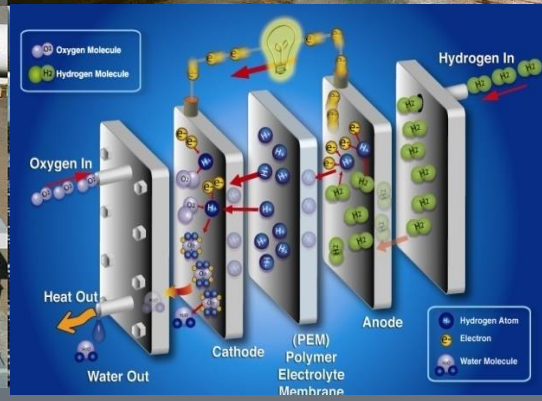
U.S Department of Energy Hydrogen and Fuel Cells Program

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



2015 Annual Merit Review and Peer Evaluation Meeting

Crystal City, VA

June 8, 2015

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

U.S. Department of Energy

Energy Policy Act of 2005 (Title VIII)

Program goals include:

"To enable a commitment by automakers *no later than year 2015* to offer safe, affordable, and technically viable hydrogen fuel cell vehicles in the mass consumer market"

FCEVs are on U.S. Roads Now!

Recently Announced Publicly

Available for commercial sale in the US during late 2015

Toyota Mirai Fuel Cell Vehicle

~10 public retail H_2 stations
100 stations planned in CA
Plans underway in Northeast, Hawaii

Now Leasing…

In Auto Shows…

OEMs bringing fuel cells vehicles to showrooms and driveways.

Toyota, Hyundai, Honda, GM, Daimler, Ford, Nissan, BMW, VW, and others!

FCEV Ride-n-Drive at DOE Headquarters

Click to see video

Plenary at Glance

- Budget
- Highlights
- Future Plans

Active in social media?

Share your thoughts using:

#H2IQ

#H2AMR

Hydrogen & Fuel Cells Budget

Key Activity	FY 15 Request ($ in thousands)	FY 15 Approp. ($ in thousands)	FY 16 Request ($ in thousands)
Fuel Cell R&D	33,000	33,000	36,000
Hydrogen Fuel R&D[1]	36,283	35,200	41,200
Manufacturing R&D	3,000	3,000	4,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	6,000	11,000	7,000
Safety, Codes and Standards	7,000	7,000	7,000
Market Transformation	3,000	3,000	3,000
NREL Site-wide Facilities Support	1,700	1,800	1,800
Total	$92,283	$97,000	103,000

Office	FY 2015
EERE	$97M
Basic Science[2]	~$20M
Fossil Energy, SOFC	$30M

FY 2015 DOE Total: ~$150M

Number of Recipients funded from 2008-2015	
Industry	>110
Universities	>100
Laboratories	12

[1]Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D
[2]Estimated from FY14 appropriation

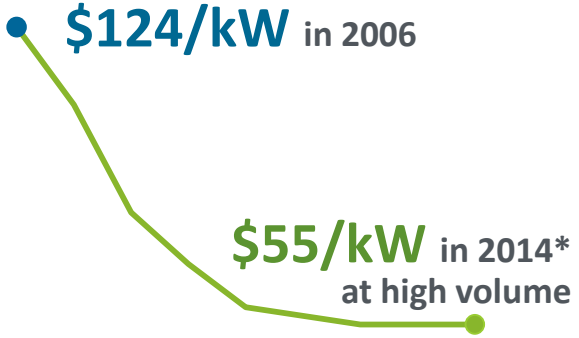
More stable R&D funding requests and appropriations in recent years
> 20 new projects including 11 new Incubator projects (2014-2015)

DOE Activities Span from R&D to Deployment

1. Research & Development

Cost Reductions

- 50% for fuel cell systems
- 5x less platinum
- > 2x increase in durability
- 80% for electrolyzers



2. Demonstration

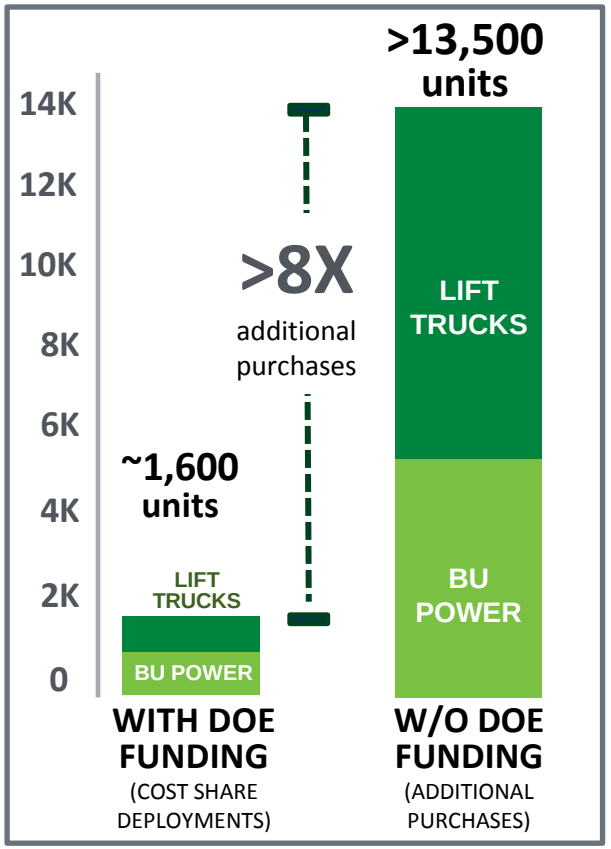
FCEV Demo

- >215 FCEVs, 30 stations, 5.7M miles traveled

World's first tri-gen station

Forklifts, back-up power, airport cargo tugs, marine APU, buses, mobile lighting

3. Deployment



Savings from Active Project Management

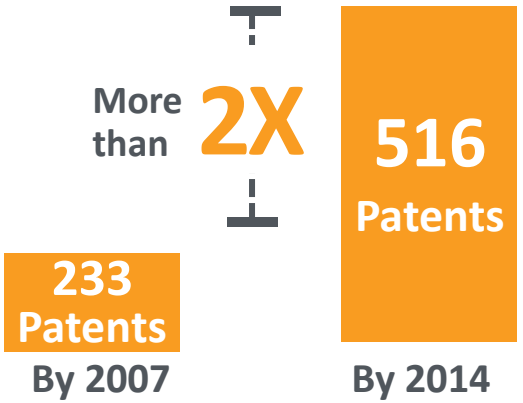
More than **$35M** last 5 yrs **&** More than **$3M** last year

6/15/2015

DOE Impact- H_2 and Fuel Cells

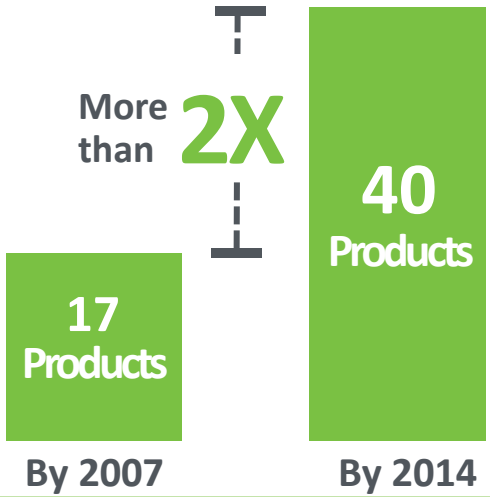
Innovation

Cumulative Number of Patents



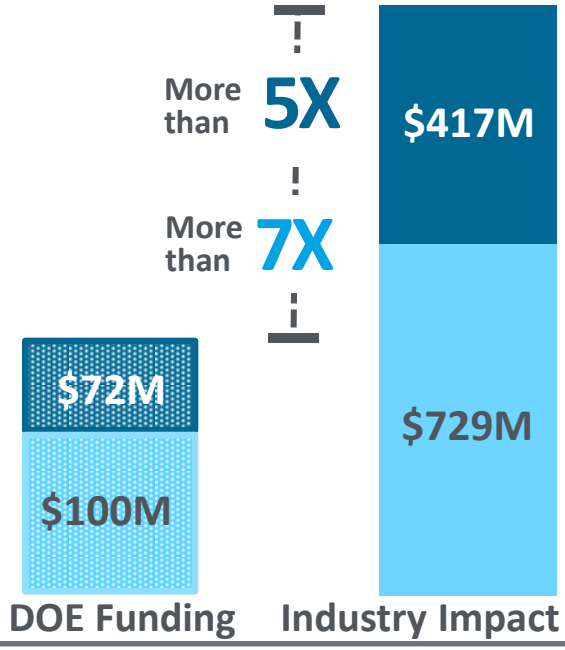
Commercialization

Commercial Products Entering the Market



Return on Investment

DOE impact on Private Investment and Industry Revenues



Jobs from commercial products and ARRA

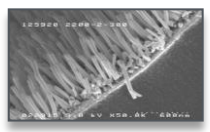
More than **450 jobs** tracked per year

1,400 jobs created or sustained

Commercial Products- Examples

Hexagon Lincoln's TITAN tube trailers

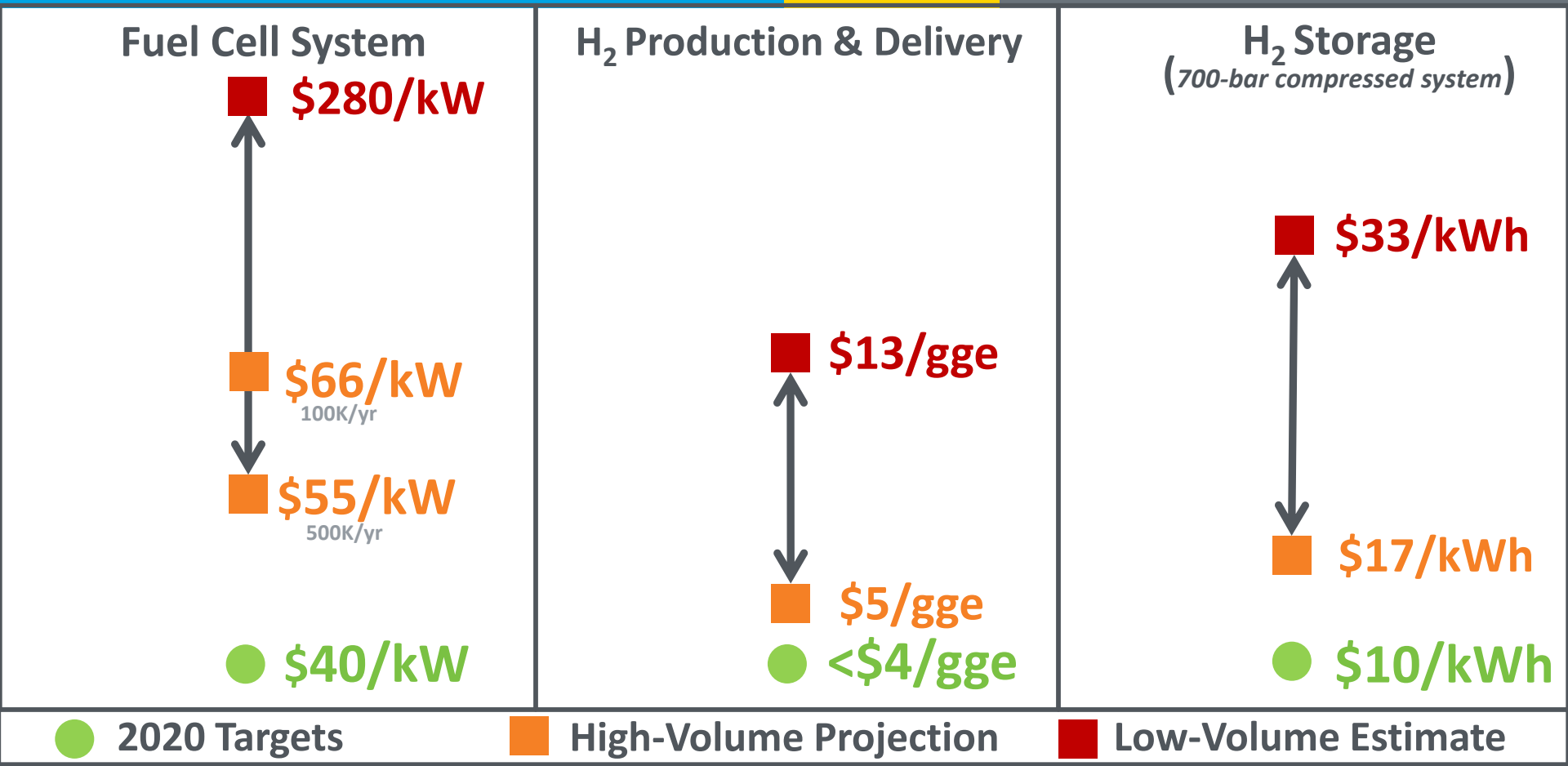
Plug Power GenDrive FCs



3M Cathode Catalysts

Proton's PEM Electrolyzer

DOE Cost Targets and Status



Key Challenges- Examples

- PGM loading
- Catalyst and membrane durability
- Electrode performance and durability

- Efficiency and Reliability
- Feedstock and Capital Costs
- Compression, Storage and Dispensing (CSD) Costs

- Carbon fiber precursors and conversion
- Composite/resin materials
- BOP and assembly costs

Techno-Economic Analysis Guides R&D Portfolio

Fuel Cells

Bipolar Plates
Membranes
BOP
MEA
Frames/Gaskets
GDLs

Focusing on…

Low and Non PGM Catalysts,

Alkaline Membranes

H_2 Station

Storage
Cooling
Dispensing
Other

Advanced Compression

Alternate Approaches

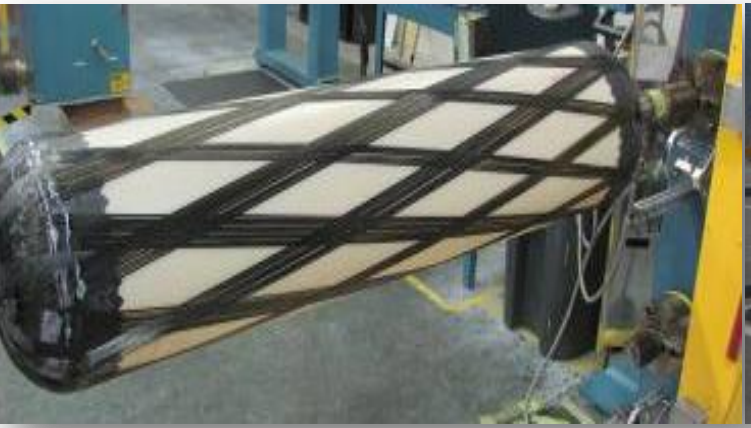
H_2 Storage

BOP/Assembly
Other processing
Resin

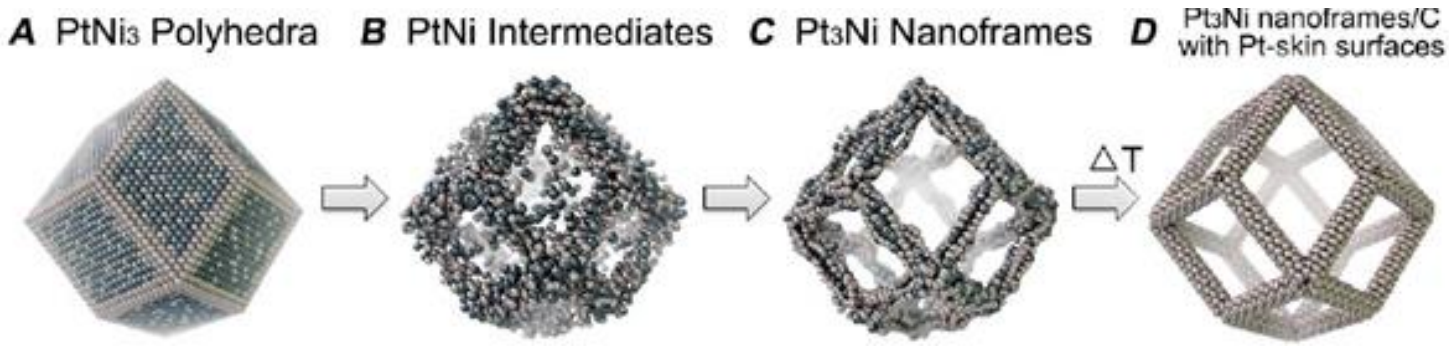
Low Cost Carbon Fiber (CF)

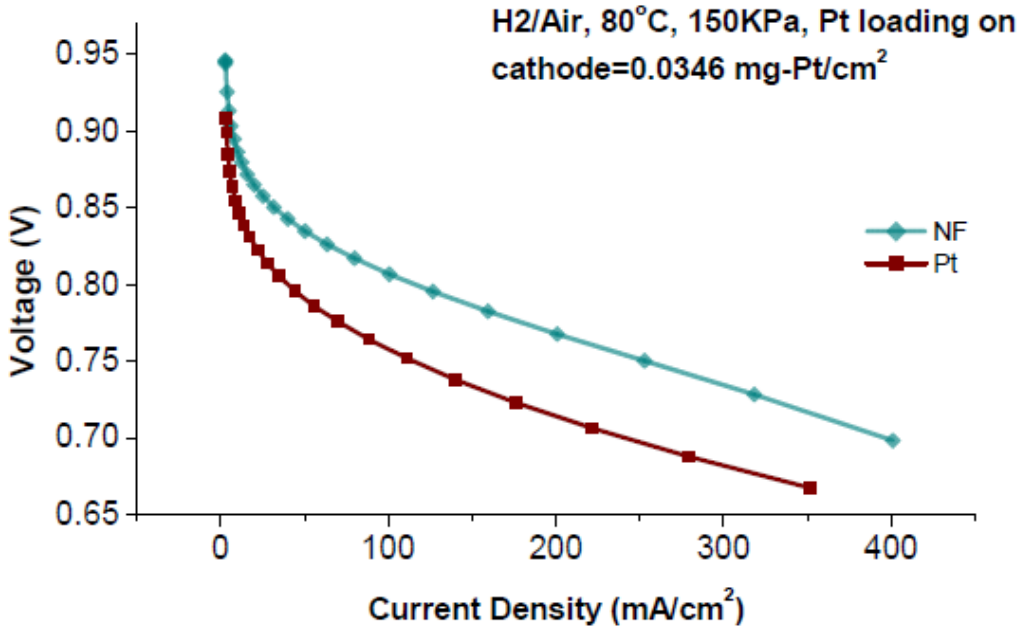
Long term Materials Approaches

Highlights



Fuel Cell Highlights: Nanosegregated Catalysts





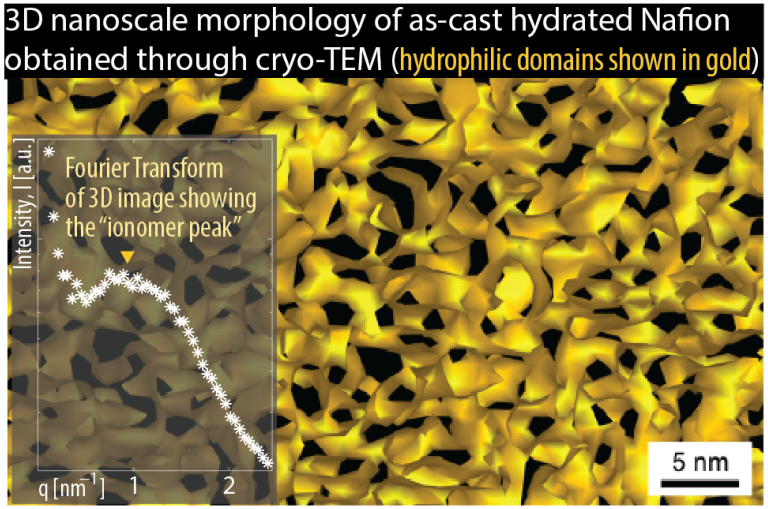
3X ↑ **in mass activity vs. Pt/C** ***(.035 mg)***

V. Stamenkovic, P. Yang, D. Myers, and coworkers, ANL, LBNL, LANL
Collaboration with BES

Nanoframe catalysts showed 3X mass activity of Pt/C in low-loaded MEA

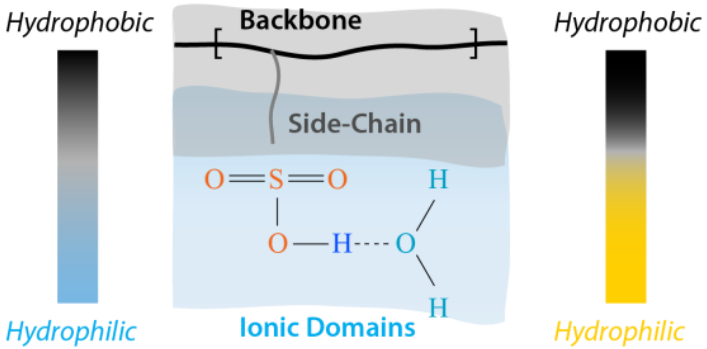
Fuel Cell Highlights: Advancing Capabilities

First Direct Imaging of 3D Morphology of Nafion



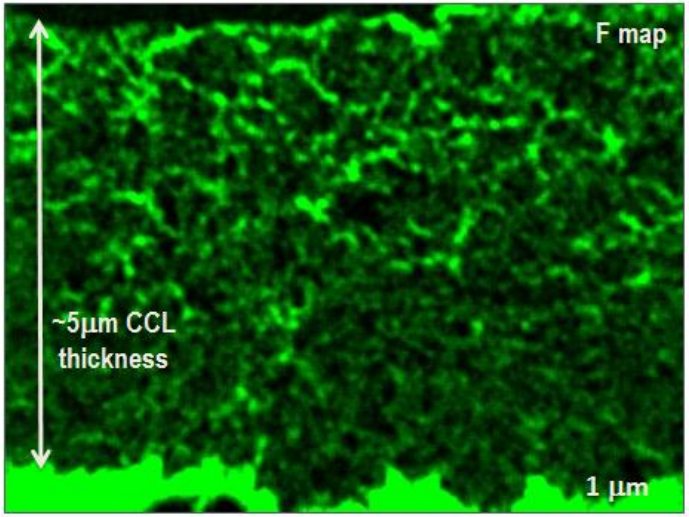
F.I. Allen, L.R. Comolli, A. Kusoglu, M.A. Modestino, A.M. Minor, A.Z. Weber, *ACS Macro Letters*, 4 (2015) 1-5 | DOI: 10.1021/mz500606

Phase-Separation with Hydration



A. Weber et al., LBNL

First Visualization of Ionomer Distributions



Ionomer distribution (Fluorine X-ray map) across full thickness of 5mm cathode catalyst layer (CCL) can be imaged

Collection Efficiencies with a 10-fold decrease in collection times

K. More et al., ORNL

Fuel Cell Highlights: FC-APOLLO

Developed Open-source application package for simulation of PEMFC performance and durability

- Includes Pt dissolution & carbon corrosion

Source code available via Source Forge at:

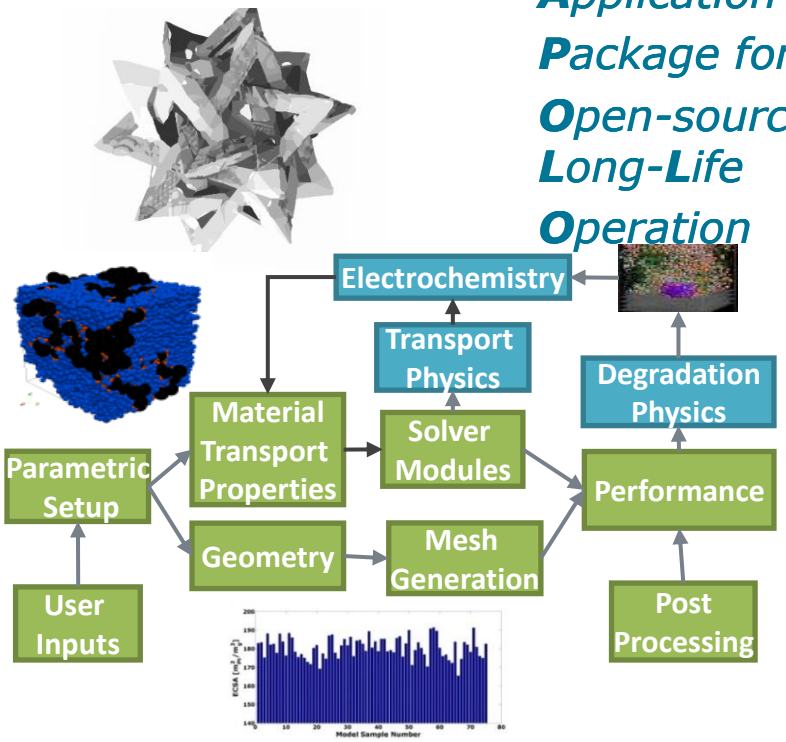
www.sourceforge.net/projects/fcapollo

Tutorial: June 10 , 4:15-6PM Gateway Salon J&K

Introduction to model, physics and reaction kinetics, the open source release, methods for access and use, and a general demonstration

FC-APOLLO

***F**uel*
***C**ell*
***A**pplication*
***P**ackage for*
***O**pen-source*
***L**ong-**L**ife*
***O**peration*



D. Harvey, et al., Ballard

2015 Goal → Catalyst Specific Power **6.5 kW/g_{PGM}**

Status → **Goal Met**

Hydrogen Production & Delivery Highlights

NSF/DOE MOU

Engineering Directorate
Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET)
NSF 14-511: NSF/DOE Partnership On Advanced Frontiers in Renewable Hydrogen Fuel Production via Solar Water Splitting Technologies

New Projects in Solar/High T Water Splitting Joint with NSF

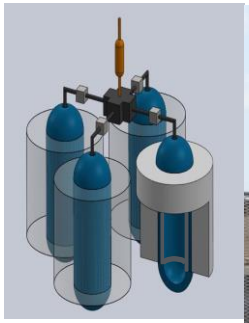
- *The University of Toledo, Yanfa Yan*
- *Stanford University: Thomas Jaramillo*
- *Rutgers University: Charles Dismukes*
- *The University of Colorado at Boulder: Charles Musgrave*

Computationally screened >1000 new compounds since 4/2015

Identified ~200 new redox materials compatible with high-efficiency flowing particle STCH reactor design

CU Boulder

Oak Ridge National Laboratory | Michigan | MegaStir – A Joint Venture of Schlumberger and Advanced Metal Products | Department of Transportation United States of America | ArcelorMittal | ASME Setting the Standard



Steel-Concrete Composite Vessel (SCCV) for Stationary High-Pressure Hydrogen Storage

Exceeded DOE 2015 cost target ($900/kg) for stationary gaseous hydrogen storage by > 20%.

2015 Goal

H_2 **from Renewables Cost:**

$6.80/gge*

* From $8.00/gge (2011, dispensed, untaxed)

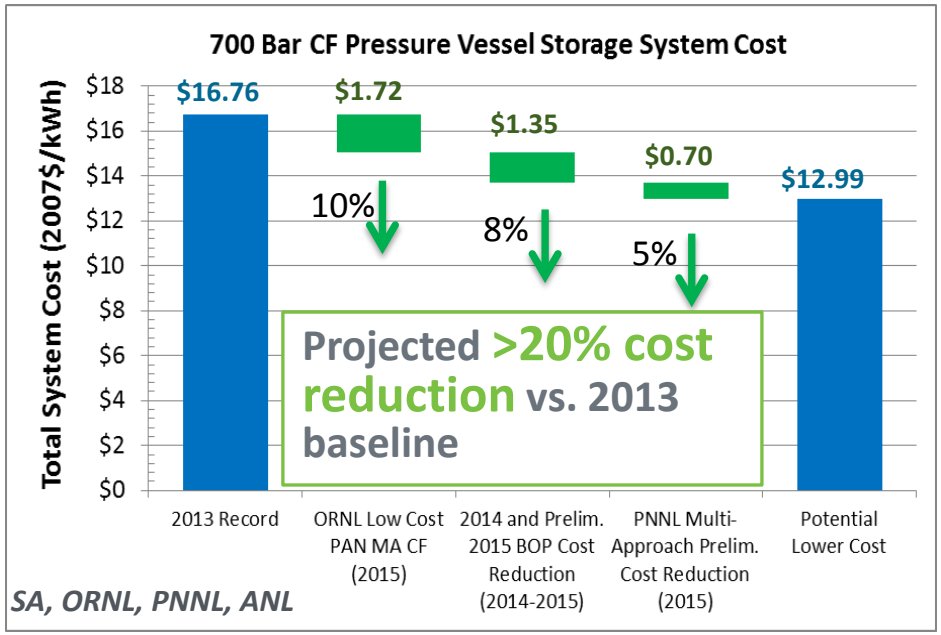
Status

On Track

High volume, projected cost

Hydrogen Storage Highlights

Cost Reduction of 700 bar H_2 Storage Systems



SA, ORNL, PNNL, ANL

- Launched 5 new storage materials projects

Class I Forklift with Fuel Cell and Metal Hydride System

- Developed metal Hydride H_2 Storage for Forklifts (SBIR Phase II) to overcome cost and high P fueling issues (fuels at < 60 bar)

Hawaii Hydrogen Carriers LLC, SNL, SRNL, Hydrogenics, URH2, Greenway Energy

2015 Goal

Reduce cost of 700-bar tanks:

15% cost reduction*

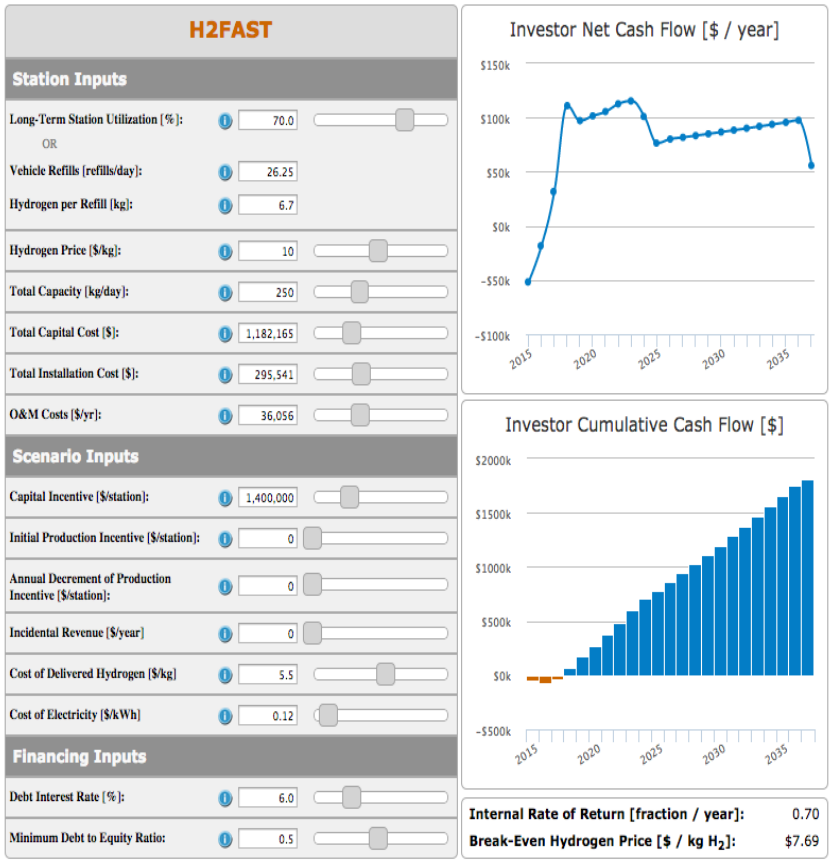
* vs. $17/kWh (baseline)

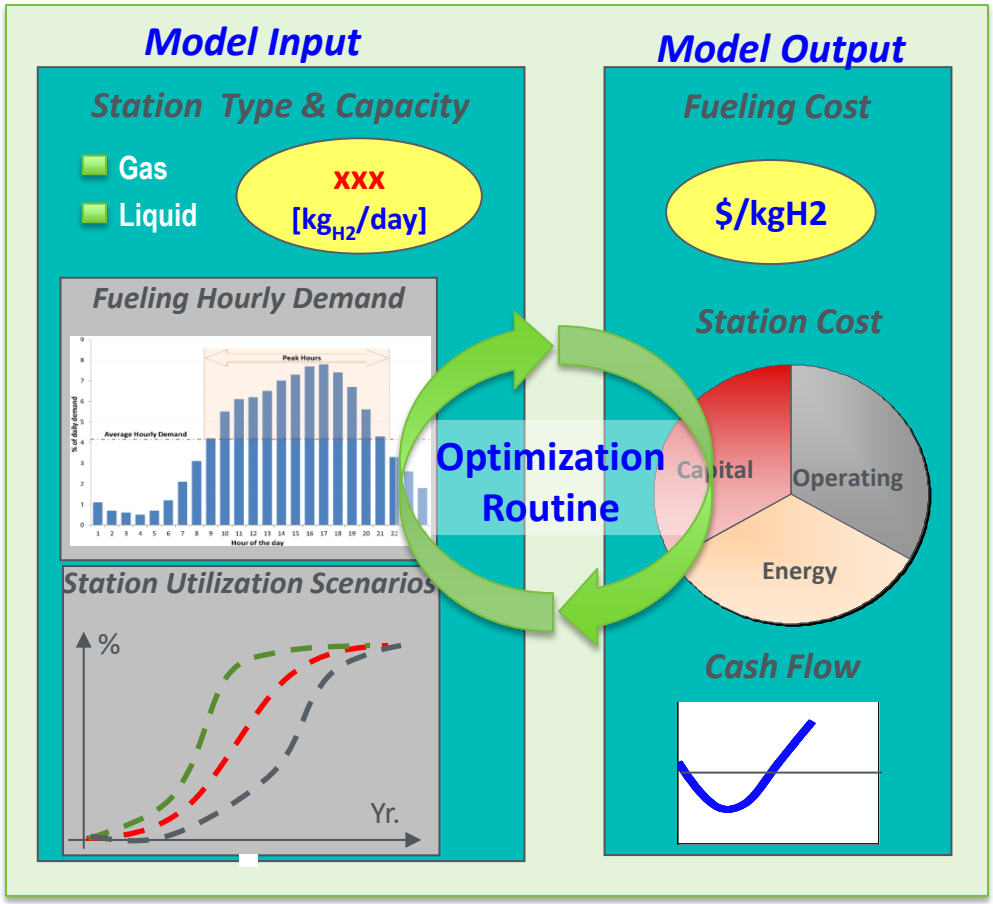
Status

On Track

High volume, modeled projected cost

Modeling and Online Tool Development for Stations



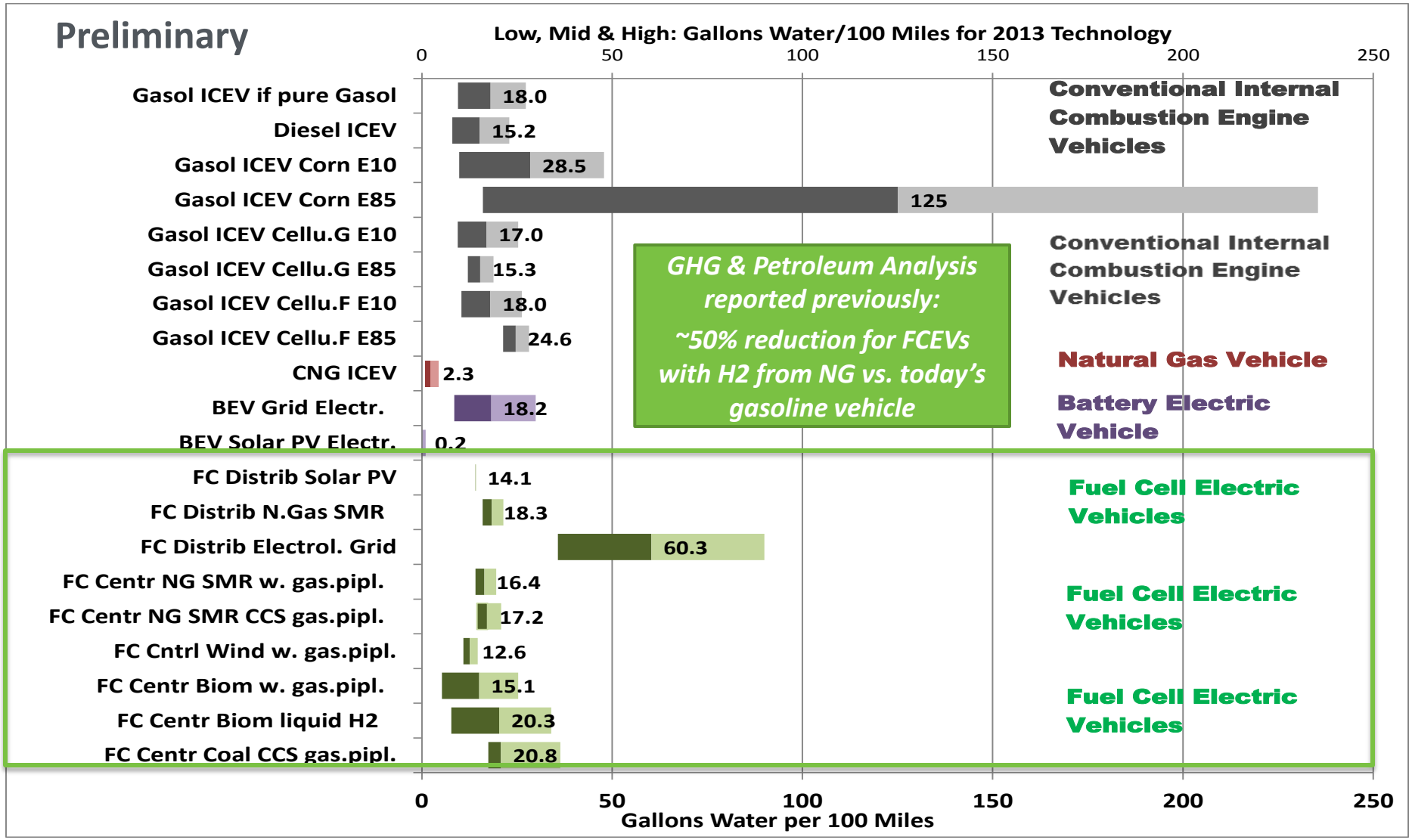


H2FAST- H2 Financial Analysis Scenario Tool
Web-based online calculator (NREL)

HRSAM- Hydrogen Refueling Station Analysis Model (ANL)

Station cost, optimized configurations and cash flow & ROI analyses to optimize financial viability of station options

Life Cycle Analysis of Water Use for Light Duty Vehicle Pathways



Numbers represent mid-range values, the left half-bar the low range, and the right half-bar the high range- DOE FCTO, VTO, BETO, ANL

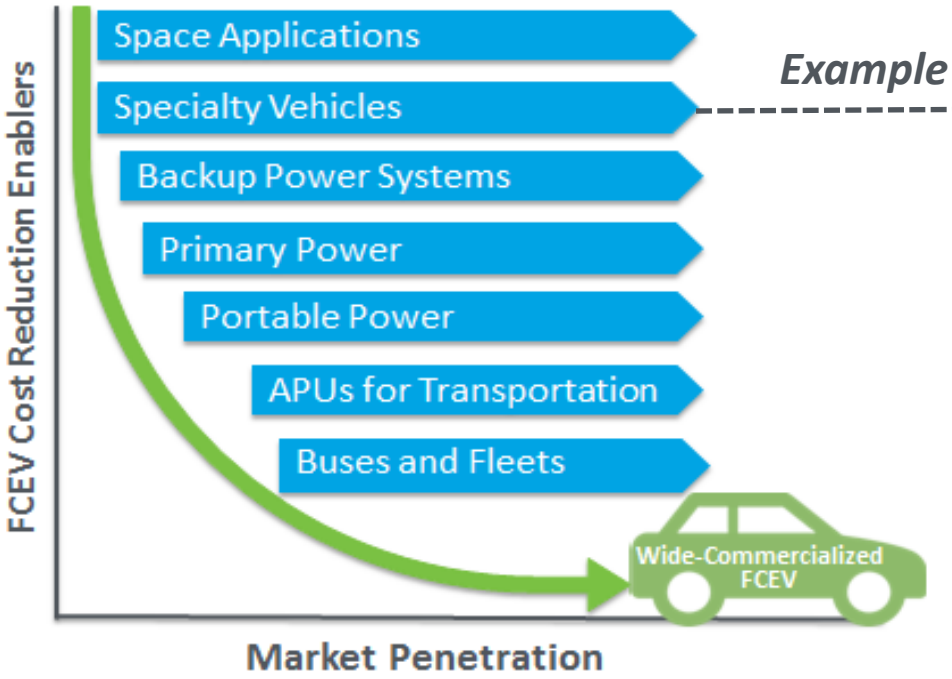
Water Consumption of H_2 Pathways Comparable to Conventional Fuels

DOE as Catalyzer of Early Markets

Early Markets enable:

- Fuel cell cost reduction
- Robust supply base
- Emerging Infrastructure
- Customer acceptance

Early Market Application Examples



Example

World's First Fuel Cell Cargo Trucks at Memphis International Airport

facebook Post Stats:

More than **180 shares** **240 likes** → **Over 45,000** people reached

World Record Set by Fuel Cell Electric Bus

AC TRANSIT **FLEET**

Operated for more than **145,000** hours

US Hybrid-AC Transit Fuel Cell Electric Bus

FTA Funding and Collaboration with DOE- NREL Data collection

AC TRANSIT **BUS**

Operated for more than **19,500** hours

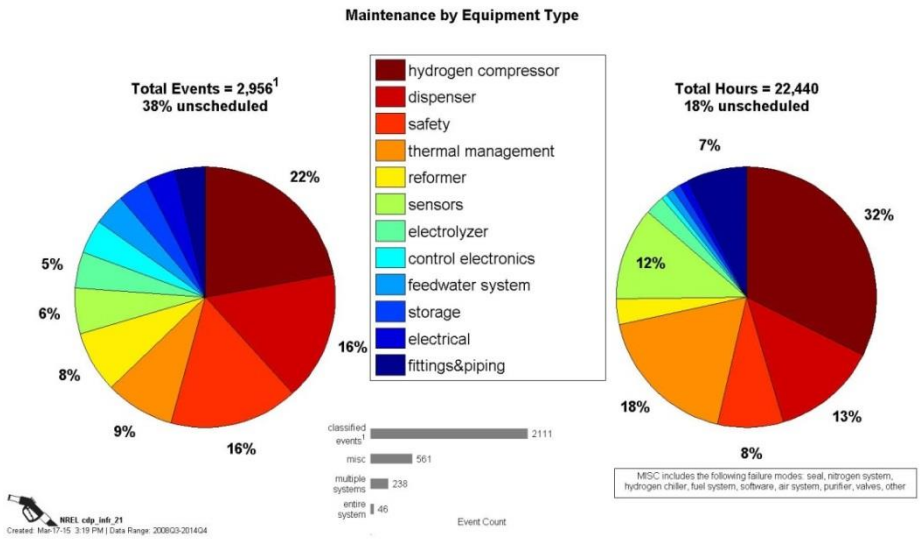
With **ZERO failure**

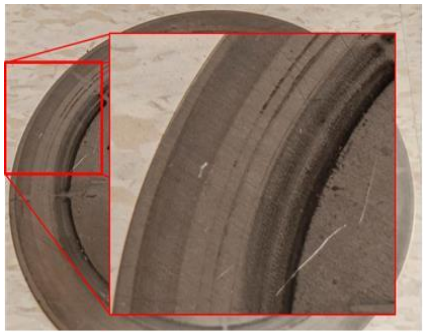
Exceeding DOE's **18,000** hours
2016 target

Fuel Cell Engine Demonstrated Reliability for Transit Bus Fleet

Highlights from Real World Operation

- CSULA- First in U.S. to receive seal of approval for sale of H_2 Jan 2015
- New **data collection** projects with OEMs (Toyota, Hyundai, Honda, Nissan, Daimler, GM)
  - **2.4 million miles**
  - >**50% of FCEVs on road showed 50-55 mpgge fuel economy**
- Determined **causes for >2,900** maintenance events
- Developed **safety and contaminant sensor** technologies at LANL
- Developed and **tested fuel cell power system** for pier-side and auxiliary sea vessel power





Determined contaminant source (siloxane) & identified potential substitutes (e.g. PTFE-based grease can be suitable replacement with minimal effects)
Fuel cell system contaminants material screening database (NREL):
www.nrel.gov/hydrogen/system_contaminants_data/

H_2USA to address H_2 Infrastructure Challenges

*Representative sample of member logos

Public-Private Partnership with 4X increase in partners since 2013

Hydrogen Fueling Infrastructure Research Station Technology

Leveraging Expertise of National Labs

NREL NATIONAL RENEWABLE ENERGY LABORATORY & Sandia National Laboratories

H_2FIRST In Support of

H_2 USA and tasked to deliver:

Outstanding Partnership Award

By the Federal Laboratory Consortium (FLC) for efforts toward deployment of hydrogen fueling infrastructure

Reference Station Design

✓ Report Delivered with Detailed Station Designs and Cost Estimates

Fuel Contaminant Detection

✓ Market Survey and Gap Analysis Complete

HyStEP Device

✓ Design Complete - Currently Under Construction

- H_2 Station Equipment Performance Device
- H_2First Inaugural Task
- HyStEP will help reduce time required to place H_2 stations in service

DOE's H_2FIRST project supports H2USA goals to address infrastructure

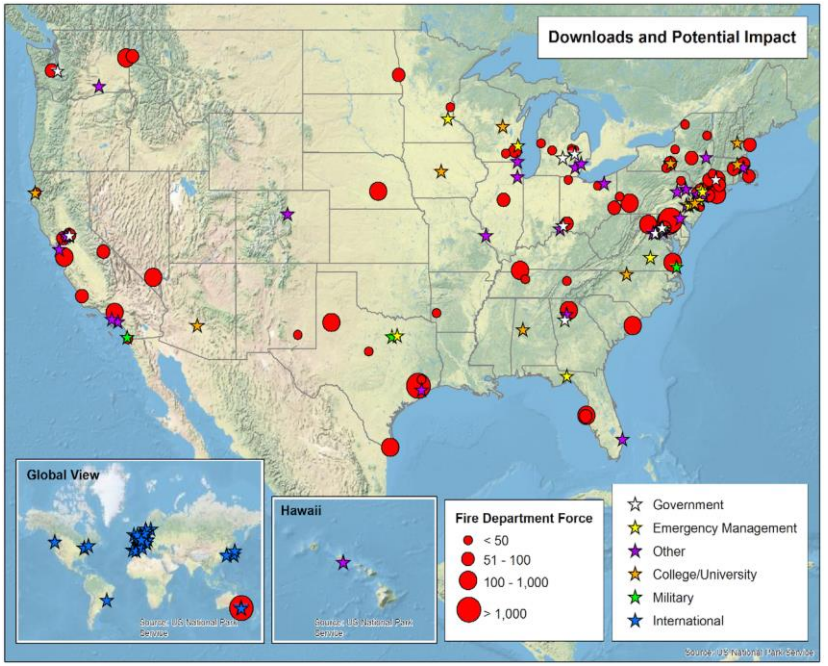
Safety Codes and Standards Highlights

H2Tools

Consolidated safety and knowledge resources into a central location, alongside newly added functionality and content

PNNL

Safety Training for First Responders

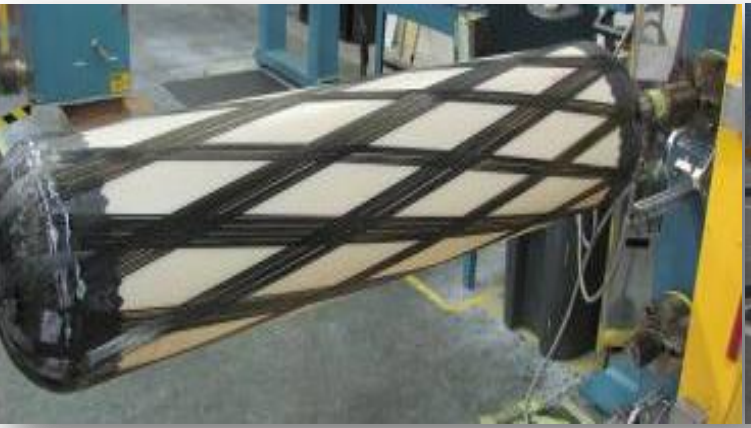


Tracking interest in first responder training resources across the country, including along the northeast corridor

PNNL, CaFCP

Reached more than 35,000 code officials and first responders

Going Forward



Recent FY15 DOE Funding Announcements

H-Prize: $1 million competition for on-site home and community-scale H_2 fueling systems.

1st Year (due 10/15)

Teams form and submit designs

2nd Year (due 10/16)

Selection of finalists and testing

Technical and cost analysis to select winner

$1M Award

For more Information visit hydrogenprize.org

FY15 FOA- Up to $35 Million

Research and Development:

H_2 production, low PGM fuel cell catalysts, H_2 dispensers, pipeline manufacturing R&D

Demonstration and Deployments:

Mobile refueling, plug-in fuel cell hybrid vehicle, technical assistance to communities deploying fuel cells

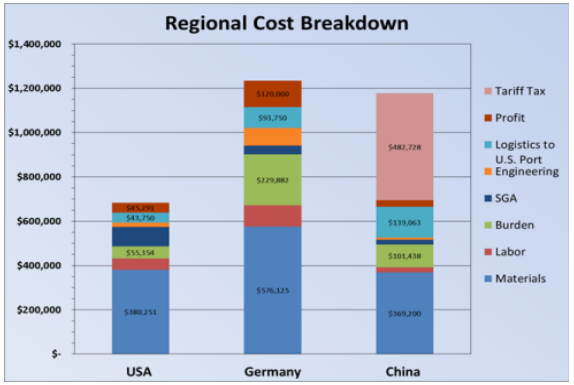
Manufacturing Highlights: 3 New Analysis Projects

Global Competitiveness Analysis

including:

- Global Cost Breakdown
- Design for Manufacturing
- Value Stream Mapping

GLWN.org



Integrated Network of Regional Technical Centers

Located at

1. East Coast (CCAT)
2. Midwest at the OFCC
3. Central States at NREL's National Fuel Cell Technology Evaluation Center
4. West Coast (UC Irvine)

Activities (Examples)

- Hold supply chain exchanges
- Promote cooperation between suppliers & standardization of component specs

OFCC OHIO FUEL CELL COALITION

Fuel Cell and H_2 Opportunity Center

- Comprehensive **online database**
- **Project activities include:**
  - Encourage **supplier engagement**
  - Release and maintain **public directory**
  - Conduct **outreach campaign** (social media, etc.)

JAMES MADISON UNIVERSITY

Emphasis on Tech to Market Activities with Labs

FCTO T2M Strategy

Increase Industry Contact

- Business-to-Business Product Theater (11 Labs)
- Manufacturing Road Show
- Small Business Vouchers, TTOs (SBIRs)

Listen to the Voice of the Customer

- Key Staff Exchange with stakeholders
- Engagement with companies

Develop Technology Transfer Skills

- Business Plan Development Training
- Lab Corps

Increase Market Understanding

Improve Private Sector Relationships

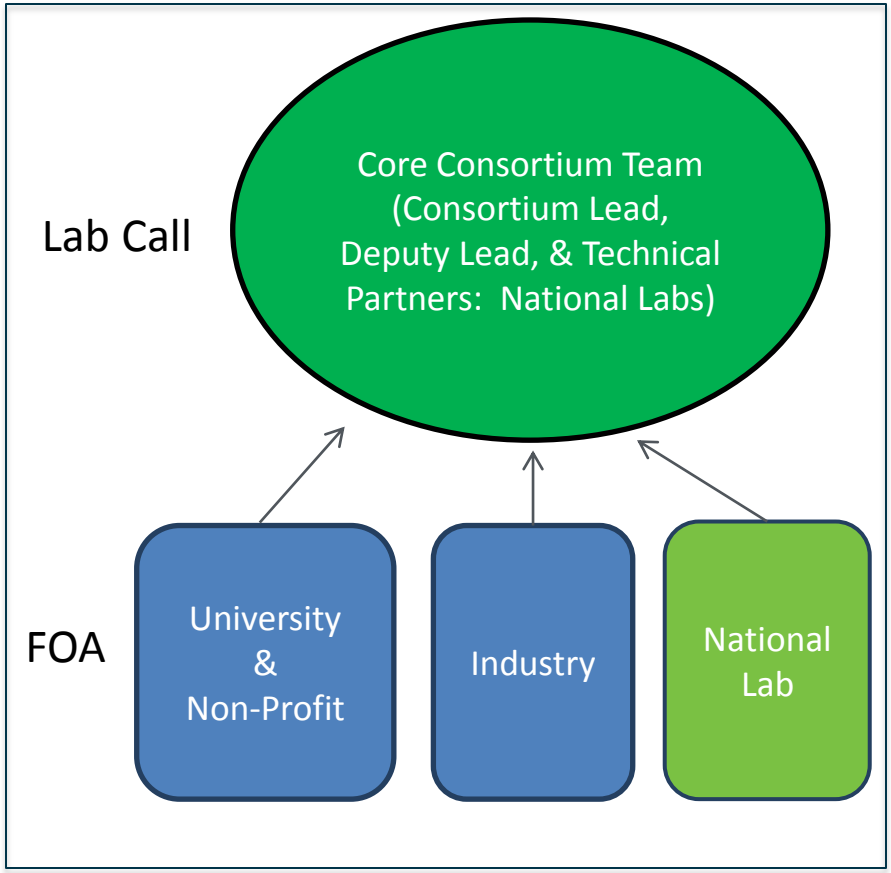
Held T2M Event at FC Seminar, future plans at ECS (Oct. 2015)

Future Plans

Consortia Strategy

Multi-Lab Team: Lab Call to competitively select core for Consortium

1) **Fuel Cells: FC-PAD**
   Fuel Cell Performance and Durability
2) **Storage: Hy-MARC**
   Hydrogen Storage Materials Advanced Research Consortium
3) **Production: H2RENEW**
   Hydrogen Production from Renewables



Future FOAs (subject to appropriations)

- Add Industry, University, Lab Projects (e.g. 2-4 yrs/project)

Potential Collaborations
Office of Science , Advanced Manufacturing Office, Relevant Offices and Other Agencies

Future Plans: Feedback from Stakeholders

Request for Information Planned, including:

- Gas clean up technologies (2014 workshop results)
- Early market opportunities
  - Targets for medium/heavy duty trucks
  - Co-locating CNG and H_2 stations/components
  - Fuel-to-you approaches (e.g. small-scale/"Peapod" delivery)
- Education and outreach gaps and needs
  - Workforce development, training, students, teachers, etc.

First Lady's and Dr. Jill Biden's Initiative: Joining Forces

Supporting veterans and their families in 3 areas:

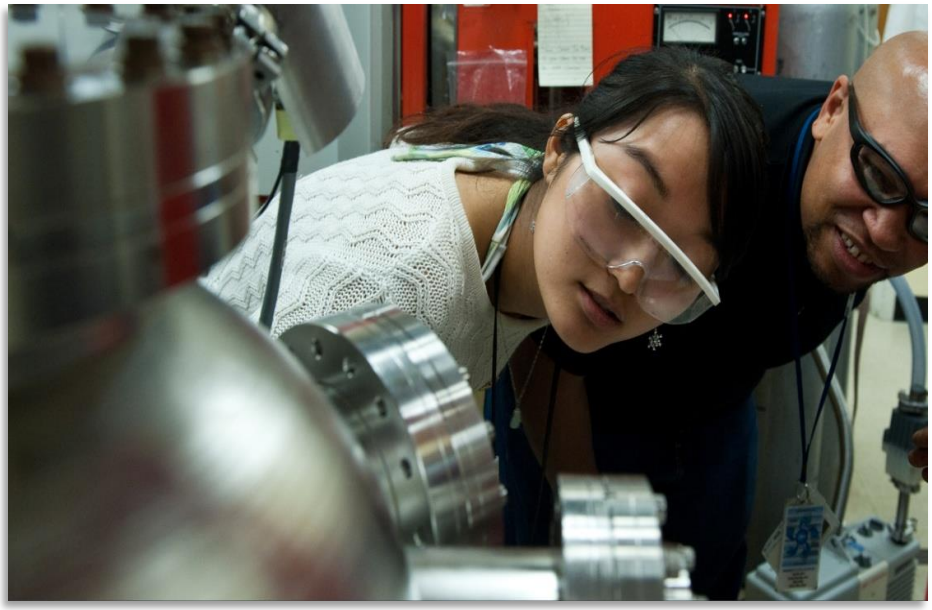
- Wellness
- Education
- Employment

Strong Commitment by the H_2 and Fuel Cells Community

Air Liquide and PDC committed to hiring veterans for 10% of their workforce

Two Fellowship Opportunities Available!

- Two Areas:
  1. **Fuel Cells R&D**
  2. **H_2 Storage Materials**
- Ph.D. is required, experience preferred
- 2 Year Fellowship
- Located in Washington, D.C.
- Health benefits and relocation expenses included



Apply now!

For Fuel Cells

https://www.zintellect.com/Posting/Details/1078

For H_2 Storage

https://www.zintellect.com/Posting/Details/1079

Collaborations and Partnerships

R&D → **Demonstration & Deployment** → **Accelerated Commercialization**

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

- Pre-Competitive R&D
- USCAR, energy companies, EPRI and utilities

California Fuel Cell Partnership
SC Hydrogen & Fuel Cell Alliance www.SCHydrogen.org
H2I Hawai'i Hydrogen Initiative
Connecticut Hydrogen-Fuel Cell Coalition
NESCAUM

- State Partnership and Collaboration

IPHE

- International Government Coordination
- 17 countries and European Commission

iea International Energy Agency

- Implementing Agreements
- 25 countries

H2FIRST
Hydrogen Fueling Infrastructure Research and Station Technology

- National Lab (SNL & NREL) led activities with industry to support H2USA

H2USA

- Public-Private Partnership to enable infrastructure >40 partners

FCTO also collaborates with multiple Agencies including DOC, DOD, DOT, EPA, NASA, NSF, USDA, USPS, and State Governments

Recent Recognitions and Awards- Examples

Rod Borup (LANL)
2015 Research Award by Energy Technology Division of the Electrochemical Society (ECS)

Jennifer Kurtz, Keith Wipke (NREL) and Daniel Dedrick (SNL)
2014 FLC Far West Regional Awards

Muhammad Arif (NIST)
NIST Fellow Honor

Jamie Holladay (PNNL)
Most-Downloaded Article from Science Direct

Adam Weber (LBNL)
2013 Presidential Early Career Award for Scientists & Engineers (PECASE) , 2014 Charles W. Tobias Award, 2014 Kavli Fellow of the National Academy Sciences Award

Y. F. (John) Khalil (UTC)
The Institution of Chemical Engineers (IChemE) Senior Moulton Medal

Piotr Zelenay (LANL)
LANL Fellows Prize for Outstanding Research

Ian M. Robertson (U. of Wisconsin)
2014 ASM Edward DeMille Campbell Memorial Lectureship Award

Proton Onsite
2015 Presidential "E- Award" and New Electrochemical Technology (NET) Award

Dr. Branko Popov (U. of South Carolina)
2014 World's Most Influential Scientific Minds & Highly Cited Researchers by Thomson Reuters

In Memory

Bill Cleary

Tribute from the Fuel Cell Technologies Office, Vehicle Technologies Office and Argonne National Lab

Thank You

Dr. Sunita Satyapal

Director

Fuel Cell Technologies Office

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hydrogenandfuelcells.energy.gov

FY13-FY15 Funding by State (FCTO)

State	FY13-FY15 Total Funding	Industry, National Laboratories, Universities, and Government Entities	
California	**$34.7M**	California Air Resources Board California State University, Los Angeles CalTech Lawrence Berkeley National Laboratory Lawrence Livermore National Laboratory NASA Jet Propulsion Laboratory Sandia National Laboratory Stanford University University of California, Davis University of California, Berkeley	Ardica Electricore H2 Technology Consulting HRL Laboratories J. Craig Venter Institute Materia Mercedes-Benz Research and Development, NA Quantum Technologies
Colorado	**$43.8M**	Colorado School of Mines National Renewable Energy Laboratory	University of Colorado, Boulder TDA Research
Connecticut	**$7.6M**	Fuel Cell Energy Proton OnSite	United Technologies Research Center
District of Columbia	**$0.04M**	U.S. Department of Transportation	
Delaware	**$0.1M**	Ion Power	
Georgia	**$1.5M**	CTE	
Hawaii	**$4.3M**	University of Hawaii	
Idaho	**$2.2M**	Idaho National Laboratory	
Illinois	**$22.3M**	Argonne National Laboratory Illinois Institute of Technology	Gas Technology Institute Northwestern University
Massachusetts	**$5.2M**	Ballard, now Avcarb Boston College Northeastern University	Giner Nuvera Fuel Cells
Maryland	**$4.6M**	National Institute of Standards and Technology (NIST) EnergyWorks	RedOx Fuel Cells W. L. Gore & Associates
Michigan	**$4.1M**	Eaton Ford	General Motors
Minnesota	**$4.0M**	3M	
Missouri	**$0.4M**	University of Missouri, Columbia	
Nebraska	**$0.8M**	Hexagon Lincoln	
New Jersey	**$0.2M**	BASF	
New Mexico	**$20.7M**	Los Alamos National Laboratory NASA	Sandia National Laboratory

FY13-FY15 Funding by State (FCTO)

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New York	**$10.1M**	Brookhaven National Laboratory General Motors	H2Pump Mohawk Innovative Technologies
North Carolina	**$0.5M**	PPG	
Ohio	**$1.3M**	Battelle	Midwest Optoelectronics
Oregon	**$0.7M**	Oregon State University	
Pennsylvania	**$1.6M**	Penn State University Air Products and Chemicals Arkema	Dynalene PPG
South Carolina	**$10.1M**	Savannah River National Laboratory	University of South Carolina
Tennessee	**$18.5M**	Oak Ridge National Laboratory ORISE	FedEx Express
Texas	**$1.8M**	Southwest Research Institute	
Virginia	**$5.2M**	Nanosonic Sprint	Strategic Analysis Wiretough Cylinders
Washington	**$12.7M**	Pacific Northwest National Laboratory	Innovatek