2007 DOE Hydrogen Program
Annual Merit Review

Hydrogen Codes and Standards

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National Renewable Energy Laboratory
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Project ID# SA1

This presentation does not contain any proprietary or confidential information
## Overview

### Timeline
- Project start date: 10-1-06
- Project end date: 9-30-07
- Percent complete: 50
  (C&S work on-going since 1997 but defined and funded annually)

### Budget
- Total project funding
  - DOE share: $2.9M
  - Contractor share: $0K
- Funding received in FY06: $1.1M
- Funding for FY07: $2.9M

### Barriers
- Codes and Standards Barriers addressed
  - Consensus national agenda on codes and standards (J,A,B,D,L)
  - Limited DOE role in development of ISO standards and inadequate representation by government and industry at international forums (F,G,H,I,K)
  - Current large footprint requirement for hydrogen fueling stations (P,N,M)

### Partners
- National H2/Fuel Cells Codes and Standards Coordinating Committee
- FreedomCAR-Fuel Partnership C&S Technical Team
- NHA, USFCC
Objectives

• Implement consensus national agenda on domestic and international codes and standards for hydrogen systems in commercial, residential, and transportation applications
• Facilitate permitting of retail H2 fueling stations in US through education and outreach to state/local code officials
• Establish requirements for hydrogen codes and standards based on scientific data, modeling, and analysis
• Enhance DOE’s role in development of ISO and other international standards and strengthen consistent and sustained representation by US government and industry at international standards forums
Approach: Program Structure

NREL Focus Highlighted

- C/S Tech Team
- C/S R&D Plan
- H2 C/S Coordinating Committee
- National Template C/S

- DOE Hydrogen Safety, Codes & Standards Program
- Standards
- Technical Requirements
- Testing Protocols & Validation
- Model Codes
- Regulations
- DOE Safety Guidelines
- P. I. SOPs
- 1st Responder Training
- ISO, IEC Standards
- GTR

- R&D Priorities
- R&D Projects
- Hydrogen Behavior
- Vehicle
- Fuel Infrastructure
- Interface
Approach

• Implement unified national agenda for codes and standards development
  – **Facilitate cost-effective, timely permitting of hydrogen fueling stations (HFS)**
    • priority for FreedomCar-Fuel Partnership and Hydrogen Technical Advisory Committee
  – Coordinate national/international codes and standards activities for DOE with NHA and USFCC
    • National H₂/Fuel Cells Codes and Standards Coordinating Committee
  – Work with prime contractor and DOE/GO to implement national templates and accelerate development of priority standards

• Establish requirements for hydrogen codes and standards based on scientific data, modeling, and analysis
  – Coordinate and conduct R&D through Codes and Standards Tech Team R&D Roadmap
    • integrated engineering approaches to hydrogen safety
      – **safe, energy-efficient building design**
    • Fuel-Vehicle Interface
      – hydrogen fuel quality specifications
      – **performance-based component testing and validation**
      – sensor testing and validation
Technical Progress: HFS Permitting Workshop
(CARB, Sacramento, Feb. 1, 2007)

- Invited fire/building code officials, HFS developers from states where HFS located or likely to be located
- Perspectives of HFS developers and code officials on permitting experience (case studies)
  - Shared lessons learned
    - Shell Benning Road HFS (Washington, DC, Office of Fire Marshall)
    - NextEnergy energy station (Michigan Dept. Environmental Quality)
    - Chevron AC Transit HFS (Oakland Fire Prevention Bureau)
- Key issues and barriers to timely and cost-effective permitting of HFS identified
- Recommendations to DOE on how it can facilitate permitting process for HFS
- Feedback on proposed DOE initiative
Technical Progress: HFS Permitting Workshop

• Key Recommendations to DOE
  - Develop Information Repository for HFS with validated, “3rd party” data and information
  - Identify applicable codes & standards (specific safety requirements) and make them more accessible to permitting officials
  - Develop detailed Process Flowchart for permitting HFS
  - Develop Template for code officials to navigate permitting process
  - Note best practices for application of codes and standards for HFS
  - Develop fact sheets on hydrogen technologies/HFS equipment for permitting officials
  - Develop permitting pathway from “behind the fence” stations to retail stations

• Proceedings/presentations posted on NHA website (www.hydrogenandfuelcellsafety.info)
Technical Progress: Permitting HFS

- Information Toolkit
  - Fact sheet(s)
    - basic information on HFS (examples, codes/standards typically used, information sources)
  - Network chart
    - contact list of code officials whose jurisdictions have issued permits for HFS
  - Flowchart of permitting requirements
    - web-based map to “navigate” requirements with database of key standards and codes
  - HFS Permitting Compendium
    - web-based “notebook” and database

- Education-outreach workshops for code officials
  - National workshops with NASFM, NCBCS
    - vet case studies, C&S permitting process, information tools
  - Workshops in key regions
    - locations where industry will focus H₂ infrastructure development and vehicle deployment
Technical Progress: Information Repository Concept

Permitting Process
- Application for Permit
  - Site Plan
  - Buildings
  - Equipment
  - Operation
- Construction
- Inspection
- Operation, Maintenance

Retail Hydrogen Station
- Addition to Existing Station
- Stand Alone Station
  - On-site Production
  - H2 Delivery
    - Elect.
    - SMR
    - ATR
    - LH2
  - CGH2
  - Storage
    - Underground (LH2)
    - At-grade
    - Canopy Top (CGH)
  - Compression
  - Dispensing

Process Flowchart
- Level of Detail

Codes and Standards
- IFC 2209
- NFPA 52
- Etc.
## Technical Progress: HFS Factsheets

### Station Descriptions

<table>
<thead>
<tr>
<th>Station</th>
<th>Description</th>
<th>Permitting Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>California</strong> (continued)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAX Airport Diesel, Los Angeles, CA</td>
<td>Demonstration project on airport property to service airport fuel-cell vehicles; on-site electrolyzer; open since October 2005</td>
<td>Dale Mayo, City of Los Angeles Fire Production Engineer, Phone: 213-486-6608, <a href="mailto:dale.mayo@lacity.org">dale.mayo@lacity.org</a></td>
</tr>
<tr>
<td>California Fuel Cell Partnership, West Sacramento, CA</td>
<td>On-going bi-fuel facility serving variety of research vehicles; using delivered liquefied hydrogen; open since 2010</td>
<td>Rod Poulos, City of West Sacramento Fire Chief, Phone: (916) 517-6000, <a href="mailto:rpoulos@cityofwestsacramento.org">rpoulos@cityofwestsacramento.org</a></td>
</tr>
<tr>
<td>Shell Refining Road Station, Washington, DC</td>
<td>Ongoing public fueling facility on part of retail gasoline station; using delivered liquefied hydrogen; dispensed as liquid or compressed gas; open since November 2014</td>
<td>Robert Haring, District of Columbia Deputy Fire Chief, Phone: 202-727-0169, <a href="mailto:robert.haring@dcd.org">robert.haring@dcd.org</a></td>
</tr>
<tr>
<td>Chevron/Prop Energy Boggy Creek Road Hydrogen Station, Dinuba, FL</td>
<td>Five-year demonstration on new site with new building on utility property for hydrogen-fueled internal combustion engines - fuel in liquid form or as gaseous hydrogen; open since October 2016</td>
<td>Thomas Hite, Manager, City of Orlando Permitting Division, Phone: 407-846-3626, <a href="mailto:thomas.hite@myorlando.com">thomas.hite@myorlando.com</a></td>
</tr>
<tr>
<td><strong>Michigan</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WestEnergy Center Hydrogen Station, Detroit, MI</td>
<td>Ongoing facility at new site to service alternative fuel vehicles; using delivered hydrogen or natural gas from research projects; open since April 2016</td>
<td>Dan Hager, City of Detroit Supervisor of Fire Production Engineering, Phone: 313-204-311, <a href="mailto:daniel.hager@cityofdetroit.org">daniel.hager@cityofdetroit.org</a></td>
</tr>
<tr>
<td><strong>New York</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>City of White Plains Hydrogen Refueling Facility, White Plains, NY</td>
<td>Ongoing facility on city property for city hydrogen-fueled internal combustion engines; fuel in liquid form or as gaseous hydrogen; open since October 2010</td>
<td>Joseph (Ted) Naccarato, Commissioner of Public Works/City Engineer, Phone: (914) 947-2500, <a href="mailto:josephn@whiteplainsny.gov">josephn@whiteplainsny.gov</a></td>
</tr>
<tr>
<td><strong>Nevada</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Las Vegas Hydrogen Energy Station, Las Vegas, NV</td>
<td>Ongoing facility on city property started as demonstration project to service city vehicles; using delivered liquid hydrogen; open since August 2002</td>
<td>Earl Russell, Director of Building and Safety, Phone: 702-229-4012, <a href="mailto:earl.russell@lv.gov">earl.russell@lv.gov</a></td>
</tr>
</tbody>
</table>

### Contact Information

For more information visit the [Hydrogen Fueling Station Sitings](http://www.energy.gov/hydrogenfuelingstation).
Future Work: HFS Permitting

- DOE workshop at NASFM annual conference (Atlanta, July 10)
  - Organizing committee (DOE/NREL, NASFM, NCBCS, Chevron, Shell)
  - Invite key fire and building code officials
    - present case studies
      - stations permitted/permitting underway
      - codes/standards applied
    - review and discussion by permitting officials for station(s)
    - network list of permitting officials whose jurisdictions have issued permits
  - Demo information repository prototype
    - web-based tools to “navigate” requirements with database of key standards and codes
    - vet repository and DOE initiative by delegates
- DOE workshop at NCBCS annual conference (Fall 2007)
  - Similar purpose, agenda, format as workshop at NASFM conference
- Regional workshops
  - Areas of focus by HFS developers/auto OEMs
  - Emphasize regional/local permitting issues
Technical Progress

• R&D to establish defensible requirements for standards
  – Integrated Engineering Approaches to Hydrogen Safety
    • CFD modeling of hydrogen leaks in residential garage
      – floor plan, characteristics from Building America model home
      – Buildings and Thermal Systems Center (NREL)
    • CFD simulation of H\textsubscript{2} leak from non-combustible enclosures
      – co-funded with industry through NFPA Research Foundation
      – data for separation distances for H\textsubscript{2}FC in telecom applications
    • Finite element analysis/simulation of high-pressure, composite tank testing
      – collaboration with Lincoln Composites
      – help establish parameters (design of experiments) for tank testing
  • Sensor testing and validation
    – fiber optic sensor under commercial licensing
    – sensor validation laboratory design
Technical Progress: Safe Building Design for Hydrogen Vehicles

Sample architecture used for case study. Pulte Homes, Las Vegas. A-frame roof. 5 kg of H₂ stored in car in garage. Leak-down times from 12 hours to 7 days.
CFD model of 2-car garage. Left half of garage is shown (bilateral symmetry). Color scale is H₂ concentration; full scale is LFL. Leak rate = 5 kg/24 hours (41.5 L/min). 2 vents, 0.85 ft² each. Elapsed time = 83 min. Steady-state achieved.

Source: Keith Gawlik, Dennis Barley
## Preliminary Vent Sizing Chart for Buoyancy-Driven Ventilation of H₂ from Building

Based on maximum H₂ concentration = 1% (25% of LFL).

* 29-day leakage rate based on SAE J2578, Appendix C.

### Leakage Rate (Based on 5kg of H₂)

<table>
<thead>
<tr>
<th>T, days</th>
<th>T, hrs</th>
<th>L/min</th>
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<tbody>
<tr>
<td>0.25</td>
<td>6</td>
<td>166</td>
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<tr>
<td>0.5</td>
<td>12</td>
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<td>1</td>
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<tr>
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<td>3</td>
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<td>7</td>
<td>168</td>
<td>5.92</td>
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<tr>
<td>29*</td>
<td>696</td>
<td>1.43</td>
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</table>

### Minimum Area, Each Vent (sq.ft) (Thermal effects excluded)

<table>
<thead>
<tr>
<th>Vent Height, ft</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
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<tbody>
<tr>
<td>0.25</td>
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<td>13.2</td>
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<td>0.5</td>
<td>8.51</td>
<td>7.37</td>
<td>6.59</td>
<td>6.01</td>
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<tr>
<td>1</td>
<td>4.25</td>
<td>3.68</td>
<td>3.29</td>
<td>3.01</td>
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<tr>
<td>2</td>
<td>2.13</td>
<td>1.84</td>
<td>1.65</td>
<td>1.50</td>
</tr>
<tr>
<td>3</td>
<td>1.42</td>
<td>1.23</td>
<td>1.10</td>
<td>1.00</td>
</tr>
<tr>
<td>7</td>
<td>0.61</td>
<td>0.53</td>
<td>0.47</td>
<td>0.43</td>
</tr>
<tr>
<td>29*</td>
<td>0.15</td>
<td>0.13</td>
<td>0.11</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Source: Keith Gawlik, Dennis Barley
Technical Progress: Component Testing

• Initiated collaboration with Lincoln Composites on carbon composite tanks
  - Drop Test Simulation
    • obtain geometry material composition and fiber orientation of current tank design
    • build structural finite element model to simulate typical drop test
  - Drop Test Simulation - Next Steps
    • validate model with available experimental results
    • perform design of experiment study to identify impact of several design parameters on structural behavior of tank
    • design exploration parameters include drop angle, material properties, fiber orientation, etc.

• Potential future collaboration
  – Fast-fill efficiency and temperature distribution
  – Low cycle fatigue
  – Crashworthiness (tank system)
Technical Progress: 45º 6 ft. Drop Test – Isometric View

Preliminary Results

Source: Andreas Vlahinos
Technical Progress: Displacement Distribution

Preliminary Results

Source: Andreas Vlahinos
Technical Progress: Stress Distribution
Preliminary Results

Equivalent (von-Mises) Stress
x 1e3 Pa
Max: 2.675e+003
Min: 1.153e+001
2006/10/30 15:04

Source: Andreas Vlahinos
Component Testing: Future Work

• Tank testing simulation/design of experiment
  – write script to automate 3D Model generation
  – build explicit 3D FEA model with composite material elements that include approximately 5000 unique material properties and fiber orientations
  – validate model with available experimental results
• Validate performance-based systems test sequence in SAE J2579
  – Type 3 and 4 tanks
  – expected service life
  – durability under extreme conditions
  – burst tests to evaluate residual strength
• Non-destructive testing, in situ monitoring for high pressure tanks
  – Type 3 and 4 tanks
  – apply advanced optical fiber methods
  – collaboration with tank manufacturers, other laboratories
• HPRD model/validation, reliability data and analysis
Summary

- Consensus national C&S agenda strengthened through National H2-FC C&S Coordinating Committee (DOE, NHA, USFCC)
  - Smooth transition for support of SDO/CDO through DOE/GO and Regulatory Logic
- DOE initiative to facilitate permitting of HFS underway
  - Web-based C&S information repository
- R&D underway for better data, modeling, analysis to support C&S requirements
  - Integrated Engineering Approach
    - safe, energy-efficient building design
    - sensor testing and validation, placement
  - Performance-based component testing
    - SAE J2579 test sequence validation
    - FEA simulation, design of experiment for composite tank testing
- Better harmonization of domestic and international requirements
  - Fuel quality: SAE J2719 and ISO 14687-2 nearly identical
  - US (through DOE/NREL) active in HyApproval to harmonize HFS requirements in EC, US, Japan, China
  - DOE support for US TAGs of ISO TC197 and IEC TC105