A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

2007 DOE Hydrogen Program Annual Merit Review

Hydrogen Codes and Standards

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National Renewable Energy Laboratory

May 17, 2007

This presentation does not contain any proprietary or confidential information

Project ID# SA1

NREL/PR-560-41545
Presented at the 2007 DOE Hydrogen Program Annual Merit Review and Peer Evaluation on May 15-18, 2007 in Arlington, Virginia.

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

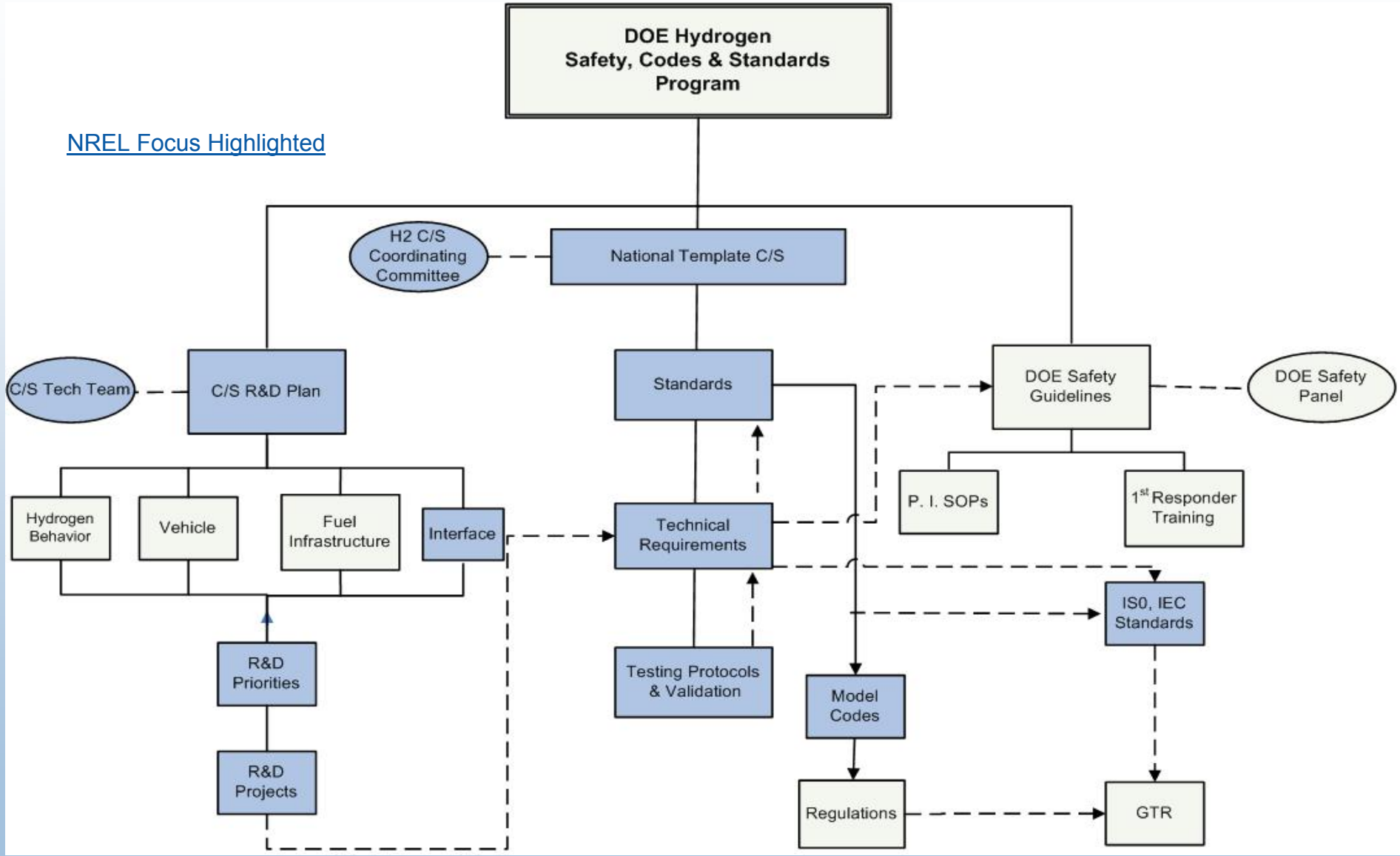
- National H2/Fuel Cells Codes and Standards Coordinating Committee
- FreedomCAR-Fuel Partnership C&S Technical Team
- NHA, USFCC

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



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 H_2/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

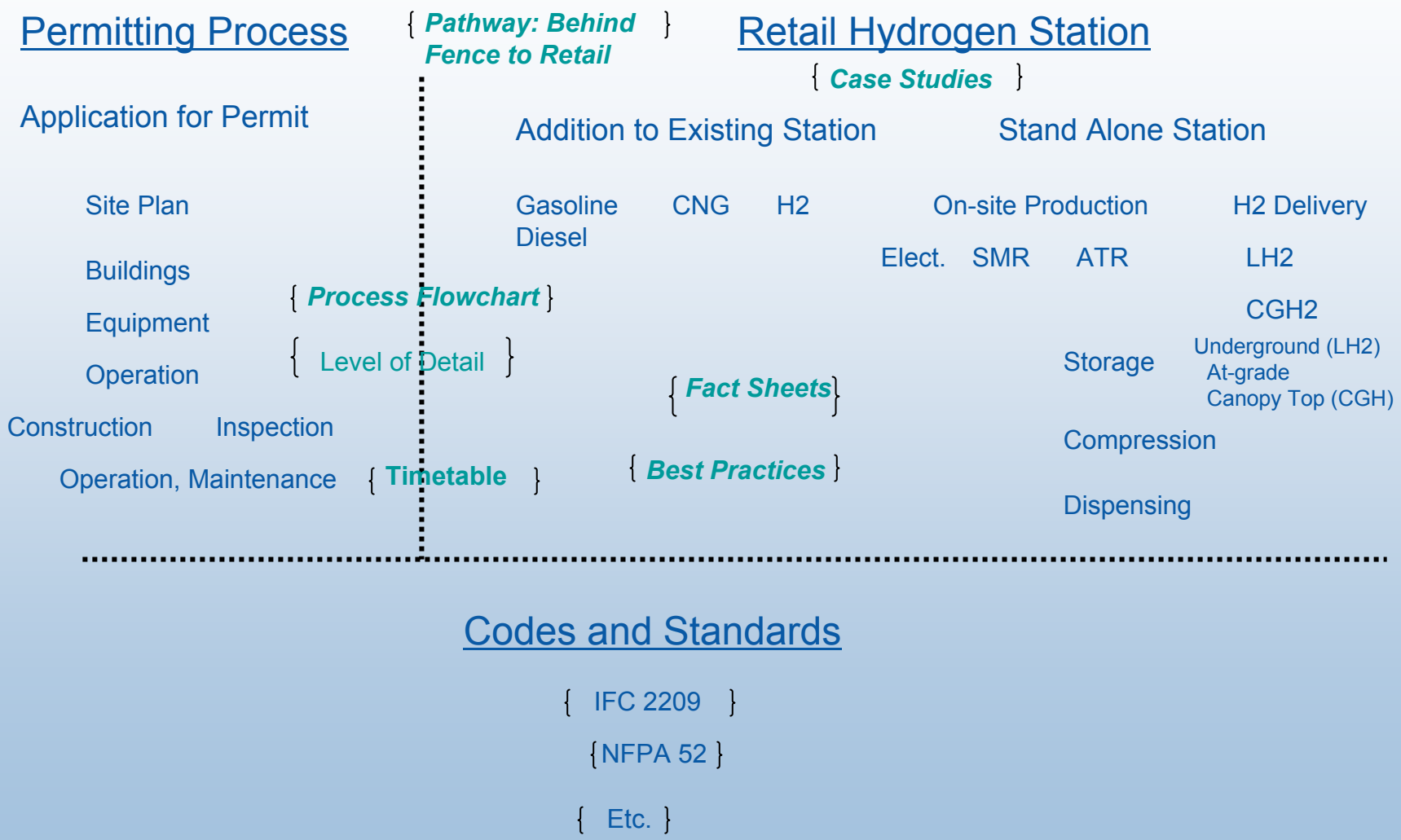
Technical Progress: HFS Permitting Workshop

- 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 H_2 infrastructure development and vehicle deployment

Technical Progress: Information Repository Concept



Technical Progress: HFS Factsheets

HYDROGEN FUELING STATION SITING

Hydrogen, Fuel Cells & Infrastructure Technologies Program

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Hydrogen Fueling—Coming Soon to a Station Near You

Hydrogen-fueled vehicles may soon become a more common and important part of a cleaner and more sustainable transportation future. The development of a network of hydrogen-dispensing fueling stations is essential if such a future is to occur. For local regulatory agencies this future poses the challenge of applying codes and standards to allow safe but expeditious permitting of new hydrogen fueling stations as well as the addition of hydrogen fueling at existing gasoline stations.

While hydrogen is a new and different fuel for vehicles, it is used extensively in other applications, such as a chemical feedstock and to power space exploration. The experience of hydrogen fueling station developers and vehicle manufacturers is still limited, but as exemplified by the examples in the box to the right, hydrogen is a safe and clean fuel if handled properly as all fuels must be.

Experience in permitting hydrogen fueling stations is thus far limited to a few states and local governments. However, enough stations have been built so that local jurisdictions do not have to reinvent the wheel. As of early 2007, there were about 50 stations in the United States, with several others planned and possibly in the process of obtaining permits. Clusters of multiple stations are located in the Greater Los Angeles (12), Greater San Francisco Bay (5), and Detroit (6) metropolitan areas. The majority of existing stations were built for fleet applications and facilities, but some also serve other customers or are open to the public. Databases maintained by the National Hydrogen Association at *http://www.hydrogenassociation.org/generalfuelingSearch.asp*, Fuel Cells 2000 at *http://www.fuelcells.org/info/charts.html#H2Stations*, and a German consulting company at *www.h2stations.org* provide more complete lists.

In approving permits for these stations, state and local jurisdictions have used existing codes and standards available from organizations such as the International Code Council (ICC) and the National Fire Protection Association (NFPA). In recent years, the ICC has adopted provisions for hydrogen fueling stations in its International Fire Code and the NFPA has consolidated and updated key hydrogen standards as noted in the box on the next page. In addition, the U.S. Department of Energy has begun a major effort to help facilitate the permitting process for hydrogen fueling stations. This fact sheet is one product of this effort. For more information, please refer to the information sources or contact the persons listed at the end of this fact sheet.

The Shell hydrogen fueling facility in Washington, D.C., is now one of a handful of such stations in the United States, but more will likely be built in the near future. Local jurisdictions can benefit greatly from the experience of other local authorities who have already gone through the permitting process.

Hydrogen Fueling Station Examples

Public Retail Stations

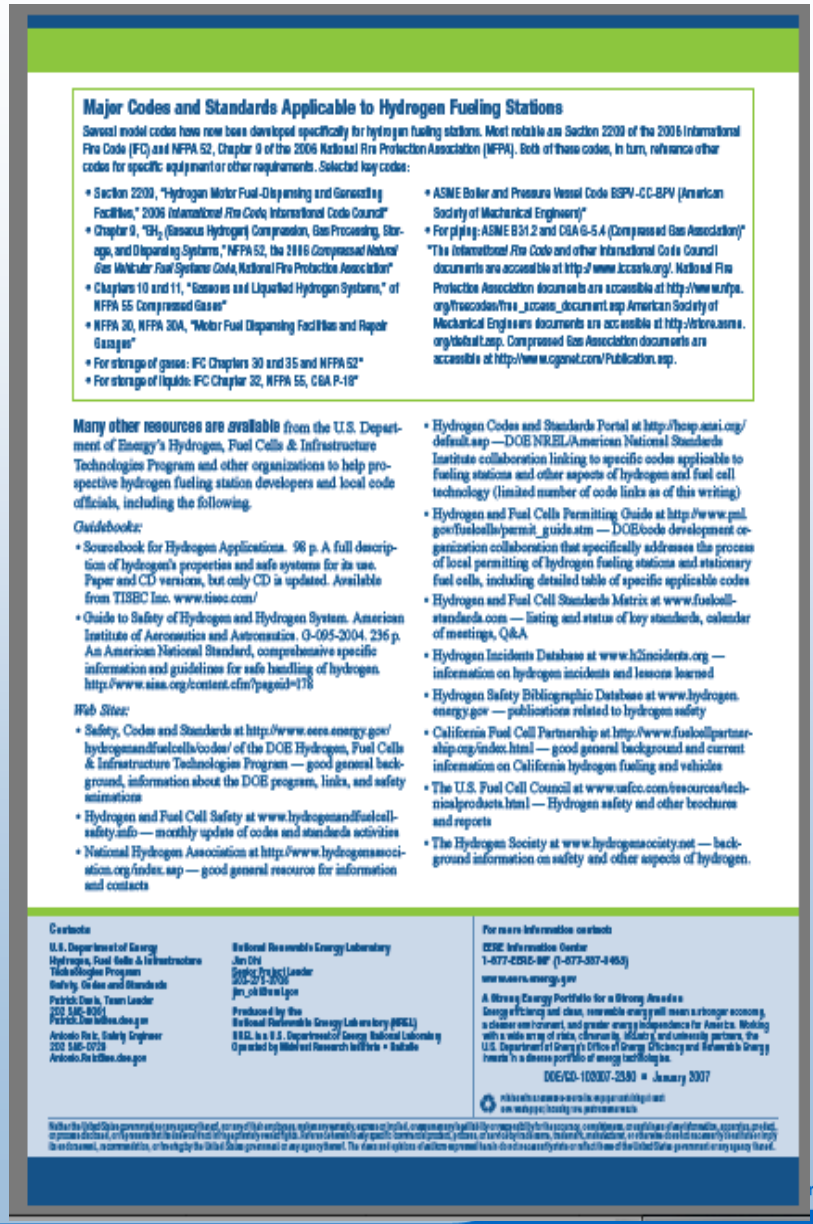
- Shell Benning Road Station, Washington, DC; retail station renovated to include hydrogen (delivered as liquid) and gasoline; operational since November 2004

Fleet and Research Facilities

- Arizona Public Service Hydrogen Pilot, Phoenix, AZ; fleet facility using delivered gas and onsite generation; operational since March 2002
- LAX Airport Station, Los Angeles, CA; fleet facility with onsite generation; operational since October 2006
- NextEnergy Center Hydrogen Station, Detroit, MI; multi-fuel research facility fleet facility operational since October 2006
- City of White Plains Hydrogen Refueling Station, White Plains, NY; city fleet facility; planned for opening in May 2007
- California Fuel Cell Partnership, West Sacramento, CA; research vehicle service using delivered liquid hydrogen; operational since 2000

Bus System Stations

- AC Transit Hydrogen Fueling Station, Oakland, CA; fuel cell bus fleet facility with onsite generation; operational since November 2005
- Progress Energy Florida, Orlando Airport Station; Orlando, FL; hydrogen internal combustion bus fleet demonstration project planned for completion by mid 2007
- SunFuels Station, Thousand Palms, CA; services fuel cell and hydrogen internal combustion buses and others; operational since April 2000.



Major Codes and Standards Applicable to Hydrogen Fueling Stations

Several model codes have now been developed specifically for hydrogen fueling stations. Most notable are Section 2209 of the 2006 International Fire Code (IFC) and NFPA 52, Chapter 9 of the 2006 National Fire Protection Association (NFPA). Both of these codes, in turn, reference other codes for specific equipment or other requirements. Selected key codes:

- Section 2209, "Hydrogen Motor Fuel-Dispensing and Generating Facilities," 2006 *International Fire Code*, International Code Council"
- Chapter 9, "GH_2 (Gaseous Hydrogen) Compression, Gas Processing, Storage, and Dispensing Systems," NFPA 52, the 2006 *Compressed Natural Gas Vehicular Fuel Systems Code*, National Fire Protection Association"
- Chapters 10 and 11, "Gaseous and Liquefied Hydrogen Systems," of NFPA 55 Compressed Gases"
- NFPA 30, NFPA 30A, "Motor Fuel Dispensing Facilities and Repair Garages"
- For storage of gases: IFC Chapters 30 and 35 and NFPA 52"
- For storage of liquids: IFC Chapter 32, NFPA 55, CGA P-18"
- ASME Boiler and Pressure Vessel Code BSPV-CC-BPV (American Society of Mechanical Engineers)"
- For piping: ASME B31.2 and CGA G-5.4 (Compressed Gas Association)"

"The *International Fire Code* and other International Code Council documents are accessible at http://www.iccsafe.org/. National Fire Protection Association documents are accessible at http://www.nfpa.org/freecodes/free_access_document.asp American Society of Mechanical Engineers documents are accessible at http://store.asme.org/default.asp. Compressed Gas Association documents are accessible at http://www.cganet.com/Publication.asp.

Many other resources are available from the U.S. Department of Energy's Hydrogen, Fuel Cells & Infrastructure Technologies Program and other organizations to help prospective hydrogen fueling station developers and local code officials, including the following.

Guidebooks:

- Sourcebook for Hydrogen Applications. 98 p. A full description of hydrogen's properties and safe systems for its use. Paper and CD versions, but only CD is updated. Available from TISEC Inc. www.tisec.com/
- Guide to Safety of Hydrogen and Hydrogen System. American Institute of Aeronautics and Astronautics. G-095-2004. 236 p. An American National Standard, comprehensive specific information and guidelines for safe handling of hydrogen. http://www.aiaa.org/content.cfm?pageid=178

Web Sites:

- Safety, Codes and Standards at http://www.eere.energy.gov/hydrogenandfuelcells/codes/ of the DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program — good general background, information about the DOE program, links, and safety seminations
- Hydrogen and Fuel Cell Safety at www.hydrogenandfuelcell-safety.info — monthly update of codes and standards activities
- National Hydrogen Association at http://www.hydrogenassociation.org/index.asp — good general resource for information and contacts
- Hydrogen Codes and Standards Portal at http://hsap.ansi.org/default.asp —DOE NREL/American National Standards Institute collaboration linking to specific codes applicable to fueling stations and other aspects of hydrogen and fuel cell technology (limited number of code links as of this writing)
- Hydrogen and Fuel Cells Permitting Guide at http://www.pnl.gov/fuelcells/permit_guide.stm — DOE/code development organization collaboration that specifically addresses the process of local permitting of hydrogen fueling stations and stationary fuel cells, including detailed table of specific applicable codes
- Hydrogen and Fuel Cell Standards Matrix at www.fuelcell-standards.com — listing and status of key standards, calendar of meetings, Q&A
- Hydrogen Incidents Database at www.h2incidents.org — information on hydrogen incidents and lessons learned
- Hydrogen Safety Bibliographic Database at www.hydrogen.energy.gov — publications related to hydrogen safety
- California Fuel Cell Partnership at http://www.fuelcellpartnership.org/index.html — good general background and current information on California's hydrogen fueling and vehicles
- The U.S. Fuel Cell Council at www.usfcc.com/resources/technicalproducts.html — Hydrogen safety and other brochures and reports
- The Hydrogen Society at www.hydrogensociety.net — background information on safety and other aspects of hydrogen.

Contacts

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Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

DOE/GO-102007-2360 • January 2007

Technical Progress: HFS Factsheets

HYDROGEN FUELING STATION SITING

Hydrogen, Fuel Cells & Infrastructure Technologies Program

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Hydrogen Fueling Station Network

Permitting a facility for a new technology such as a fueling station for hydrogen-powered vehicles may seem daunting at first. However, you can benefit from the experience of those who have already done so. There are already more than fifty operational hydrogen fueling stations in the United States and many more throughout the world. The stations listed below provide examples of types and locations of facilities that might be similar to proposals you may face. The contact people listed are willing to share information about their experience permitting hydrogen fueling stations in their jurisdictions and to answer questions that might help you with proposed stations in your jurisdiction.

Station	Description	Permitting Contact
Arizona		
Arizona Public Service Hydrogen Pilot, Phoenix, AZ	Five-year demonstration project on utility property now being continued as an ongoing technology demonstration; indoor station by regulation definition, in historic building; dispensing hydrogen and hydrogen/natural gas blends for a number of different fleets; on-site electrolysis; open since March 2002	Mike Wojcik City of Phoenix Fire Protection Engineer 602-495-7890 mike.wojcik@phoenix.gov
California		
AC Transit Hydrogen Fueling Station, Oakland, CA	Two-and-a-half-year demonstration project to service three fuel-cell buses, also manufacturer research fuel-cell passenger vehicles; on-site gas reformation; open since November 2005	Lacy Griffin City of Oakland Assistant Fire Marshal 510-238-7759 lgriffin@oaklandnet.com
Santa Monica Hydrogen Fueling Station, Santa Monica, CA	Five-year demonstration project on city property to service five hydrogen internal-combustion-engine conversions; on-site electrolysis adjacent to existing CNG fueling facility; hydrogen storage on top of CNG tanks; open since June 2006	Jim Glaw City of Santa Monica Fire Marshal 310-458-2201 x8782 jim.glaw@smgov.net
SunFuels Station, Thousand Palms, CA	Ongoing project on bus company property to service two SunLine buses (one fuel-cell and one hydrogen internal combustion) plus arranged fleet and research vehicles; on-site gas reformation; open since April 2000	Walter Brandes Riverside County Assistant Fire Marshal 760-863-8886 walt.brandes@fire.ca.gov

Station	Description	Permitting Contact
California (continued)		
LAX Airport Station, Los Angeles, CA	Demonstration project on airport property to service airport fuel-cell vehicles; on-site electrolysis; open since October 2005	David Myers City of Los Angeles Fire Protection Engineer 213-482-6008 david.myers@lahfd.lacity.org
California Fuel Cell Partnership, West Sacramento, CA	Ongoing facility servicing variety of research vehicles; using delivered liquefied hydrogen; open since 2000	Fred Postal City of West Sacramento Fire Chief 916-617-4600 fredp@cityofwestsacramento.org
District of Columbia		
Shell Benning Road Station, Washington, DC	Ongoing public fueling facility as part of retail gasoline station; using delivered liquefied hydrogen, dispensed as liquid or compressed gas; open since November 2004	Richard Fleming District of Columbia Deputy Fire Chief 202-727-3659 richard.fleming@dc.gov
Florida		
Chevron/Progress Energy Boggy Creek Road Hydrogen Station, Orlando, FL	Five-year demonstration at new site with new building on utility property for hydrogen-fueled internal combustion shuttle-bus fleet; on-site gas reformation and delivery; in commissioning process, planned for opening March 2007	Thomas Hile Manager, City of Orlando Permitting Division 407-246-2525 thomas.hile@cityoforlando.net
Michigan		
NextEnergy Center Hydrogen Station, Detroit, MI	Ongoing facility at new site to service alternative fuel research center; using delivered hydrogen or onsite generation from research projects; open since October, 2006	Derek Sayers, City of Detroit Supervisor of Fire Protection Engineering, 313-224-1311 sayersd@ddfdhq.ci.detroit.mi.us Marcia Pearson, Storage Tank Unit Engineer, Michigan Department of Environmental Quality, 517-373-3290, pearsonm@michgov
New York		
City of White Plains Hydrogen Refueling Facility, White Plains, NY	Ongoing facility on city property for city hydrogen-fueled internal combustion fleet and blending with CNG; dispensing pump on common island with other fuels; on-site electrolysis; planned for completion May 2007	Joseph (Bud) Nicoletti Commissioner of Public Works/City Engineer 914-422-1210 jnicoletti@ci.white-plains.ny.us
Nevada		
Las Vegas Hydrogen Energy Station, Las Vegas, NV	Ongoing facility on city property started as demonstration project to service city vehicles; using delivered liquefied hydrogen; open since August 2002	Earl Russell Deputy Director of Building and Safety 702-229-6092 erussell@lasvegasnevada.gov

Contents

U.S. Department of Energy
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DOE/GO-102007-2385 • January 2007

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

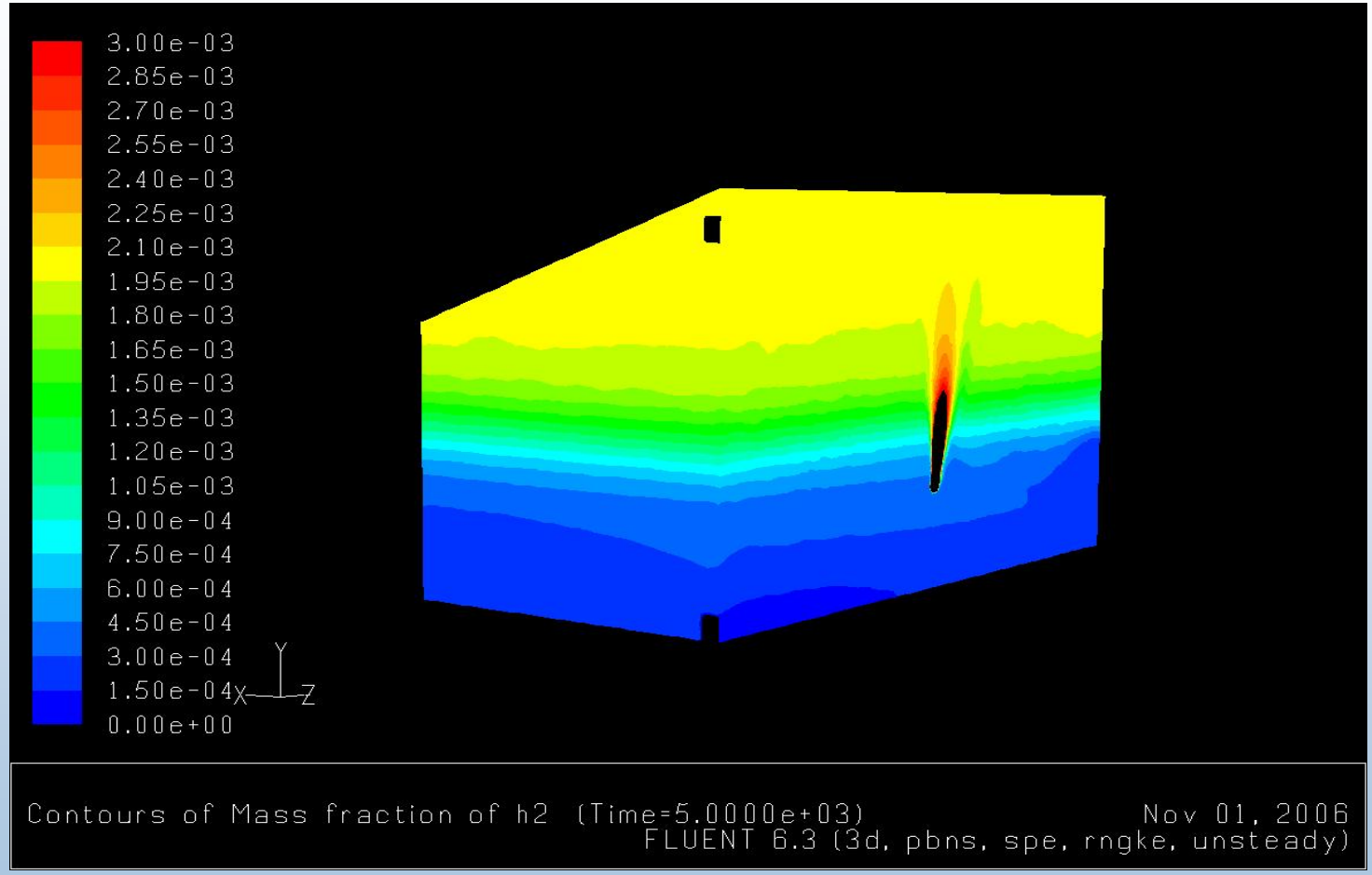
- R&D to establish defensible requirements for standards
  - Integrated Engineering Approaches to Hydrogen Safety
    - CFD modeling of hydrogen leaks in residential garage
      - floor plan, characteristics from Building America model home
      - Buildings and Thermal Systems Center (NREL)
    - CFD simulation of H_2 leak from non-combustible enclosures
      - co-funded with industry through NFPA Research Foundation
      - data for separation distances for H_2FC 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

Building AMERICA
U.S. Department of Energy

Sample architecture used for case study. Pulte Homes, Las Vegas. A-frame roof. 5 kg of H_2 stored in car in garage. Leak-down times from 12 hours to 7 days.

Technical Progress: Safe Building Design for Hydrogen Vehicles



CFD model of 2-car garage. Left half of garage is shown (bilateral symmetry). Color scale is H_2 concentration; full scale is LFL. Leak rate = 5 kg/24 hours (41.5 L/min). 2 vents, 0.85 ft^2 each. Elapsed time = 83 min. Steady-state achieved.

Source: Keith Gawlik, Dennis Barley

Technical Progress: Safe Building Design for Hydrogen Vehicles

Leakage Rate (Based on 5kg of H2)			Minimum area, each vent (sq.ft) (Thermal effects excluded)			
T, days	T, hrs	L/min	Vent Height, ft			
			6	8	10	12
0.25	6	166	17.0	14.7	13.2	12.0
0.5	12	82.9	8.51	7.37	6.59	6.01
1	24	41.5	4.25	3.68	3.29	3.01
2	48	20.7	2.13	1.84	1.65	1.50
3	72	13.8	1.42	1.23	1.10	1.00
7	168	5.92	0.61	0.53	0.47	0.43
29*	696	1.43	0.15	0.13	0.11	0.10

Preliminary vent sizing chart for buoyancy-driven ventilation of H_2 from building. Based on maximum H_2 concentration = 1% (25% of LFL).

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

Preliminary—Do Not Cite

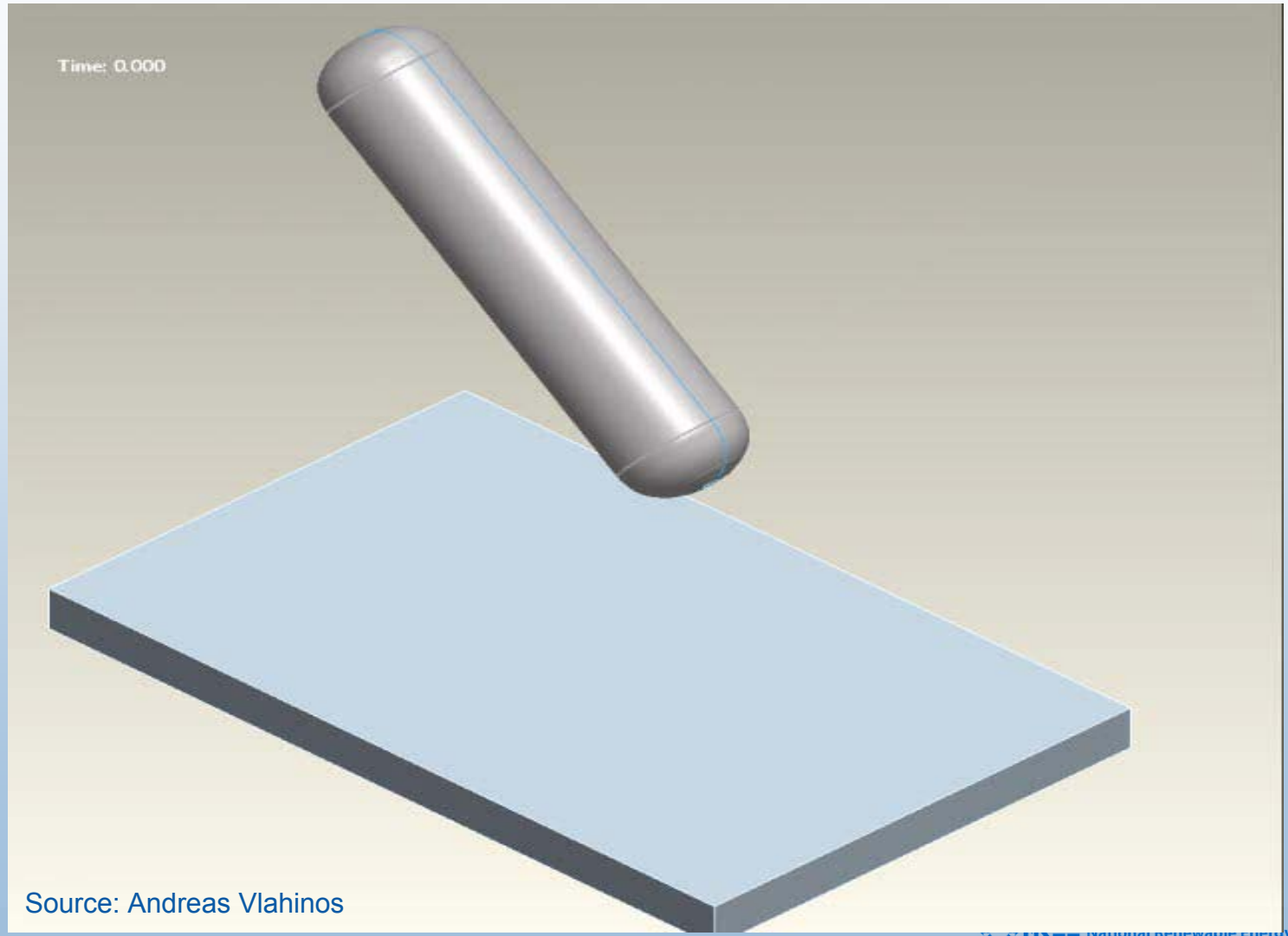
Source: Keith Gawlik, Dennis Barley

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

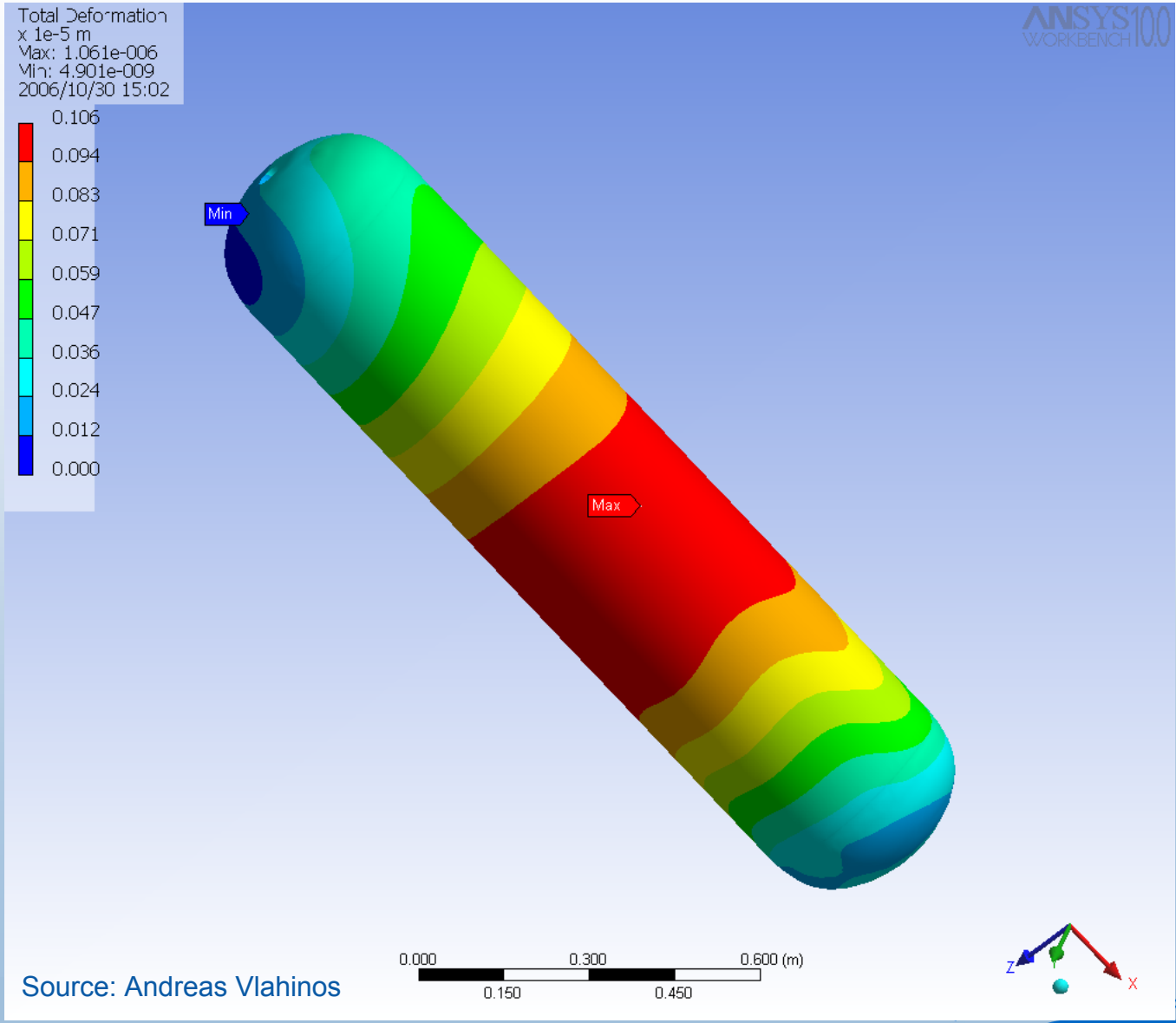
Preliminary Results



Source: Andreas Vlahinos

Technical Progress: Displacement Distribution

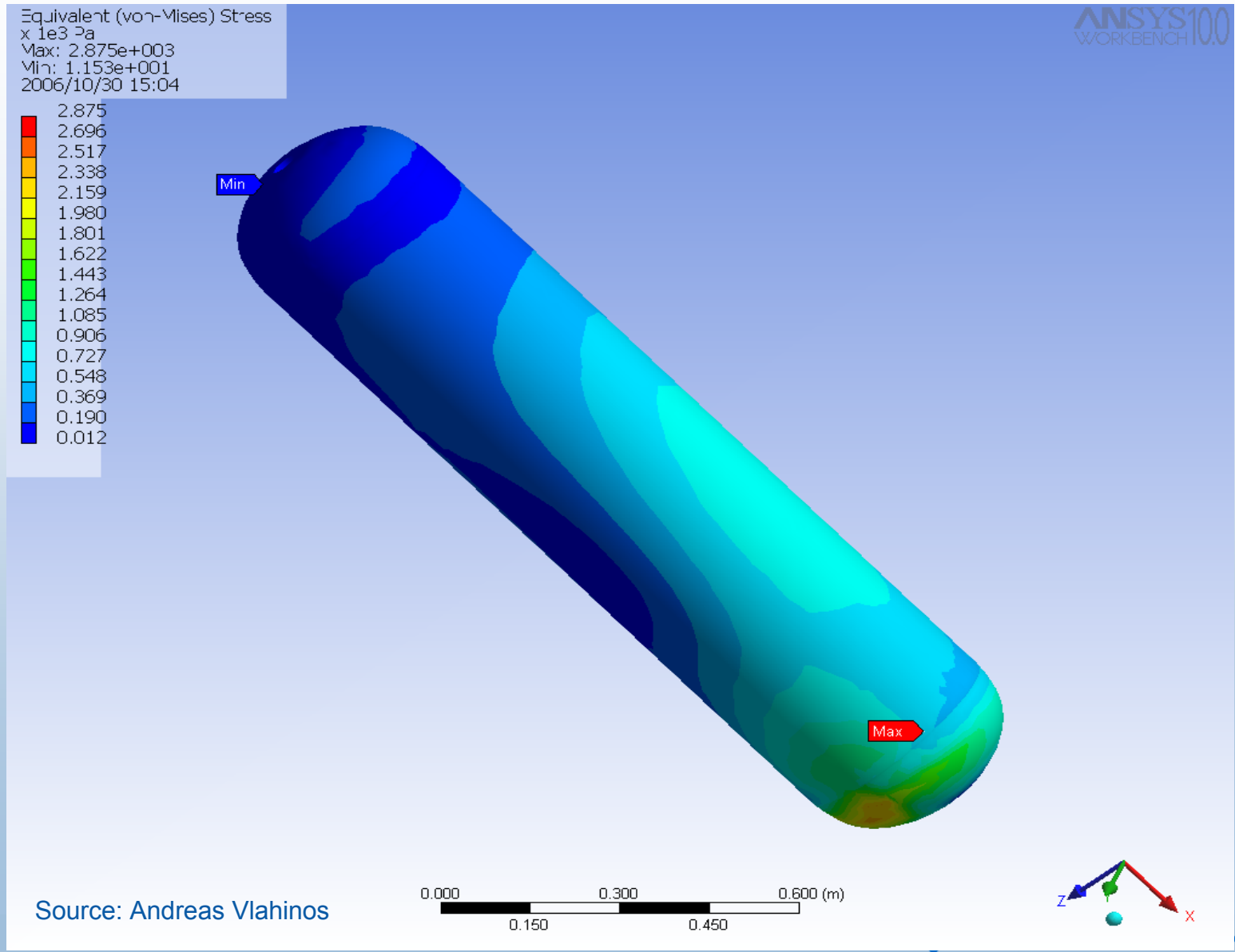
Preliminary Results



Source: Andreas Vlahinos

Technical Progress: Stress Distribution

Preliminary Results



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