FUEL CELL TECHNOLOGIES PROGRAM
Hydrogen Storage

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Compressed Hydrogen Gas Workshop

February 14, 2011
Crystal Gateway Marriott
Crystal City, Virginia

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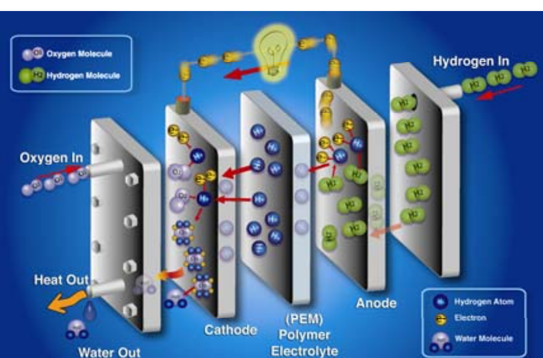
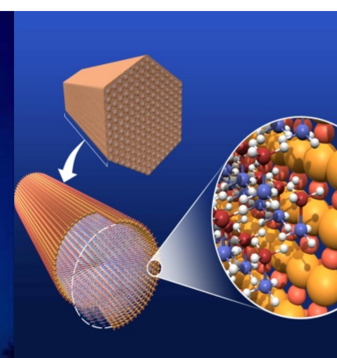
Acting Hydrogen Storage Team Lead
Fuel Cells Technologies Program
U.S. Department of Energy

Presentation Overview

- Welcome and Introductions!
- DOE Hydrogen Storage Activities
- Objectives and Scope of Workshop




Key Workshop and DOE Contacts

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The Workshop Team

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FreedomCAR and Fuel Partnership

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The FreedomCAR and Fuel Partnership is a government-industry partnership to advance pre-competitive automotive research and development (R&D)

Purpose: Bring together technical experts from DOE / national laboratories and industry to –

(1) Discuss R&D priorities
(2) Develop technology-specific roadmaps, goals, and technical targets
(3) Review R&D progress toward goals

Partners:

- **Federal:** U.S. Department of Energy (EERE – Vehicle Technologies Program and Fuel Cell Technologies Program)
- **Automotive:** U.S. Council for Automotive Research (cooperative research organization for Chrysler, Ford, and General Motors)
- **Energy/fuels:** BP, Chevron, ConocoPhillips, ExxonMobil, Shell
- **Utilities:** DTE Energy, Southern California Edison

FreedomCAR & Fuel Partnership

On-board Hydrogen Storage Targets to enable at least a 300 mile range

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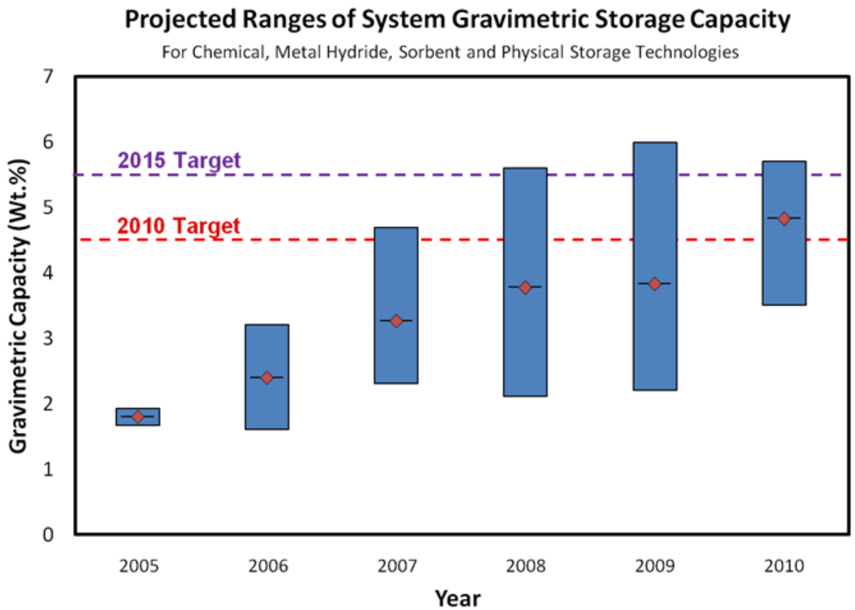
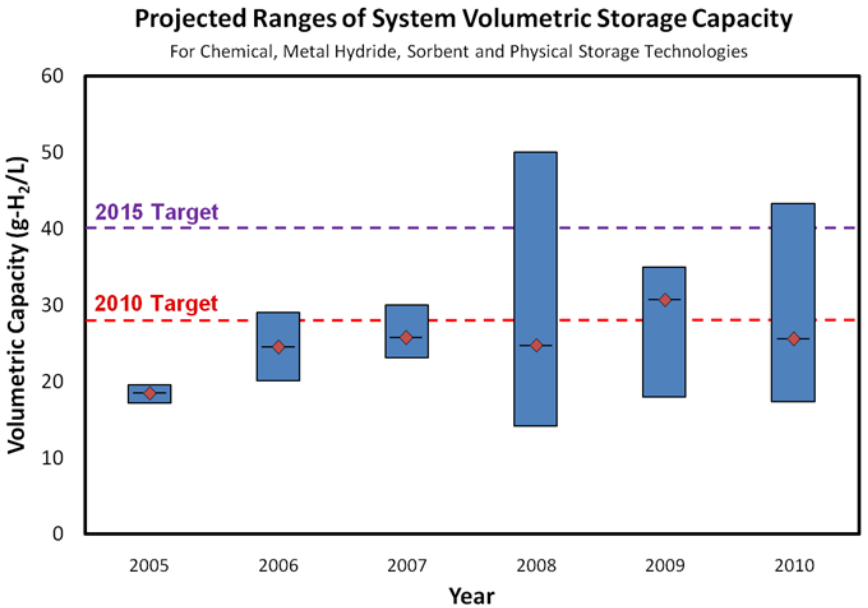
Specific-energy from usable H_2 (grav. capacity): 7.5 wt%	Weight
Energy density from usable H_2 (vol. capacity): 70 g/L	Volume (& conformability)
• Storage system cost: under revision • H_2 fuel cost includes off-board costs: $2 – 3/gge	System cost (& fuel cost)
• Operating ambient temperature: -40ºC/ 60ºC • Min/Max delivery temperature: -40ºC/ 85ºC • Cycle life variation: 90%/ 99% • Cycle life: 1500 • Min/Max delivery pressure: 3/ 12 bar	Durability/ Operability
• System fill time: 2.5 min • Start time to full-flow at -20ºC: 15 sec • Start time to full-flow at 20ºC: 5 sec • Min full-flow rate: 0.02 g/s/kW • Transient response (10 – 90% and 90 – 0%): 0.75 sec	Charging/ Discharging Rates
• 90% energy efficiency for reversible on-board systems • 60% for regenerable off-board (well-to-wheels)	Efficiency
• Fuel purity/quality specifications: meet ISO & SAE specs	Fuel Purity
• Permeation & leakage • Toxicity • Safety • Loss of usable H_2 } Meet or exceed applicable standards	Environmental Health & Safety

There is a full range of performance targets other than just weight, volume and cost!

Projected Capacities for Complete 5.6-kg H_2 Storage Systems



Based on analysis using the best available data and information for each technology analyzed in the given year.



Based on analysis using the best available data and information for each technology analyzed in the given year.

- Assessed and updated targets as planned in 2009 — based on real-world experience with vehicles, weight and space allowances in vehicle platforms, and needs for market penetration
- Developed and evaluated more than 400 material approaches experimentally and millions computationally

Projected high-volume costs still too high!

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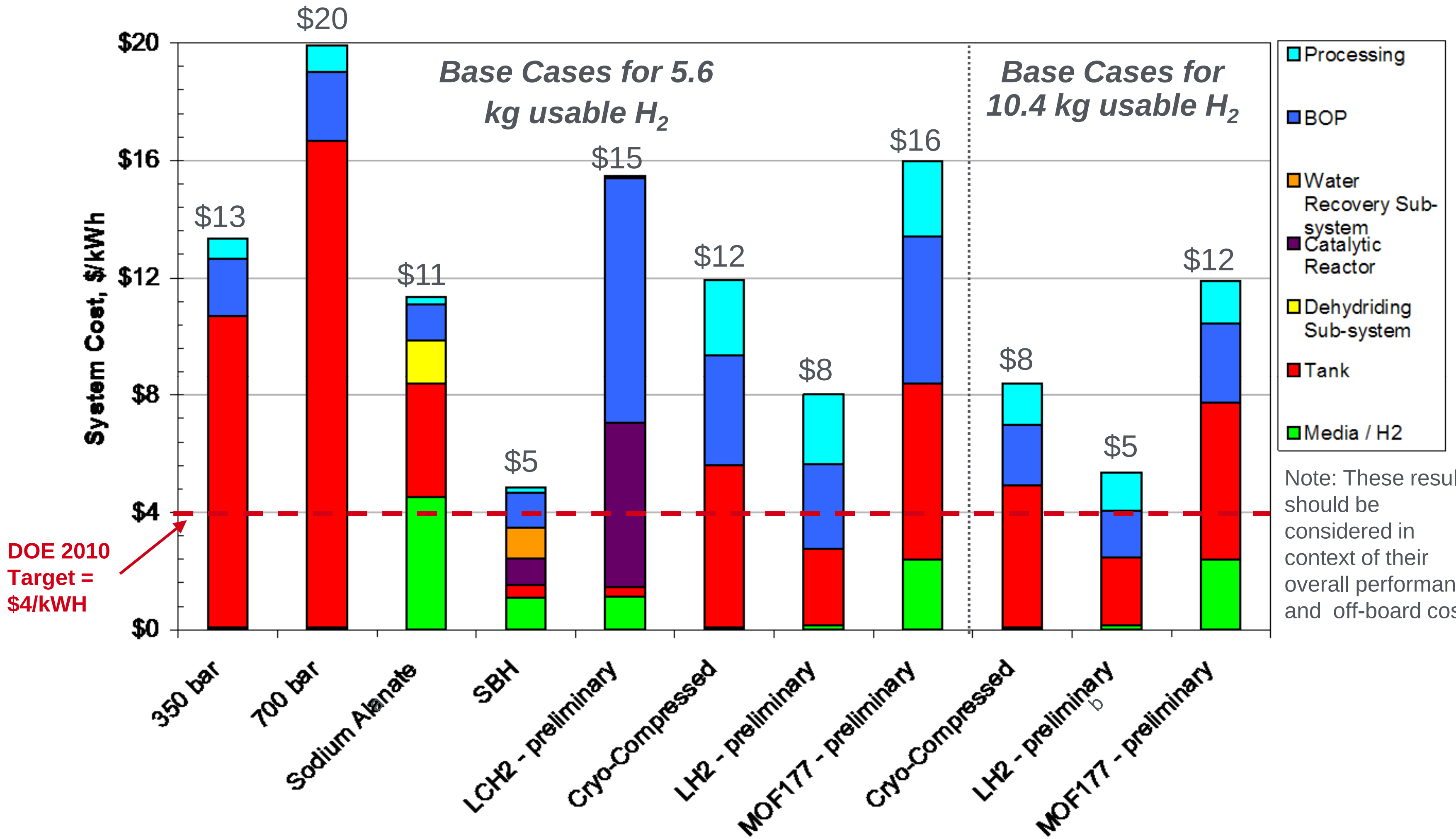

Note: These results should be considered in context of their overall performance and off-board costs.

Note: not all hydrogen storage systems shown are at the same stage of development, and each would have different on-board performance characteristics.
[a] The sodium alanate system requires high temp. waste heat for hydrogen desorption, otherwise the usable hydrogen capacity would be reduced.
[b] The larger tank (10.4 kg useable H2) LH2 case is not applicable for most vehicular application due to its excessive volume.

Lasher, TIAX, LLC, "Analyses of Hydrogen Storage Materials and On-Board Systems," 2010 DOE Hydrogen Program Annual Merit Review Proceedings, http://www.hydrogen.energy.gov/pdfs/review10/st002_lasher_2010_o_web.pdf

Technology Validation – Real World Demonstrations and Evaluations

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DOE Vehicle/Infrastructure Demonstration

Four teams in 50/50 cost-shared projects with DOE

- **152 fuel cell vehicles and 24 fueling stations demonstrated**
- **>2.8 million miles traveled, >134,000 kg H_2 produced or dispensed***
- **Analysis by NREL shows:**
  - **Efficiency: 53 – 59% (>2x higher than gasoline engines)**
  - **Range: ~196 – 254 miles**
  - **Fuel Cell System Durability: ~ 2,500 hrs (~75,000 miles)**

**includes hydrogen not used in the Program's demonstration vehicles*

Demonstrations of Specialty Vehicles: *NREL is collecting operating data from federal deployments and Recovery Act projects—to be aggregated, analyzed, and reported industry-wide.*

→ **Will include data such as:** reliability & availability; time between refueling; operation hours & durability; efficiency; H_2 production; refueling rate; costs (installation, operation, and lifecycle); and others.

→ 40 forklifts at a Defense Logistics Agency site have already completed more than 18,000 refuelings.

Other Demonstrations: *DOE is also evaluating real-world bus fleet data (DOD and DOT collaboration) and demonstrating stationary fuel cells — e.g., tri-generation (combined heat, hydrogen & power with biogas).*

Demonstrations are essential for validating the performance of technologies as integrated systems under real-world conditions.

Recommendations from the review of the FreedomCAR and Fuel Partnership

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- The "Review of the Research Program of the FreedomCAR and Fuel Partnership," 3rd Report (2010), by the National Research Council of the National Academies, includes the following:
  - Recommendation 3-10. "Research on compressed-gas storage should be expanded to include safety-related activities that determine cost and/or weight, …"
  - Recommendation 3-11. "The high cost of aerospace-quality carbon fiber is a major impediment to achieving cost-effective compressed-hydrogen storage. The reduction of fiber cost and the use of alternative fibers should be a major focus for the future. Systems analysis methodology should be applied to needed critical cost reductions."
  - Recommendation 3-12. "The hydrogen storage program is one of the most critical parts of the hydrogen/fuel cell vehicle part of the FreedomCAR and Fuel Partnership – both for physical (compressed gas) and for materials storage. … Efforts should also be directed to compressed-gas storage to help achieve weight and cost reduction while maintaining safety."

Projected high-volume costs still too high!

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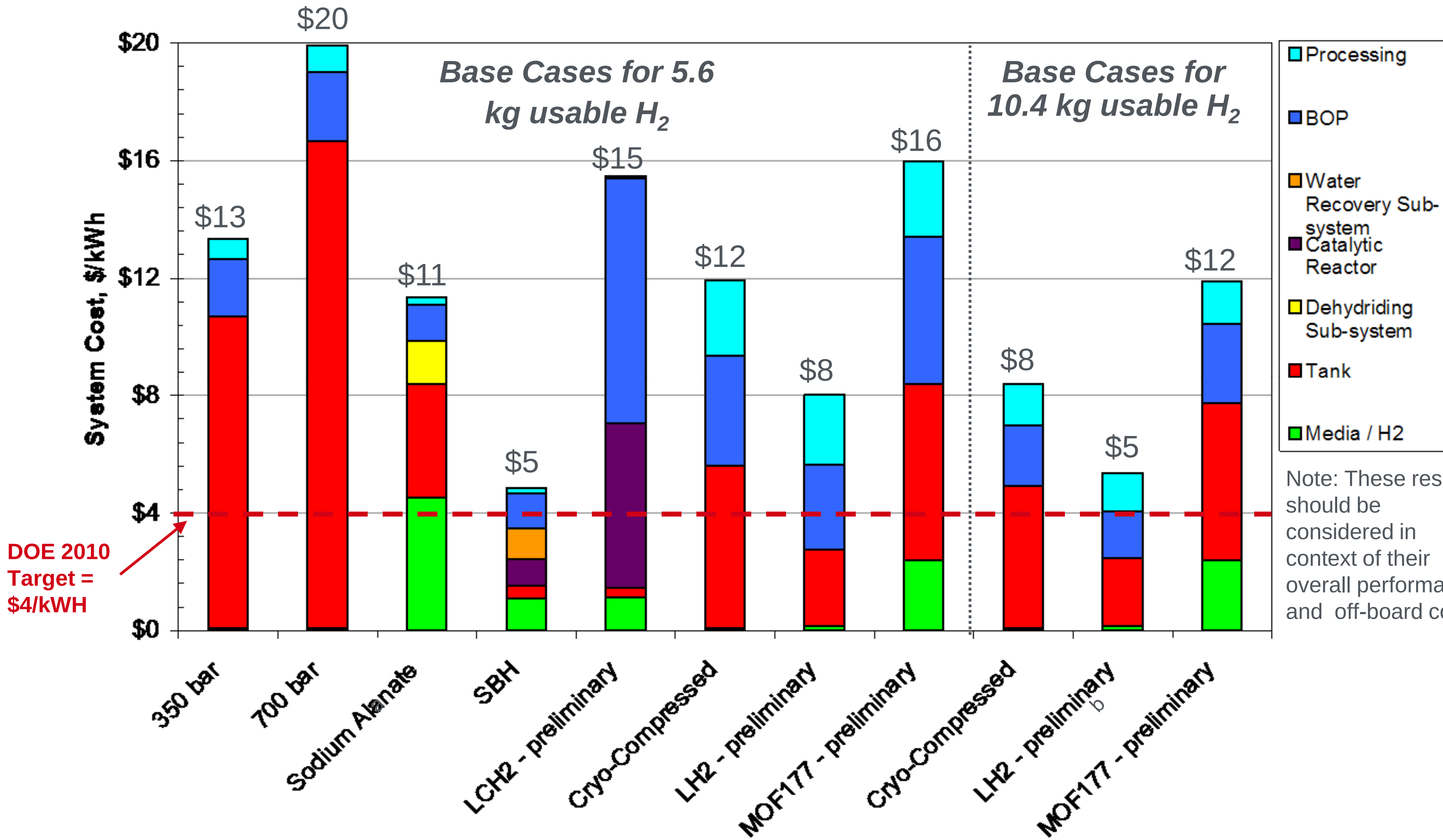

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TIAX

Carbon fiber layer dominates cost of composite cylinder systems

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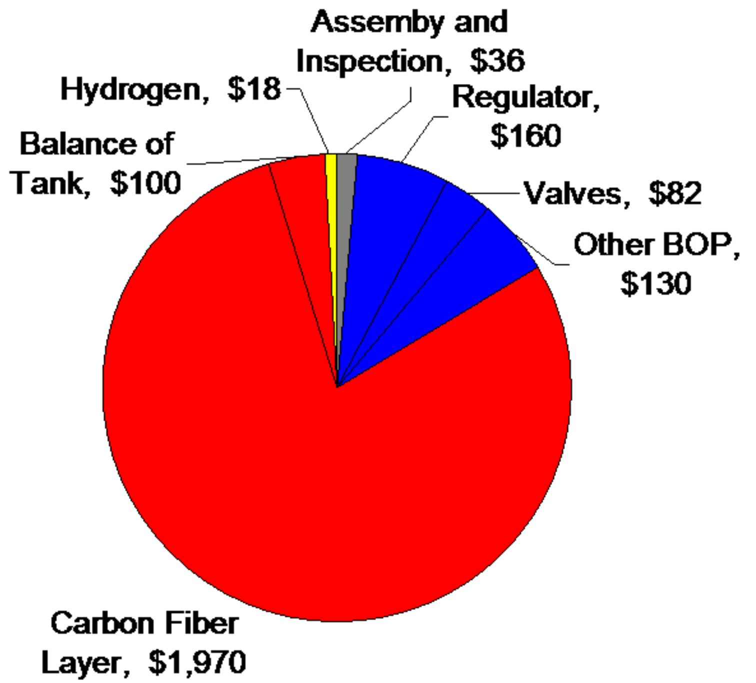
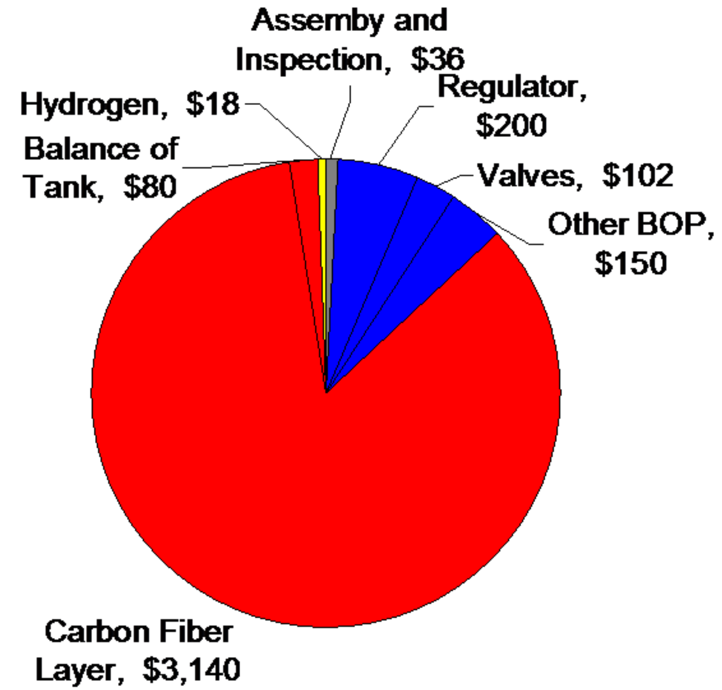
350-bar Base Case Factory Cost[1] = $2,500
$13/kWh based on 5.6 kg usable H_2 (6 kg stored H_2)



700-bar Base Case Factory Cost[1] = $3,700
$20/kWh based on 5.6 kg usable H_2 (5.8 kg stored H_2)



[1] Cost estimate in 2005 USD. Includes processing costs.

TIAX

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The carbon fiber composite layer accounts for about 80% and 85% of the base case 350-bar and 700-bar system costs, respectively.

Workshop Objectives

- Identify R&D strategies for lowering the cost of compressed hydrogen gas systems, e.g.,
  - lower cost carbon fiber
  - alternatives to carbon fiber
  - novel tank designs or concepts
  - improved manufacturing
  - choice of operating pressure
  - other innovative concepts and ideas
- Identify the likelihood strategies could succeed in the near- or long-term
- Looking for input from the range of expert stakeholders

Scope of Workshop

- In-Scope:
  - the "on-board" compressed gas system hardware
  - materials of construction
  - manufacturing and processing
- Out-of-scope:
  - off-board systems and processing, e.g.,
    - compression, storage and dispensing
  - cryo-storage, e.g.,
    - cryo-compressed, cryo-sorbents and cryo-liquids

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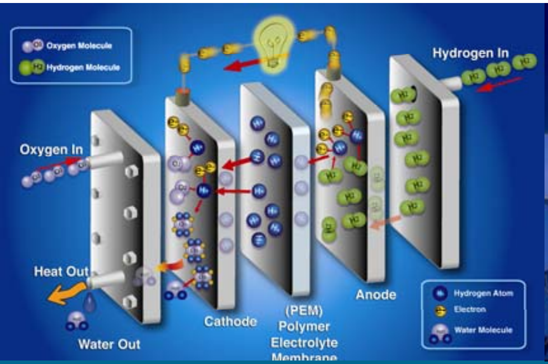
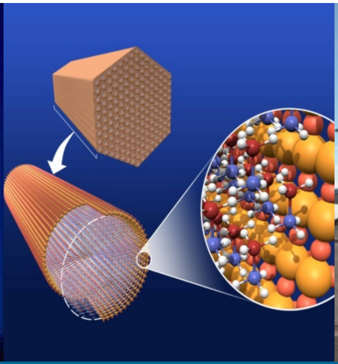
Thank you for your participation!




Topic areas

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1. Carbon fiber
   - Materials costs
   - Manufacturing
   - Alternatives to carbon fiber

2. Balance of Plant
   - How do we reduce BOP costs?
   - Requirements for multi-tank systems?
   - Safety considerations

3. Alternative materials and designs
   - Alternative designs
   - Alternative operating pressures
   - Trade-offs between cost and other performance factors