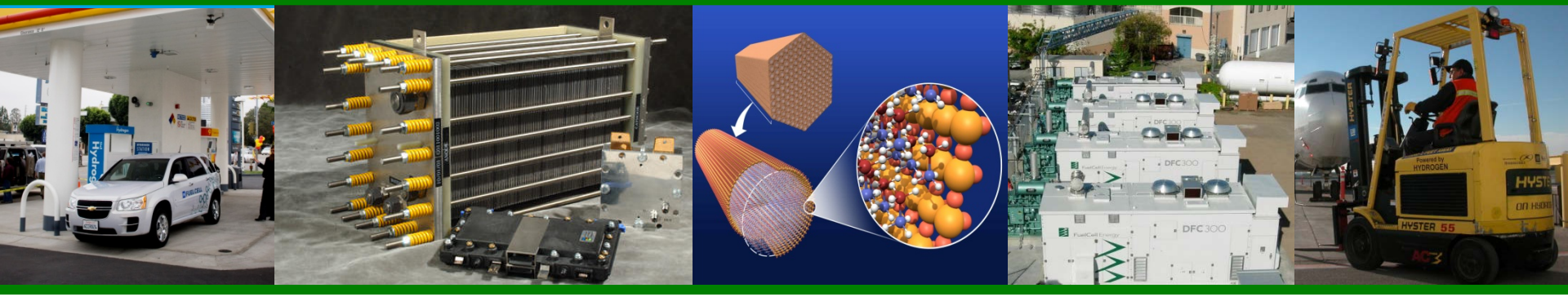
U.S. DEPARTMENT OF ENERGY



Hydrogen Transmission and Distribution Workshop

Sara Dillich

U.S Department of Energy
Office of Energy Efficiency & Renewable Energy
Fuel Cell Technologies Office

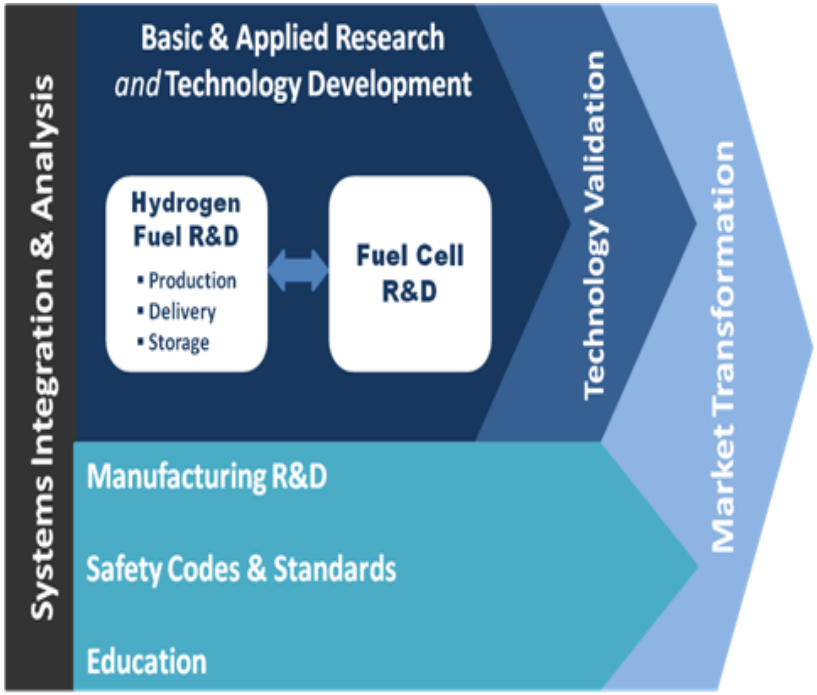
National Renewable Energy Laboratory
Golden, Colorado
February 25, 2014

Hydrogen and Fuel Cells Program Overview

U.S. DEPARTMENT OF ENERGY

Mission: Enable widespread commercialization of a portfolio of hydrogen and fuel cell technologies through applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges.

Key Goals : Develop hydrogen and fuel cell technologies for early markets (stationary power, lift trucks, portable power), mid-term markets (CHP, APUs, fleets and buses), and long-term markets (light duty vehicles).



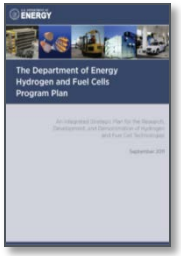
WIDESPREAD COMMERCIALIZATION ACROSS ALL SECTORS

- Transportation
- Stationary Power
- Auxiliary Power
- Backup Power
- Portable Power

Examples of Key Targets

- **Fuel Cells:**
  - **Transportation: $30/kW, 5K hours**
  - **Stationary: $1,500/kW, 60-80K hours**
- **Hydrogen: $2 to $4/gge**

DOE H_2 and Fuel Cell Program includes: EERE (Fuel Cell Technologies Office), and DOE Offices of Science, Fossil Energy and Nuclear Energy



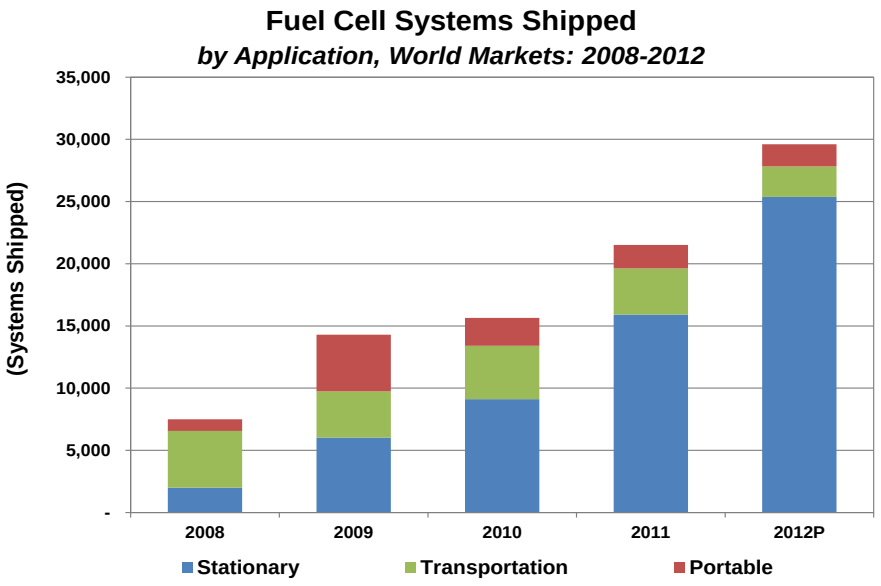
EERE Multi-year RD&D Plan updated

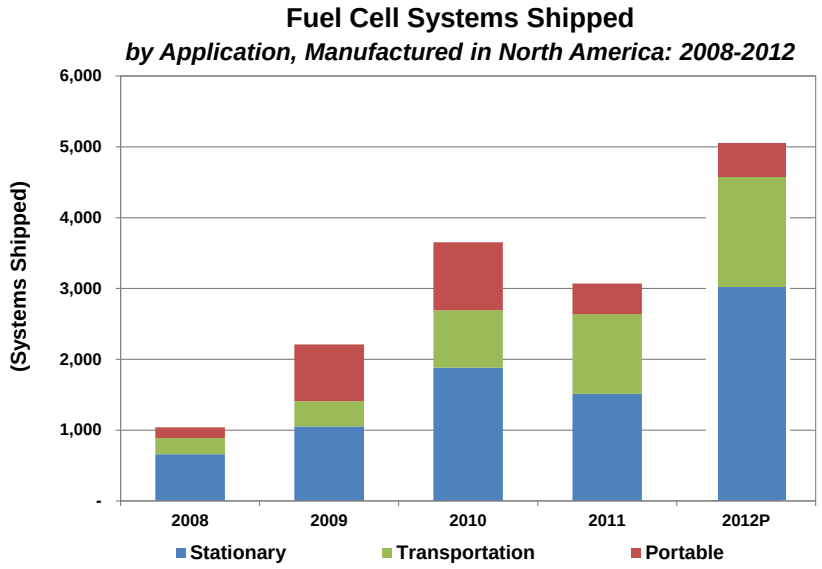
Nearly 300 projects currently funded at companies, national labs, and universities/institutes

Program Plan at: http://www.hydrogen.energy.gov/pdfs/program_plan2011.pdf

Basic research conducted thru Office of Science; Applied RD&D conducted through EERE, FE, NE

Fuel Cell Market Overview





Source: Navigant Research

Market Growth

Fuel cell markets continue to grow

- **48% increase in global MWs shipped**
- **62% increase in North American systems shipped in the last year**

The Market Potential

Independent analyses show global markets could mature over the next 10–20 years, producing revenues of:

- **$14 – $31 billion/year for stationary power**
- **$11 billion/year for portable power**
- **$18 – $97 billion/year for transportation**

Several automakers have announced commercial FCEVs in the 2015-2017 timeframe.

For further details and sources see: *DOE Hydrogen and Fuel Cells Program Plan,* http://www.hydrogen.energy.gov/pdfs/program_plan2011.pdf; FuelCells 2000, Fuel Cell Today, Navigant Research

Hydrogen Production & Applications

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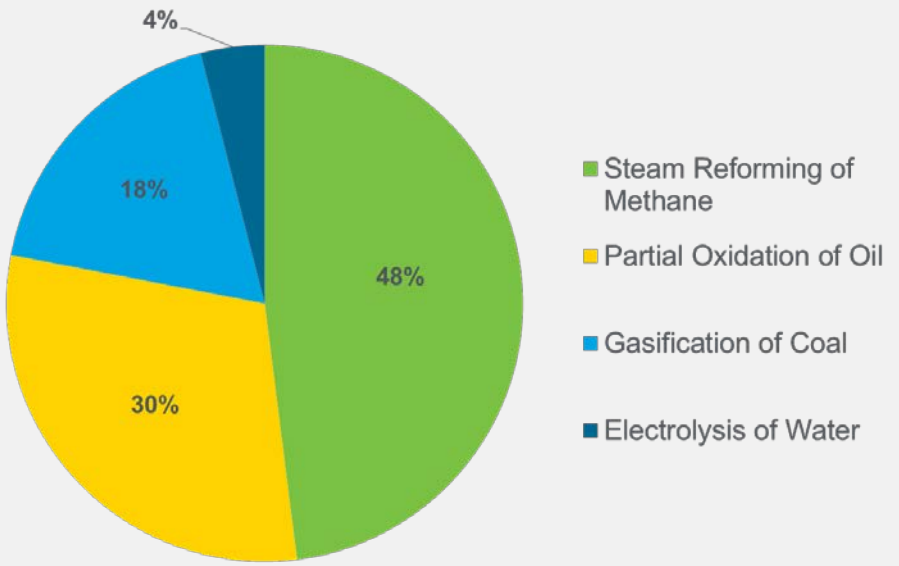
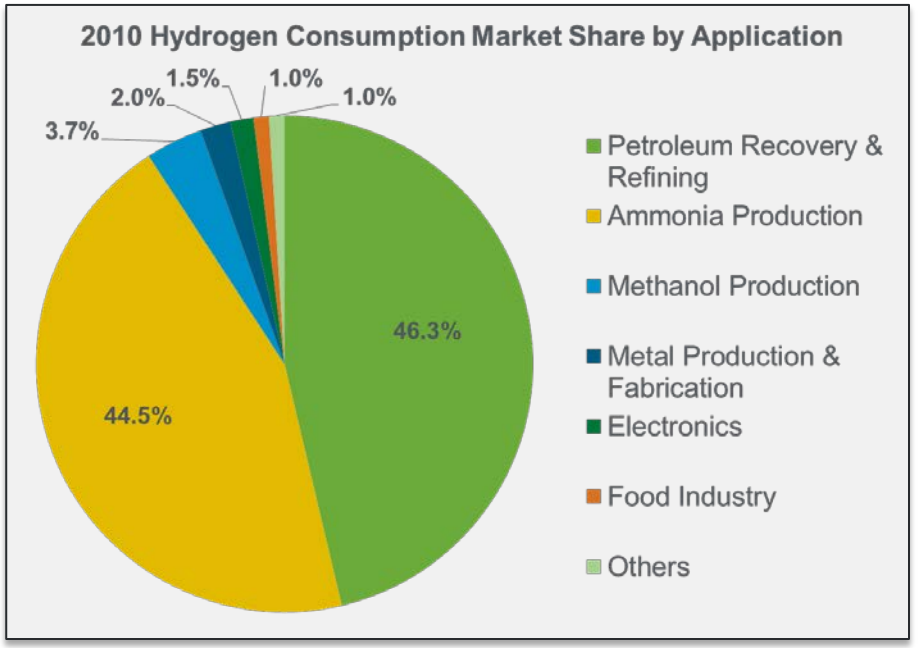


Hydrogen is produced through a variety of technologies, though ~95% of U.S. hydrogen production comes from SMR.

Hydrogen is used in a broad range of applications including electronics and metal production and fabrication in addition to its traditional role in refinery operations and ammonia production.

Major merchant suppliers

- Air Products and Chemicals, Inc.
- Airgas, Inc.
- Air Liquide
- BOC India Limited
- Linde AG
- Praxair Inc.
- Taiyo Nippon Sanso Corp.



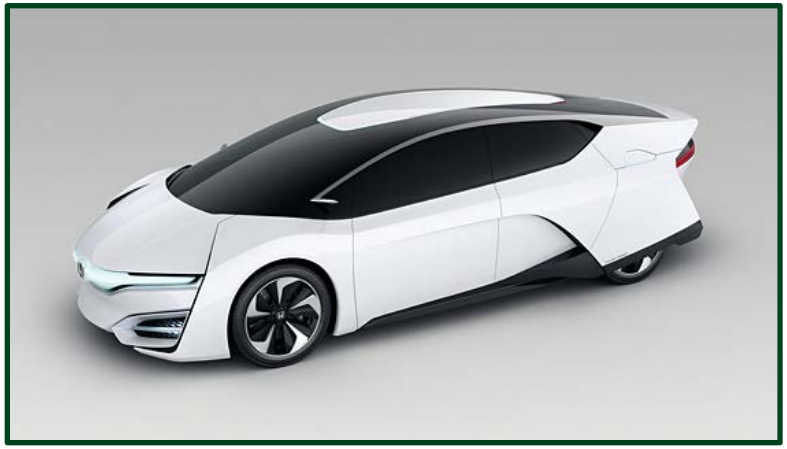
Fuel Cell Electric Vehicles at U.S. Auto Shows

U.S. DEPARTMENT OF ENERGY

FCEVs on display at North American auto shows.

Hyundai Tucson Fuel Cell Electric Vehicle

To be launched in California in Spring 2014—lease includes **free H_2 and maintenance**.



Honda Fuel Cell Electric Vehicle

Toyota Fuel Cell Electric Vehicle

Public-Private Partnership

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H_2USA

States will be included in H_2USA partnership to overcome the hurdles for hydrogen infrastructure development.

Mission: To promote the commercial introduction and widespread adoption of FCEVs across America through creation of a public-private partnership to overcome the hurdle of establishing hydrogen infrastructure.

Current partners include (additional in process):

- Air Liquide
- American Gas Association
- American Honda Motor Company
- ARC: Hydrogen
- Argonne National Lab
- Association of Global Automakers
- California Fuel Cell Partnership
- Daimler
- Electric Drive Transportation Association
- Fuel Cell and Hydrogen Energy Association
- General Motors
- Hydrogenics
- Hyundai Motor America
- ITM Power
- Massachusetts Hydrogen Coalition
- Mercedes-Benz USA
- Nissan North America Research and Development
- Nuvera
- NREL
- ORNL
- Plug Power
- Proton OnSite
- Sandia National Lab
- South Carolina Research Authority
- Toyota Motor North America

H_2USA – Key Activities

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- Situational assessment and analysis
- Forming a strategy to coordinate vehicle and infrastructure rollout by:
  - Identifying potential investments and funding opportunities
  - Developing an action plan to identify and address key barriers
  - Conducting a rigorous evaluation of potential infrastructure deployment, including promising locations and timeframes
- Identifying synergies and opportunities to leverage other alternative fueling infrastructure – such as natural gas – to enable cost reductions and economies of scale
- Identifying actions to incentivize early adopters for deploying infrastructure and FCEVs
- Evaluating the business cases required for national commercialization of vehicle and hydrogen infrastructure technologies
- Supporting participation in programs for the deployment of advanced technology vehicles, such as the National Community Deployment Challenge

Steering Committees
(Executive / Operational)

Secretariat
(Administered by FCHEA)

Hydrogen Fueling Station
Working Group

- Specification, design, and deployment
- Fueling Resources
- Delivery
- Dispensing technology
- Reliability
- State and local Regulations
- Etc.

Market Support & Acceleration
Working Group

- Product launch and timeline
- Studies and whitepapers
- Codes and standards (non-vehicle related)
- Component development
- Cost reduction
- Public education
  - First-responders
  - State and local authorities
  - Opinion leaders
- Etc.

Working GRP Coordinating (Chairs and Vice Chairs)

Locations Roadmap
Working Group

- Identify and prioritize markets
  - Market Modeling Methodology
  - Clustering, destinations and locations
- Regulatory barriers (zoning)
- Station rollout timing

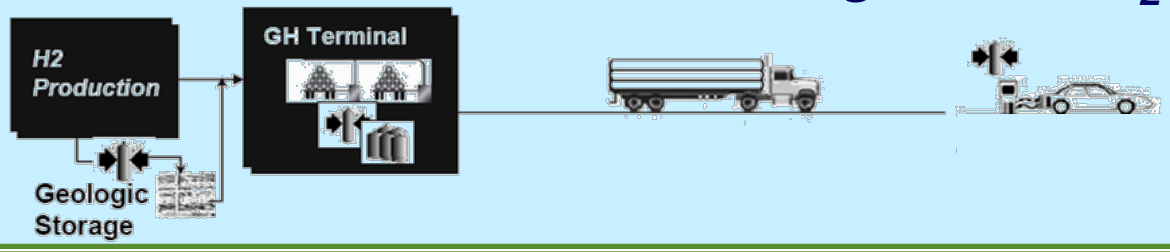
Investment & Finance
Working Group

- Private sector financing
- Government support
- Etc.

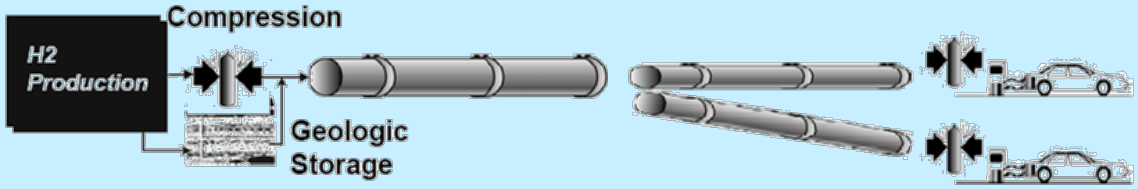
Primary Delivery Pathways

U.S. DEPARTMENT OF ENERGY

1. Transmission and distribution of *gaseous H_2 by tube trailer*



2. Transmission and distribution of *gaseous H_2 by pipeline*



3. Transmission and distribution of *liquid H_2 by tanker*

Delivery Technologies

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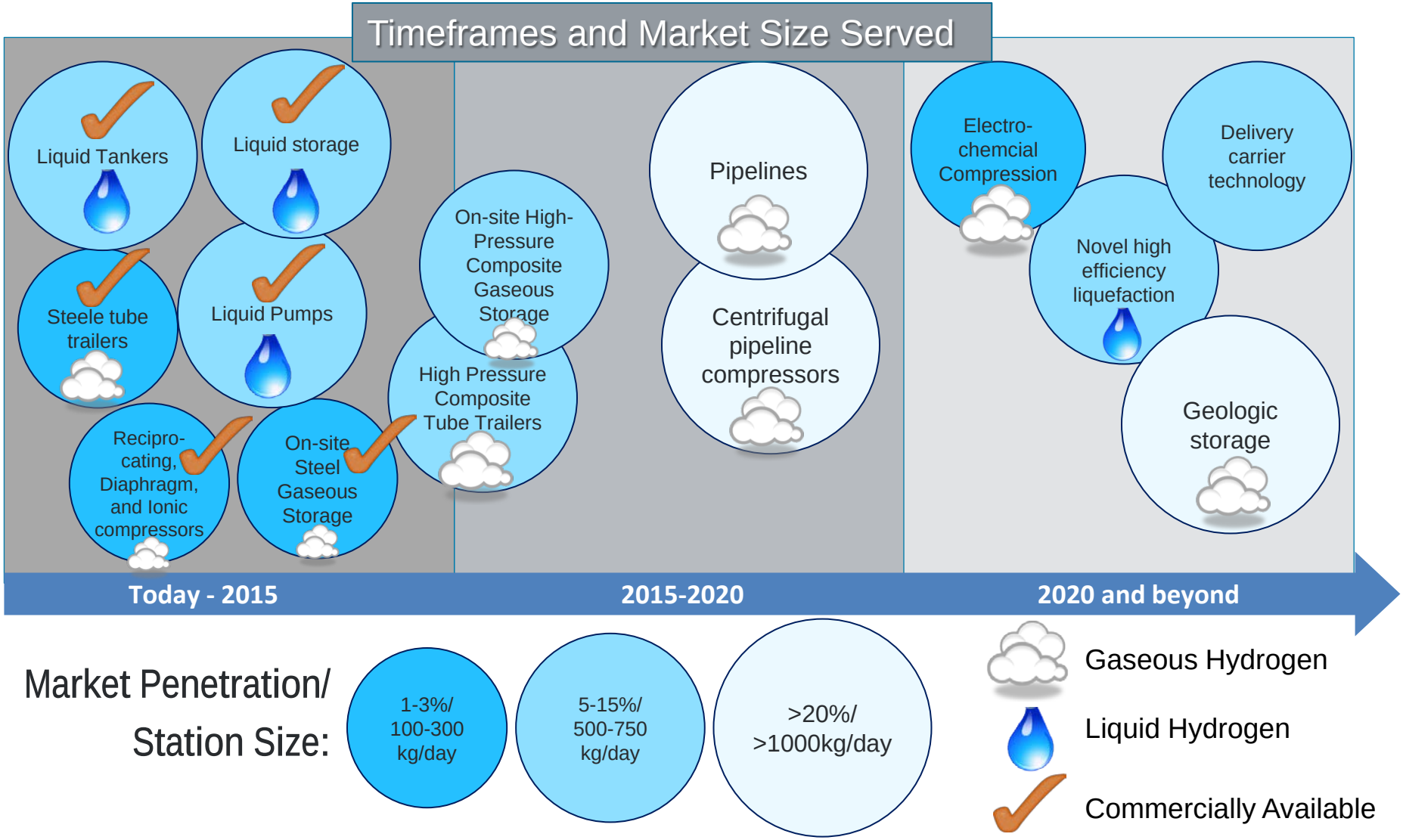
Objective: Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of $2-$4/kg H_2 by 2020



Critical Challenges in H_2 Delivery

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Broad challenges to maintain broad R&D portfolio of near- to longer-term pathways

Compression

- Capital costs
- Operating and maintenance costs
- Throughput
- Efficiency
- Reliability

Dispensing

- Hose durability
- Meter accuracy
- Robust communication

Storage

- Capital cost
- Durability
- Footprint

➢ **Meeting H_2 delivery cost threshold for all near- and longer-term pathways requires improvements in durability and reductions in overall capital costs**

Pipelines

- Capital cost
- Diameter of FRP
- Durability
- Manufacturing

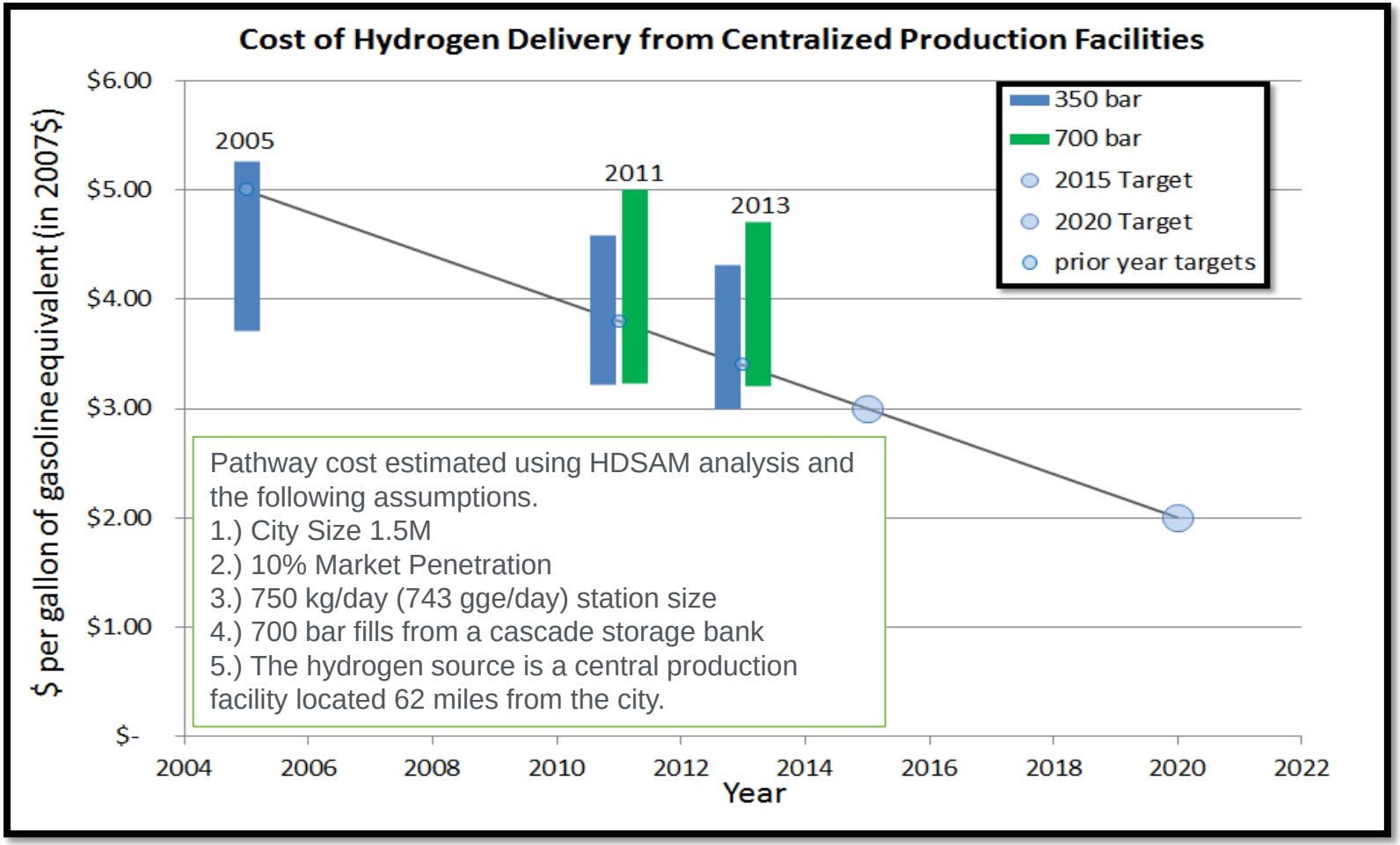
Tube Trailers

- Pressure capability
- Carbon fiber cost

Liquid Delivery

- Liquefaction efficiency
- Capital cost of liquefaction plants
- Capital cost of liquid pumps

Current Status and Hydrogen Delivery Cost Targets[a]



Range of HDSAM projected costs of hydrogen delivery from central production facilities in 2005, 2011, and 2013 along with the relevant targets.

[a] See Fuel Cell Technologies Office Record 13013 for details : http://hydrogen.energy.gov/program_records.html

Active Projects

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Year Ending	Organization	Project
Compression, Storage and Dispensing		
FY14	Nanosonic (SBIR)	700 bar delivery hose
FY14	Fuel Cell Energy	Electrochemical hydrogen pump
FY14	NREL	Dispenser hose reliability evaluation
FY15	ORNL	Low-cost, in-ground station storage
Cross Cutting		
TBD	ANL and PNNL	Delivery analysis
FY14	GVD Corp. (SBIR)	High pressure seals (selected for award)
Pipelines		
FY14	SNL	Steel pipelines
FY14- Ended	Concepts NREC	Centrifugal compressor
FY15	SRNL	FRP Pipelines
Tube Trailers		
FY15	Lincoln Composites	High pressure tube trailers
Liquid Delivery		
FY15 – On Hold	Emerald Energy Northwest	Magnetocaloric-based cryo-refrigeration

Recent Technical Accomplishments

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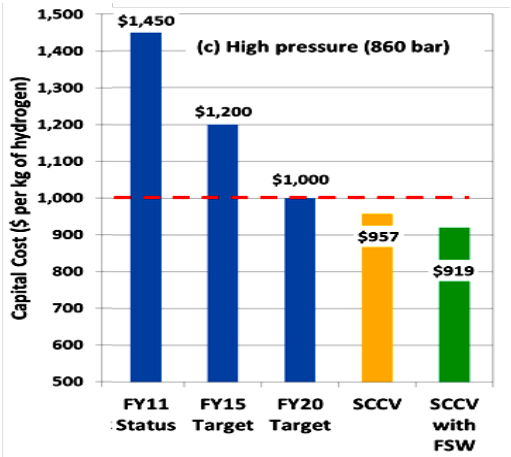
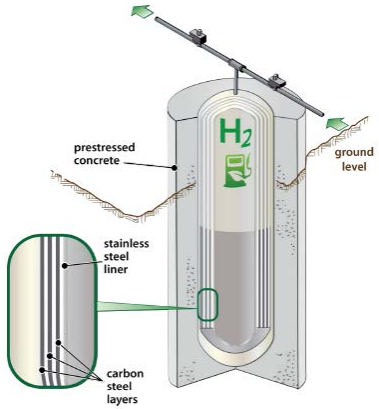
- ✓ Lowered the cost of stationary storage below the 2015 target - *ORNL*

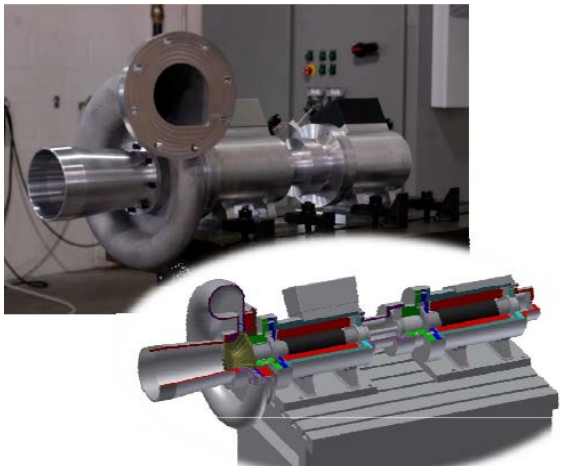
  Cost reductions of 30% or more for a steel concrete composite vessel using commodity materials and an optimized design.

  Cost < $1200/kg H2 stored at 860 bar (based on supplier & manufacturer quotes.





- ✓ Successfully completed the prototype evaluation of an oil free centrifugal pipeline compressor operating at 60,000 RPM- *Mohawk Innovative Technologies Inc.*

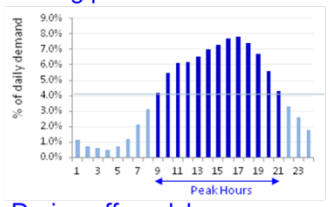


World's First

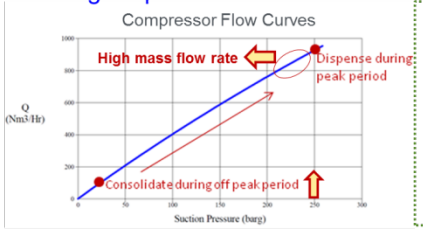
- Oil-Free
- 200 KW PM Motor
- Internally Gas Cooled
- Direct-drive
- No Transmission or Gearbox
- 60,000 rpm
- Made In USA

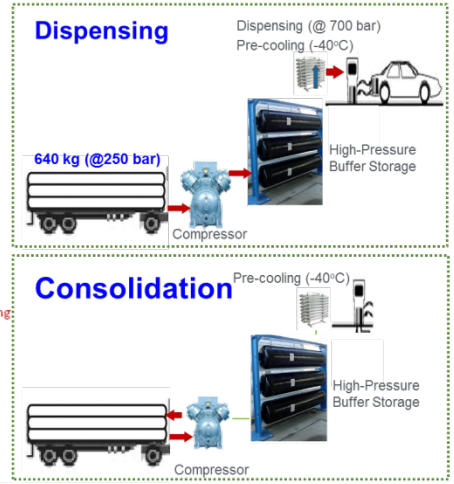
- ✓ Created high pressure tube trailer control algorithms to reduce station cost by 20% - *ANL*

1. During peak hours



2. During off-peak hours





Recent Key Activities

Interactions

- U.S.DRIVE Hydrogen Delivery Tech Team
- H2USA Station working group
- IEA-HIA Hydrogen Infrastructure Task
- Leveraging of BES SBIR Funding
  - *New project selection for hydrogen sealing materials (GVD Corp)*

Workshops & Meetings

- Forecourt CSD Workshop and Report
- Joint NOW/NEDO/DOE Workshops
- DOE/DOT/NIST pipeline RD&D coordination meeting

Assessments and Reports

- Independent panel review of CSD cost estimates
- Report on Polymer and Composite compatibility with hydrogen (with FCTO SCS)

Funding Opportunity Announcement

- Closed February 18, 2014

Broader Collaborations

U.S. DEPARTMENT OF ENERGY

New in 2013: H_2USA- Public-private partnership to enable the widespread commercialization of FCEVs and address the challenge of hydrogen infrastructure

Federal Agencies

- DOC
- DOD
- DOE
- DOT
- EPA
- GSA
- DOI
- DHS
- NASA
- NSF
- USDA
- USPS

- *Interagency coordination through staff-level Interagency Working Group (meets monthly)*
- *Assistant Secretary-level Interagency Task Force mandated by EPACT 2005.*

External Input

- Annual Merit Review & Peer Evaluation
- H2 & Fuel Cell Technical Advisory Committee
- National Academies, GAO, etc.

Industry Partnerships & Stakeholder Assn's.

- Tech Teams (U.S.DRIVE)
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- Hydrogen Utility Group
- ~ 65 projects with 50 companies

Universities

~ 50 projects with 40 universities

DOE Hydrogen & Fuel Cells Program

State & Regional Partnerships

- California Fuel Cell Partnership
- California Stationary Fuel Cell Collaborative
- SC H_2 & Fuel Cell Alliance
- Upper Midwest Hydrogen Initiative
- Ohio Fuel Coalition
- Connecticut Center for Advanced Technology

International

- IEA Implementing agreements – 25 countries
- International Partnership for Hydrogen & Fuel Cells in the Economy – 17 countries & EC

National Laboratories

National Renewable Energy Laboratory P&D, S, FC, A, SC&S, TV, MN	Sandia P&D, S, SC&S	Lawrence Livermore P&D, S, SC&S
Argonne A, FC, P&D, SC&S	Pacific Northwest P&D, S, FC, SC&S, A	Savannah River S, P&D
Los Alamos S, FC, SC&S	Oak Ridge P&D, S, FC, A, SC&S	Brookhaven S, FC
	Lawrence Berkeley FC, A	Idaho National Lab P&D

Other Federal Labs: Jet Propulsion Lab, National Institute of Standards & Technology, National Energy Technology Lab (NETL)

P&D = Production & Delivery; S = Storage; FC = Fuel Cells; A = Analysis; SC&S = Safety, Codes & Standards; TV = Technology Validation, MN = Manufacturing

Meeting Objectives and Outcomes

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Objectives:

To identify research, development, and demonstration (RD&D) to enable low-cost, effective delivery of hydrogen from centralized production facilities to the point of use.

Outcomes:

- Summary of key barriers to development of low-cost hydrogen delivery
- Summary of key R&D activities with potential to reduce the cost of hydrogen delivery
- A workshop report for public dissemination of findings.-

Workshop Strategy

U.S. DEPARTMENT OF ENERGY

Tuesday: Pipelines

Wednesday: Over-the Road Delivery

Expert panel discussions and Breakout Sessions to address:

- Challenges (internal and external) to achieving DOE's cost goals for hydrogen delivery
- RD&D activities needed to overcome these barriers, including timeframe. When should these start and end?
- Key Issues such as cost, codes and standards adoption, and safety

Target $/gge	FY 2015	FY2020
Transport & Distribution	1.40	<1.30
Forecourt Station	1.60	<0.70

For More Information on the Hydrogen Delivery Portfolio

Fuel Cell Technologies Office Hydrogen Delivery website

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

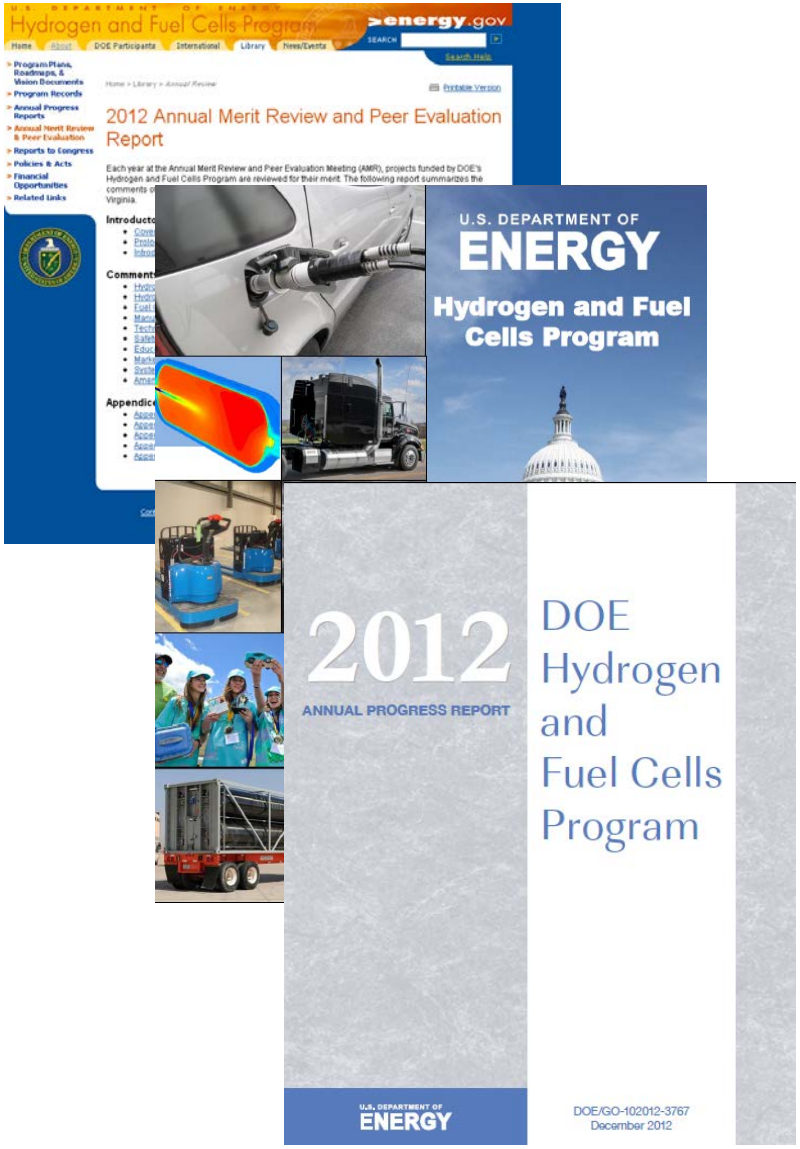
Multi-Year Research, Development and Demonstration Plan

http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/delivery.pdf

U.S. Drive Hydrogen Delivery Technical Team Roadmap

http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/hdtt_roadmap_june2013.pdf

Annual Merit Review



Annual Merit Review & Peer Evaluation Proceedings

Includes downloadable versions of all presentations at the Annual Merit Review

http://www.hydrogen.energy.gov/annual_review13_proceedings.html

Annual Merit Review & Peer Evaluation Report

Summarizes the comments of the Peer Review Panel at the Annual Merit Review and Peer Evaluation Meeting

http://www.hydrogen.energy.gov/annual_review12_report.html

Annual Progress Report

Summarizes activities and accomplishments within the Program over the preceding year, with reports on individual projects

http://www.hydrogen.energy.gov/annual_progress12.html

Save the Date

Next Annual Review: June 16–20, 2014 Washington, DC

http://annualmeritreview.energy.gov/

Thank You

For questions please contact:

Erika.Sutherland@ee.doe.gov

Or

Chris.Ainscough@go.doe.gov

Co-Launched Public-Private Partnership

U.S. DEPARTMENT OF ENERGY

H_2USA

Mission: To promote the commercial introduction and widespread adoption of FCEVs across America through creation of a public-private partnership to overcome the hurdle of establishing hydrogen infrastructure.

Current partners include (additional in process):

Fuel Cell & Hydrogen Energy Association

GlobalAutomakers

GM

U.S. DEPARTMENT OF ENERGY

DAIMLER

HYDROGENICS
Advanced Hydrogen Solutions

HONDA
The Power of Dreams

EDTA
Electric Drive Transportation Association

NISSAN

HYUNDAI

ITM POWER
Energy Storage | Clean Fuel

Mercedes-Benz

OAK RIDGE National Laboratory

AGA
American Gas Association

California Fuel Cell Partnership
DRIVING FOR THE FUTURE

SCRA

Sandia National Laboratories

PROTON
THE LEADER IN ON SITE GAS GENERATION.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

AIR LIQUIDE

arc:HYDROGEN

plug power

NUVERA
Making hydrogen make sense.

Massachusetts Hydrogen Coalition

TOYOTA

Argonne NATIONAL LABORATORY