U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Fuel Cell Technologies Office Update

Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office

Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) Meeting

Washington, DC– Feb 13, 2018

Overview

- **HTAC Scope**
  - **Membership**
  - **Energy Policy Act (EPACT) 2005 Title VIII**
- **Program History and Updates**
- **Next Steps**
  - **Examples of outputs and recommendations**

2018 HTAC Membership

HTAC Member and Affiliation	Expertise
Ayers, Katherine Proton OnSite	**Hydrogen Production Companies**
Azevedo, Ines Co-Director of the Climate and Energy Decision Making Center, Carnegie Mellon University	**Behavioral/ Decision making Science**
Clay, Kathryn American Gas Association	**Natural Gas Industry Association**
Dunwoody, Catherine California Air Resources Board	**Clean Air Regulation**
Eggert, Anthony Program Director, Climateworks	**Environmental Policy Analysis**
Freese, Charles F. (Chair) General Motors Company	**Automotive Companies**
Koyama, Harol H2 PowerTech	**Stationary Power and Markets**
Leggett, Paul Morgan Stanley, Investment Banking Division	**Venture Capital / Investment**
Lipman, Timothy Transportation Sustainability Research Center, UC Berkeley; Director, DOE Pacific Region Clean Energy Application Center	**Clean Power Technologies**

HTAC Member Name and Affiliation	Expertise
Mannan, M. Sam Regents Professor of Chemical Engineering, Texas A&M University; Executive Director, Mary Kay O'Connor Process Safety Center	**Safety, Codes and Standards**
Markowitz, Morry Fuel Cell and Hydrogen Energy Association (FCHEA)	**Hydrogen and Fuel Cells Industry Association**
Mizroch, John Managing Member, John F Mizroch, LLC	**Clean Energy Technology Exports and Investments**
Nocera, Daniel Professor, Chemistry and Chemical Biology, Harvard University	**Hydrogen Production R&D**
Novachek, Frank Xcel Energy	**Utilities (Electricity and Natural Gas)**
Powell, Joseph Chief Scientist, Shell Global Solutions	**Fuels Production and R&D**
Ratcliff, Adele Director, Manufacturing Technology Office of the Deputy Assistant Secretary of Defense	**Federal Gov't/ Manufacturing Technology R&D**
Scott, Janea California Energy Commission	**State Energy Policies and Regulations**
Thompson, Levi University of Michigan	**Physical Sciences**

Indicates new members as of January 2018

Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) Scope

To advise the Secretary of Energy on:

1. **The implementation of programs and activities under Title VIII of EPACT**

2. **The safety, economical, and environmental consequences of technologies to produce, distribute, deliver, store or use hydrogen energy and fuel cells**

3. **The DOE Hydrogen & Fuel Cells Program Plan**

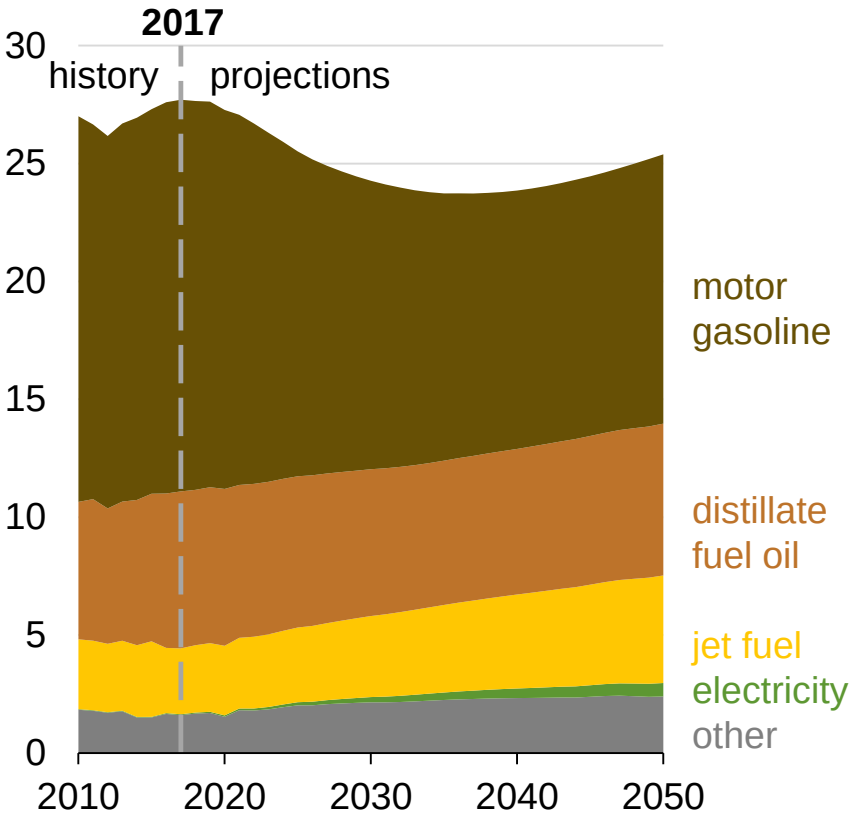
Title VIII Sec. 802- Purposes

1. Enable and promote comprehensive **development**, **demonstration**, and **commercialization** of H_2 and fuel cells with industry
2. Make **critical public investments** in building strong links to private industry, universities and National Labs to expand innovation and industrial growth
3. Build a mature H_2 economy for **fuel diversity** in the U.S.
4. Decrease the **dependency on foreign oil & emissions** and enhance energy security
5. Create, strengthen, and protect a **sustainable national energy economy**

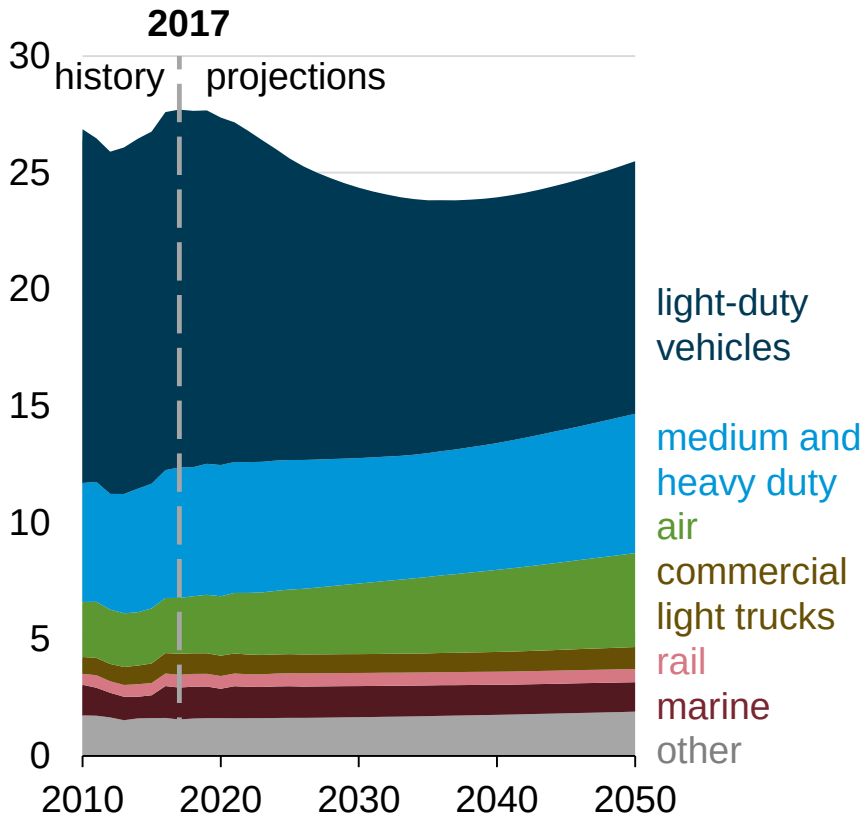
Primary focus light duty vehicles

Over 90% of transportation sector relies on petroleum

Transportation sector consumption by fuel type
quadrillion British thermal units

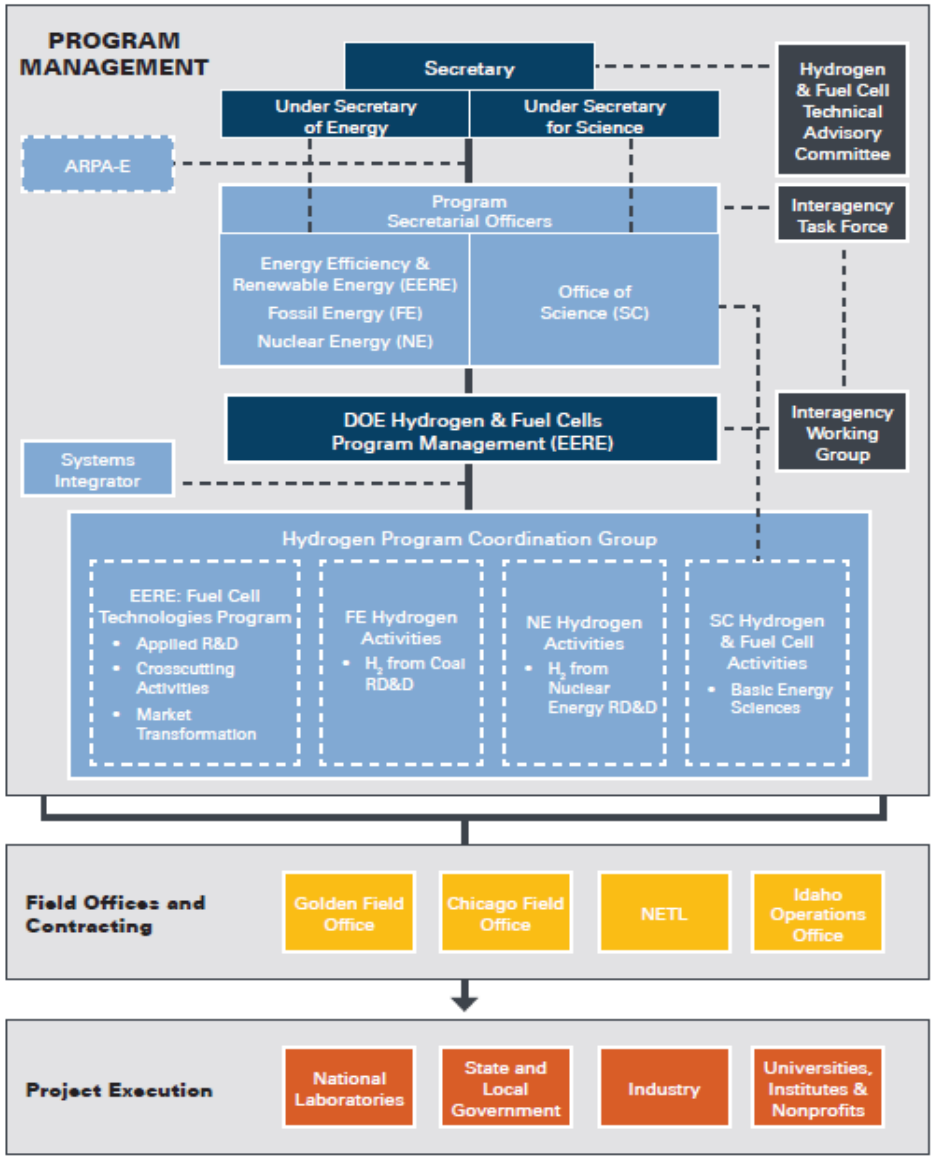


Energy consumption by travel mode
quadrillion British thermal units



Source: DOE EIA Annual Energy Outlook 2018

Overall Hydrogen and Fuel Cells Program Organization



Historical Org chart for Program

History:

- **Hydrogen and Fuel Cells Program: Includes EERE, FE, NE and SC.** Led by EERE since 2004; started coordination with ARPA-E after its creation
- **Monthly coordination and integrated strategic plan** (update underway)
- **Interagency Working Group** (~ 10 Agencies) meets monthly (led by EERE FCTO)

Program Funding – FY 2017:

EERE	$101M
NE	$2M
BES	$22M
FE	$30M
ARPA-E	$40M*

Total: ~$195M

*Includes funding in coordination with FCTO

Funded in the last decade:

- ~ 110 companies
- ~ 100 universities & institutes
- 12 national labs

Rigorous Program Management - Examples

FOA Topic Selection

- **Stakeholders**
  - e.g.: RFIs, industry, HTAC, etc.
- **U.S. DRIVE**
- **Peer Reviews**
  - NAS
  - GAO
  - Others

→ **Targets**
- **"Critical Path" needs**
- **Technology Gaps**

→ **RD&D Plan and Solicitation Topics**

- **Risk Analysis**
- **Technology Reviews**

Project & Program Review Processes

- Annual Merit Review & Peer Evaluation meetings
- Tech Team reviews (monthly)
- Other peer reviews- National Academies, GAO, etc.
- DOE quarterly reviews and progress reports

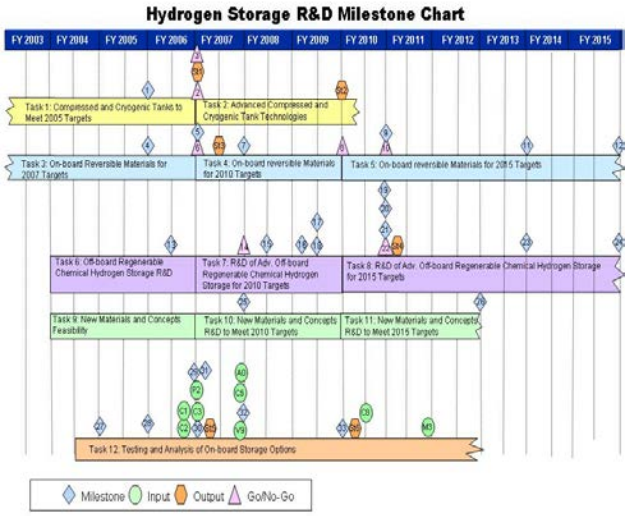
Technical Targets and Program Plans

Example Fuel Cell Membrane Targets

Characteristic	Units	2011 status	2017 target	Nafion® NRE211
Maximum oxygen crossover	mA/cm²	<1	2	2.7
Maximum hydrogen crossover	mA/cm²	<1.8	2	2.2
Area specific resistance at:				
Max operating temp and 40 – 80 kPa water partial pressure	ohm cm²	0.023 (40 kPa) 0.012 (80 kPa)	0.02	0.186
80°C and water partial pressures from 25 - 45 kPa	ohm cm²	0.017 (25 kPa) 0.006 (44 kPa)	0.02	0.03-0.12
30°C and water partial pressures up to 4 kPa				
-20°C				
Operating temperature				
Minimum electrical resistance				
Cost				
Durability				
Mechanical	C			
Chemical				

Technical targets help guide go/no-go decisions.

Update of Multiyear RD&D Plan and Targets in process



Project Number	Project Title *PI Name & Organization*	Final Score	Continue	Discontinue	Other	Summary Comment
123	New Polymer/ Inorganic Proton Conductive Composite Membranes for PEMFC	2.1		X		The project was unable to meet conductivity targets or significantly improve upon Nafion®, and the membranes developed have poor chemical stability. The project will not be continued.

Reviewer comments for projects posted online annually. Projects discontinued/ work scope altered based on performance & likelihood of meeting goals.

$18M saved

from Active Project Management & Downselects from FY 2013 to FY 2017

DOE EERE Funding – Impact Examples

Innovation

650 H_2 and fuel cell patents enabled by FCTO funds

Approx. 30% of H_2 and fuel cell patents come from National Labs

Market Impact

More than 30 Technologies commercialized by private industry

and over 75 with potential to be commercial in the next 3-5 years

can be traced back to FCTO R&D

Examples of Progress enabled by DOE FCTO in the last decade

Fuel Cell R&D

Reduced cost 60%

Quadrupled durability

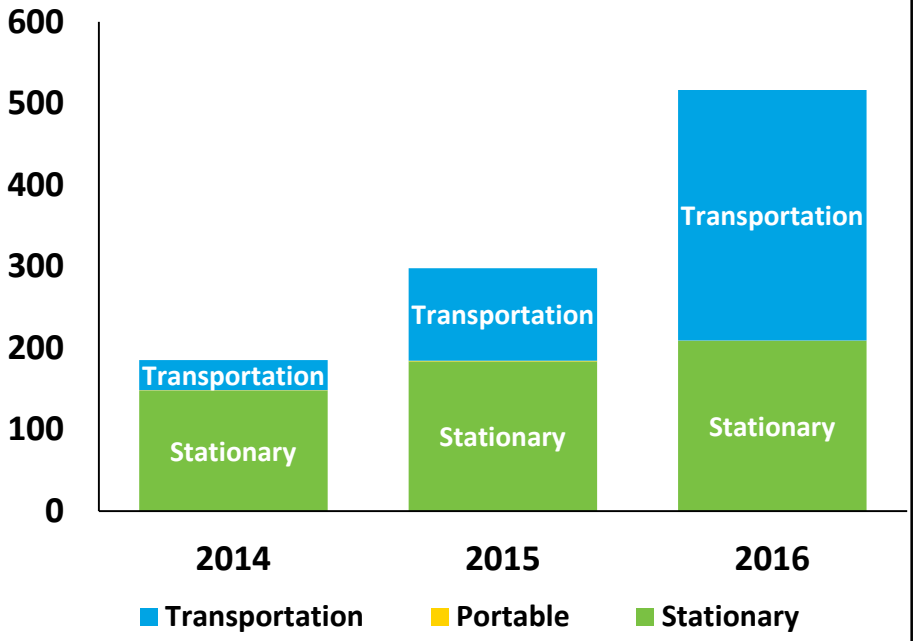
H2 Production R&D

Cut electrolyzer costs 80%

Significant Growth in the Fuel Cell Industry

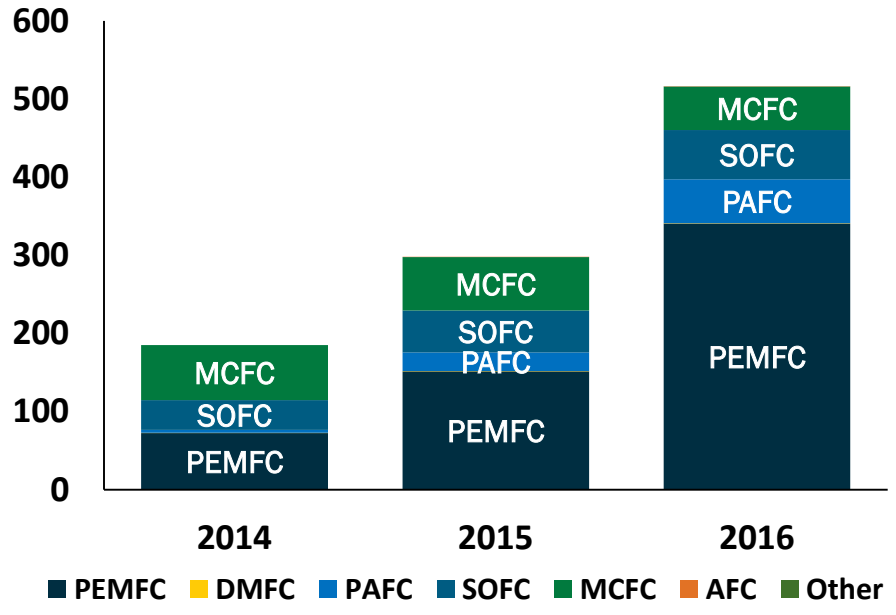
Total power (in MW) shipped by application

Growth in Transportation



Total power (in MW) shipped by fuel cell chemistry

Growth in PEMFC



500 MW fuel cell power shipped worldwide

62,000 fuel cell units shipped worldwide

Approximately **$1.6 Billion** fuel cell revenue

Source: DOE Fuel Cell Technologies Market Report. Available at: https://energy.gov/eere/fuelcells/market-analysis-reports

For the first time in history….

Hyundai Tucson Fuel Cell SUV

Over **3,500** | **sold or leased** in the United States

Honda Clarity

Commercial **fuel cell electric cars are here**


Toyota Mirai

- No petroleum, no pollution
- Refuels in minutes
- More than 360 mi driving range
- Over 60 mpgge

More models coming soon…


Hyundai Nexo

Mercedes-Benz GLC F-Cell

Longer driving ranges, greater efficiencies, more space


Toyota "Fine-Comfort Ride" Concept


Audi h-tron

Hydrogen and Fuel Cell Applications in the U.S.

U.S. Snapshot

>235MW
Backup Power

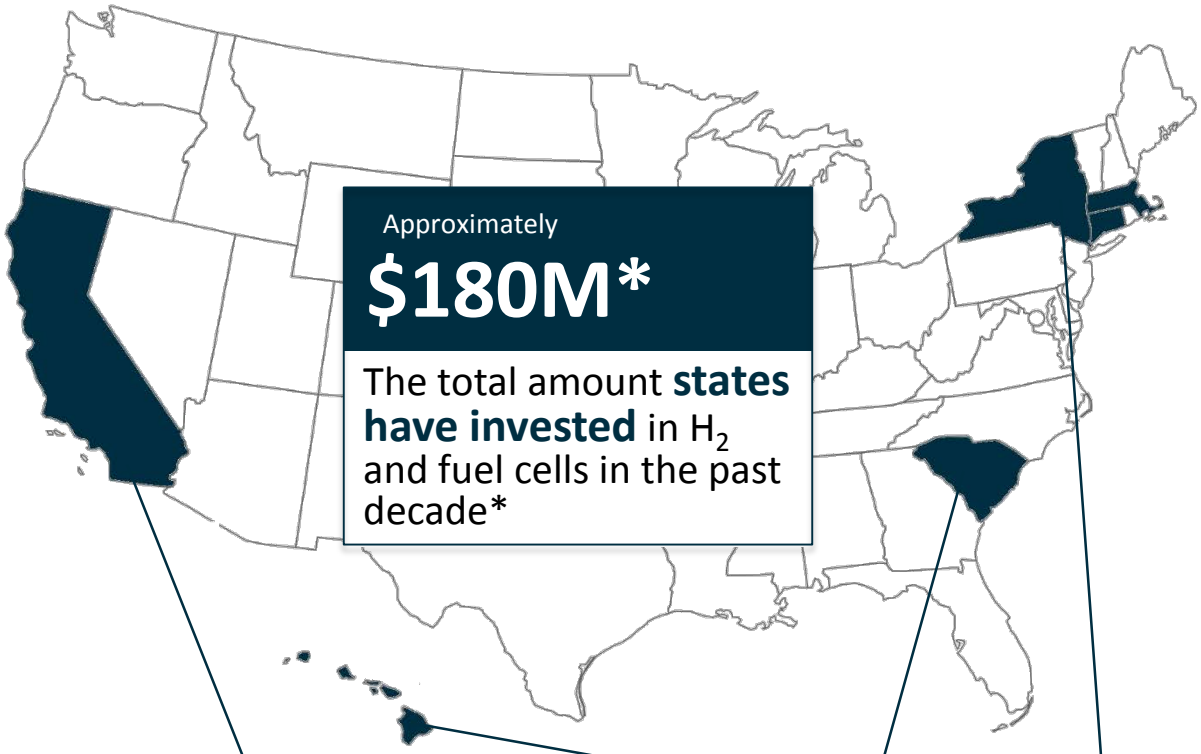
>16,000
Forklifts

26
Fuel Cell Buses

>30
H_2 retail stations

More than
3,500
fuel cell cars

Cumulative State Funding



Approximately
$180M*

The total amount **states have invested** in H_2 and fuel cells in the past decade*

CA
- 200 stations planned
- Over 30 public stations open
- $150M invested so far
- $235M announced in 2018

HI, SC, NY, CT, MA and others
- $27M invested so far
- 12-25 stations planned in the NE

*Excludes recent announcement from CA to invest $235M in electric vehicles

Central data collection helps guide further R&D

Data Validation of Real World Applications through the NREL's NFCTEC

- Data products provide insights on technology improvements, issues and gaps

NFCTEC: The National Fuel Cell Technology Evaluation Center

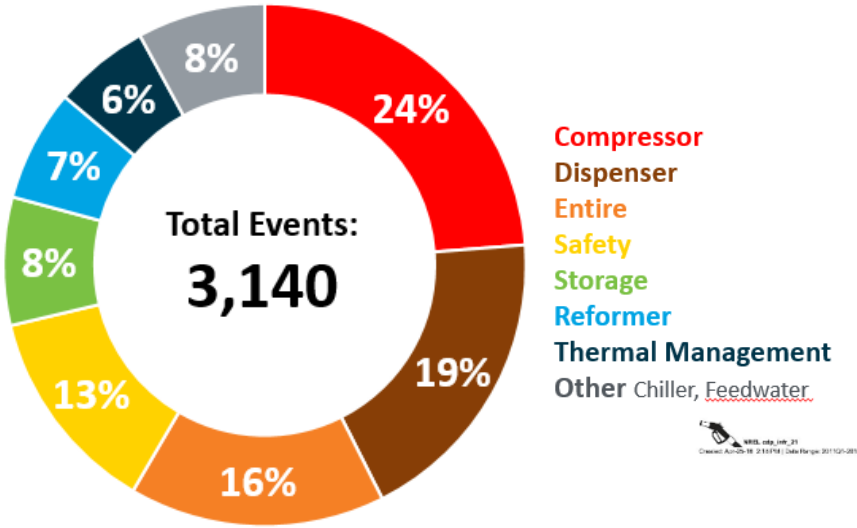
To Participate

techval@nrel.gov

Models "Toolbox" Online

- Financial, technical and economic models covering H_2 infrastructure, jobs, and more.
- Visit: **energy.gov/eere/fuelcells/hydrogen-analysis-toolbox**

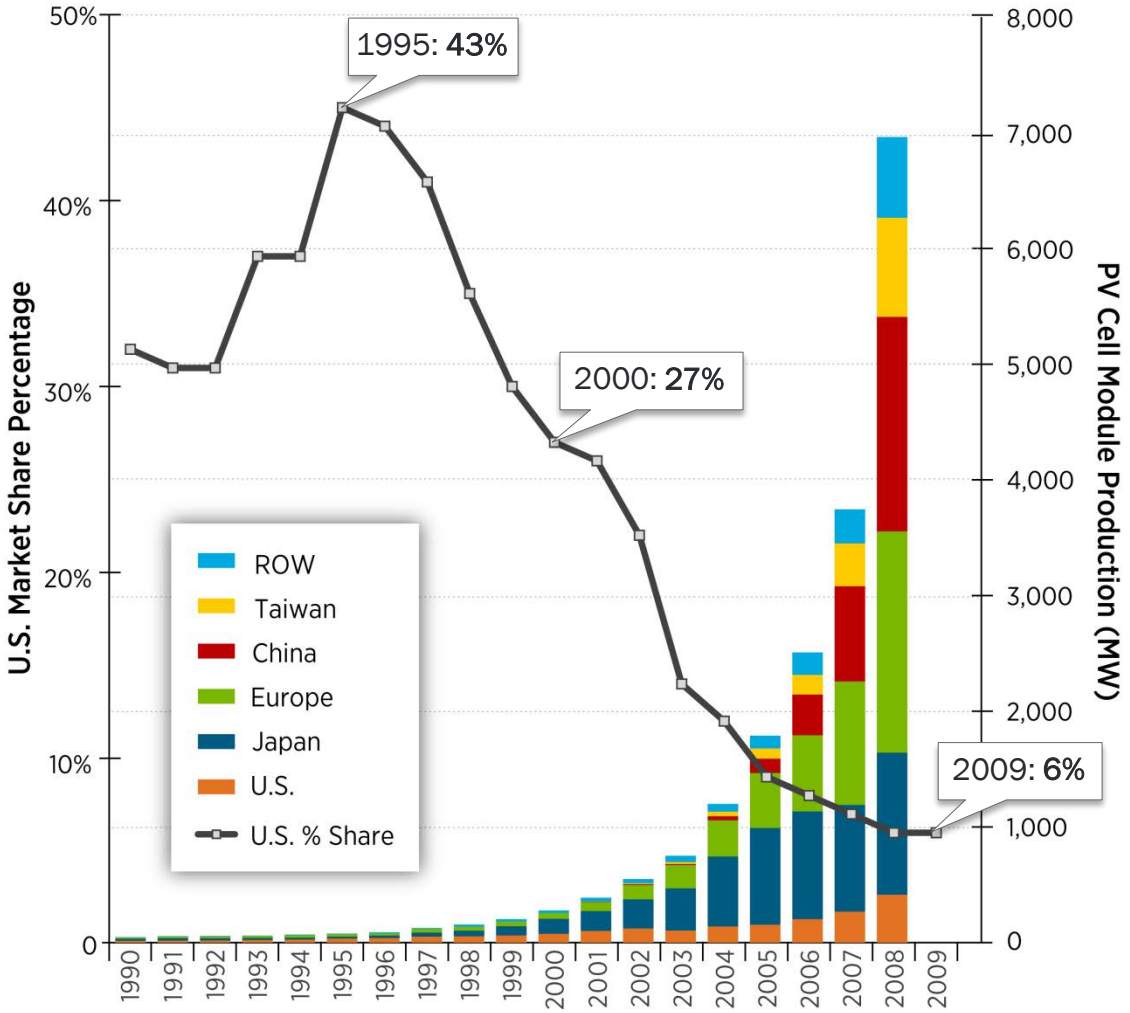
Example: Sources of H_2 Infrastructure Maintenance



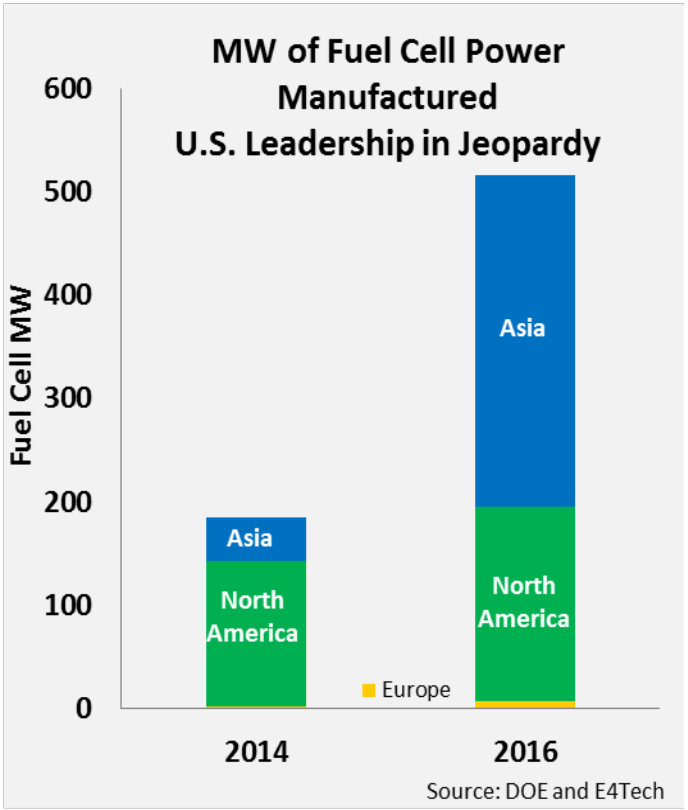
Most maintenance related to compressors and dispensers

Challenges: Example from Solar Industry

Global & U.S. Annual PV Production by Region

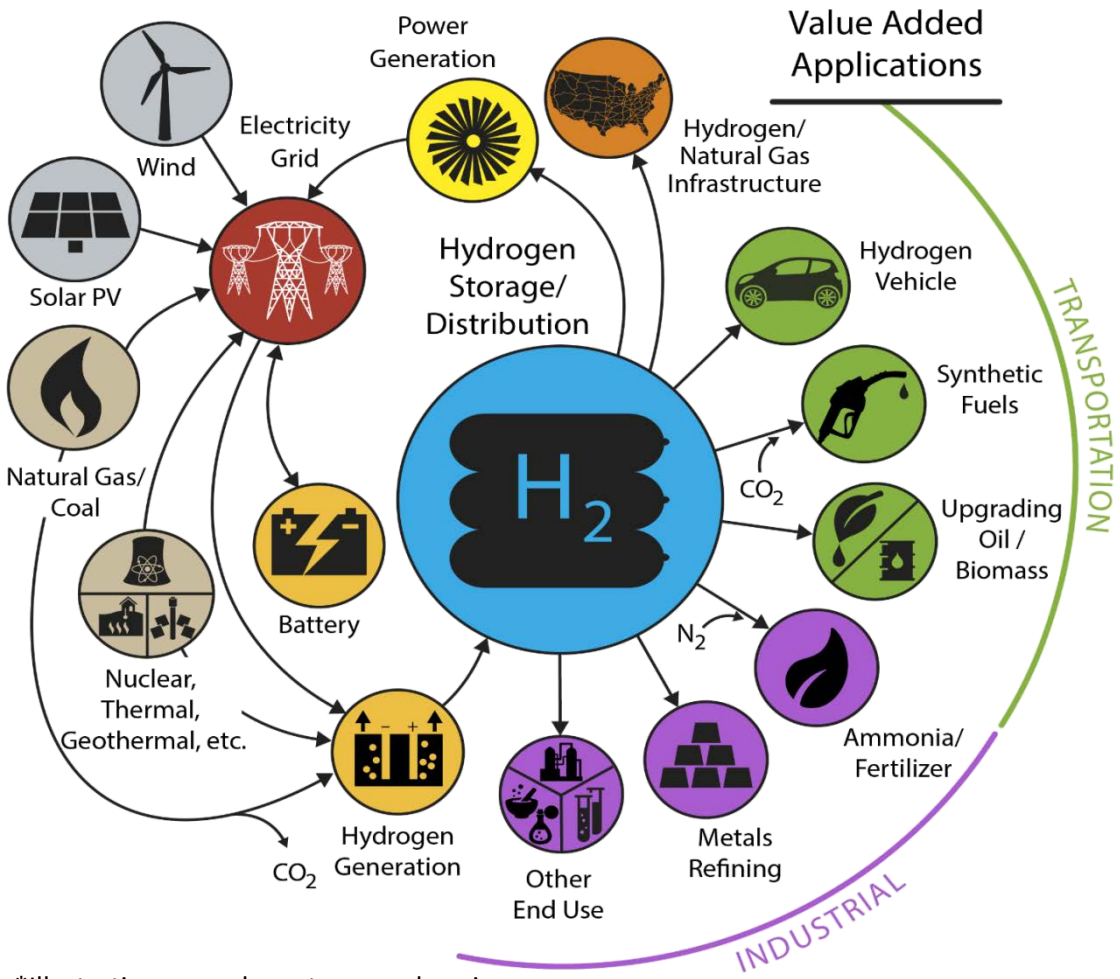


What can we learn from other industries- solar, batteries?



H2@Scale Opportunity: Scale drives demand

H2@Scale Energy System



*Illustrative example, not comprehensive
Source: NREL

What is "H2@Scale"?

A 'Big Idea' concept developed through 14 National Labs

Enables H_2 across multiple sectors and resources: Industrial (e.g., petroleum refining, fertilizer production, steel manufacturing), transportation (vehicles, marine, rail, etc.), power generation (including coal, nuclear and renewables), as well as energy storage.

Impact Potential
Estimated by Global Industry

By 2050:

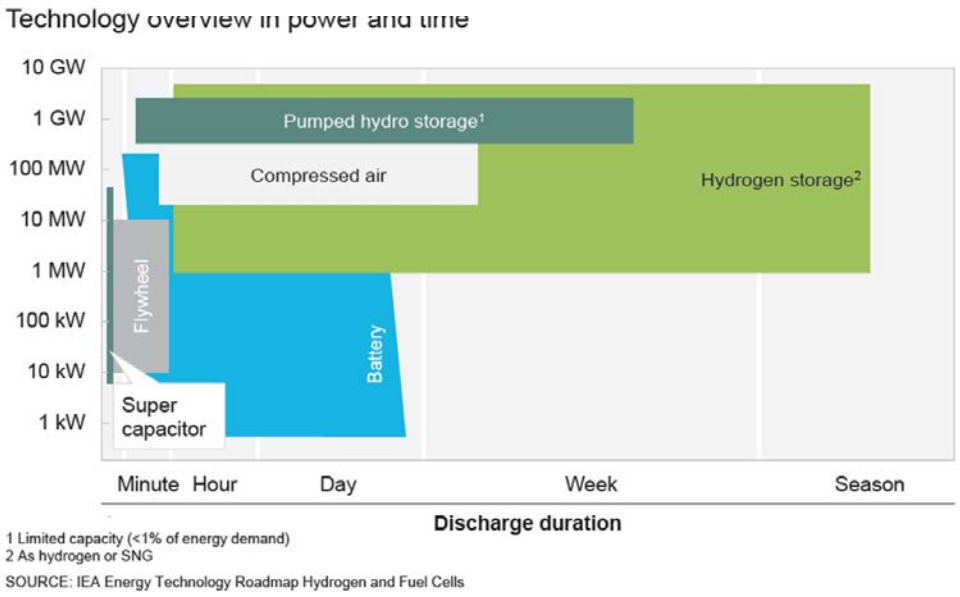
- **$2.5 trillion in global revenues**
- **30 million jobs worldwide**
- **400 million cars, 15-20 million trucks**
- **18% of total global energy demand**
- **Potential for 10-fold increase in hydrogen demand**

Source: Hydrogen Council (>20 companies with >$10B for H_2)

Impact Potential & Alignment with Priorities

Hydrogen can enable use of diverse domestic resources and address priorities of energy security, energy storage, resiliency and economic prosperity. R&D is required. Aligns with national & DOE priorities.

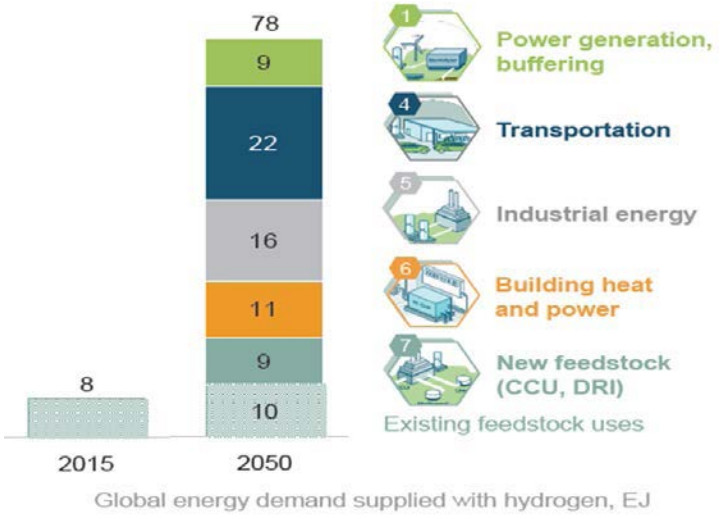
High capacity energy storage potential



1 Limited capacity (<1% of energy demand)
2 As hydrogen or SNG

SOURCE: IEA Energy Technology Roadmap Hydrogen and Fuel Cells

Potential for Global H2 Demand
10-fold increase by 2050



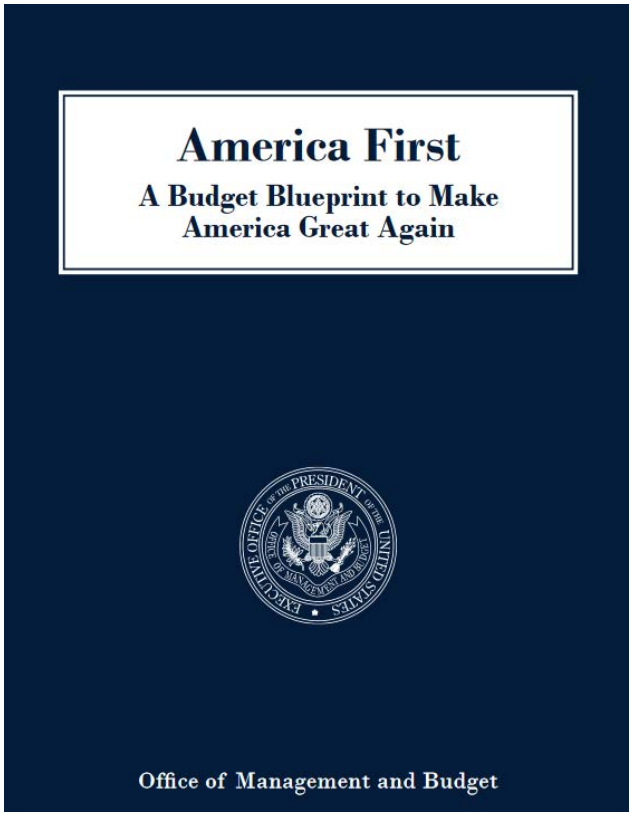
"Agencies should invest in early-stage, innovative technologies that show promise in harnessing American energy resources safely and efficiently."

-Aug. 17, 2017 OMB/OSTP Memo

DOE Updates

- Former Governor of Texas **Rick Perry sworn in as the Energy Secretary** on March 2, 2017

- White House **budget proposal released**
  - "…reflects an **increased reliance on the private sector to fund later-stage research, development, and commercialization** of energy technologies…"
  - "… **focuses resources toward early-stage research and development.**"



WH Budget Blueprint released on March 16, 2017

Hydrogen & Fuel Cells Budget (EERE FCTO)

Stronger emphasis on early R&D and relying on industry for later stage R&D

Key Activity	FY 2017	FY 2018		
	($ in thousands)			
	Approp.	Request	House Mark	Senate Mark
Fuel Cell R&D	**32,000**	**15,000**	*No direction*	**27,000**
Hydrogen Fuel R&D[1]	**41,000**	**29,000**	*No direction*	**36,000**
Systems Analysis	**3,000**	**1,000**	*No direction*	**1,000**
Technology Acceleration	**18,000**			
Technology Validation	-	-	**9,000**[2]	**14,000**[4]
Manufacturing R&D	-			
Market Transformation	-			
Safety, Codes and Standards	**7,000**	-	*Direction*[3]	**7,000**
Total	**101,000**	**45,000**	**53,000**	**85,000**

[1]Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D
[2]Specific language directing $2M for integrated hybrid energy systems work with NE and $7M for integrated energy systems using high and low temperature electrolyzers to advance H2@scale concept. [3] To collaborate with NIST on accurate measurement at H2 refueling stations. [4] $3M for manufacturing R&D and $7M for industry-led efforts to demonstrate a renewable hydrogen fueling stations.

FY18 House and Senate Language

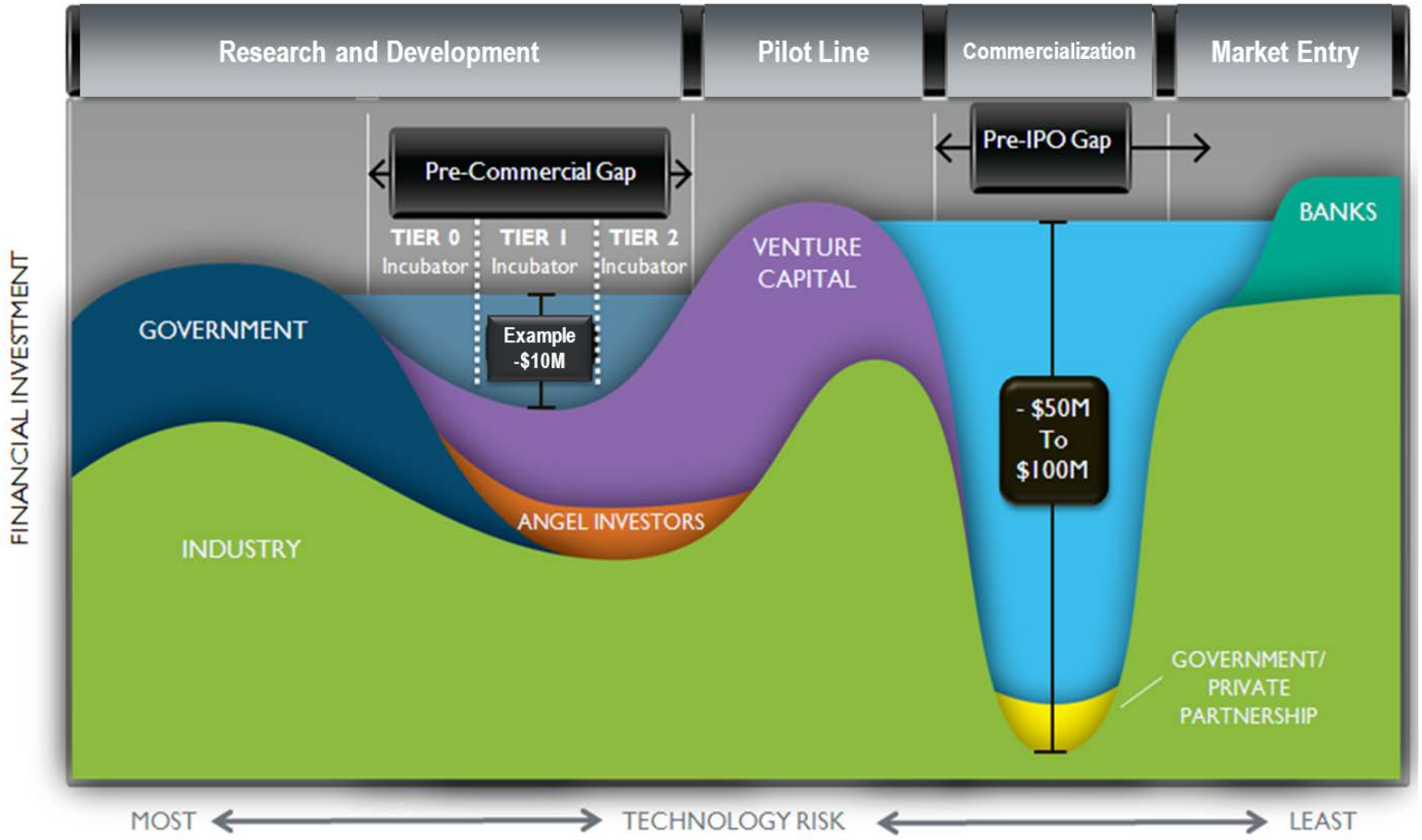
Program Area	House	Senate
Fuel Cell R&D	The Committee recognizes the progress of the program and expresses continued **support for stationary, vehicle, motive, and portable power** applications of this technology.	Within the amounts recommended, **$27,000,000 is for Fuel Cell Research and Development.**
H_2 Fuel R&D	DOE is encouraged to explore technologies that **advance storage and transportation fuel distribution, such as hydrogen compressors and carbon fiber tanks, and retail fueling systems.** DOE is encouraged to **work with the Department of Transportation** on supporting hydrogen fueling infrastructure.	**$36,000,000 for Hydrogen Research and Development.** The Committee encourages the Secretary to work with the Secretary of Transportation and industry on coordinating efforts to deploy hydrogen fueling infrastructure. The Department is further encouraged to identify competitive opportunities to help develop affordable H_2 infrastructure components. The Department is directed to use funds to improve H_2 measurement devices for retail fueling stations and work to reduce costs for H_2 compressors and carbon fiber tanks.

FY18 House and Senate Language

Program Area	House	Senate
Systems Analysis	N/A	**$1,000,000 for systems analysis** activities.
Safety, Codes and Standards	Committee recognizes the need to support the development of alternative fueling infrastructure for U.S. consumers. DOE is encouraged to **collaborate with the National Institute of Standards and Technology to allow accurate measurement of hydrogen** at fueling stations.	The Committee **recommends $7,000,000 for Safety, Codes, and Standards.**
Technology Acceleration & Other Language	Within available funds, **$2,000,000 is for the EERE share of the integrated hybrid energy systems work with the Office of Nuclear Energy.** **$7,000,000 to enable integrated energy systems using high and low temperature electrolyzers** with the intent of advancing the H2@Scale concept.	The Committee recommends **$14,000,000 for Technology Acceleration** activities, including **$3,000,000 for manufacturing research and development, and $7,000,000 for industry-led efforts** to demonstrate a hydrogen-focused integrated renewable energy production, storage, and transportation fuel distribution/retailing system.

Government vs. Private Sector Roles

Example— illustrative timeline for innovation & commercialization



Adapted from SunShot Incubator briefing. Pictorial example, not representative of all industry start ups

Program Focus, Work Areas and Approach

Early R&D Focus

Applied research, development and innovation in emerging hydrogen and fuel cell technologies leading to:

- Energy security
- Energy resiliency
- Strong domestic economy

Early R&D Areas

Fuel Cells

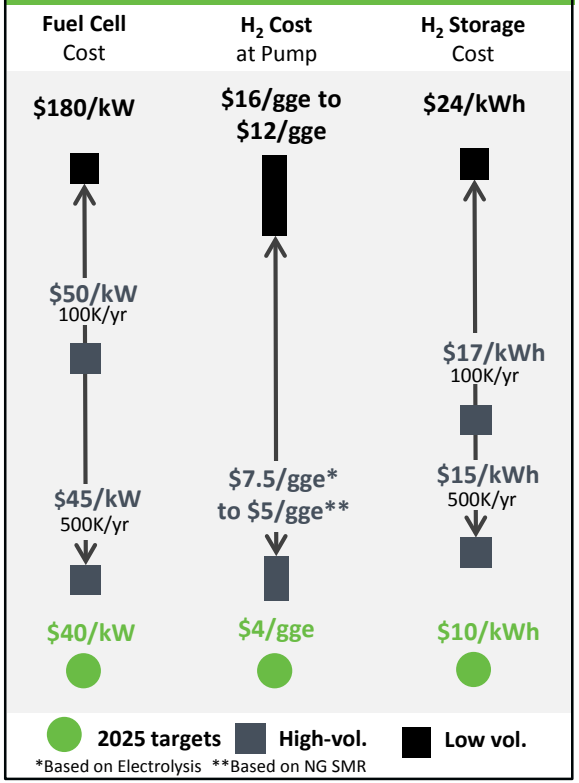
- PGM- free catalysts
- Durable MEAs
- Electrode performance

Hydrogen

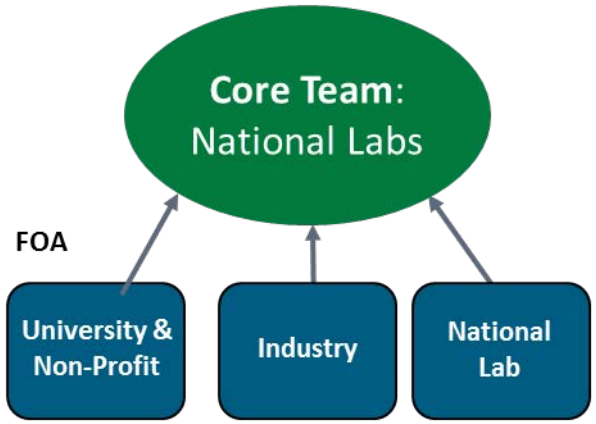
- Production pathways
- Delivery components (i.e. compressors)
- Advanced materials for storage

PGM = Platinum group metals
MEA = Membrane Electrode Assembly

Status and Targets



Consortium Approach



Launched and addressing R&D needs:

ElectroCat Electrocatalysis Consortium
HyMARC
HydroGEN Advanced Water Splitting Materials

Part of:

Energy Materials Network U.S. Department of Energy (EMN)

Note: Graphs not drawn to scale and are for illustration purposes only.

Lab Consortia to Address Key Materials R&D Challenges

Energy Materials Network
U.S. Department of Energy

Research Capabilities & Core Principles guiding EMN

Predictive Simulation Across Scales	Synthesis & Characterization	Rapid Screening	End Use Performance
Process Scalability	Process Control	Real-time Characterization	Reliability Validation

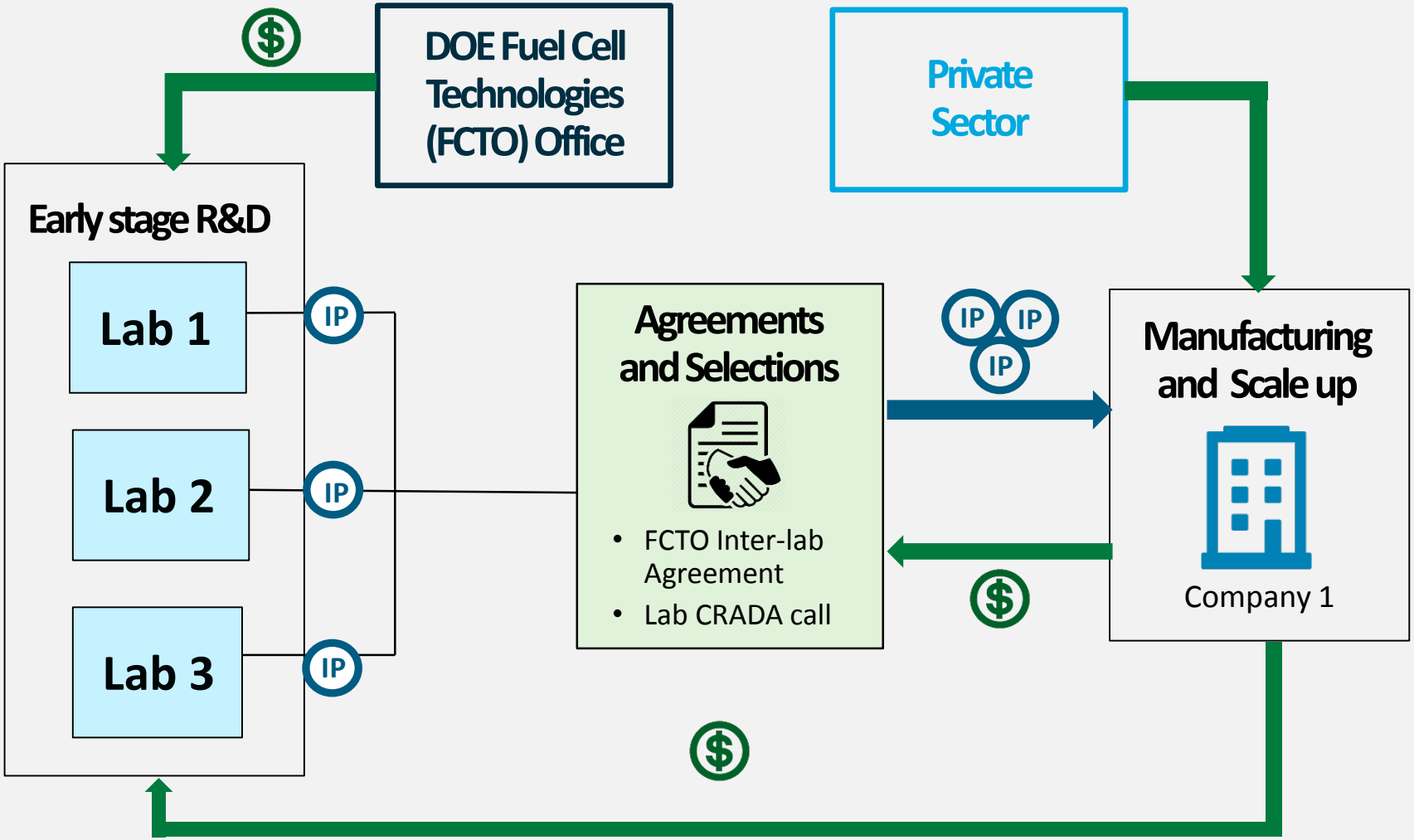
Data Management & Informatics

- Establishes **world class materials capability network**
- Sets up **clear point of engagement through concierge**
- Offers a **streamlined access through standard agreements**
- Encourages **data and tools collaboration**

Lab Consortia supporting EMN spanning multiple DOE offices and technologies

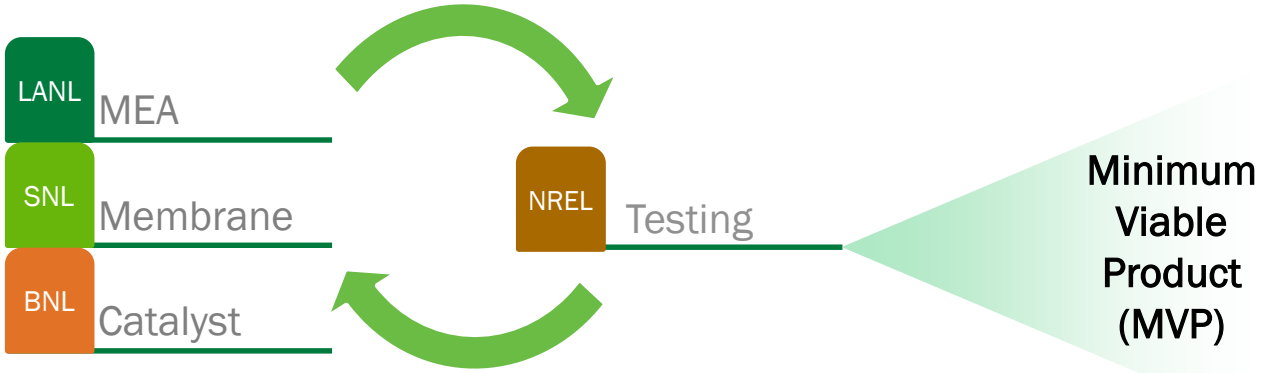
Innovations Provided to Industry & Investors

L'Innovator= "Lab Innovator" FCTO Pilot

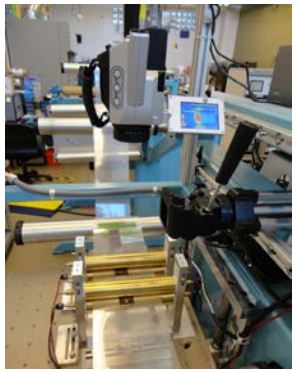


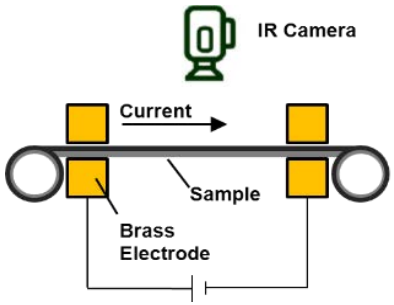
Example of L'Innovator Bundled IP

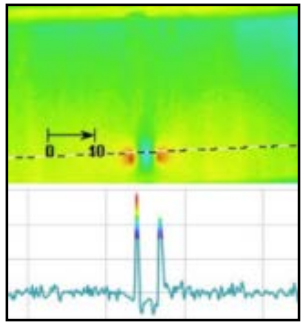
Bundled IP and Lab engagement offer greater value than conventional Tech Transfer approach by Labs. Accelerates development of MVP.



Example: Includes quality control method for use in electrode manufacturing

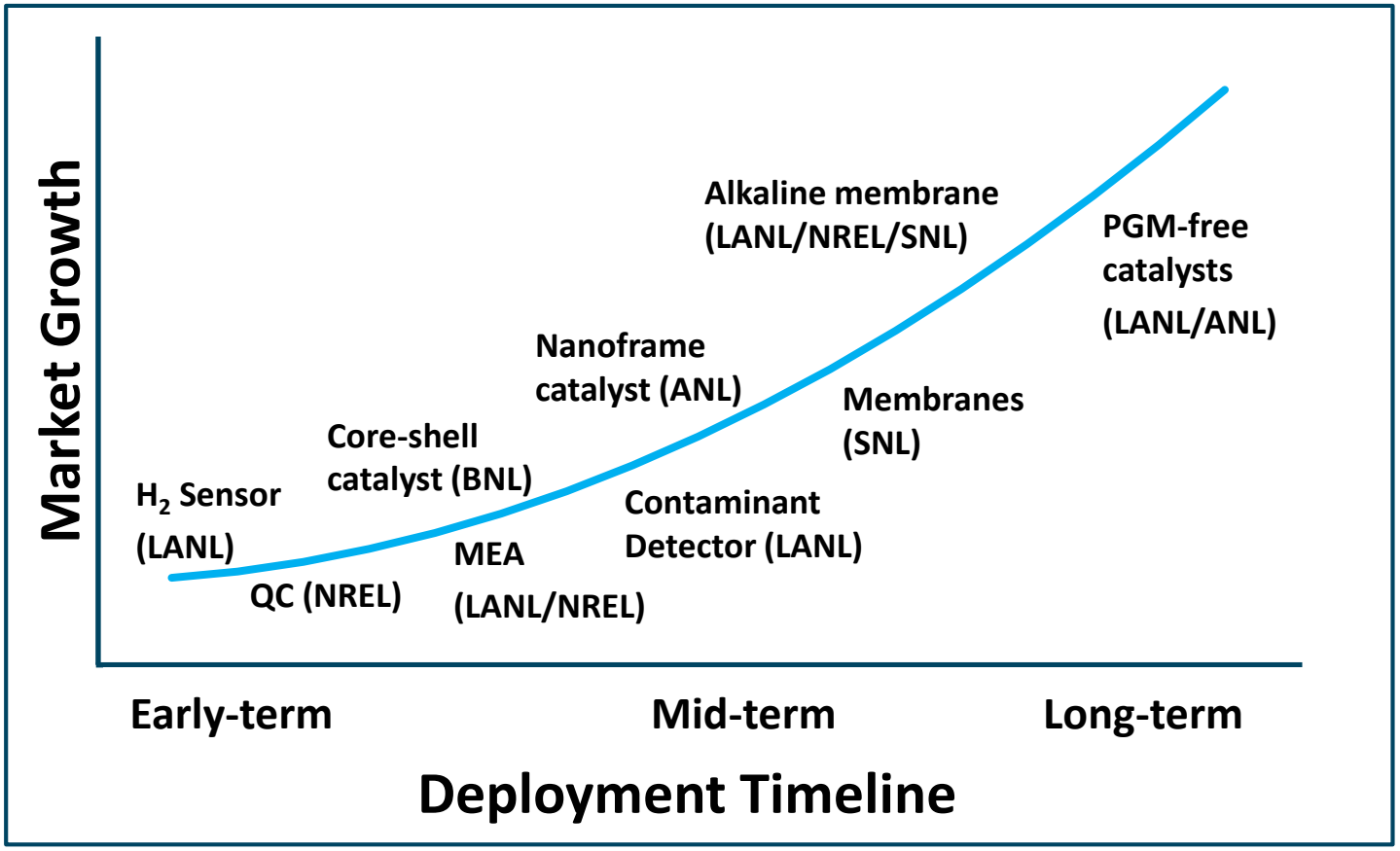






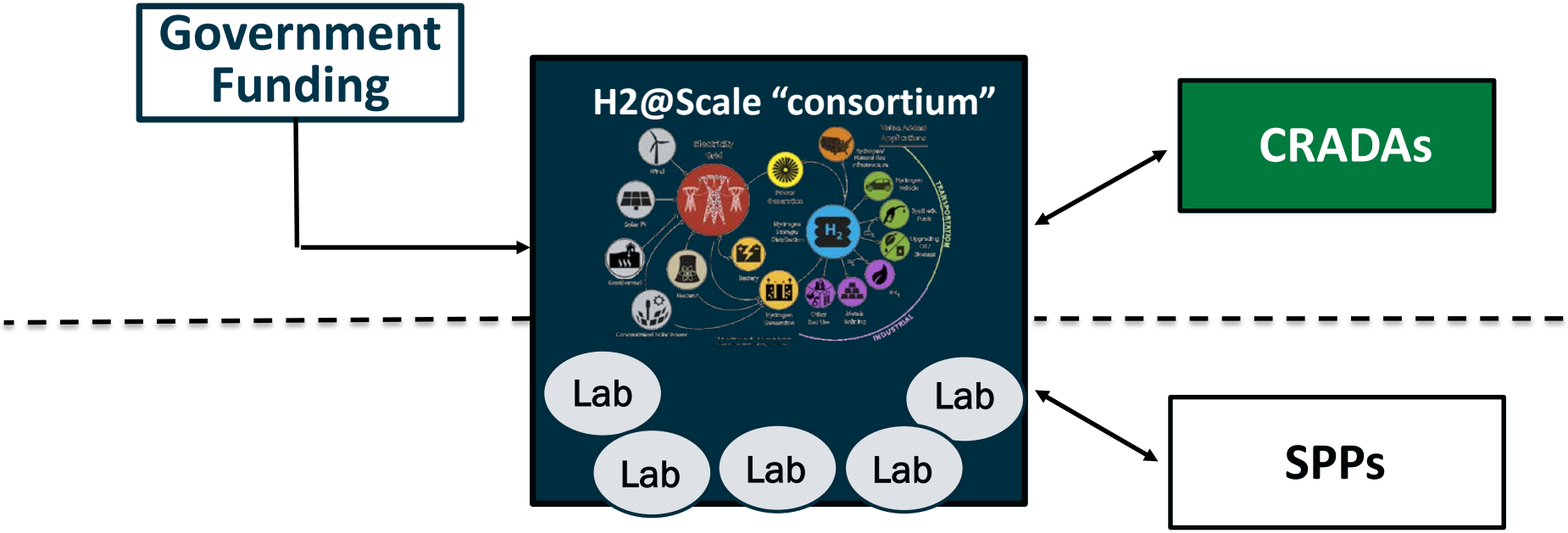
Examples of IP Topics by National Labs

Labs do not commercialize technology. Focus is early R&D but need active engagement and partnership with private sector



Leveraging for non-early stage R&D

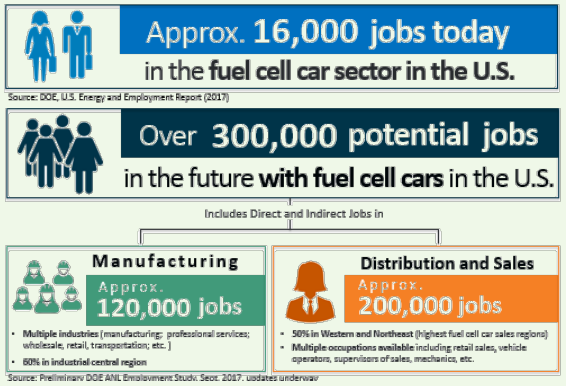
- **H2@Scale CRADA call: Leverages Lab capabilities and expertise to address challenges- materials R&D, analysis, safety R&D, etc.**
- **Round 1 in 2017. Future rounds planned in 2018, pending appropriations.**



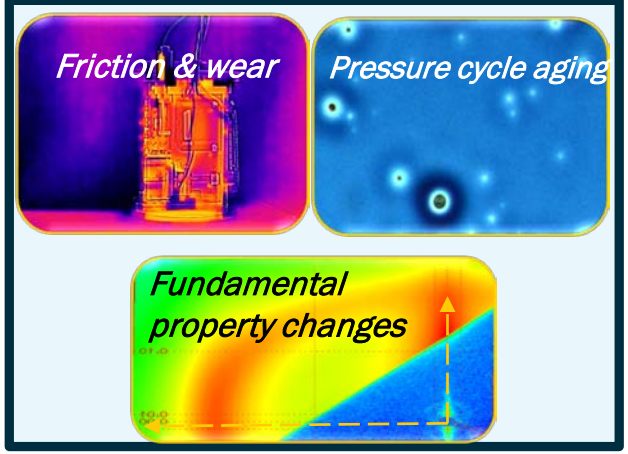
CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project ('Work for Others')

H2@Scale R&D Lab Capabilities– Examples

Technoeconomic Modeling and Analysis



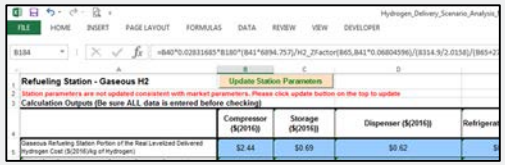
Hydrogen Materials R&D

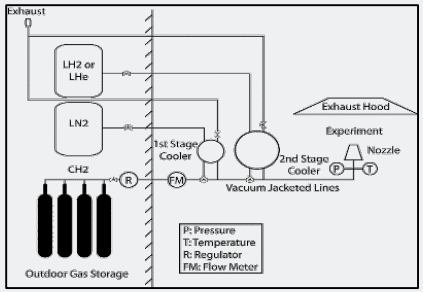


Grid simulation and Testing R&D

Safety and Infrastructure R&D

HyRAM
HYDROGEN RISK ASSESSMENT MODELS





H2@Scale CRADA Call Partners and Working Groups

First round of Selections Include 25 Projects

H_2 Quantitative Analysis R&D

- Air Liquide
- California Energy Commission
- Connecticut Center for Advanced Technology
- PDC Machines
- Quong & Associates, Inc.

H_2 Production Concepts R&D

- AquaHydrex
- Honda
- C4-MCP, Inc.
- GinerELX
- GTA, Inc.

Selections and subsequent working group assignments are subject to negotiation.

H_2 Integration with Energy Generation R&D

- Electric Power Research Institute
- Exelon
- Southern Company / Terrestrial Energy
- Nikola Motor
- Pacific Gas & Electric
- TerraPower

H_2 Distribution Component R&D

- California Go-Biz Office
- Frontier Energy
- HyET
- Honda
- NanoSonic
- RIX
- Tatsuno

Argonne NATIONAL LABORATORY · INL Idaho National Laboratory · BERKELEY LAB · NREL NATIONAL RENEWABLE ENERGY LABORATORY · Pacific Northwest NATIONAL LABORATORY · Sandia National Laboratories · SRNL SAVANNAH RIVER NATIONAL LABORATORY OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

Complementing Retail Stations: H_2 Refuel H-Prize

The competition

H2refuel U.S. Department of Energy

- DOE **$1M prize**
- Focuses on system for **small-scale refueling**
- Authorized in **Energy Independence and Security Act**

More info: hydrogenprize.org

The winning system

simple.fuel.™

- Designed by **three-member team:**
  - Ivys Energy Solutions and McPhy Energy (MA)
  - PDC Machines (PA)
- Produces **H2 via electrolysis**
- Dispenses **1 kg of H_2 in 15 mins** or less
- Allows **700 bar refueling**

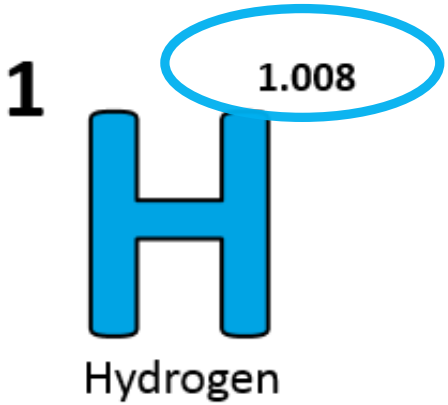
More info: www.teamsimplefuel.com
Email: connect@ivysinc.com

Collaboration Tools: Increasing Awareness

Celebrate Hydrogen & Fuel Cell Day

October 8 or 10/8

(Held on its very own atomic- weight-day)



Learn more:

energy.gov/eere/fuelcells

Give an *"Increase your H2IQ"* presentation in your community

Download slide deck for free at at:

energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Upcoming

Save the Dates!

H2@Scale Workshop
April/May (planning in process)

AMR and Industry Expo
June 12-15, 2018
Washington, DC

Requests for Information

Identifying priorities for reducing barriers to deployment of hydrogen infrastructure
(tentative release date – March 2018)

Hydrogen to capture remote energy resources (tentative release date – Feb/ 2018)

HTAC Recommendations Being Addressed

Recommendation	Actions Taken (Examples)
Ensuring positive retail hydrogen fueling experience	• **13 projects on H_2 fueling components** selection through NREL's 2017 CRADA call • **Modified H_2 metrology standard of 5% was accepted** through NREL and NIST collaboration • **DOE's $10M investment in H2FIRST** (Hydrogen Refueling Infrastructure Research and Station Technology) to jumpstart collaborations addressing H_2 infrastructure challenges
Continue efforts in material and process integration and technology acceleration in order to meet the 2020 EPACT Title VIII goals	• Lab-led consortia **HydroGEN, ElectroCAT, and HyMARC part of DOE's EMN and focusing on materials R&D challenges** for H_2 and fuel cells • **H2@Scale launched to leverage H_2 across multiple sectors**; 25 CRADA projects • **U.S. supply chain strengthening activities**: regional technical exchange centers, public supply chain database (HFC Nexus), etc.
Maximize the role of the Hydrogen Safety Panel (HSP)	• **DOE and HSP strategic plan** underway • Pursued **collaborations with NFPA** on standard permitting template
Leverage the capabilities of public-private partnerships	• Continued **communication with key regional partnerships** (CaFCP, CCAT, OFCC, etc.) • **Engaged Clean Cities Coalitions to include hydrogen** information into their programs
Identify and support other federal and state agencies	• Ongoing **coordination through IWG** (Interagency Working Group) • HSP course on safety at FEMP's Energy Exchange to **encourage safe incorporation of hydrogen into federal fleets**

HTAC Impact – Examples

- **HTAC Annual Reports and Letters to DOE Secretary**
  - 2007 to 2016
- **Subcommittee Outputs**
  - Hydrogen Safety & Event Response (2017)
  - Communication & Outreach (2017)
  - Manufacturing (2014)
- **Other Examples**
  - Input on H-Prize
  - Peer review of H2 cost target
  - Input on R&D Plan
  - H2@Scale

Potential Areas of Input by HTAC

- **Potential topics for future prizes**
  - Complement conventional grant process
- **Additional feedback on H2@Scale including**
  - Medium and heavy duty applications
  - Market segmentation analysis
  - Enabling lower cost storage, delivery, infrastructure
  - Clustering approach to increase demand
- **Leveraging resources**
  - L'Innovator (investment community & mfg)
  - Industry and other agencies for later stage R&D
  - Lessons learned from other industries
- **Other**


Powered by
Hydrogen Fuel Cells

Thank You
&
Additional Information

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energy.gov/eere/fuelcells