U.S. Department of Energy Hydrogen Program

Hydrogen Storage Technical Status

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Presentation to:
Hydrogen Technical Advisory Committee

July 22, 2008

Goal and Objectives

GOAL: On-board hydrogen storage for > 300 mile driving range across different vehicle platforms, WITHOUT COMPROMISING passenger/cargo space, performance (wt, vol, kinetics, safety, etc.) or cost

Develop on-board storage systems to meet DOE targets, including:

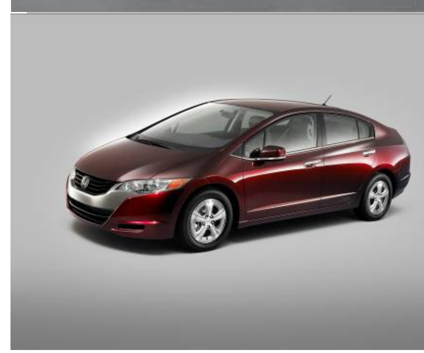
- Capacity
- Operating temperature range (-40 to +85°C)
- Hydrogen supply rate/refueling rate
  - 0.02 g H_2 per sec. per kW of power
  - Refueling time <3 min. for 5 kg H_2
- System cost
- Fuel cost
- Safety, C&S, reliability, cycle life, efficiency, etc.

See: http://www1.eere.energy.gov/hydrogenandfuelcells/storage/pdfs/targets_onboard_hydro_storage.pdf

Industry has made significant progress with vehicle designs

- **Vehicles are being designed by OEMs that can achieve > 300 miles**
  - **350 or 700 bar**
  - **1 to 4 tanks**
  - **Specified range from ~200 to > 350 miles**
- **But performance, space on-board and cost are still challenges for mass market penetration…**
- **Is there a low pressure alternative?***

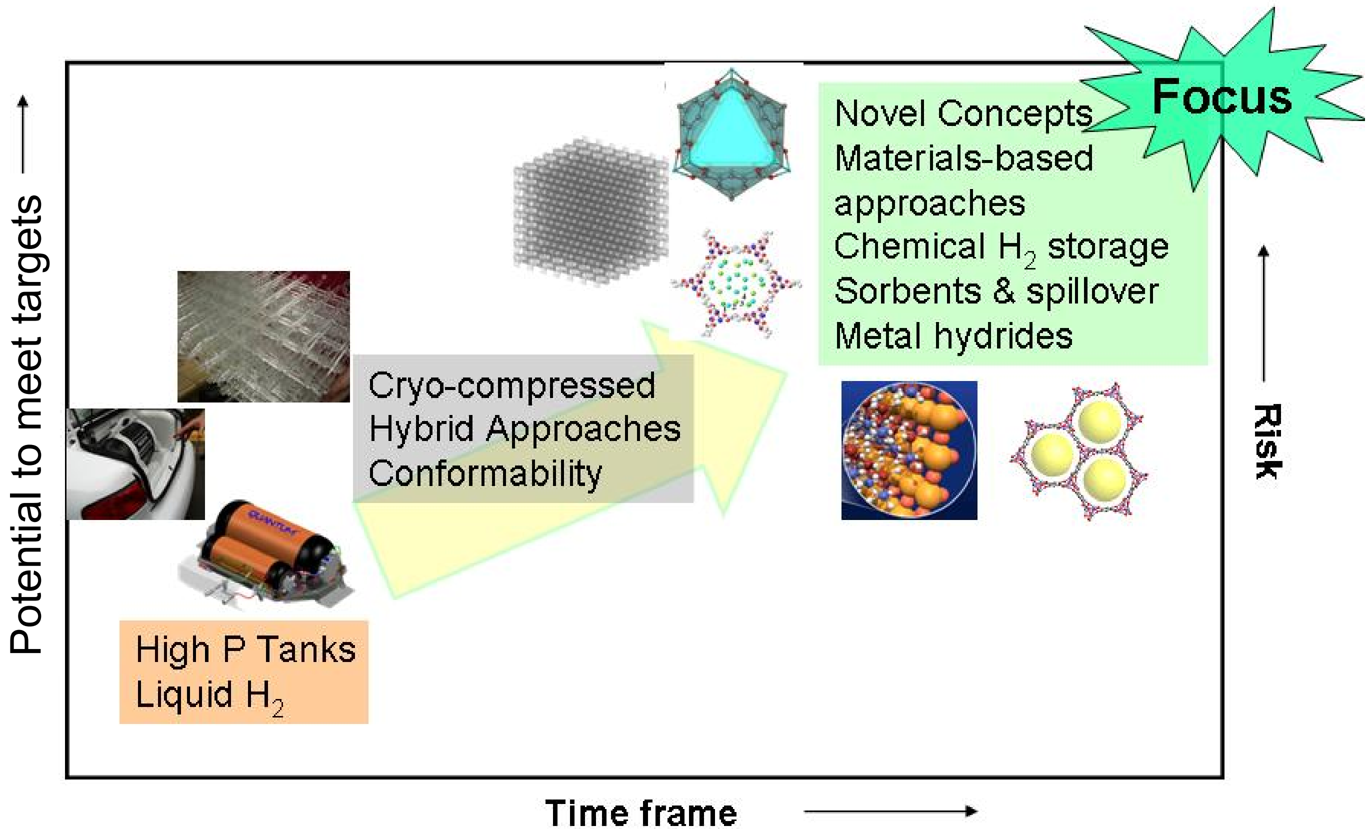





* Focus of DOE-funded R&D

Strategy for DOE-funded R&D

- **Focus is on novel approaches, high risk- high impact concepts**
- **Complements current industry work on tanks**



Technology Validation Learning Demonstration

LATEST KEY FIGURES:

- ***NUMBER of VEHICLES: 92***
- ***NUMBER of STATIONS: 16***
- ***EFFICIENCY: 53 – 58%***
- ***RANGE: 103 – 190 miles***
- ***FUEL CELL SYSTEM DURABILITY:*** ***1900 hours*** *(~57,000 miles)*

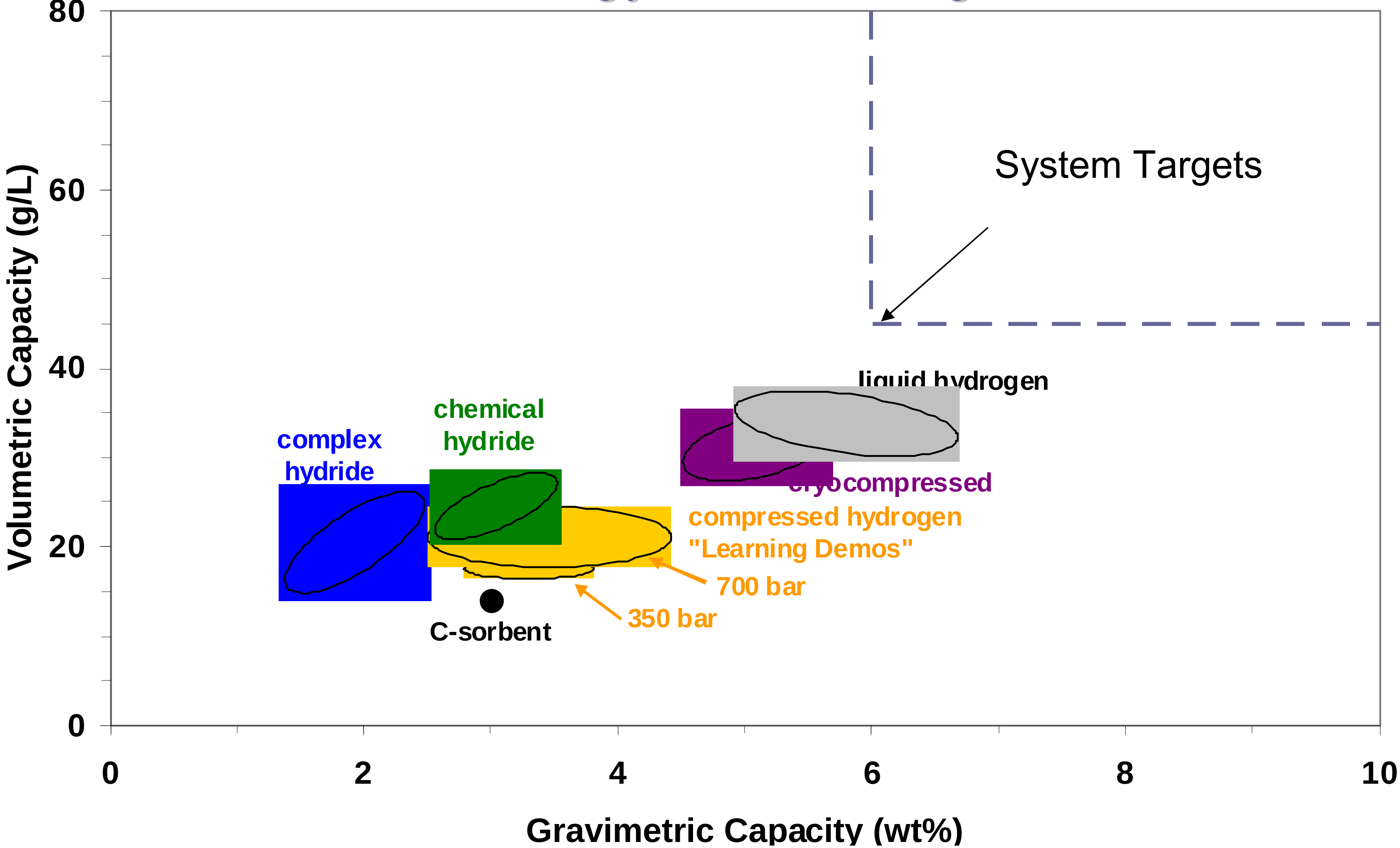
Summary:
Improved on-board hydrogen storage technologies are necessary to meet range targets across multiple vehicle platforms in the long term.

Ford | bp | GM | Shell | ChevronTexaco | Hyundai | UTC Fuel Cells | DaimlerChrysler | bp

http://www.nrel.gov/hydrogen/cdp_topic.html

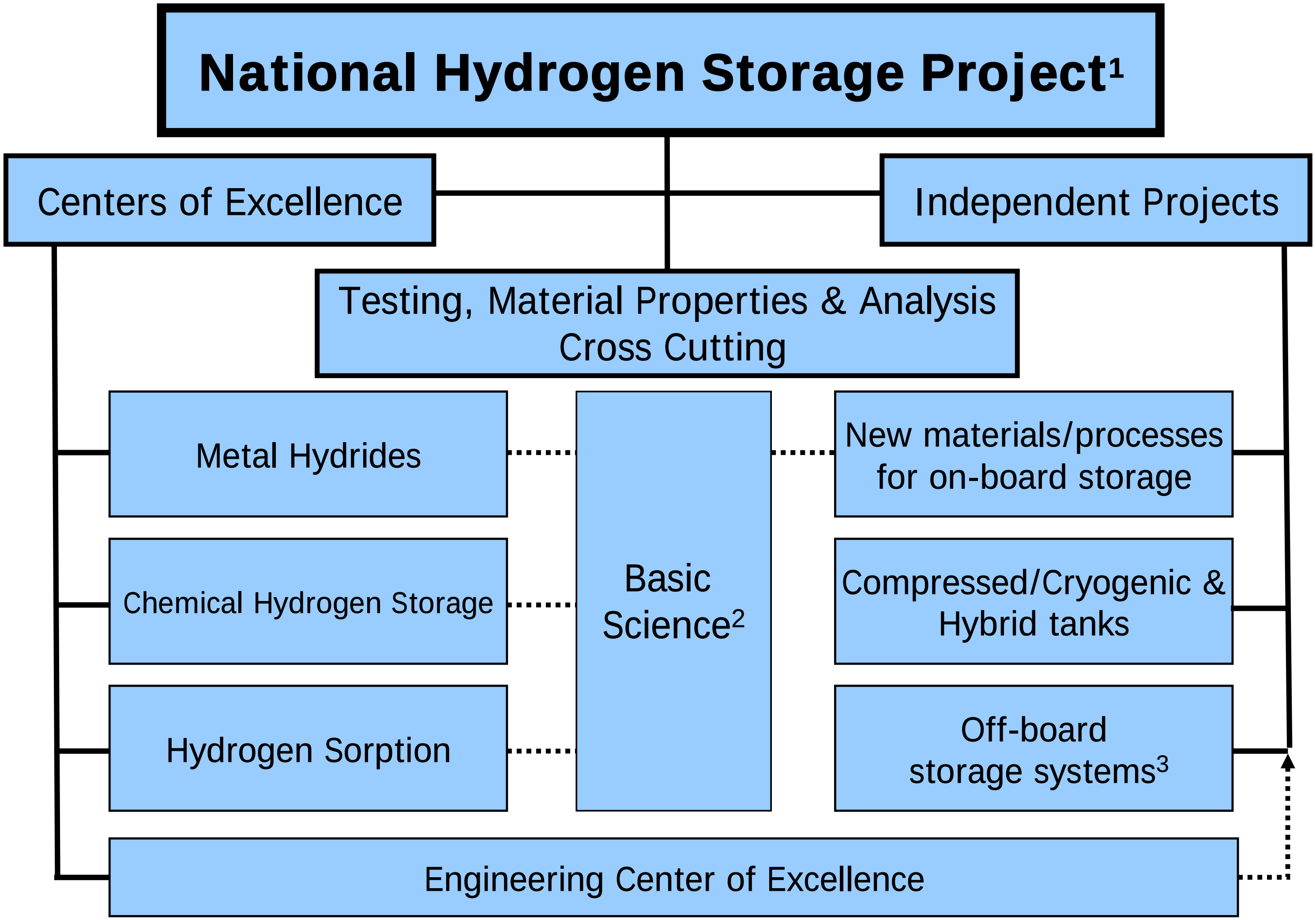
Current Status: Capacity

No technology meets targets



This led to the launching of the National Hydrogen Storage Project.

Strategy – Diverse, Balanced Portfolio



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

~40 Universities, ~20 Companies, ~15 Federal Laboratories

Applied R&D Hydrogen Storage "Grand Challenge" Partners

Diverse Portfolio with University, Industry & National Labs

Centers of Excellence

Metal Hydride Center

National Laboratory:
- Sandia-Livermore

Industrial partners:
- General Electric
- HRL Laboratories
- Intematix Corp.

Universities:
- CalTech
- Stanford
- Pitt / GATech
- Hawai'i / UNB
- Illinois
- Ohio State
- 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
- Miami Univ.-OH
- Michigan
- North Carolina
- Penn State
- Rice
- Univ. of Chicago

Federal Lab Partners:
- Argonne
- 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

Federal Lab Partners:
- INL

Independent Projects

Advanced Metal Hydrides
- UOP
- Univ. of Connecticut
- Delaware State

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

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

Other New Materials & Concepts
- Alfred University
- Michigan Technological University
- UC-Berkeley/LBL
- UC-Santa Barbara
- Univ. of Arkansas
- Purdue
- UNLV

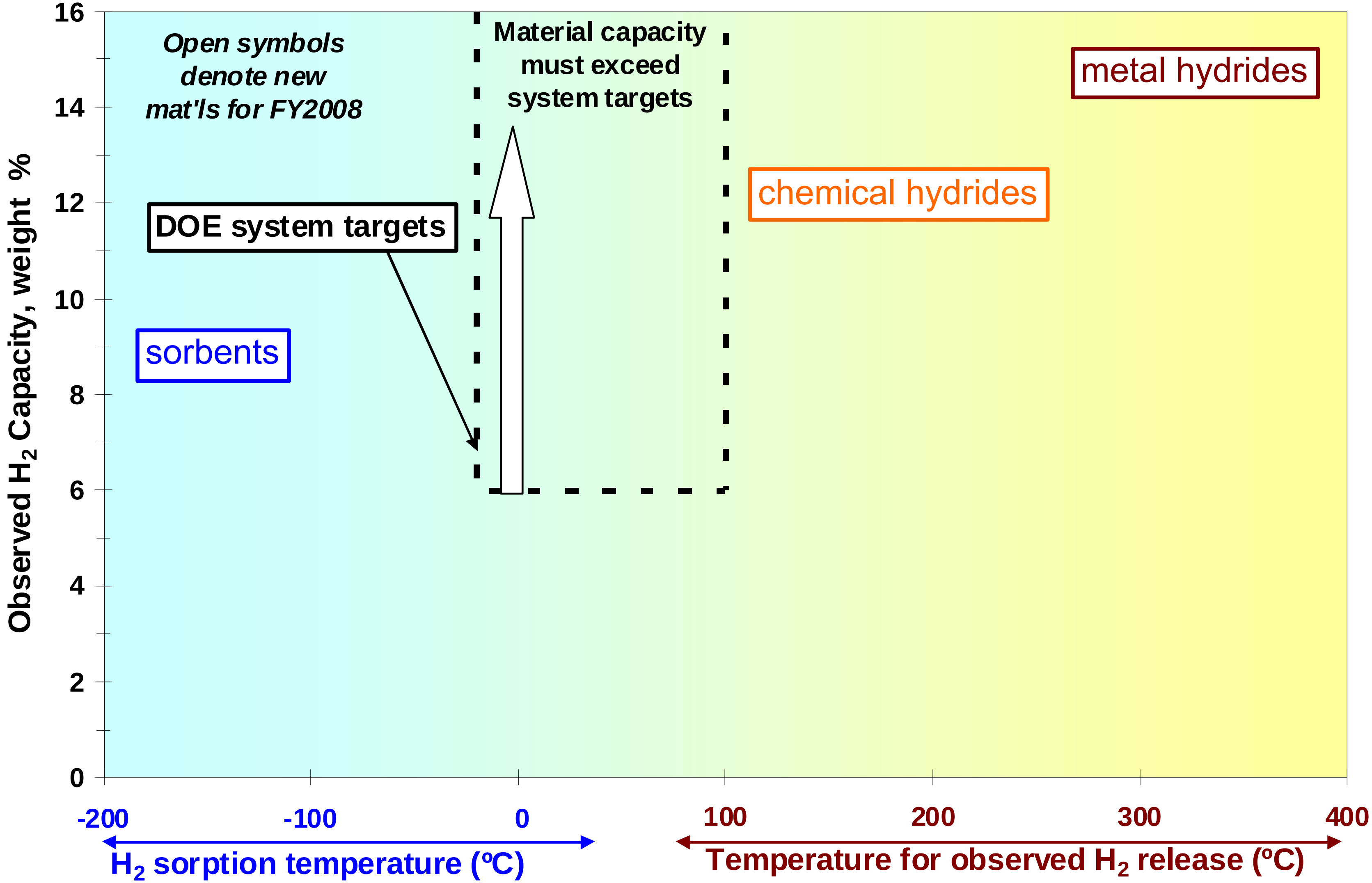
Tanks, Safety, Analysis & Testing
- Lawrence Livermore Nat'l Lab
- Quantum
- Argonne Nat'l Lab, TIAX LLC
- SwRI, UTRC, Sandia Nat'l Lab
- Savannah River Nat'l Lab

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

MIT, U.WA, U. Penn., CO School of Mines, Georgia Tech, Louisiana Tech, U.Georgia, Missouri-Rolla, Tulane, Southern Illinois, Rutgers, Stonybrook, UC Davis, UC Santa Barbara, Sth Florida, Missouri-Columbia; Labs: Ames, BNL, LBNL, ORNL, PNNL, SRNL

Progress

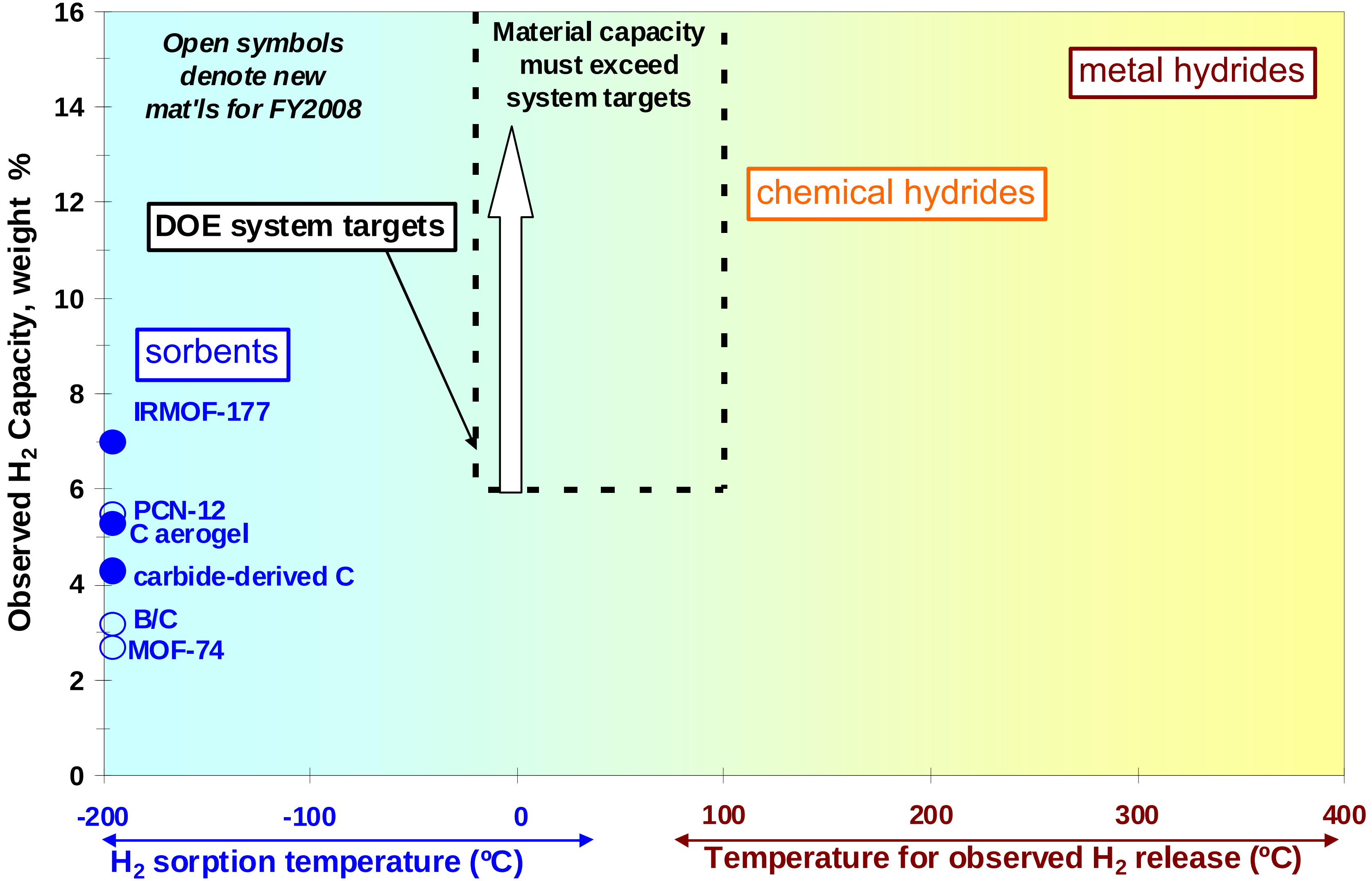
Material Capacity vs. Temperature



DOE: G. Thomas (2007), G. Sandrock (2008)

Progress

Material Capacity vs. Temperature



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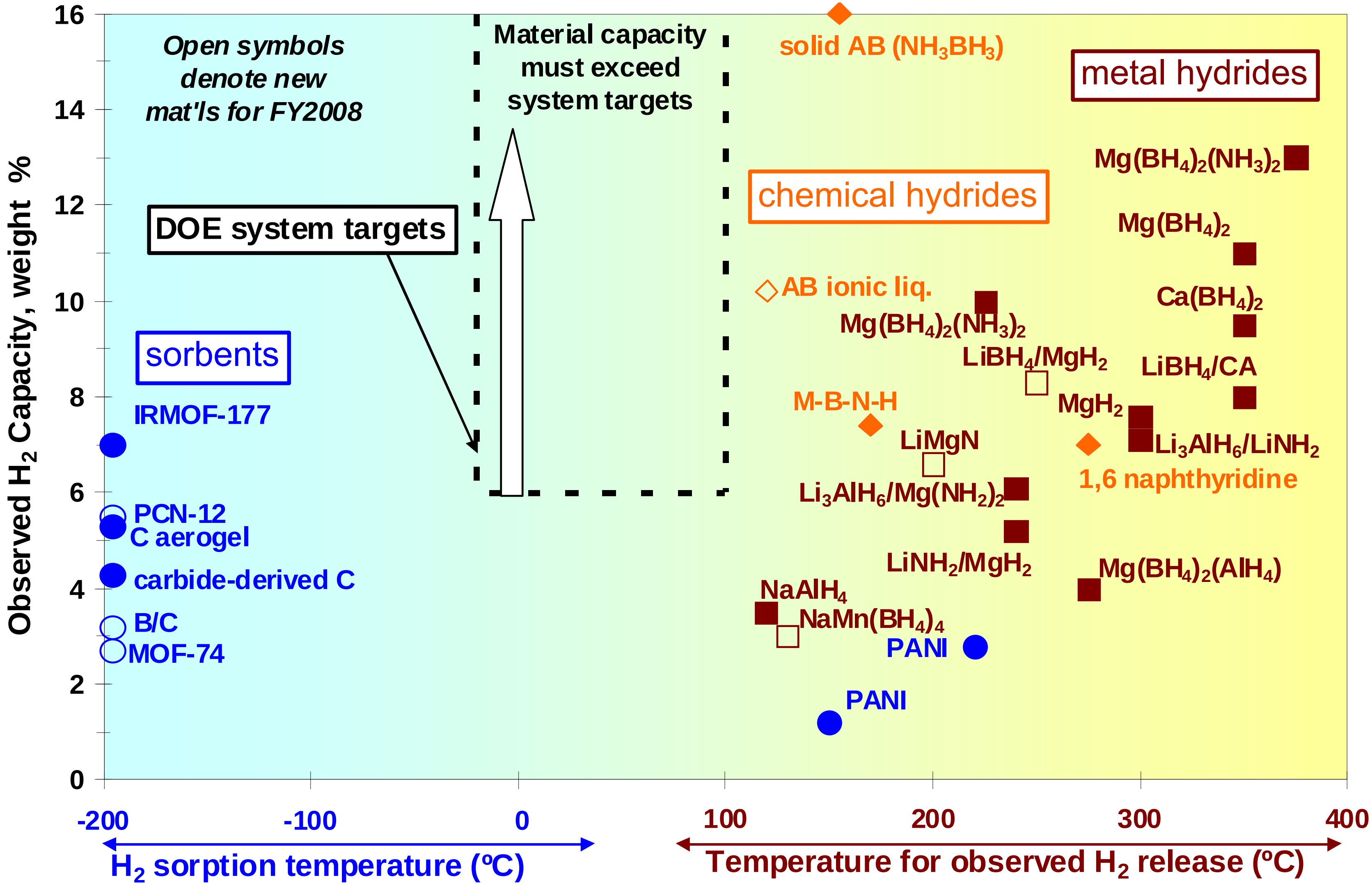

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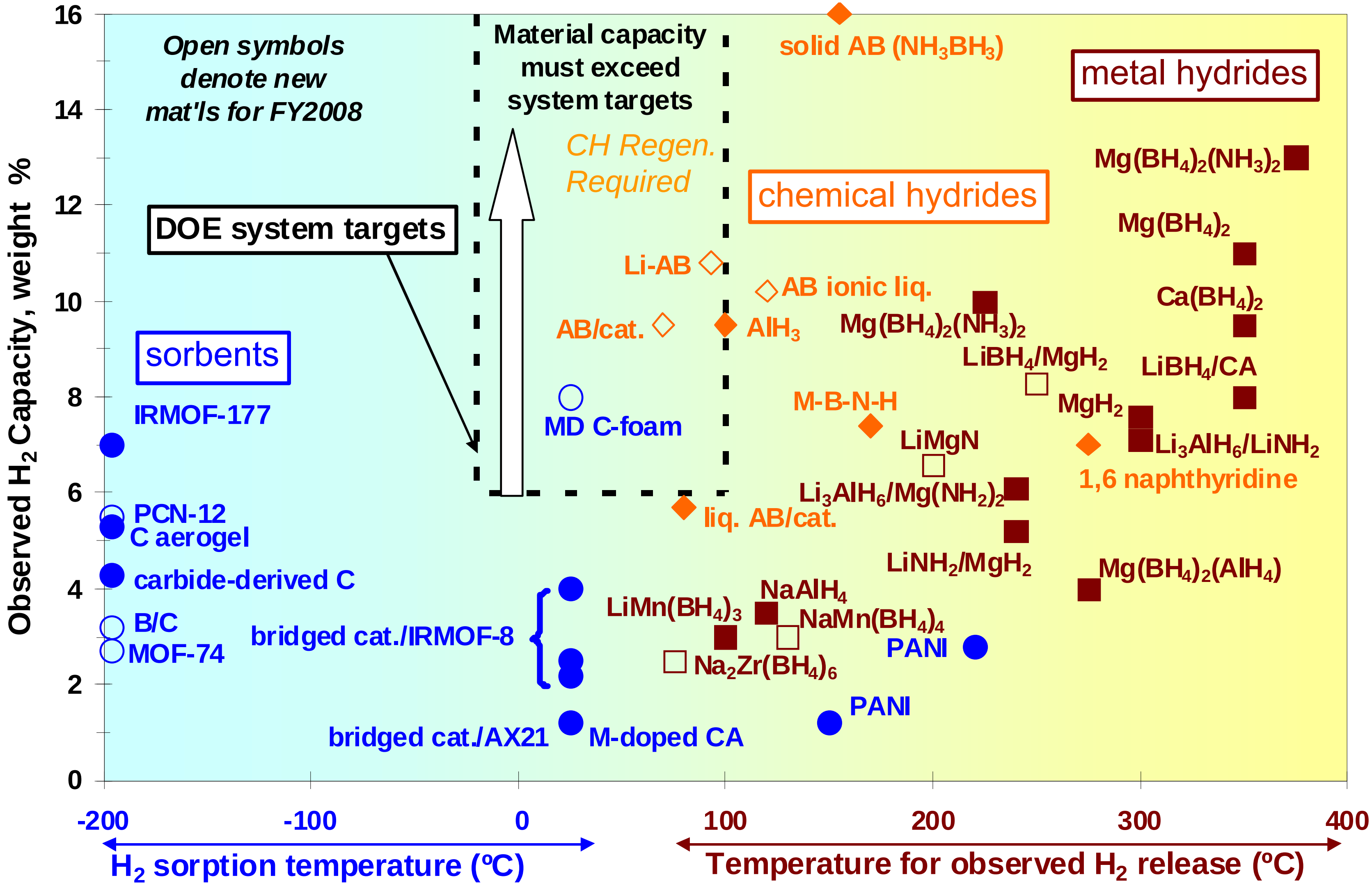

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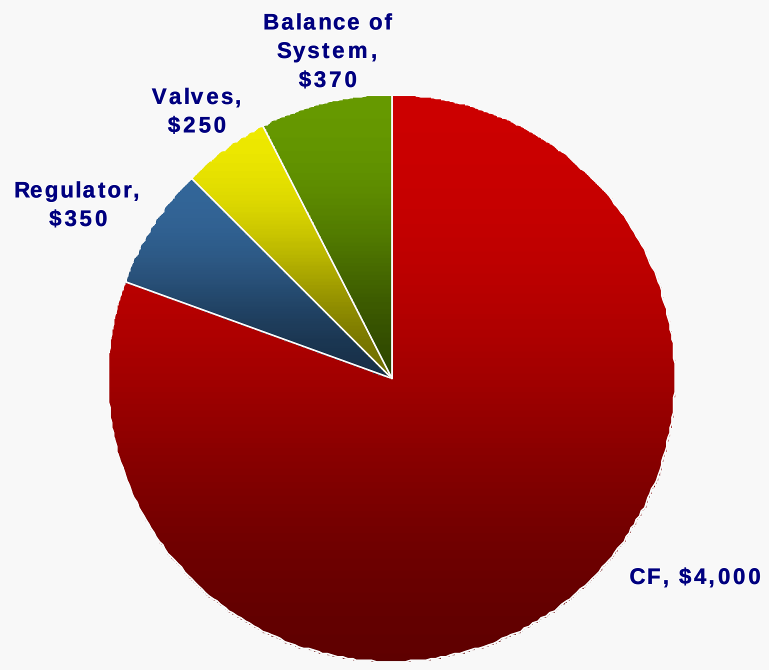
Progress
Tanks

- **Demonstrated 103 to 190 mile range across 92 vehicles (Gen 1) through Technology Validation activity**
- **Demonstrated ~ 2X increase in dormancy using cryo-compressed tanks (LLNL)**
- **Assessed high P tank cost (TIAX)**
  - **High volume cost projections:**
    - **~ $27/kWh (700 bar)**
  - **Assessed cryo-compressed tank cost & sensitivity analysis**

System Gravimetric Capacity
350 bar: 2.8-3.8 wt.%
700 bar: 2.5-4.4 wt%

System Volumetric Capacity
350 bar: 17-18 g/L
700 bar: 18-25 g/L

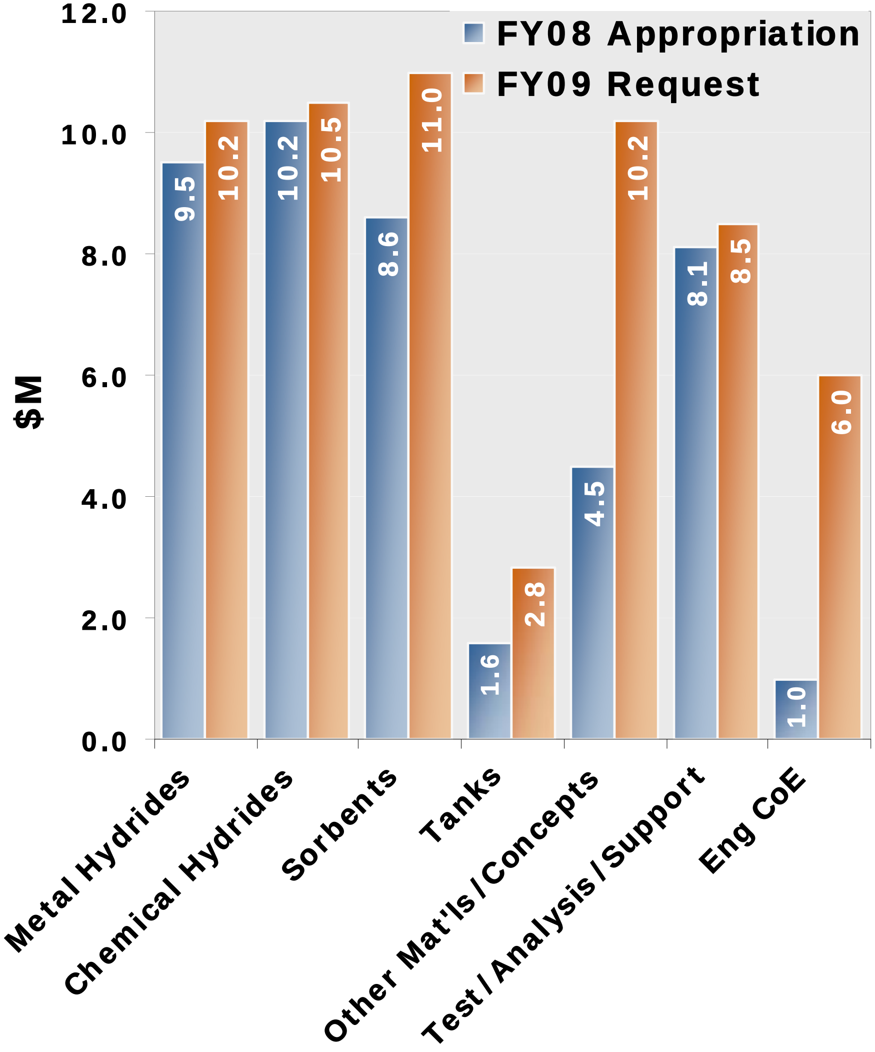


700 bar, 5.6 kg net, $5,000 (500,000 units)

Hydrogen Storage Budget

FY 2009 REQUEST = $59.2M

FY 2008 APPROPRIATION = $43.5M



FY2009 Emphasis

- Increase engineering in addition to materials R&D through Centers of Excellence and independent projects to enable system targets.
- Focus on kinetics, temperature, pressure, cycle life, spent fuel regeneration, etc. *in addition* to capacity
- Strengthen tank R&D to address NAS recommendations. Focus on cost reduction and advanced concepts. Also applicable to materials-based approaches.
- Continue close coordination with Basic Science

Hydrogen Storage Collaborations

Applied R&D under the President's Hydrogen Fuel and Advanced Energy Initiatives is coordinated among national and international organizations

INTERNATIONAL ACTIVITIES

Examples

- **IEA HIA Task 22**

  ~ 15 countries

  ~ 50 projects

- **IPHE**

  5 projects

  (EU, Russia, Canada, US)

DOE

(Energy Efficiency & Renewable Energy- EERE)

National Hydrogen Storage Project

H_2 Storage Applied R&D

- **3 Centers of Excellence**
- **Independent projects**
- **Total of ~80 projects**

INDUSTRY

- **FreedomCAR & Fuel Partnership**

  ***Tech teams*:**
  - H_2 Storage
  - Fuel Cells, Delivery
  - Fuel Pathways
  - Vehicle Systems
- **Codes & Standards Organizations**

TECHNOLOGY VALIDATION (DOE EERE)

~92 vehicles & 15 stations

National Collaboration *(inter- and intra-agency efforts)*

DOE – Basic Energy Sciences
~30 Projects

NSF
New projects in basic science

NIST
- **Neutron scattering**
- **Measurements**

DOT
Material handling/transport

DOD – Defense Logistics Agency
6 projects & prototypes

H_2 STORAGE – Examples of International Collaborations

HYDROGEN IMPLEMENTING AGREEMENT

IEA – HIA TASK 22

A total of 50 projects are active.

This includes participation by 17 countries and the European Commission and 52 official experts.

Project Types:

- Experimental, engineering or theoretical modeling (scientific or engineering)
- Projects cover:
  - ✓ Reversible metal hydrides
  - ✓ Nanoporous materials
  - ✓ Regenerative chemical hydrides
  - ✓ Environmental reactivity properties of materials

International Partnership for the Hydrogen Economy

A total of 5 projects are IPHE endorsed.

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

H_2 STORAGE – International Collaboration Examples: Chemical Hydrogen Storage CoE

MOU Between LANL, AIST and NEDO

- LANL established a MOU with NEDO and AIST for technical exchange.
- The MOU was signed in September, 2007, to be updated every two years.

Status

- Three technical exchange workshops on hydrogen fuel cells and hydrogen storage were conducted.
- LANL and AIST will collaborate to study hydrogen storage materials using neutron diffraction techniques at LANL.
- U.S. scientists are visiting AIST, Hiroshima University and Tohoku University to learn about new advancements in hydrogen storage in Japan.

IPHE Hydrogen Storage Project Summary

Name	Recent Accomplishments	Participants
Reversible Solid State Hydrogen Storage for Fuel Cell Power Supply System	• Development of heat and mass transfer calculation methods in the systems of solid-state hydrogen storage. • Integrated hydrogen storage and purification system for FC based power units with capacity up to 10 kW(e).	RU, CN, DK, IS, JP, KR, NO, US
NESSHY- Novel Efficient Solid Storage for Hydrogen	• Promising capacity on metal doped aerogels observed via spillover mechanism, including room temperature storage.	EC, CN, FR, DE, IS, NO, UK, US, DK, GR, NL, PO, SE, CH, TR
Mechanical Synthesis and Rehydrogenation of Complex Hydrides and Nanocomposites in Hydrogen Ball Mills	• Project involves research on direct synthesis of new complex hydrides and nanocomposites conducted in specialized ‘hydrogen ball mills’ and other synthesis approaches.	CA, AU, RU, US
Combination of Amine Boranes with MgH2 & LiNH2 for High Capacity Reversible Hydrogen Storage	• Recent initial results are promising, showed higher storage capacity and release kinetics for Li-amine borane as compared to that of amine borane.	US, UK, NZ
Fundamental Safety Testing and Analysis of Hydrogen Storage Materials & Systems	• Project involves analyzing the reactivity of select hydrogen storage materials with air and water under various exposure conditions. Results will be used in risk analyses and development of mitigation strategies; and made available for codes and standards development efforts.	US, CA, DE, JP

For More Information

http://www1.eere.energy.gov/hydrogenandfuelcells/storage/

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