The U.S. National Hydrogen Storage Project Overview

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U.S. DOE Hydrogen Program

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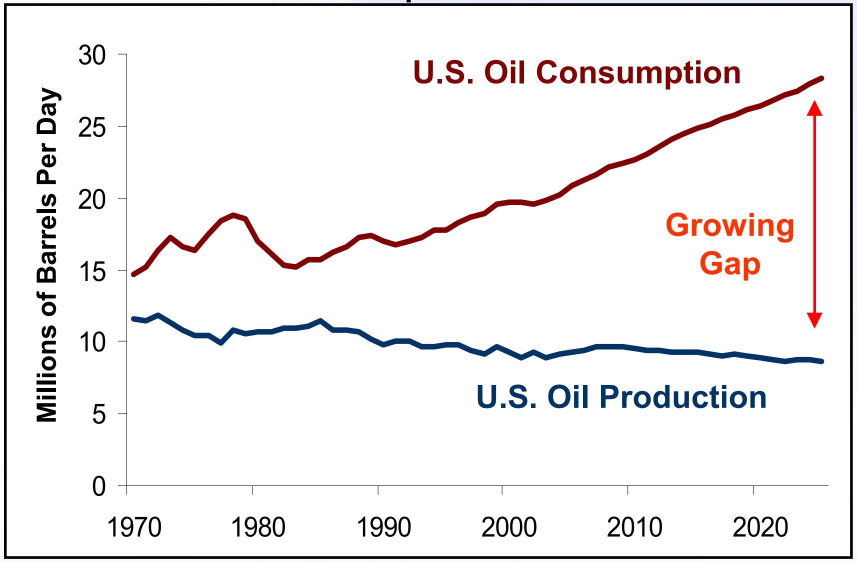
Combinatorial/High Throughput Techniques for Hydrogen Storage Meeting
Bethesda, MD

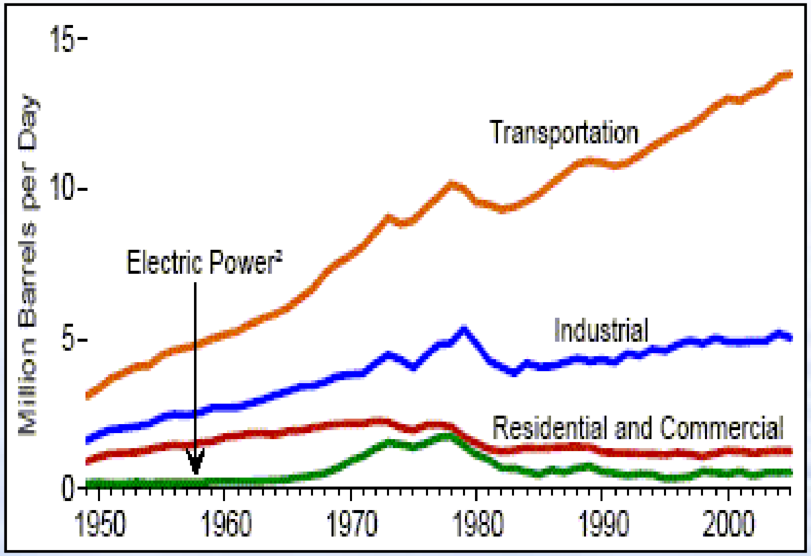
U.S. Energy Overview

- **We import ~ 55% of our oil today – projected to go up to 68% by 2025 if we continue business as usual**

U.S. Oil Consumption vs. Production



Petroleum Consumption by Sector

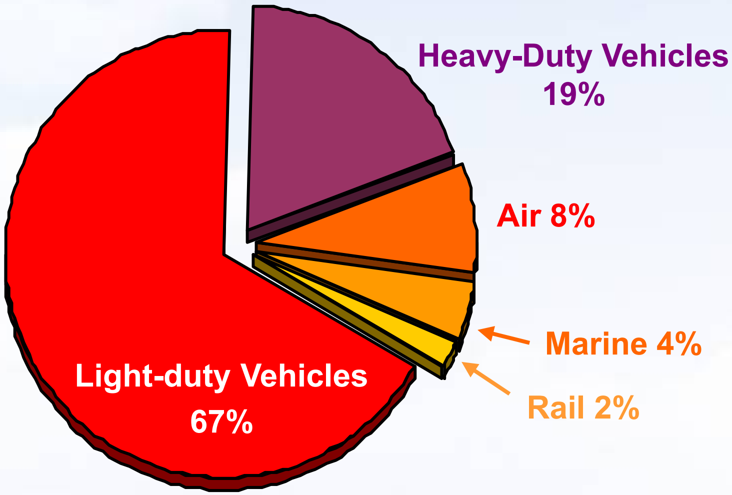


- **Transportation is largest consuming sector of petroleum (67% of total U.S. consumption)**

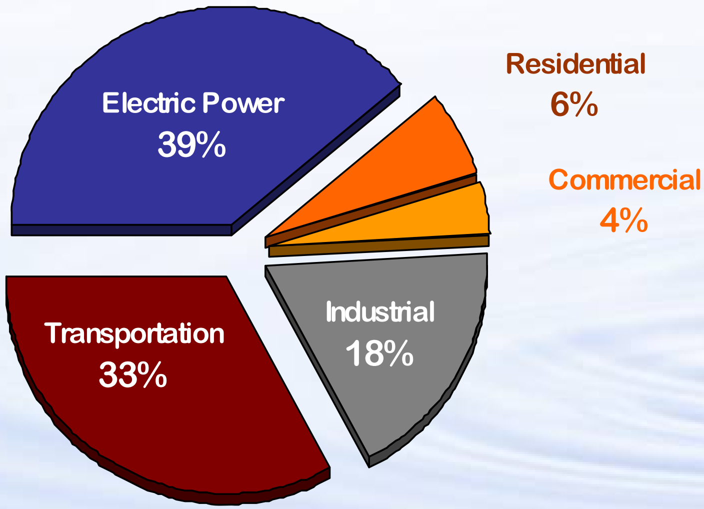
U.S. Energy Overview

- About 2/3rd of petroleum demand within the transportation sector is for light duty vehicles

Petroleum Use in Transportation Sector



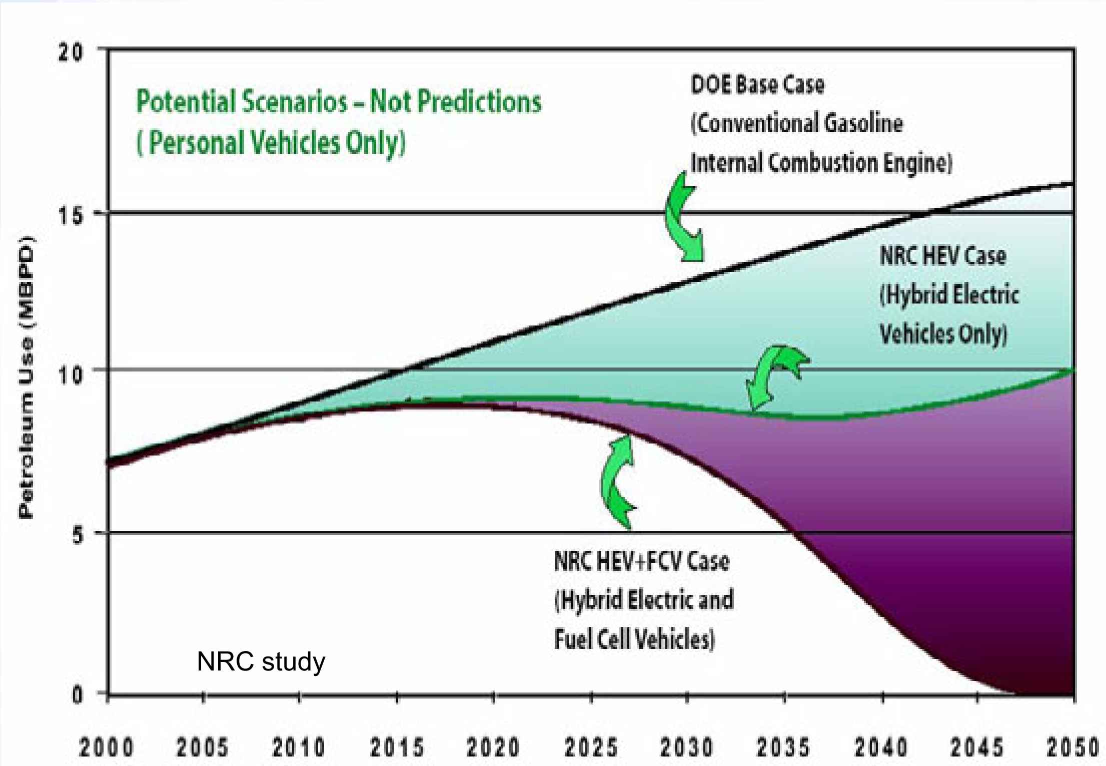
U.S. CO_2 Emissions by Sector



- About 1/3rd of CO_2 emissions is due to the transportation sector

Source: EIA, *Annual Energy Review, 2005.*

Potential Oil Savings Scenarios- Fuel Substitution needed in the long term



Hydrogen is one part of a comprehensive strategy

Hydrogen.gov

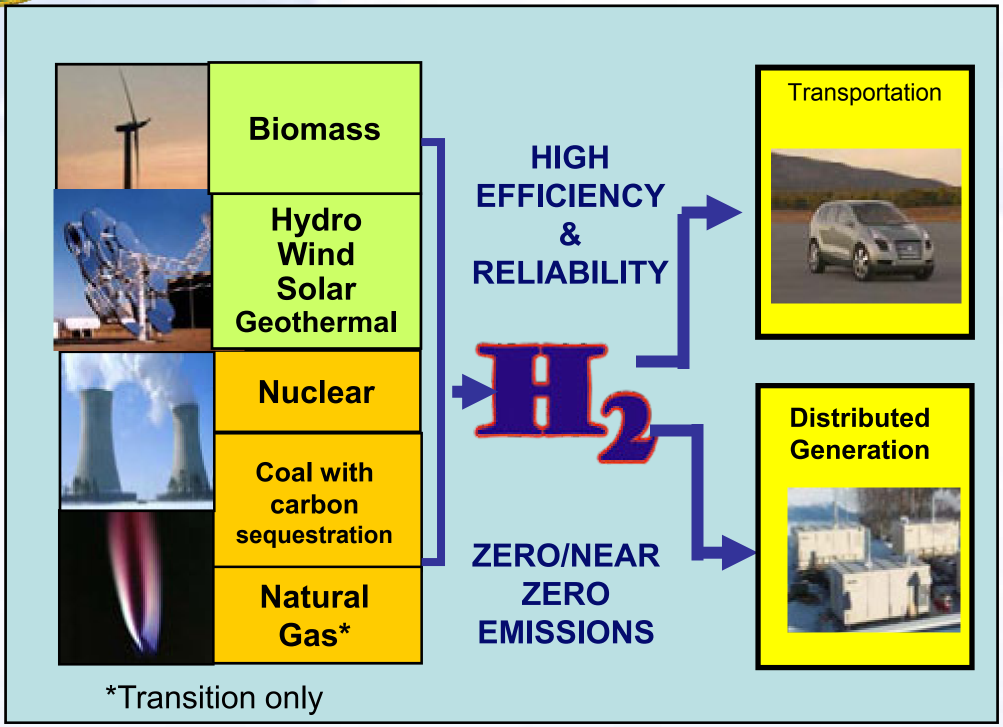
FreedomCAR & Fuel Partnership

IPHE

Near term reduction in oil use → Hybrid vehicles for improved efficiency

Long term elimination of oil dependency → Hydrogen substitution in fuel cell vehicles

Hydrogen as an Energy Carrier



Why H_2?

- Multiple domestic resources
- Non toxic, water vapor emissions
- Decouple C emissions from tailpipe
- Flexibility (transportation, stationary, portable)
- High energy content; efficiency of fuel cells

Critical Path Technology Barriers:

- Hydrogen Storage (>300 mile range)
- Hydrogen Production Cost ($2.00- 3.00 per gge)
- Fuel Cell Cost (~ $30 per kW)

Economic/Institutional Barriers:

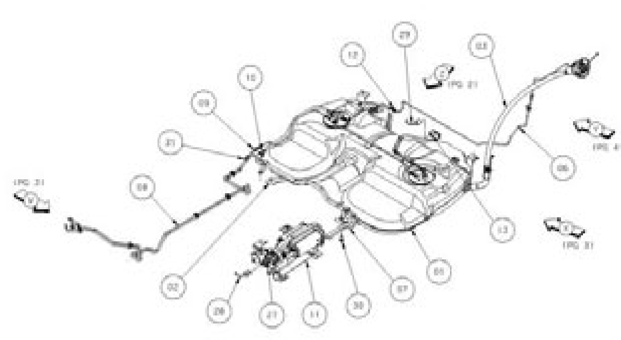
- Codes and Standards (Safety, and Global Competitiveness)
- Hydrogen Delivery (Investment for new Distribution Infrastructure)
- Education

The Hydrogen Storage Challenge

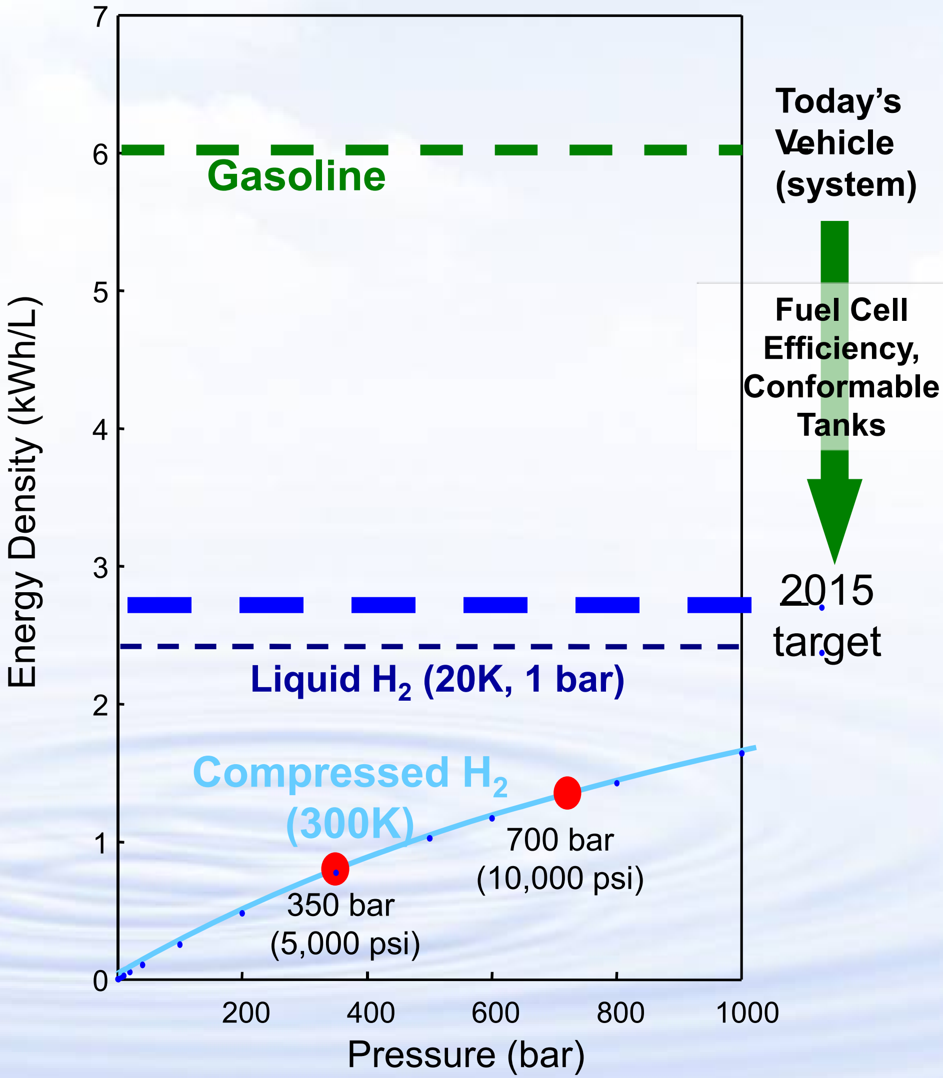
FreedomCAR & Fuel Partnership

Key System Targets

	2010	2015
Gravimetric capacity	**6 wt%** (2 kWh/kg)	**9 wt%** (3 kWh/kg)
Volumetric capacity	**45 g/L** (1.5 kWh/L)	**81 g/L** (2.7 kWh/L)
System Cost	**$4/kWh**	**$2/kWh**
Many more: www.hydrogen.energy.gov		



Gasoline System



U.S. Department of Energy

Many other requirements…

There are many more DOE targets, not just wt%!

Commercially viable & efficient H_2 Storage Systems

Weight
- Usable, specific-energy from H_2 (Gravimetric Capacity) (3 kWh/kg)

Volume (& conformability)
- Usable, energy density from H_2 (Volumetric Capacity) (2.7 kWh/L)

System cost (& fuel cost)
- System cost ($2/kWh net)
- Fuel cost includes off-board costs such as liquefaction, compression, regeneration etc. ($2-3/gge)

Durability/ Operability
- Operating ambient temperature (-40/60ºC (sun))
- Cycle life (1500 cycles)
- Min/max delivery temperature (-40/85ºC)
- Min/max delivery pressure (3/100 Atm (abs))
- Cycle life variation (99% of mean (min) @ 90% confidence)

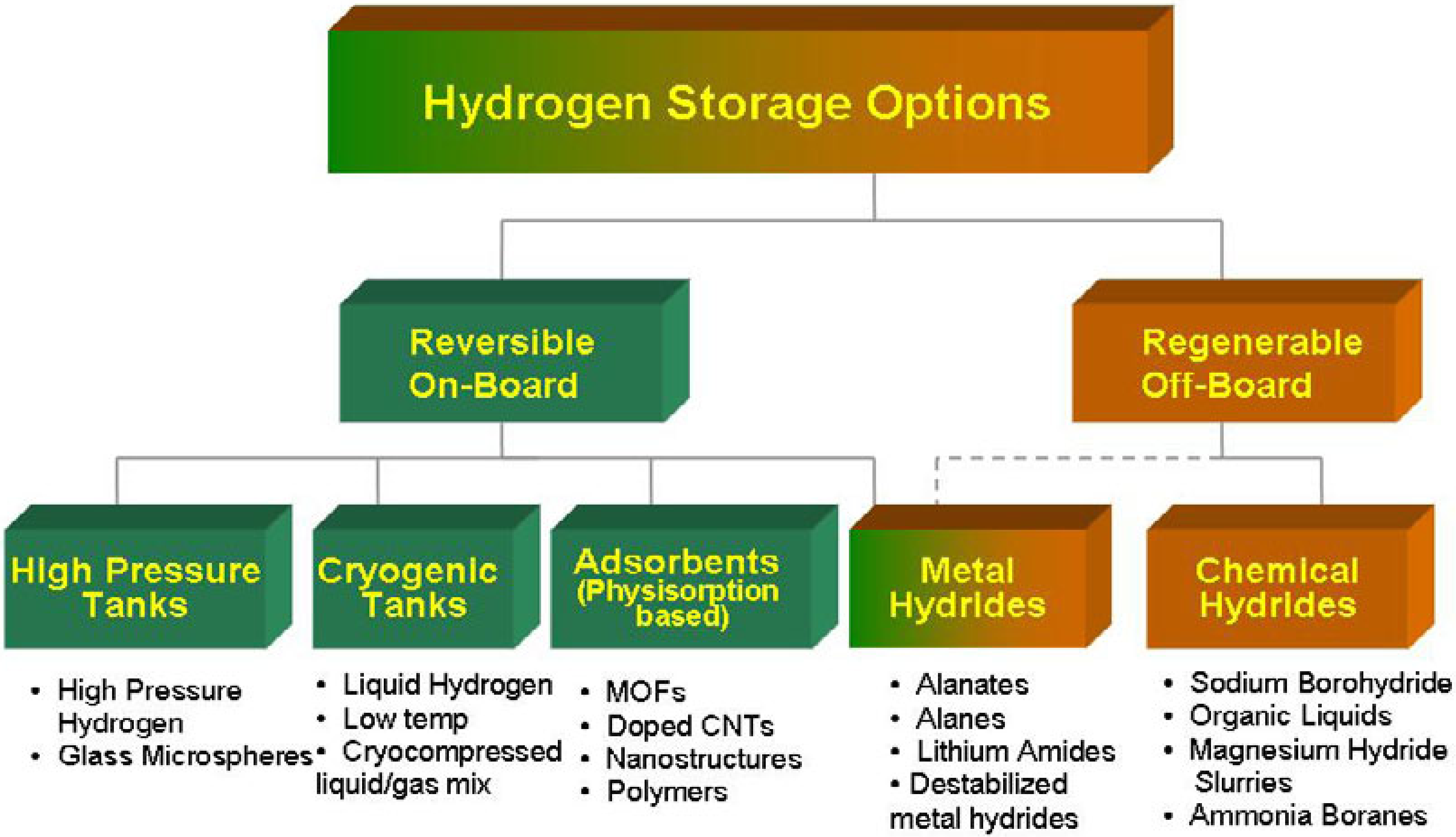
Charging/ Discharging Rates
- System fill time (2.5 min)
- Start time to full flow (min. ambient) (2 sec)
- Start time to full flow (20ºC) (0.5 sec)
- Transient response (0.5 sec)
- Min full flow rate (0.02 g/s kW)

Efficiency
- 90% energy efficiency for reversible onboard systems
- 60% for regenerable off-board (well-to-wheels)

Fuel Purity
- Require 99.99% H_2 (4 max. levels for selected contaminants)

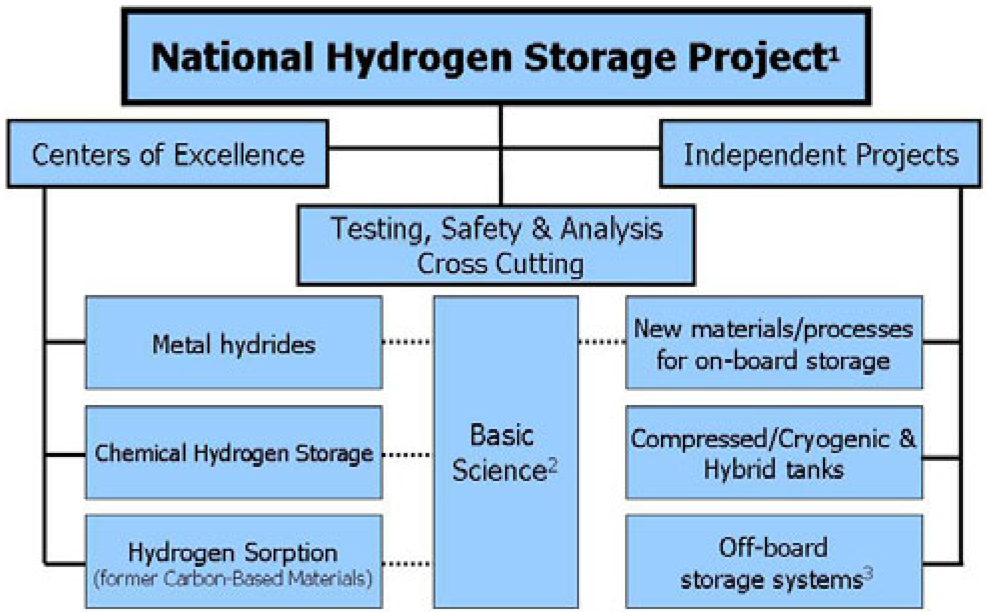
Environmental Health & Safety
- Permeation & leakage (Federally enclosed area safety standard in Scc/h)
- Toxicity (Meets/exceeds applicable standards)
- Safety (Meets/exceeds applicable standards)
- Loss of useable H_2 (0.05 g/h/kg H_2 Stored)

Hydrogen Storage Options



Strategy: Diverse Portfolio with Materials Focus

"…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."[1]



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

- Balanced portfolio
- ~ 40 universities, 15 companies, 10 federal labs
- Robust effort in both theory & expt'l work
- Annual solicitation for increased flexibility
- Close coordination with basic science
- Coordination with industry, other agencies & globally

1. NRC H_2 Economy Report (2004) p.44

Applied R&D Hydrogen Storage "Grand Challenge" Partners:
Diverse Portfolio with University, Industry and National Lab Participation

Centers of Excellence

Metal Hydride Center

National Laboratory:
Sandia-Livermore

Industrial partners:
General Electric
HRL Laboratories
Intematix Corp.

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

Federal Lab Partners:
Brookhaven
JPL, NIST
Oak Ridge
Savannah River

Hydrogen Sorption 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 Storage 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
Univ. of Missouri
Pennsylvania
Washington

Independent Projects

Advanced Metal Hydrides
UTRC, UOP
Savannah River Nat'l Lab
Univ. of Connecticut

Sorbent/Carbon-based Materials
UCLA
State University of New York
Gas Technology Institute
UPenn & Drexel Univ.
Miami Univ. of Ohio

Chemical Hydrogen Storage
Air Products & Chemicals
RTI
Millennium Cell
Safe Hydrogen LLC
Univ. of Hawaii

Other New Materials & Concepts
Alfred University
Michigan Technological University
UC-Berkeley/LBL
UC-Santa Barbara
Argonne Nat'l Lab

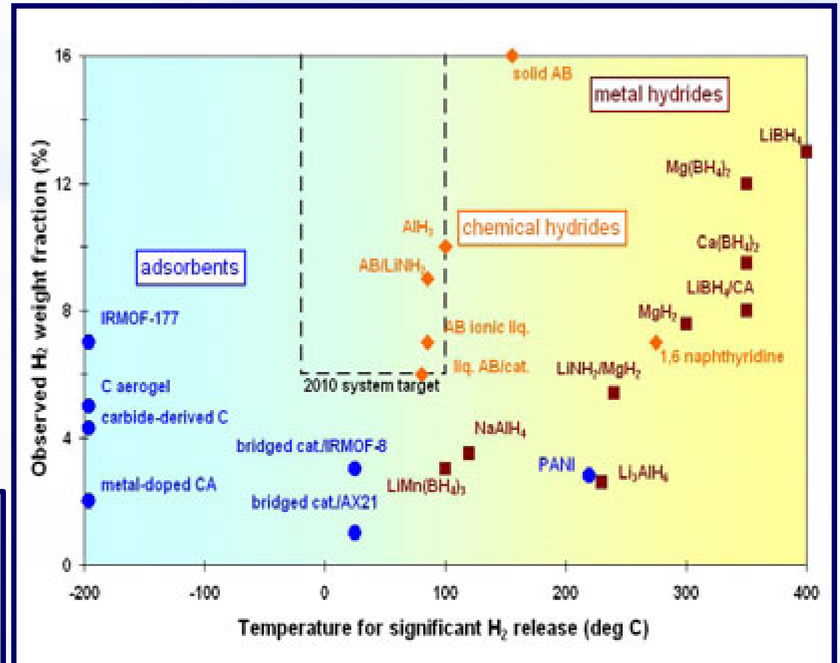
Tanks, Safety, Analysis & Testing
Lawrence Livermore Nat'l Lab
Quantum
Argonne Nat'l Lab, TIAX LLC
SwRI, UTRC, Sandia Nat'l Lab
Savannah River Nat'l Lab

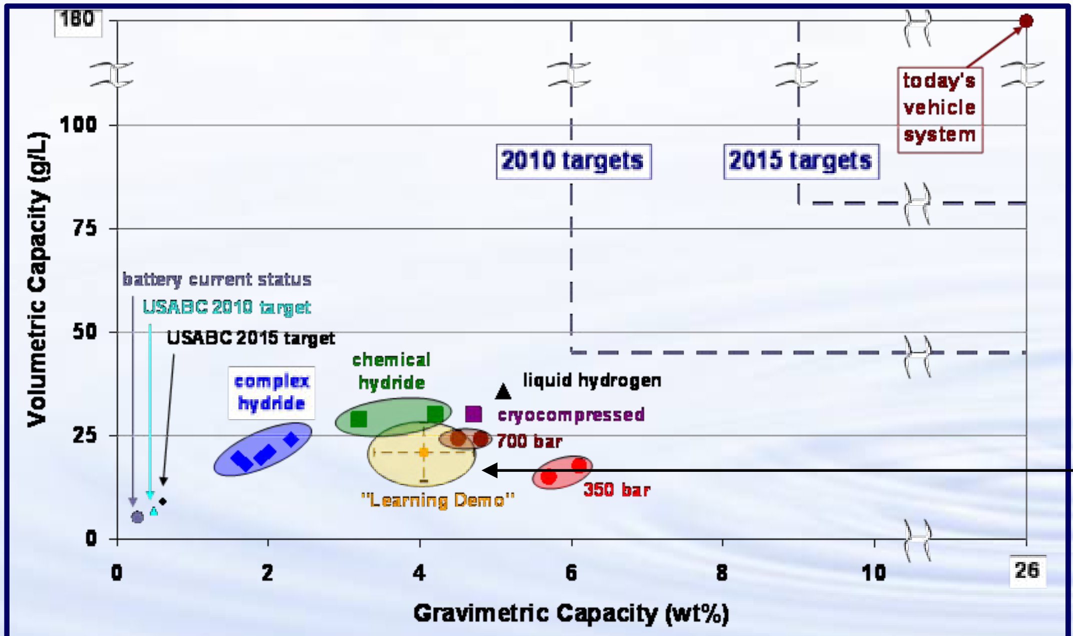
Coordination with: Basic Science (Office of Science, BES)

MIT, U.WA, U. Penn., CO School of Mines, Georgia Tech, Louisiana Tech, Georgia, Missouri-Rolla, Tulane, Southern Illinois; Labs: Ames, BNL, LBNL, ORNL, PNNL, SRNL

Hydrogen Storage- Current Status & Recent Progress

No technology meets targets
Promising materials continue to be identified



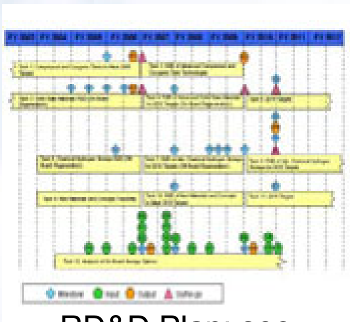


Current status:
~ 103-190 miles through independent validation
(DOE "Learning Demonstration" activity)

Estimates from developers & analysis results; periodically updated by DOE. "Learning Demo" data is for 63 vehicles.

Summary of Current Assessment

Challenges are technology specific: Pros and Cons for each
Progress is being made but too early to eliminate whole areas



RD&D Plan: see http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/

Key 2010 Targets:	High P Tanks	Chemical Hydrides	Metal Hydrides	Carbon/ Sorbents
Volume (1.5 kWh/L)	H	M	M	M/H
Weight (2.0 kWh/kg)	M	M	M/H	M
Cost ($4/kWh)	M/H	M/H[1]	M/H	M/H
Refueling Time (3 min, for 5 kg)	L[2]	L	M/H	M
Discharge Kinetics (0.02 g/s/kW)	L	M	M	L/M
Durability (1000 cycles)	L	M	M	M

Thermal Mgmt: Key Issues for MH (CH, C/S) (applies to Refueling Time and Discharge Kinetics)

H = High (Significant challenge) M/H = Medium/High M = Medium L = Low (minimal challenge)

For CH, MH and S- assessment based on potential to meet targets, though systems not yet demonstrated in most cases.
[1]For CH: Storage system may meet cost but fuel cost of $2-$3/kg is challenge for CH regeneration.
[2] Assumes communication protocols

Examples of Hydrogen Storage Collaboration

IEA – HIA TASK 22

A total of 43 projects have been proposed for Task 22. This includes participation by 15 countries, 43 organizations, and 46 official experts.

Project Types:

- Experimental
- Engineering
- Theoretical Modeling (scientific or engineering)
- Safety Aspects of Hydrogen Storage Materials

Classes of Storage Media

- Reversible Metal Hydrides
- Regenerative Hydrogen Storage Materials
- Nanoporous Materials
- Rechargeable Organic Liquids and Solids

IPHE

- **Reversible Solid State Hydrogen Storage for Fuel Cell Power supply system** *(Russian Academy of Sciences)*
- **NESSHY – Novel Efficient Solid Storage for Hydrogen** *(National Center for Scientific Research "Demokritos," EU)*
- **Hydrodes & Nanocomposites in Hydrogen Ball Mills** *(University of Waterloo, Canada)*
- **Combination of Amine Boranes with MgH_2 & $LiNH_2$** *(Los Alamos & Pacific Northwest National Labs, USA)*
- **Fundamental Safety Testing & Analysis** *(Savannah River National Lab, USA)*

DoD: DEFENSE LOGISTICS AGENCY

New Storage Awards (4/07):

- **High throughput - Combinatorial Screening:** U of Central Florida, UC Berkeley & Symyx, Miami U (Ohio) & NREL
- **Reversible System Dev't & Demonstration:** Energy Conversion Devices, U of Missouri (phase 1 design)

Interagency Hydrogen R&D Task Force (OSTP)

NSF- proposal review in process (5/07)

NIST- neutron scattering

Summary

We need to accelerate the pace of hydrogen storage R&D!

Theory-guided experimental approach is current focus.

Combinatorial/high throughput techniques for both synthesis and screening are needed to complement current portfolio.

For More Information

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www.hydrogen.energy.gov

Thank you

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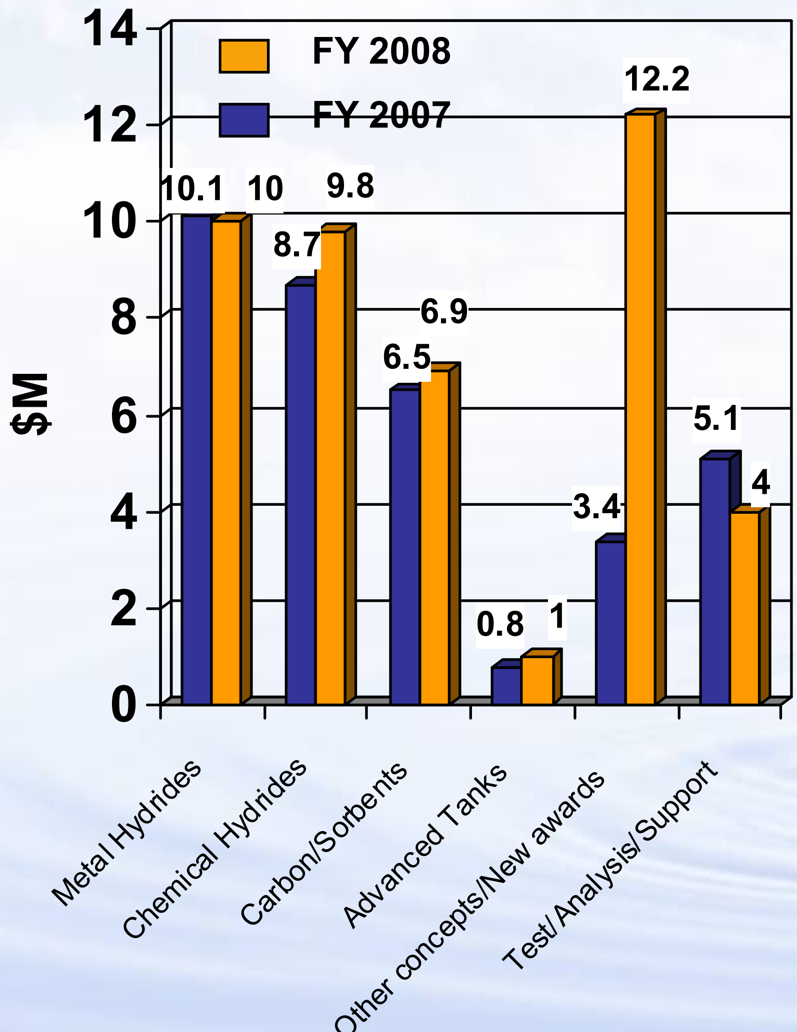
Applied R&D Hydrogen Storage Budget

FY2008 Budget Request = $43.9M
FY2007 Appropriation = $34.6M
(FY2006 Appropriation = $26.0M)

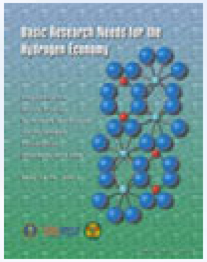


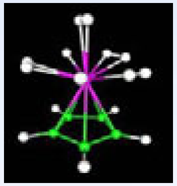
- **Emphasis:** Ramp up materials R&D through CoE & independent projects
- Tailor materials to focus on T, P, kinetics (as well as capacity)
- New Center of Excellence planned- Engineering Sciences*

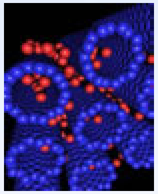
Close coordination with Basic Science
$36.4M (FY07)
$59.5M (FY08)
Includes basic science for hydrogen storage, production and use (e.g., catalysis, membranes, etc.)

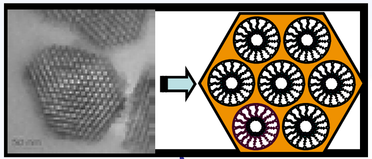
*subject to appropriations

Synergy between Basic Science and Applied Research, Development and Demonstration







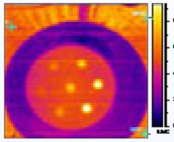


Basic Research

Develop and use theoretical models & fundamental experimentation to generate knowledge:

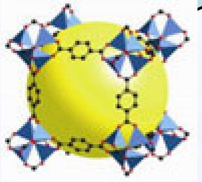
- Fundamental property & transport phenomena
- Novel material structures, characterization
- Theory, modeling, understand reaction mechanisms

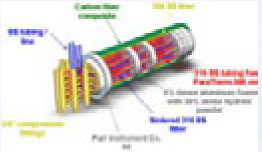
Applied Research & Development

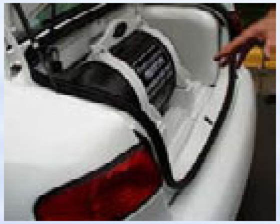


Apply theory & experimentation to design & develop novel, high-performance materials to meet specific performance targets:

- Develop new materials, leverage knowledge from basic research
- Optimize materials and testing to improve performance
- Design, develop and demonstrate materials, components and prototype systems to meet milestones.







Technology Validation & Demonstration

Test Systems under Real World Conditions

- Demonstrate and validate performance against targets
- Gain knowledge (e.g. fueling time, driving range, durability, cost, etc.) and apply lessons learned to R&D