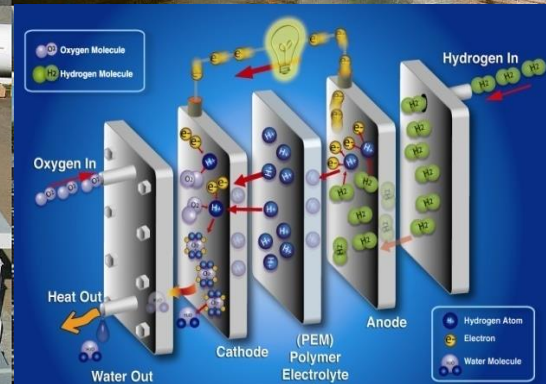


U.S Department of Energy Hydrogen and Fuel Cells Program

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 H₂ stations
100 stations planned in CA
Plans underway in Northeast, Hawaii

Now Leasing...



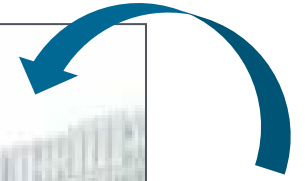
In Auto Shows...

Honda Fuel Cell Electric Vehicle



OEMs bringing fuel cells vehicles to showrooms and driveways.

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



[Click to see
video](#)

- **Budget**
- **Highlights**
- **Future Plans**



Active in social media?
Share your thoughts using:

#H2IQ
#H2AMR

Hydrogen & Fuel Cells Budget

Key Activity	FY 15	FY 15	FY 16
	(\$ in thousands)		
	Request	Approp.	Request
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

¹Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

²Estimated 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

\$124/kW in 2006

\$55/kW in 2014*
at high volume

*\$280/kW low volume



2. Demonstration

FCEV Demo

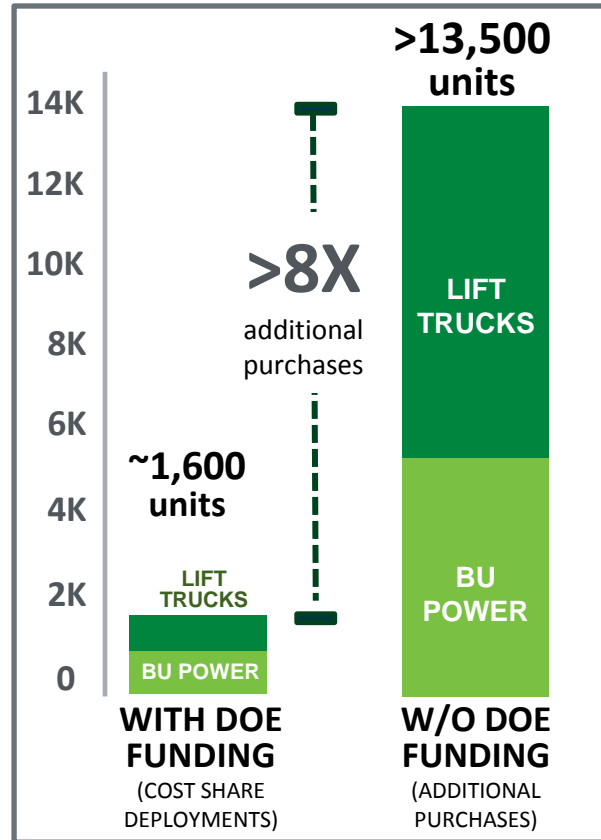
- **>215** FCEVs, **30** stations,
5.7M miles traveled

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



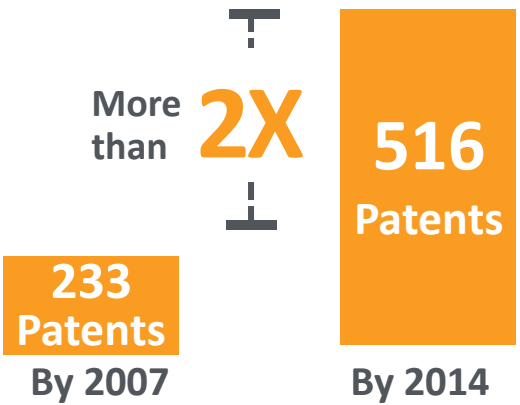
**More than
\$3M** last year

DOE Impact- H₂ and Fuel Cells



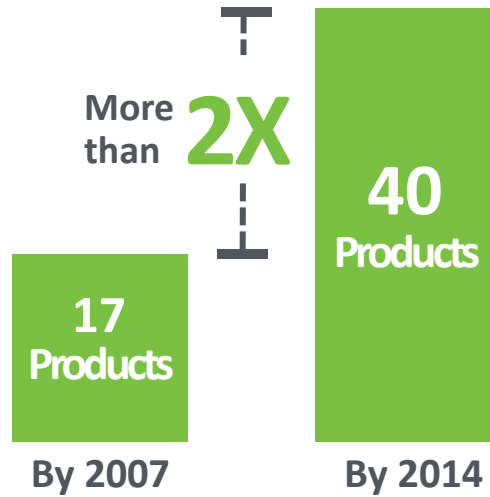
Innovation

Cumulative Number of Patents



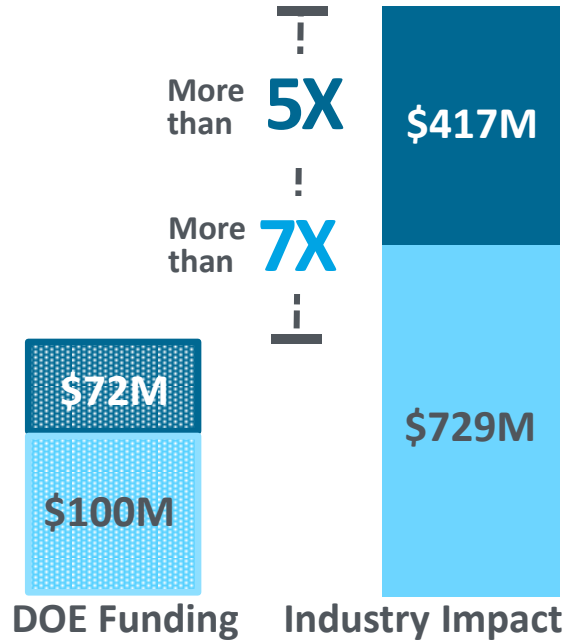
Commercialization

Commercial Products Entering the Market



Return on Investment

DOE impact on **Private Investment** and **Industry Revenues**



Jobs from commercial products and ARRA



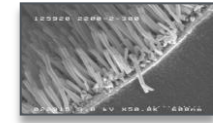
Commercial Products- Examples



Hexagon Lincoln's TITAN tube trailers



Plug Power GenDrive FCs



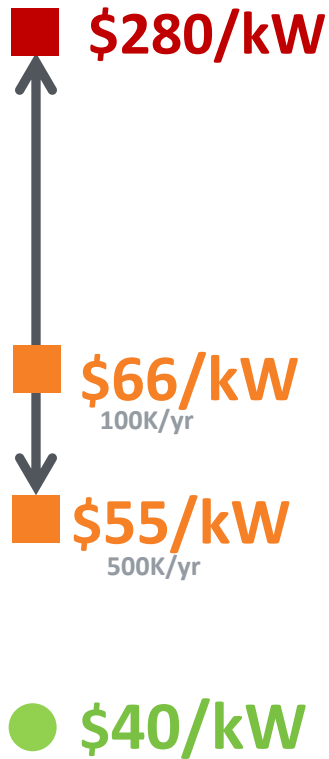
3M Cathode Catalysts



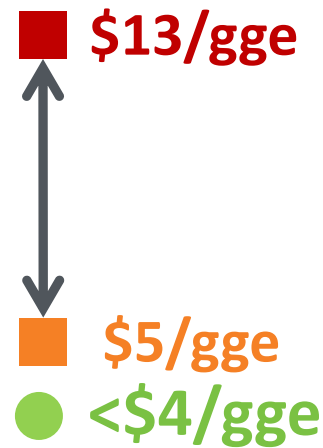
Proton's PEM Electrolyzer

DOE Cost Targets and Status

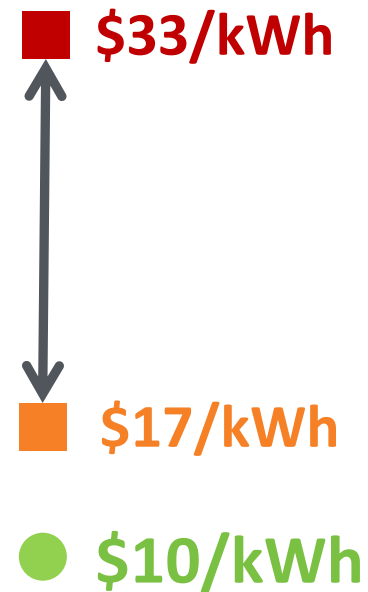
Fuel Cell System



H₂ Production & Delivery



H₂ Storage (700-bar compressed system)



● 2020 Targets

■ High-Volume Projection

■ Low-Volume Estimate

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

H₂ Station

- Storage
- Cooling
- Dispensing
- Other



Advanced Compression Alternate Approaches

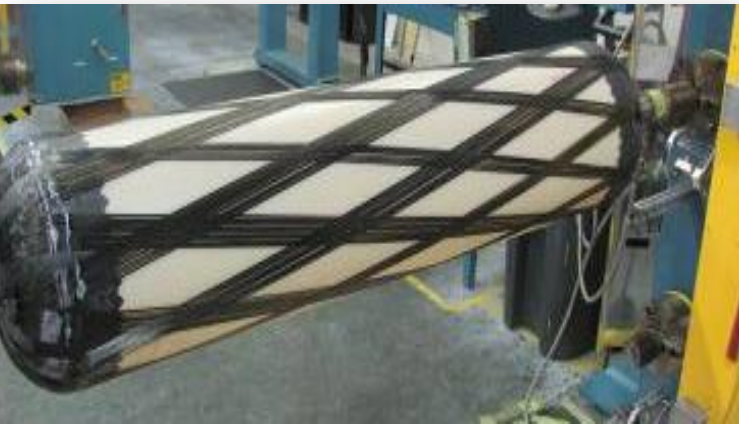
H₂ Storage

- BOP/Assembly
- Other processing
- Resin

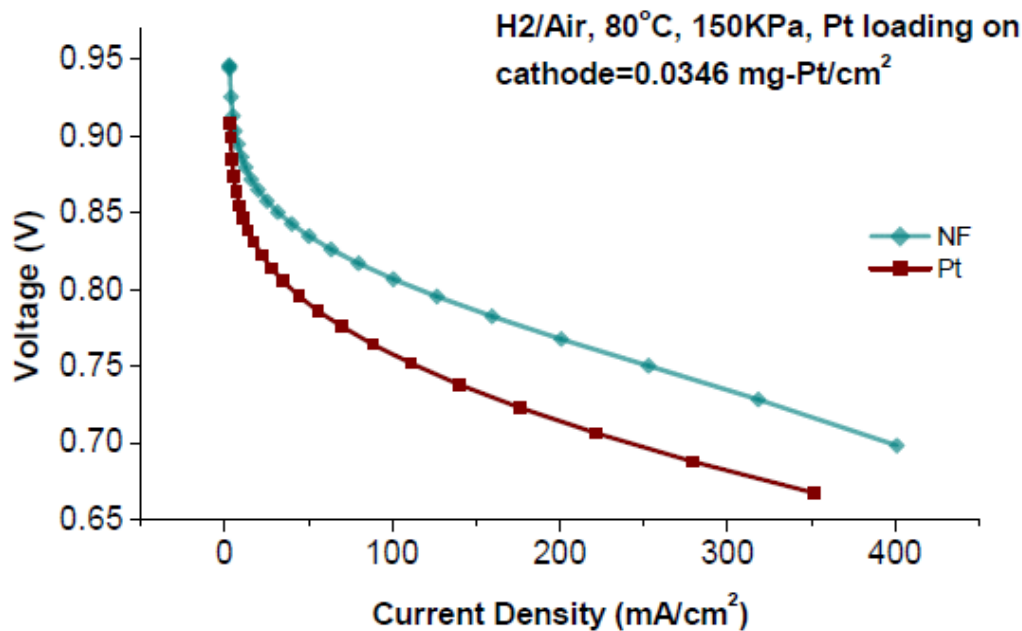
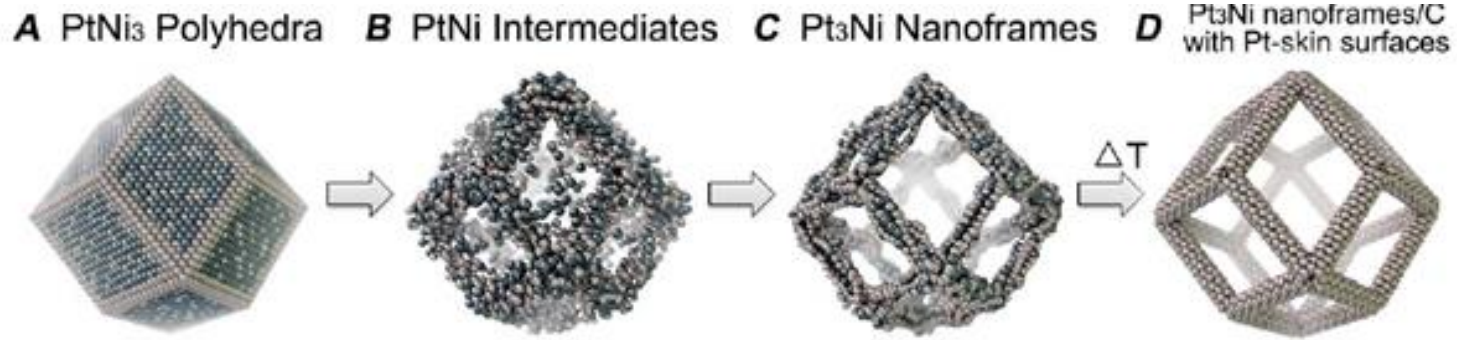


Low Cost Carbon Fiber (CF) Long term Materials Approaches

Highlights



Fuel Cell Highlights: Nanosegregated Catalysts



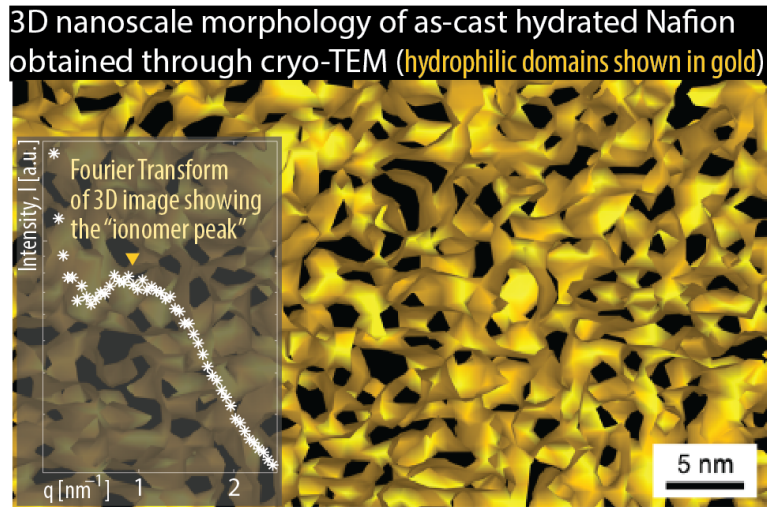
3X ↑
 in mass activity
 vs. Pt/C
 (.035 mg)

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

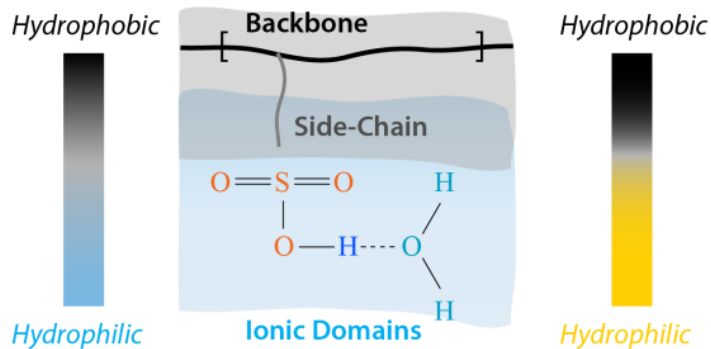
Fuel Cell Highlights: Advancing Capabilities

First Direct Imaging of 3D Morphology of Nafion



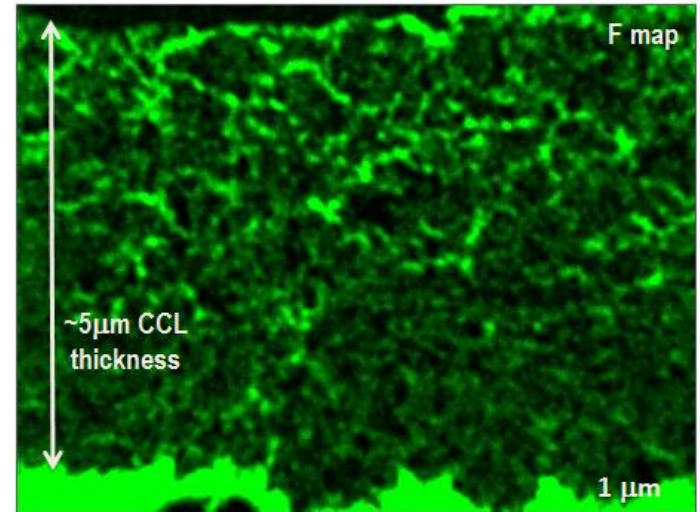
F.I. Allen, L.R. Comolli, A. Kusoglu, M.A. Modestino, A.M. Minor, A.Z. Weber, *ACS Macro Letters*, 4 (2015) 1-5 | DOI: 10.1021/mz500606

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
 6/15/2015

Fuel Cell Highlights: FC-APOLLO

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

- Includes Pt dissolution & carbon corrosion

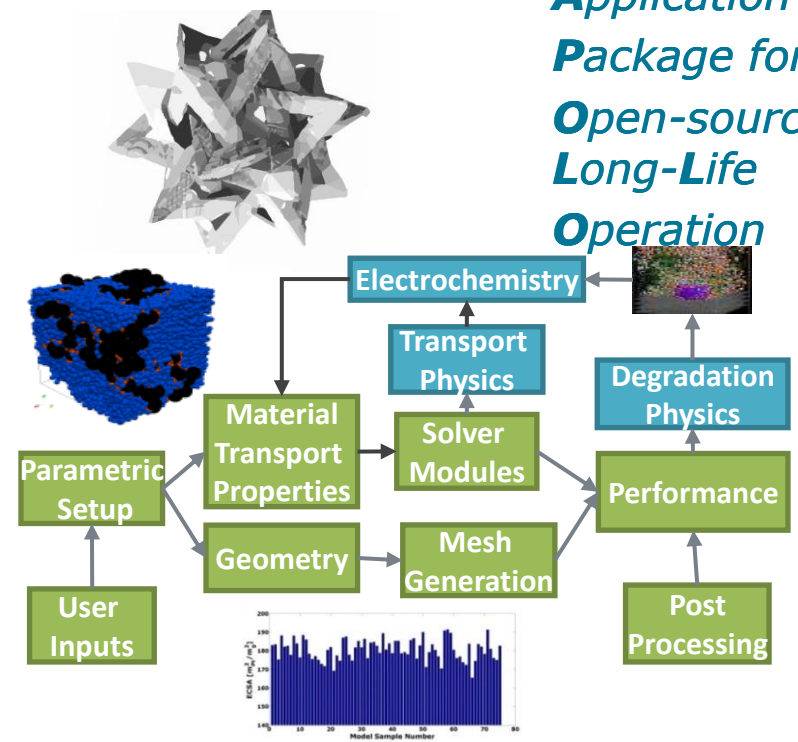
Source code available via Source Forge at:
www.sourceforge.net/projects/fcapollo

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

Fuel Cell Application Package for Open-source Long-Life Operation




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**

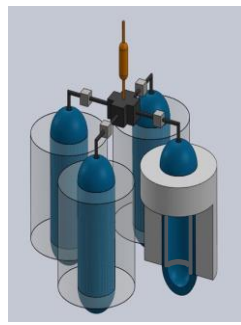
New Projects in Solar/High T Water Splitting Joint with NSF

- *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

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

H₂ from Renewables Cost:
\$6.80/gge*
 * From \$8.00/gge (2011,
 dispensed, untaxed)

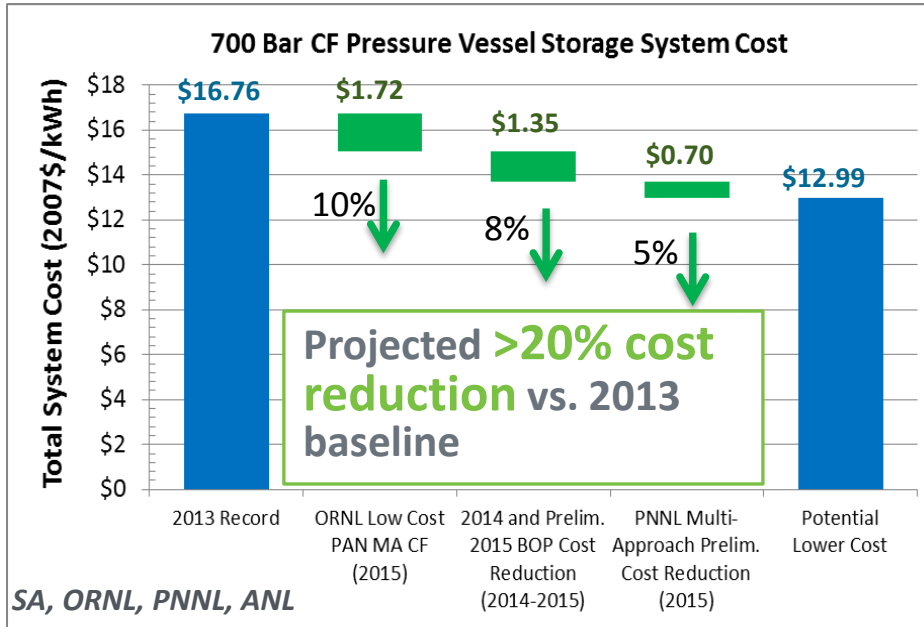


Status

On Track
 High volume,
 projected cost

Hydrogen Storage Highlights

Cost Reduction of 700 bar H₂ Storage Systems



- Launched 5 new storage materials projects

Class I Forklift with Fuel Cell and Metal Hydride System



- Developed metal Hydride H₂ 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



Reduce cost of 700-bar tanks:

15% cost reduction*

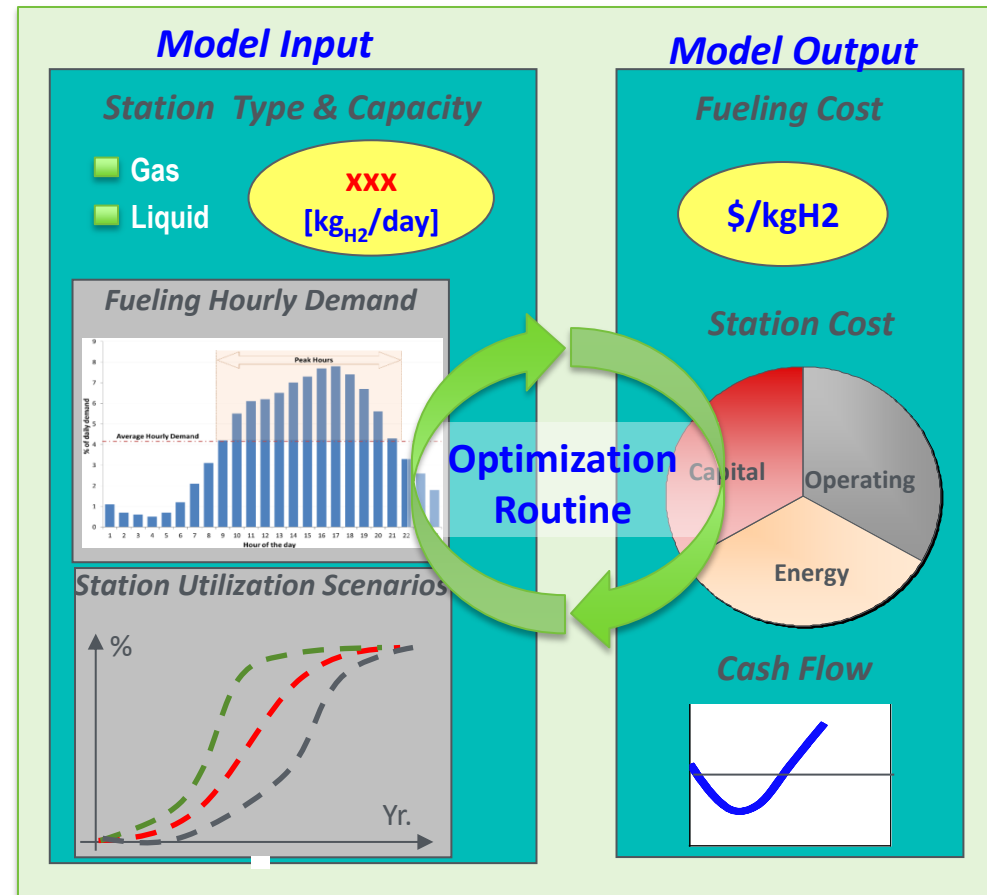
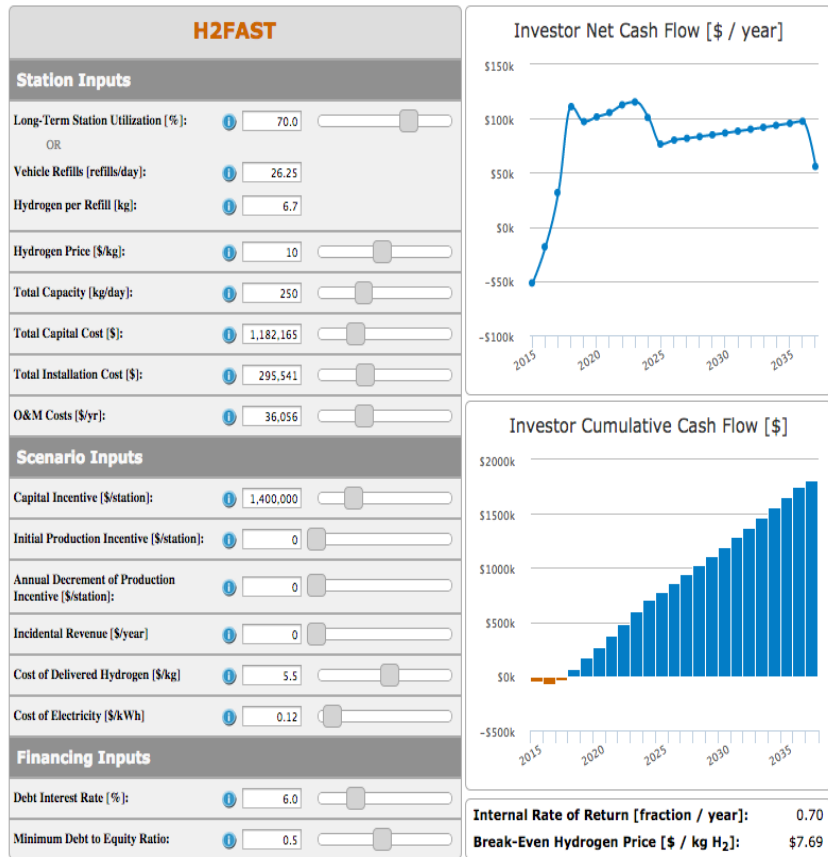
* vs. \$17/kWh (baseline)



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)

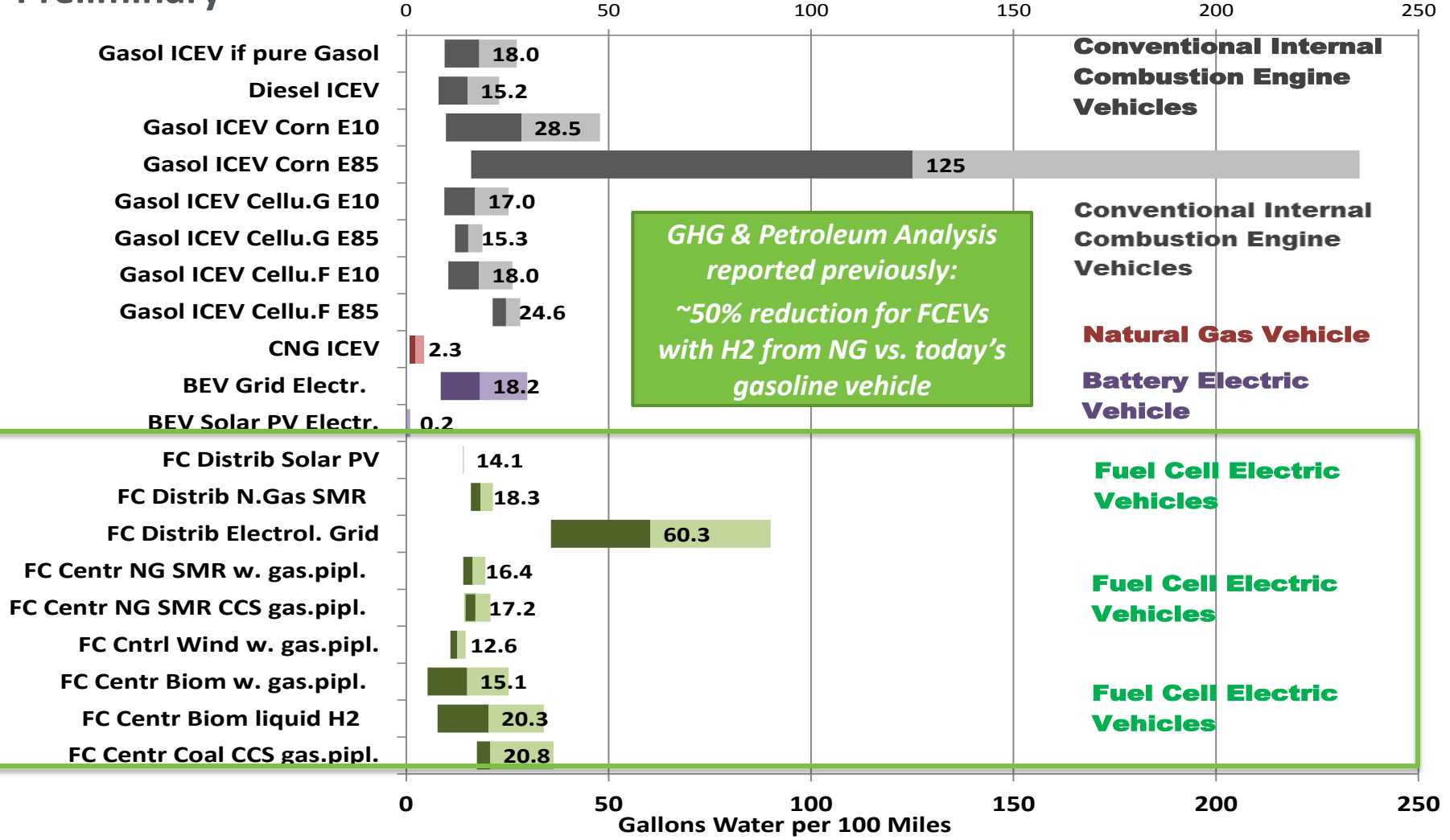
HRSAM- Hydrogen Refueling Station
 Analysis Model (ANL)

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

Preliminary

Low, Mid & High: Gallons Water/100 Miles for 2013 Technology



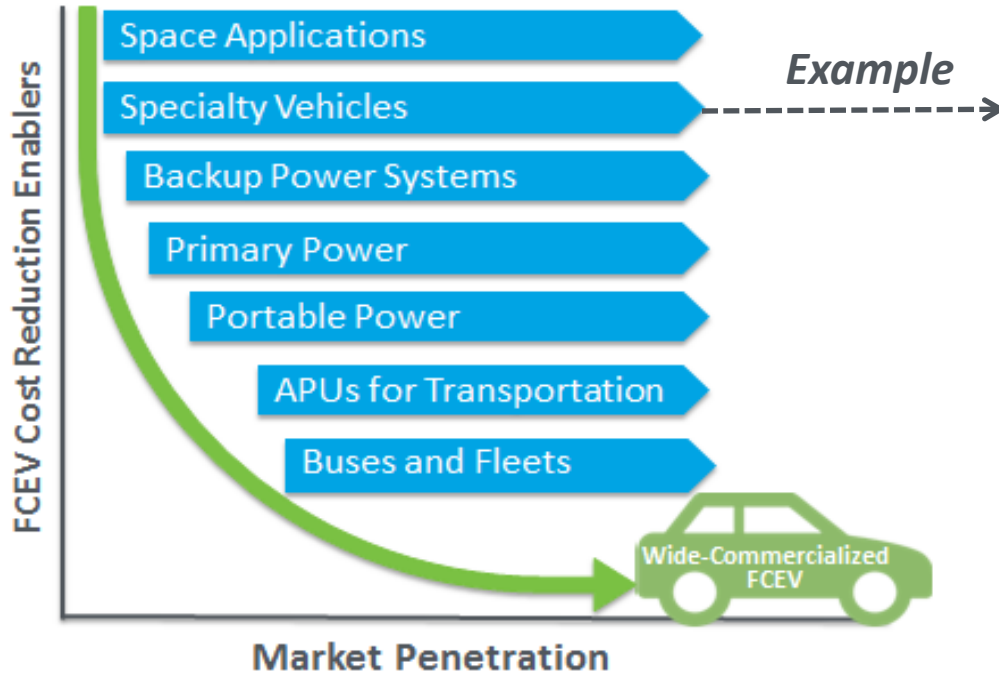
Numbers represent mid-range values, the left half-bar the low range, and the right half-bar the high range- DOE FCTO, VTO, BETO, ANL

Water Consumption of H₂ 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



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



facebook Post Stats:
 More **180 shares**
 than **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

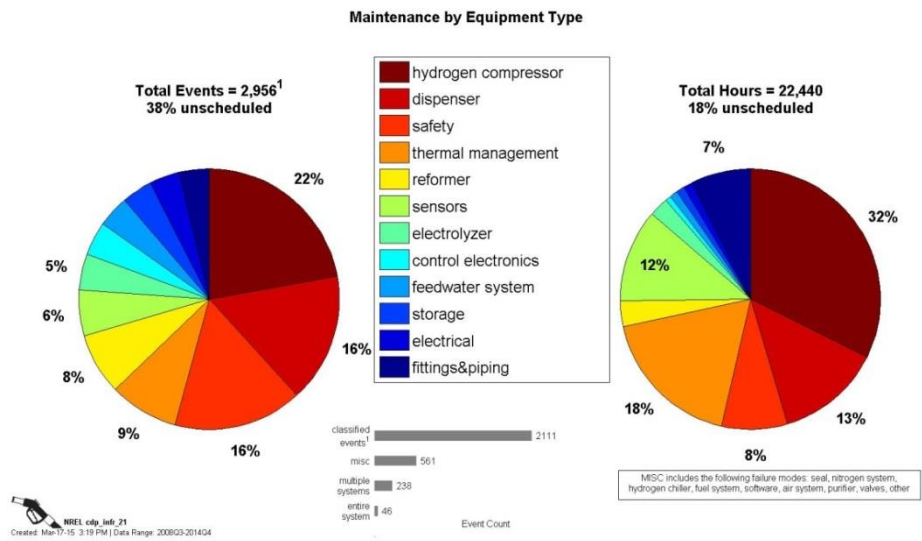


 Exceeding DOE's
18,000 hours
2016 target

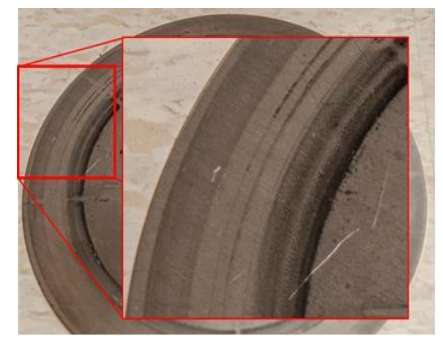
Fuel Cell Engine Demonstrated Reliability for Transit Bus Fleet

Highlights from Real World Operation

- CSULA- First in U.S. to receive seal of approval for sale of H₂ 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



NREL edp_inf_21
 Created: Mar7:15 3:19 PM | Data Range: 2008Q3-2014Q4



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/

H₂USA to address H₂ Infrastructure Challenges

H₂ USA



*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



In Support of

H₂USA 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

- H₂ Station Equipment Performance Device
- H₂First Inaugural Task
- HyStEP will help reduce time required to place H₂ stations in service

DOE's H₂FIRST project supports H2USA goals to address infrastructure

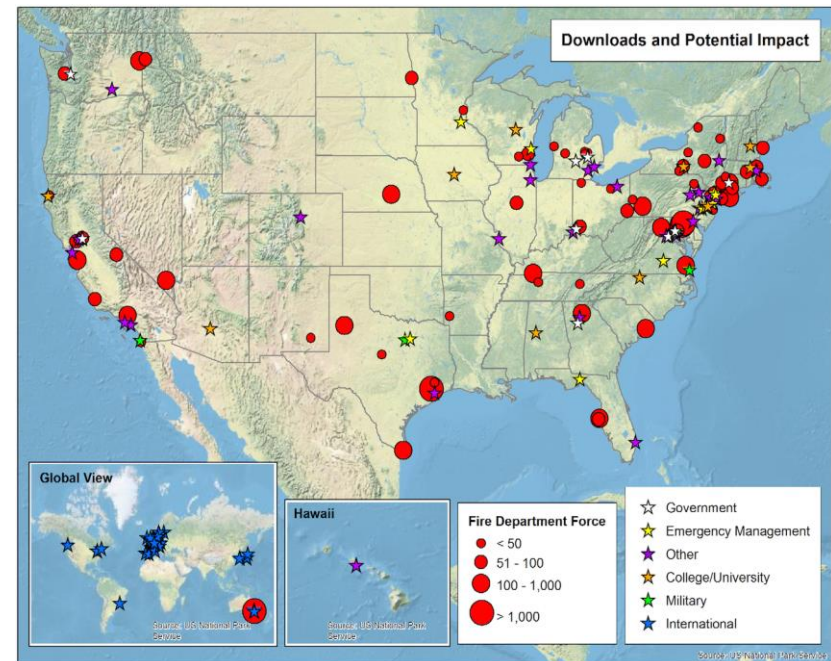
H2Tools



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

PNNL

Safety Training for First Responders

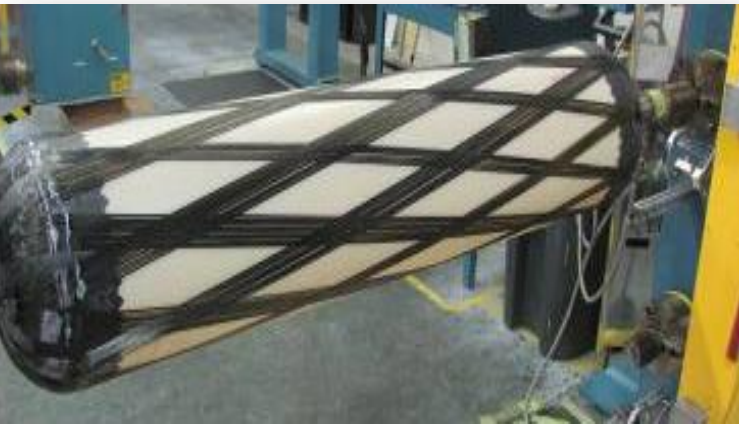


Tracking interest in first responder training resources across the country, including along the northeast corridor

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 H₂ fueling systems.

1st Year (due 10/15)

2nd Year (due 10/16)

Teams form and
submit designs

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:

H₂ production, low PGM fuel cell catalysts, H₂ dispensers, pipeline manufacturing R&D

Demonstration and Deployments:

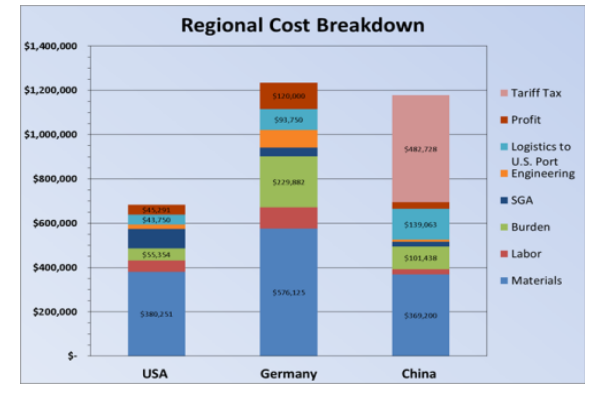
Mobile refueling, plug-in fuel cell hybrid vehicle, technical assistance to communities deploying fuel cells

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



Fuel Cell and H₂ Opportunity Center

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



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)

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

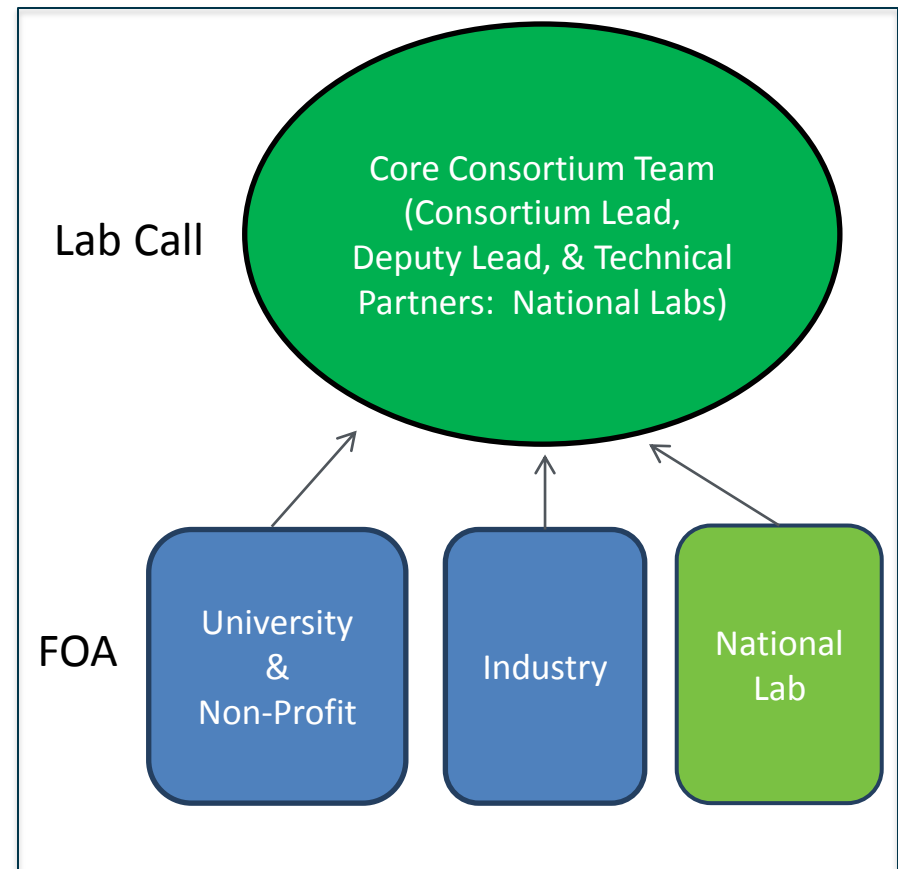
Hydrogen Storage Materials
Advanced Research Consortium

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

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 H₂ stations/components
 - Fuel-to-you approaches (e.g. small-scale/“Peapod” delivery)
- **Education and outreach gaps and needs**
 - Workforce development, training, students, teachers, etc.



Supporting **veterans** and their families in 3 areas:



Wellness



Education



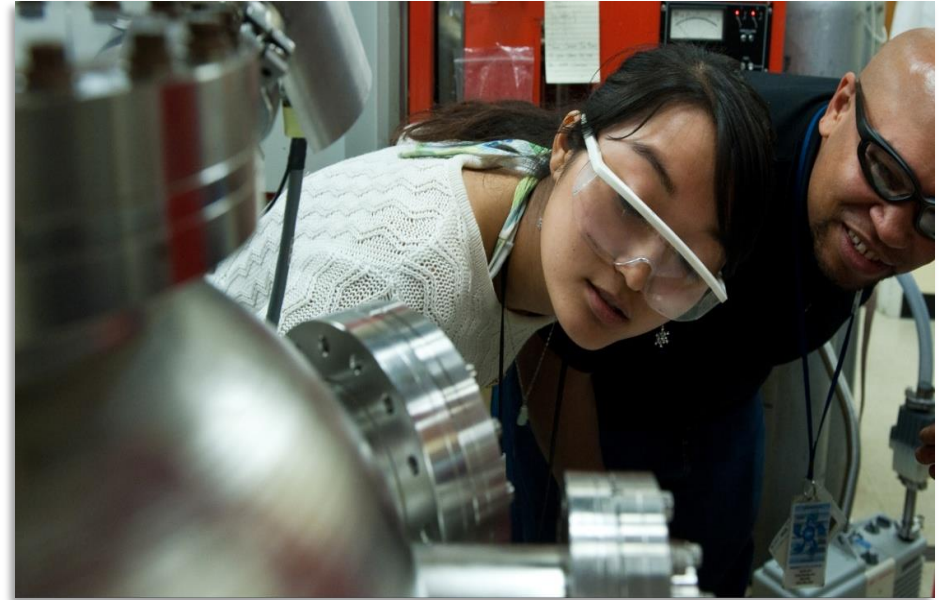
Employment

Strong Commitment by the H₂ and Fuel Cells Community



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

- Two Areas:
 1. Fuel Cells R&D
 2. H₂ 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 H₂ Storage

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

Collaborations and Partnerships

R&D

Demonstration & Deployment

Accelerated Commercialization



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



- Implementing Agreements
- 25 countries



- State Partnership and Collaboration



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



- International Government Coordination
- 17 countries and European Commission



- 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)

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

Piotr Zelenay (LANL)

LANL Fellows Prize for Outstanding Research

Jennifer Kurtz, Keith Wipke (NREL) and Daniel Dedrick (SNL)

2014 FLC Far West Regional Awards

Ian M. Robertson (U. of Wisconsin)

2014 ASM Edward DeMille Campbell Memorial Lectureship Award

Muhammad Arif (NIST)

NIST Fellow Honor

Proton Onsite

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

Jamie Holladay (PNNL)

Most-Downloaded Article from Science Direct



Y. F. (John) Khalil (UTC)

The Institution of Chemical Engineers (IChemE) Senior Moulton Medal

Dr. Branko Popov (U. of South Carolina)

2014 World's Most Influential Scientific Minds & Highly Cited Researchers by Thomson Reuters



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

Sunita.Satyapal@ee.doe.gov

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)

State	FY13-FY15 Total Funding	Industry, National Laboratories, Universities, and Government Entities	
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