



U.S. DEPARTMENT OF
ENERGY

2006 Annual DOE Hydrogen Program Merit Review

Hydrogen Storage

Sunita Satyapal

Carole Read

Grace Ordaz

George Thomas¹



Hydrogen Storage: The “Grand Challenge”

On-board hydrogen storage to meet all performance (wt, vol, kinetics, etc.) , safety and cost requirements and enable a more than 300 mile driving range.

These
Are
System
Targets

Material
capacities
must be
higher!

Targets	2010	2015
System Gravimetric Capacity (net)= “specific energy”	6 wt.% (7.2 MJ/kg) (2.0 kWh/kg)	9 wt.% (10.8 MJ/kg) (3.0 kWh/kg)
System Volumetric Capacity (net)= “energy density”	1.5 kWh/L (5.4 MJ/L) (45 g/L)	2.7 kWh/L (9.7 MJ/L) (81 g/L)
Storage system cost	\$4/kWh (~\$133/kg H ₂)	\$2/kWh (\$67/kg H ₂)

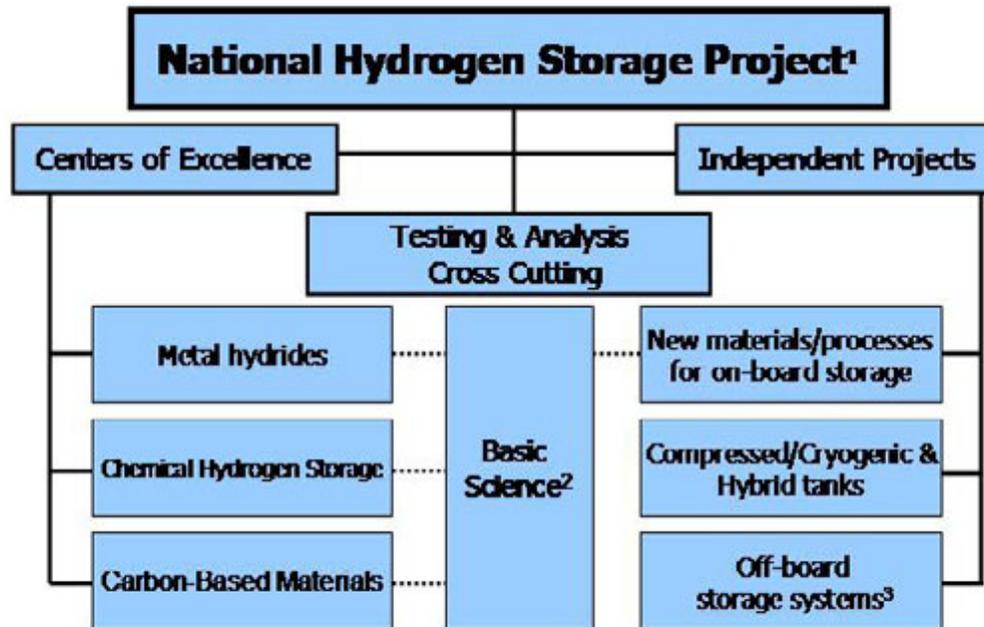
Explanations at www.eere.energy.gov/hydrogenandfuelcells/

Many additional targets





Strategy and Program Plans



1. Coordinated by DOE- Energy Efficiency and Renewable Energy, Office of Hydrogen, Fuel Cells and Infrastructure Technologies
2. Basic science for hydrogen storage conducted through DOE Office of Science, Basic Energy Sciences
3. Coordinated with Delivery Program element

- **Centers of Excellence** (\$5-6M/yr) plus independent projects, launched at \$150 M over 5 years (plan- subject to appropriations)
- ~ **40 universities, 15 companies, 10 federal labs** (including 17 new BES awards)
- **Diverse portfolio addresses NAS recommendations**

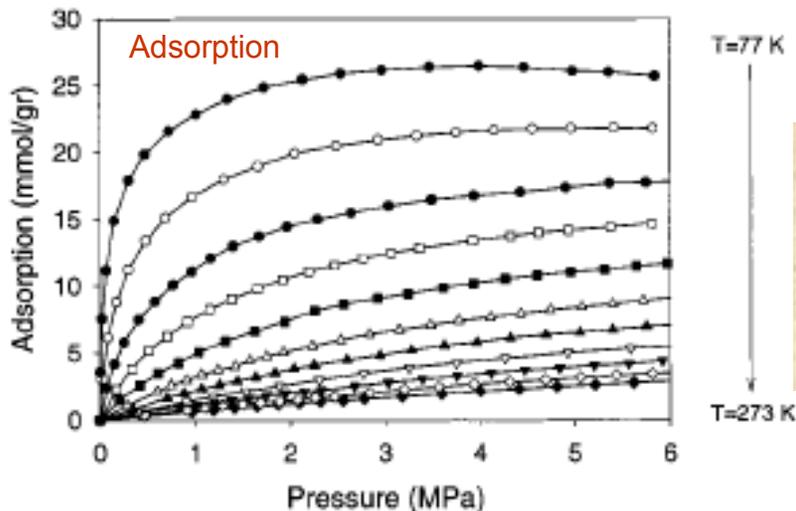
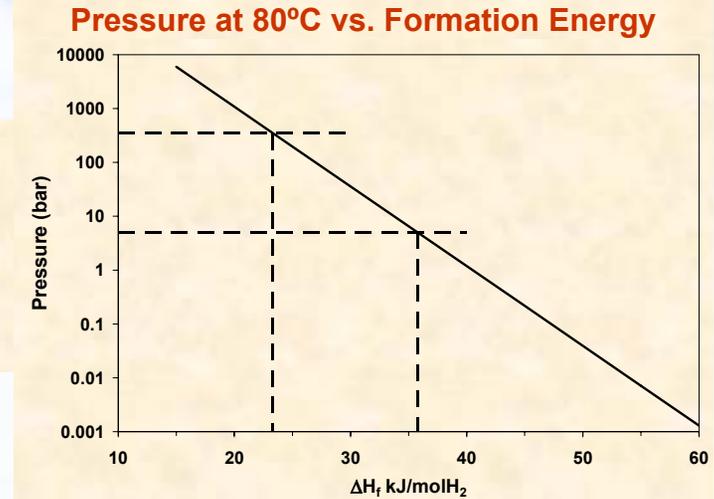
“...DOE should continue to elicit new concepts and ideas, because **success in overcoming the major stumbling block of on-board storage is critical** for the future of transportation use of fuel cells.” (NRC Report,p.44)



Strategy: Optimize Materials Properties

Hydride heat of formation

- Pressure limits (20-35 kJ/molH₂)
- Refueling (<20 kJ/molH₂)

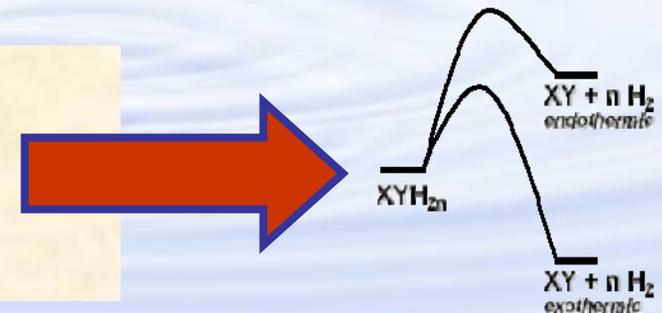


Surface heat of adsorption

- Operating temperature (> 100 K)
- Release temperature (< 80 C)

Activation barrier for regeneration

- Energy efficiency
- Thermoneutral for H₂ release





Results: Examples of Progress (2005-2006)

New materials with higher capacities being found

Material Capacities for Hydrogen Storage

Advanced Metal Hydrides	Chemical H ₂ Storage	Carbon/ Sorbents & New Materials
<p>Li Mg Amides ~5.5wt%, ~2.8 kWh/L (>200 C)</p> <p>Alane ~7-10 wt%, ~5 kWh/L (<150 C)</p> <p>Li borohydrides >9 wt%, ~3.5 kWh/l (~350 C)</p> <p>Destabilized Binary hydrides ~5-7wt%, ~2-3 kWh/L (250 C)</p> <p>LiMgAlane, M-B-N-H ~ 7-8.8 wt%, > 1.3 kWh/L (~150-340 C)</p>	<p>Phenanthraline/ organic liquids ~7 wt%, ~1.8 kWh/L (>150 C)</p> <p>Ammonia Borane/Scaffolds ~6 wt%, ~2-4 kWh/L (<100 C)</p>	<p>Metal/carbon hybrids, MetCars 6 to > 8wt%*, ~1.3* kWh/l (*theory)</p> <p>Bridged catalysts IRMOF-8 ~1.8 wt.%, ~0.3 kWh/L (room T)</p> <p>Metal-Organic Frameworks IRMOF-177 ~7 wt%, ~1 kWh/L (77 K)</p>

Note: Material capacities only. No balance of plant. Estimates for volumetric capacities.

We are excited by these results but there are still issues...

Next steps: Operability (Temperature, pressure, kinetics, etc.)

Other Examples of Accomplishments: Test Facility (SwRI), Storage Systems Analysis



Programmatic Accomplishments

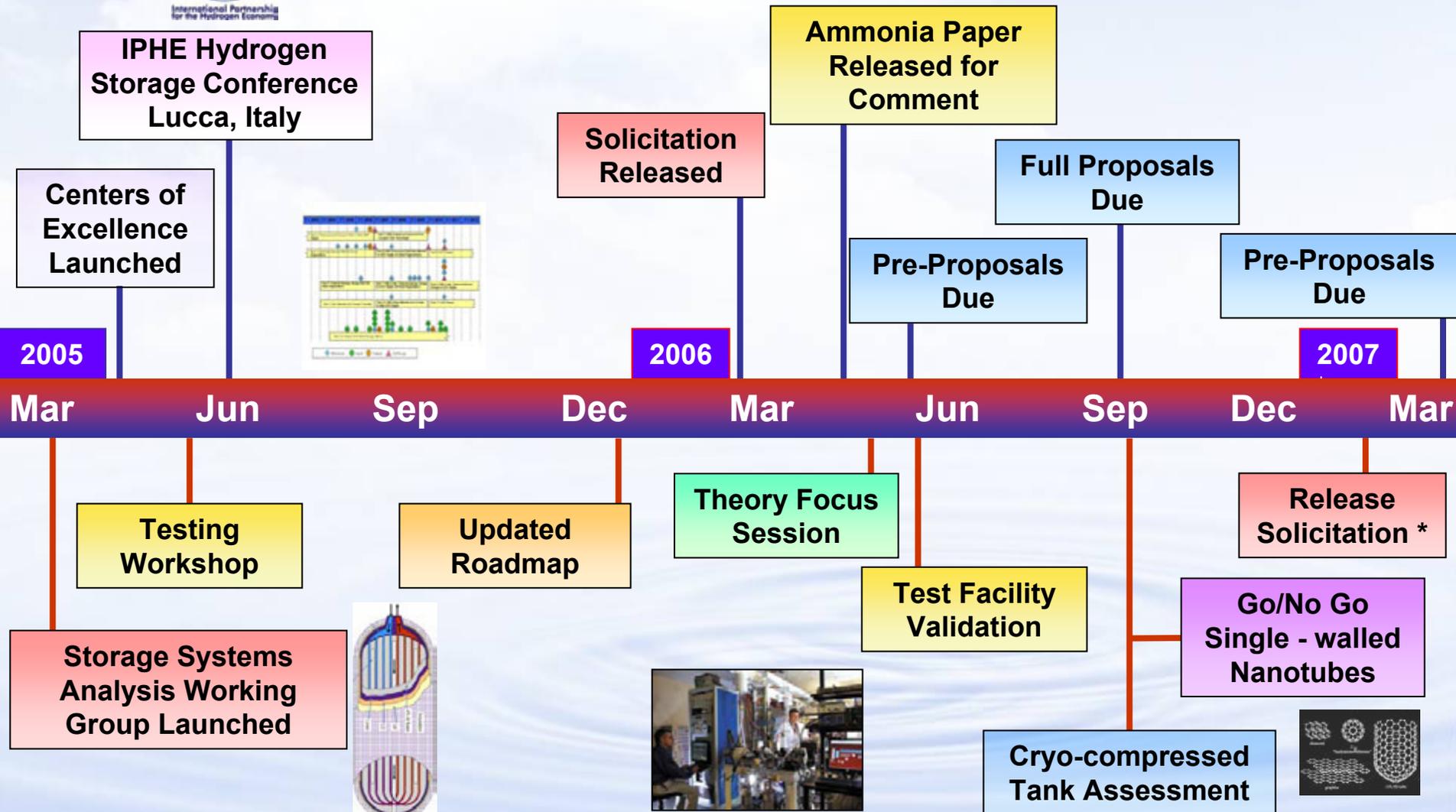
- IPHE Hydrogen Storage Conference
 - Leveraging global activities
 - See www.iphe.net
- Expanded Basic Science
- Theory Focus Session
 - May 18, 2006
- Updated Targets & Multiyear Plan
 - New versions on web
- Addressing NAS recommendations (e.g. revolving solicitation for new concepts)



- Water Availability Model
 - For hydrolysis
- Paper on Ammonia
 - Draft on web for public comment
- Updated Roadmap & Targets
 - New versions on web
- Joint Tech Team meetings
 - Defining requirements



Hydrogen Storage – Future Plans



*Subject to appropriations



Current Solicitations

1) Applied Research and Development (EERE)

- Up to \$6M total (\$2M planned in FY07, subject to appropriations)

Complements current DOE Centers of Excellence & existing Independent projects:

- Material discovery
 - Engineering Science (including materials safety properties)
 - Systems, safety and environmental analyses
- 3-6 awards at \$200-400k/yr for 2-5 years
 - Preproposals due **June 7**

2) Basic Science (Office of Science, BES)

- Up to \$52.5M total (\$17.5M/yr starting in FY07, subject to appropriations)

- Novel Materials for Hydrogen Storage
 - Functional Membranes
 - Nanoscale Catalysts
- Preproposals due **July 6**

See <http://www.grants.gov> or follow links from www.hydrogen.energy.gov



For More Information

Hydrogen Storage Team

Sunita Satyapal, Team Leader

Overall Storage/ FreedomCAR Tech
Team/International

202-586-2336

sunita.satyapal@ee.doe.gov

Grace Ordaz

Chemical Hydrides, Chemical Hydrogen
Storage Center of Excellence

202-586-8350

grace.ordaz@ee.doe.gov

Carole Read

Metal Hydrides, Metal Hydride Center
of Excellence

202-586-3152

carole.read@ee.doe.gov

George Thomas*

On Assignment to DOE

**retired, Sandia*

202-586-8058

george.thomas@ee.doe.gov

New Hire

Carbon/Sorbents, Carbon

Center of Excellence

see website below

(closes May 19)

Jesse Adams

303-275-4954

jesse.adams@go.doe.gov

James Alkire

303-275-4795

jim.alkire@ee.doe.gov

Paul Bakke

303-275-4916

paul.bakke@go.doe.gov

Basic Science: Harriet Kung

(harriet.kung@science.doe.gov)

or

Tim Fitzsimmons

(tim.fitzsimmons@science.doe.gov)

www.hydrogen.energy.gov



Additional Information



Hydrogen Storage "Grand Challenge" Partners

Centers of Excellence

Metal Hydride Center

National Laboratory:
Sandia-Livermore

Industrial partners:
General Electric
HRL Laboratories
Intematix Corp.

Universities:
CalTech
Stanford
Pitt/Carnegie Mellon
Hawaii
Illinois
Nevada-Reno
Utah

Federal Lab Partners:
Brookhaven
JPL
NIST
Oak Ridge
Savannah River

Carbon Materials Center

National Laboratory:
NREL

Industrial partners:
Air Products & Chemicals

Universities:
CalTech
Duke
Penn State
Rice
Michigan
North Carolina
Pennsylvania

Federal Lab Partners:
Lawrence Livermore
NIST
Oak Ridge

Chemical Hydrogen Center

National Laboratories:
Los Alamos
Pacific Northwest

Industrial partners:
Intematix Corp.
Millennium Cell
Rohm & Haas
US Borax

Universities:
Northern Arizona
Penn State
Alabama
California-Davis
UCLA
Pennsylvania
Washington

Independent Projects

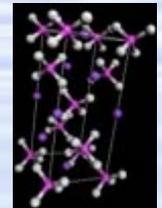
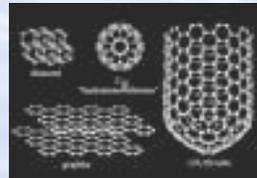
New Materials & Concepts
Alfred University
Carnegie Institute of Washington
Cleveland State University
Michigan Technological University
TOFTEC
UC-Berkeley
UC-Santa Barbara
University of Connecticut
University of Michigan
University of Missouri

High-Capacity Hydrides
UTRC
UOP
Savannah River NL

Carbon-based Materials
State University of New York
Gas Technology Institute
UPenn & Drexel Univ.

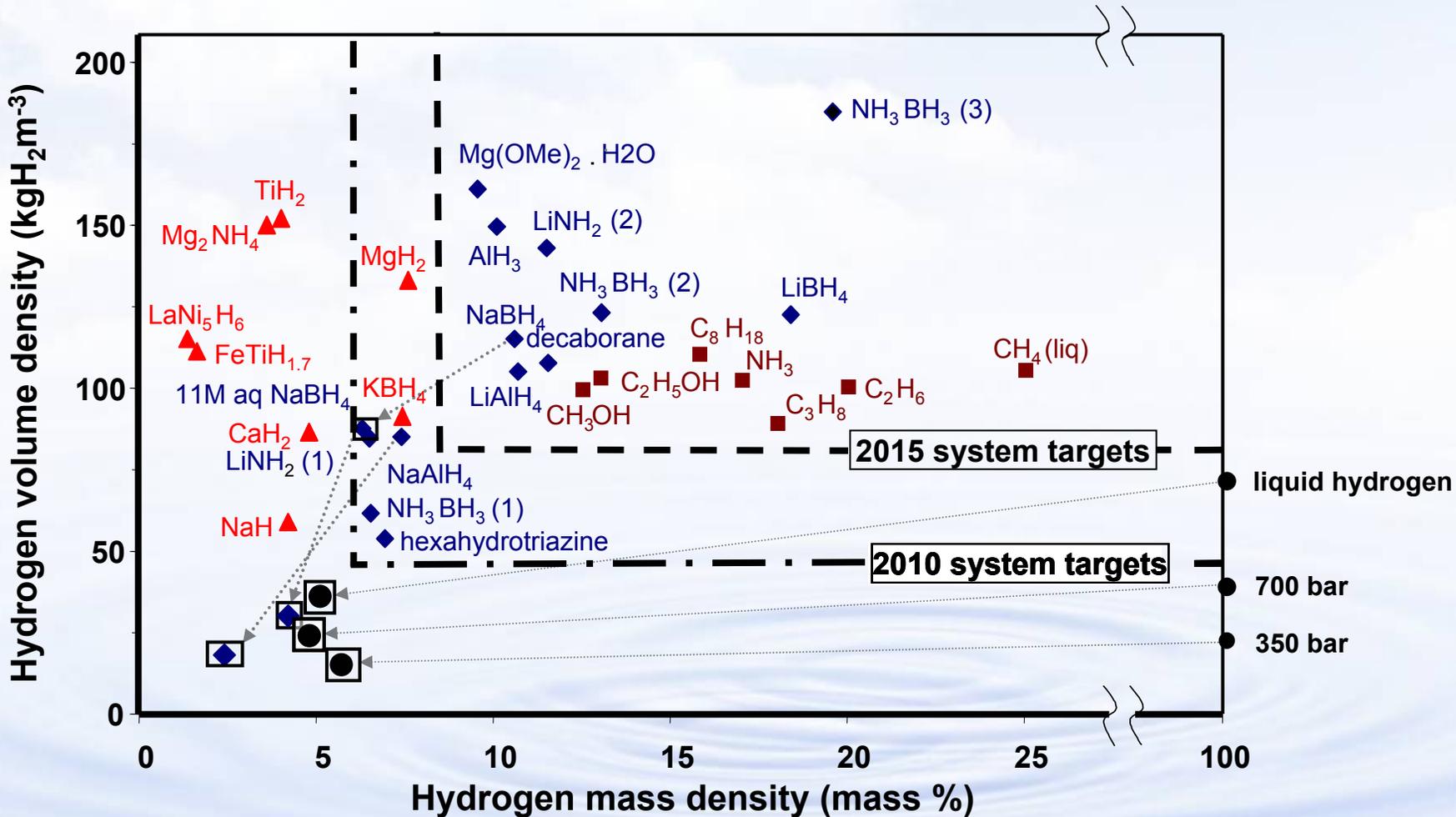
Chemical Hydrogen Storage
Air Products & Chemicals
RTI
Millennium Cell
Safe Hydrogen LLC

OffBoard, Tanks, Analysis & Testing
Gas Technology Institute (w/Delivery)
Lawrence Livermore
Quantum
Argonne Nat'l Lab & TIAX LLC
SwRI





No current system meets targets, but there are some materials with potential...





Hydrogen Storage Budget

DOE- EERE

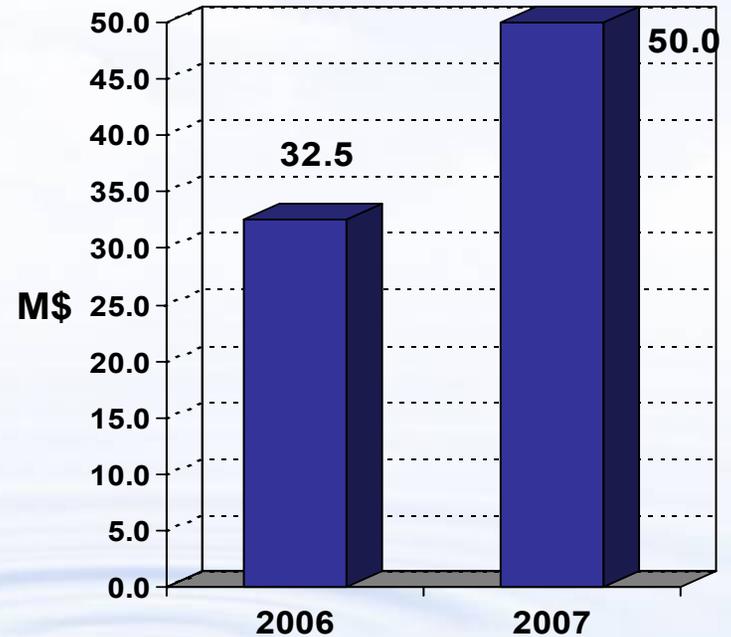
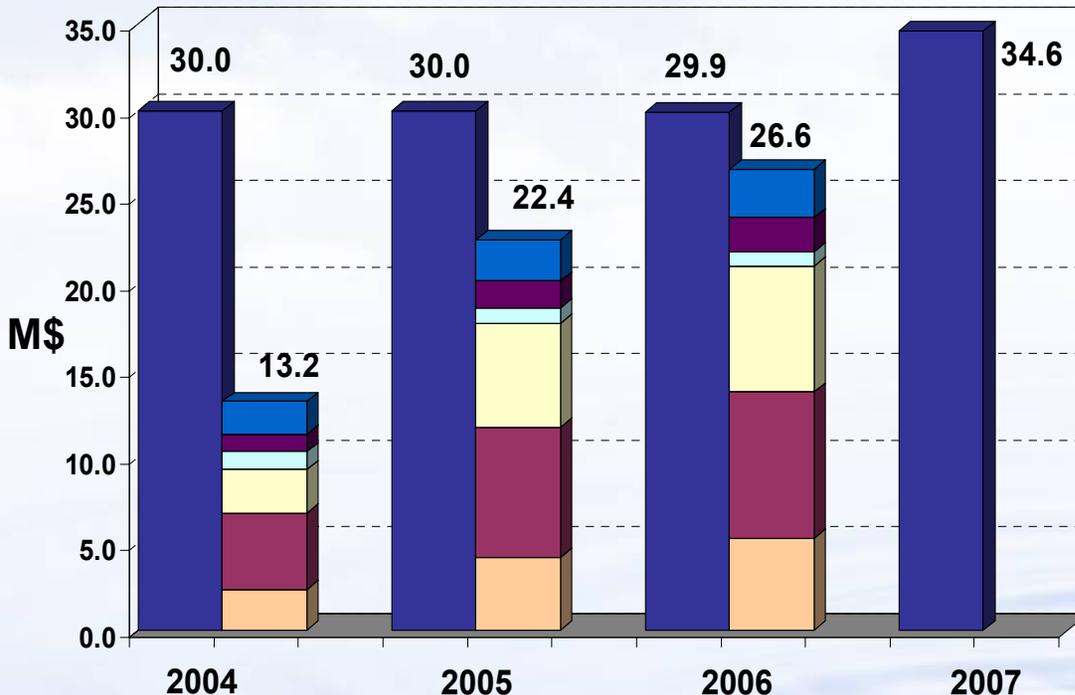
FY2007 Budget Request = \$34.6M

FY2006 Funding = \$26.6M

DOE- Office of Science

FY2007 Budget Request = \$50.0M

FY2006 Funding = \$32.5M



- Carbon-based Materials
- Chemical Hydrogen Storage
- New Materials & Concepts
- Budget Request
- Metal Hydrides
- Compressed/Tanks
- Test/Analysis/Support

Planned funding for Basic Science in Hydrogen Storage in FY06: \$7.13M