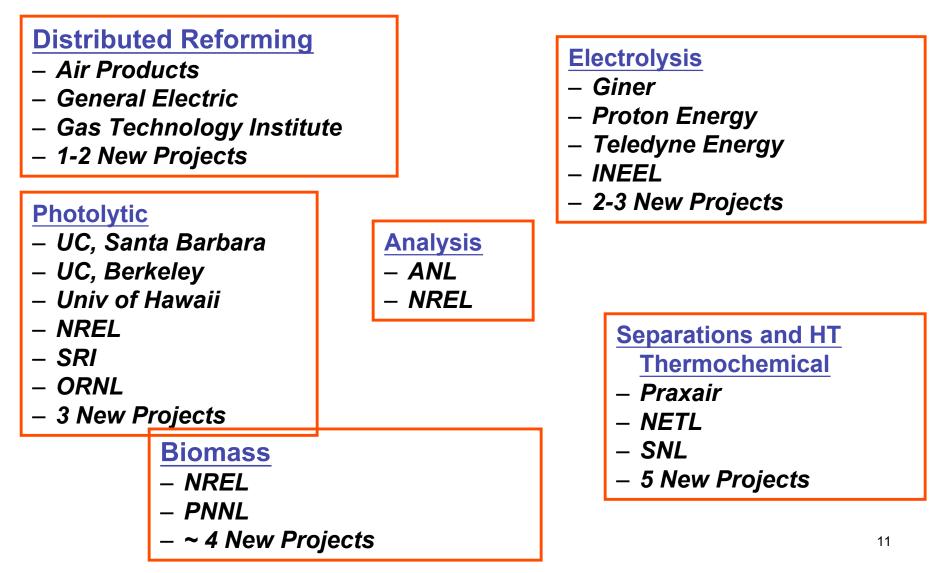
- Initiated research to reduce capital cost of small (25kg / day) electrolyzer systems (Giner, Teledyne, Proton)
- Accelerated and expanded research on: photobiological, photoelectrochemical, biomass pyrolysis

Delivery technologies:

 Held hydrogen delivery workshop with industry and government in May 2003 to identify research needs supporting central production

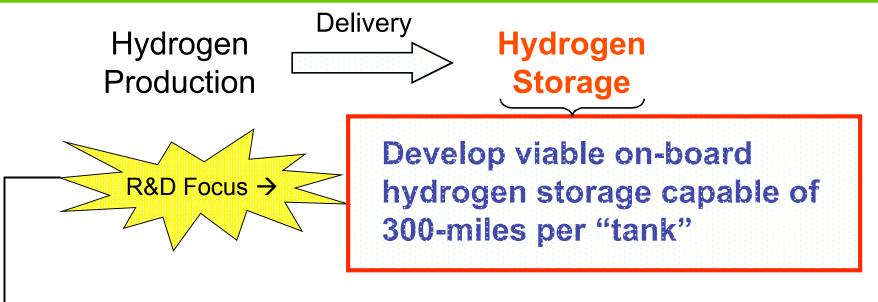


Major DOE Hydrogen Production Activities FY-04:



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Storage Objectives



- On-board hydrogen storage systems achieving:
 - 2005: 4.5 wt%, 1.2 kWh/L, and \$6/kWh
- → 2010: 6 wt%, 1.5 kWh/L, and \$4/kWh
 - [2015: 9 wt%, 2.7 kWh/L, and \$2/kWh]
- Low cost, off-board storage to support transportation, stationary and portable power markets by 2015

Current Technologies- Pros and Cons

	Pros	Cons
High	Gravimetric capacity	Volumetric capacity
Pressure	Availability	High pressure issues
Tanks		Compression & regulation
Liquid	Gravimetric capacities	Boil off
Hydrogen	(& volumetric)	Energy penalty
Metal	Volumetric capacity	Gravimetric capacity
Hydrides 7	Reversible on board	Optimum T, P, kinetics
	No leakage issues	
Chemical	Gravimetric & Volumetric	Irreversible on board
Hydrides	capacities	Regeneration cost
- Free		Infrastructure

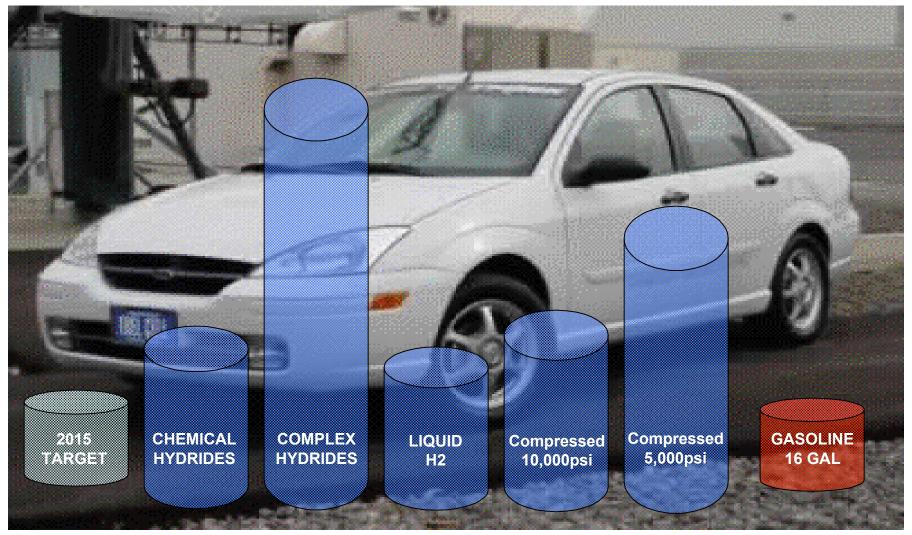
No one technology meets the targets

NEED BREAKTHROUGHS!



Storage SYSTEM Volume Comparison Where we are, WHERE WE NEED TO BE

System Volume Estimates- Based on 5 kg hydrogen



Estimates from current developers of various hydrogen storage technologies ('03) Fuel Cell Vehicle- Photo from www.cafcp.org

High Pressure Storage:

Quantum- Achieved the following system-level performance*

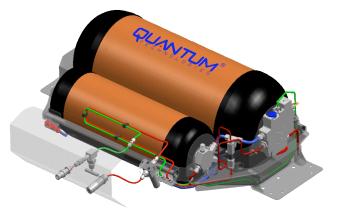
	Gravimetric Capacity	Volumetric Capacity	Cost
Quantum 5,000 psi Storage	2.07 kwh/kg	0.81 kwh/L	\$12.2/kWh
Quantum 10,000 psi Storage	1.9 kwh/kg	1.3 kwh/L	\$16.0/kWh

* 5 kg storage using one tank; volume of 500,000 tanks/year

- Achieved >45,000 cycles fatigue life for 10,000 psi storage tanks (10 X improvement from 2002)
- Completed successful fast-fill (~3 min.) demonstrations of 10,000 psi

Development Needs:

Reduce cost from \$16/kWh to \$4/kWh (2010 target)





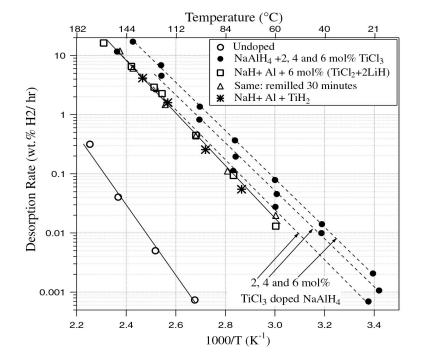
Recent Accomplishments- Metal Hydrides

Metal Hydrides:

• Developing Ti-precursors that do not degrade hydrogen storage capacity (SNL, UH, SRTC)

•Achieved 110 cycles with 3.2 wt% reversible capacity at 120 C (UH)

•Achieved 40 cycles with > 4wt% reversible capacity at 150°C (UH)



Arrhenius plot of desorption rates of NaAlH₄ doped with different Ti-precursors (K. Gross, et al, SNL)

$3NaAIH_4 \rightarrow Na_3AIH_6 + 2AI + 3H_2 \rightarrow 3NaH + AI + 3/2H_2$ 3.7 wt% 1.8 wt%

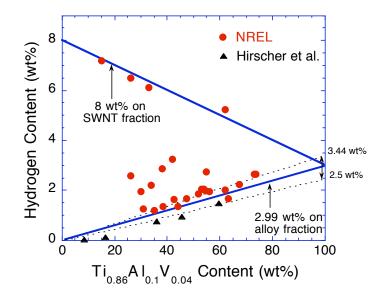


Recent Accomplishments- Carbon & New Materials

Carbon Nanotubes & New Materials:

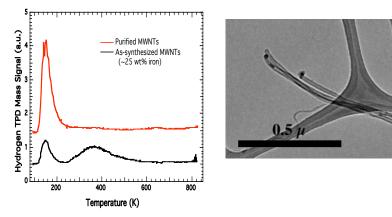
•Preliminary measurement of 6-8 wt% material capacities in CNTs (NREL)

•FY-04 Focus: Is this reproducible??

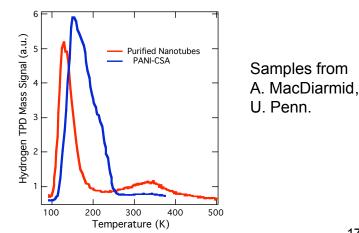




Evidence suggests that metal nanoparticles in CNTs may increase H_2 storage capacity

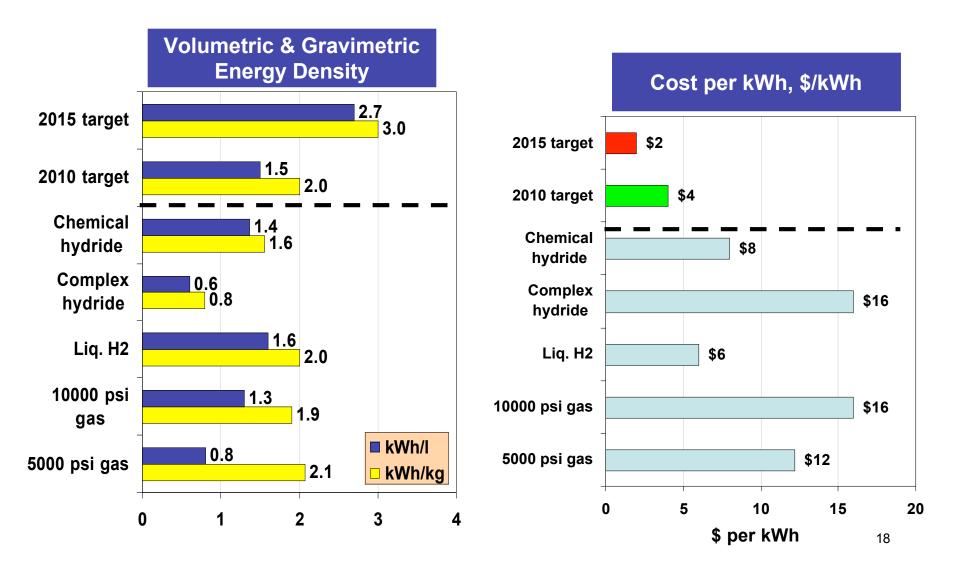


New materials: Polyaniline (PANI) shows high temperature H binding

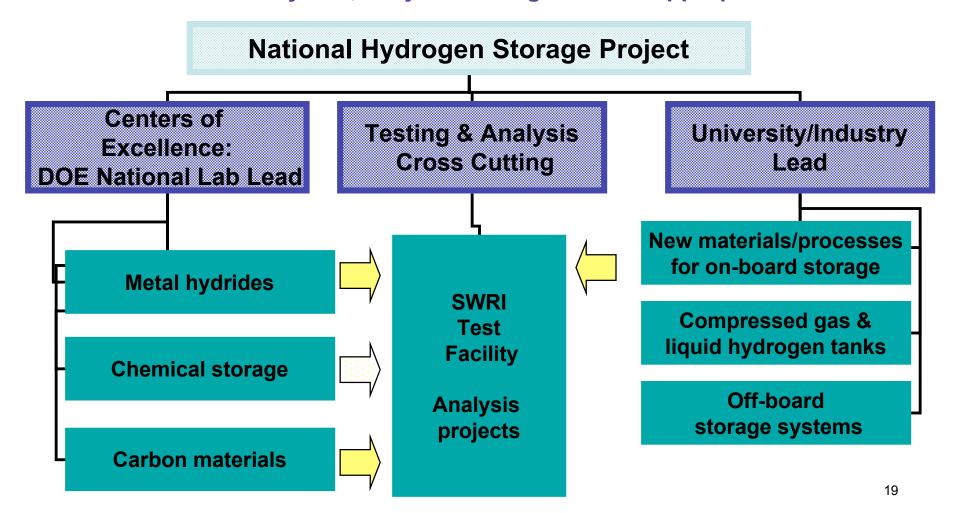


Technology Status

No current H₂ storage technology meets the targets

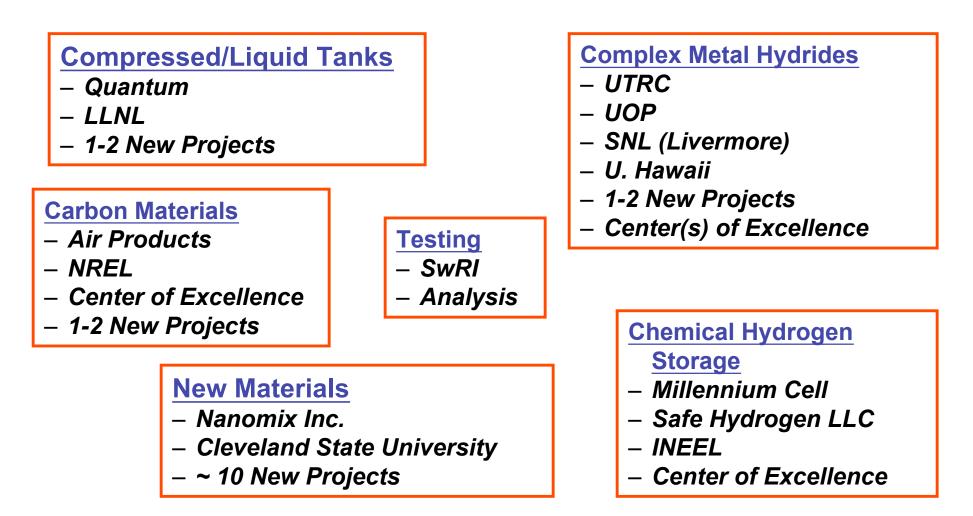


The DOE 2003 "Grand Challenge" will form the basis for a National Hydrogen Storage Project (March '04) \$150M over 5 years, subject to congressional appropriations





DOE Hydrogen Storage Projects FY-04:



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For More Information...

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^o Storage Team:

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Production & Delivery Team:

Arlene Anderson- Fossil/Separations Matt Kauffman- Electrolysis **Roxanne Danz-Biological** Mark Paster- Delivery Chris Bordeaux- Power parks Pete Devlin- Team Lead

www.eere.energy.gov/hydrogenandfuelcells

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