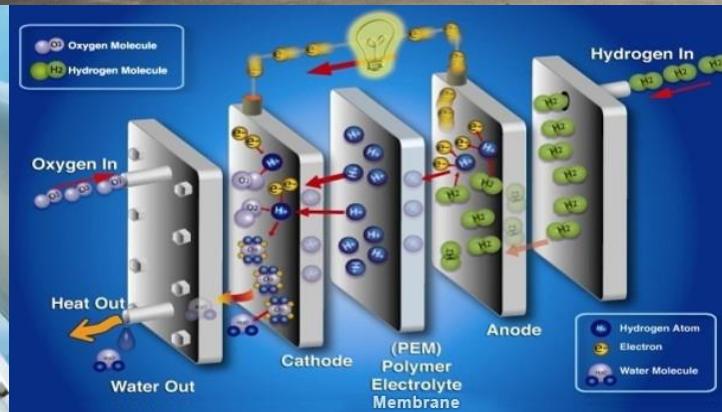


# U.S. Department of Energy Hydrogen and Fuel Cells Program

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



## 2017 Annual Merit Review and Peer Evaluation Meeting

Washington, DC

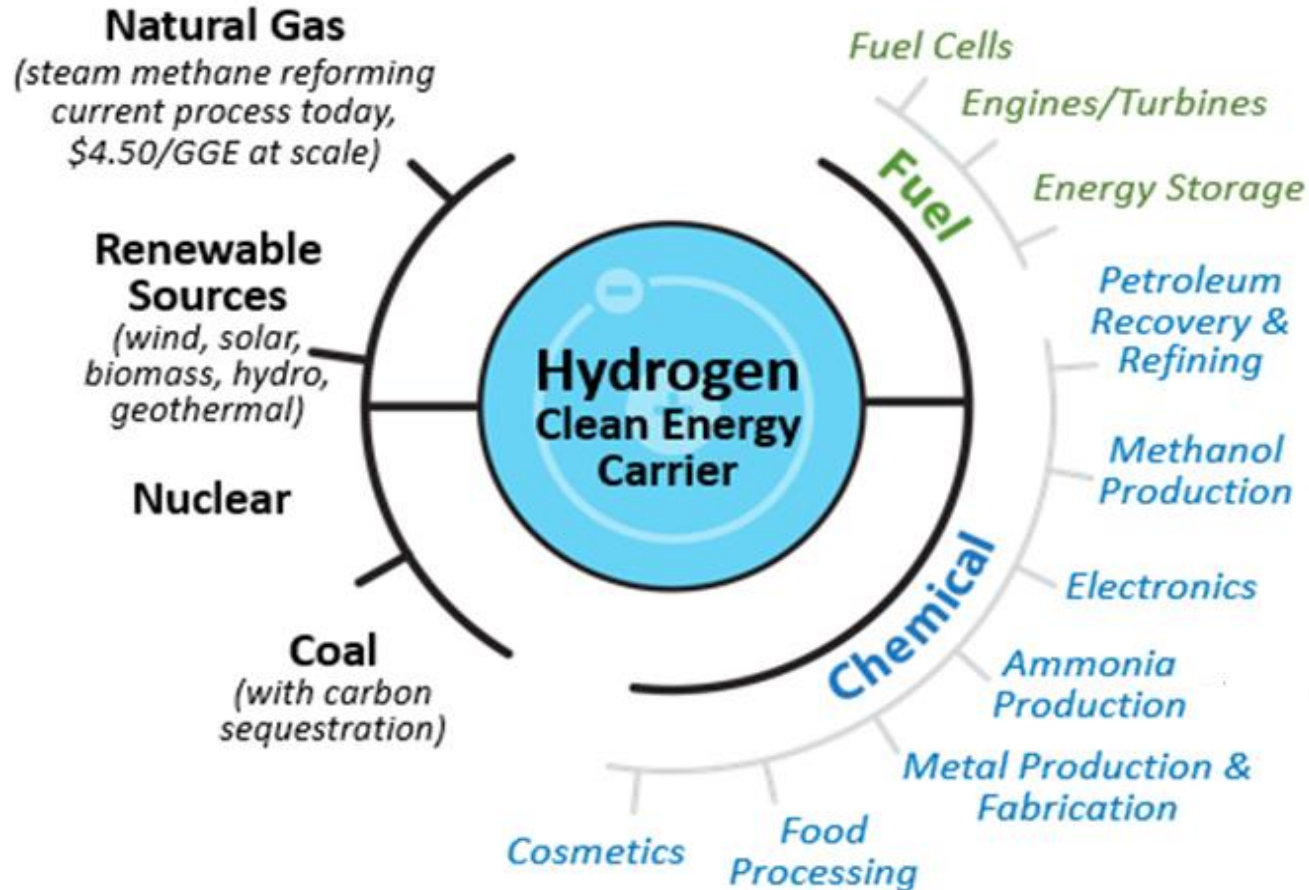
June 5, 2016

Dr. Sunita Satyapal

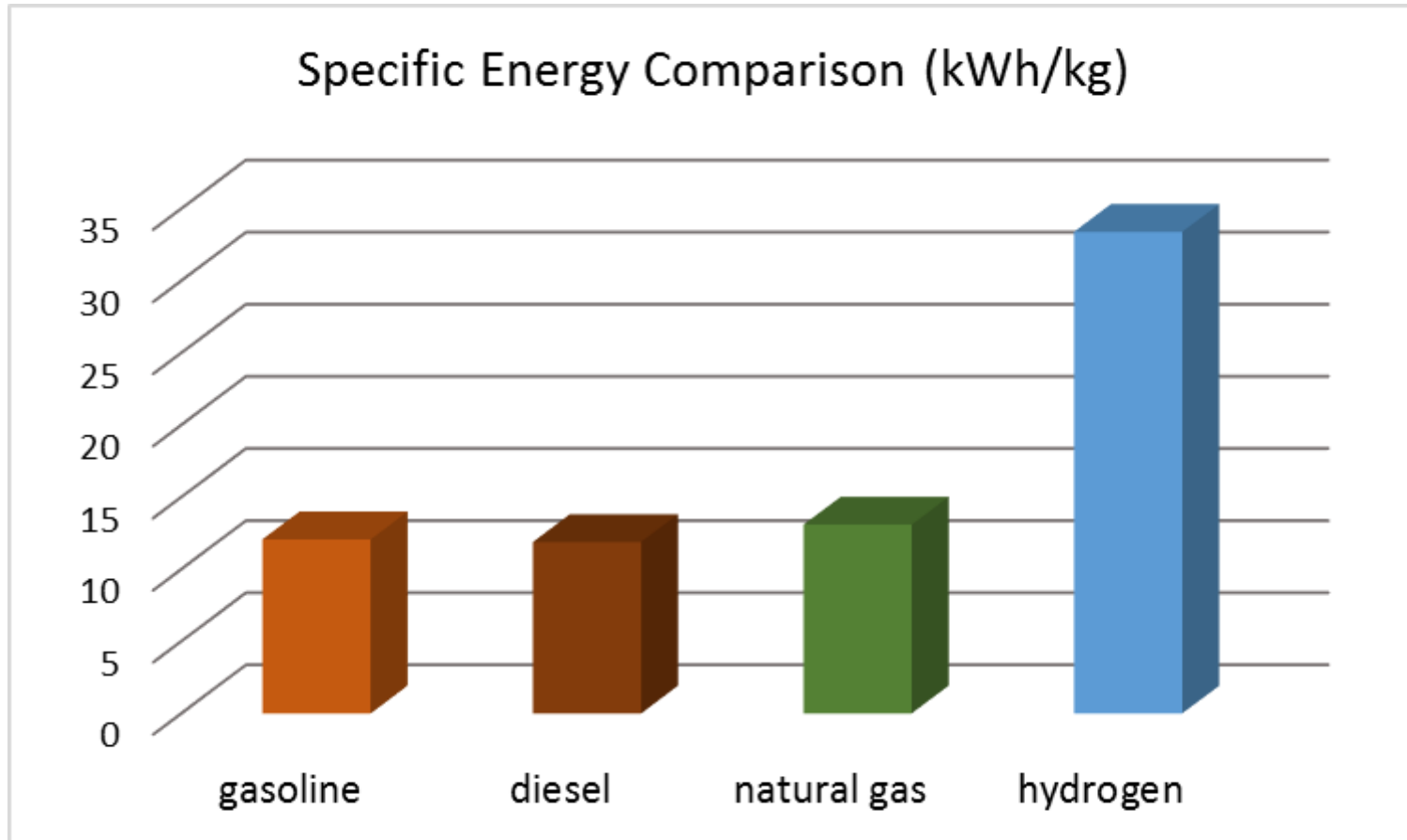
Director  
Fuel Cell Technologies Office  
U.S. Department of Energy

Diverse domestic sources  
can be used to produce H<sub>2</sub>

Many applications rely on  
or can benefit from H<sub>2</sub>



*Hydrogen is a versatile, clean, and efficient energy carrier*



**~ Three times more energy by mass than most other fuels but need higher volumes to store**

## 1970s

A group from labs, government and industry met at Los Alamos to set the foundation for DOE fuel cell programs



Lab researchers taught scientists around the world how to fabricate fuel cell electrodes. Group from GM relocated to Los Alamos.

Forty years later, for the first time in history....



# Commercial fuel cell electric cars are here!

Power, performance,  
petroleum-free, pollution-free

- ✓ Refuels in minutes
- ✓ Up to 360 mi driving range
- ✓ Up to 66 mpgge

# 2017 Preliminary Jobs Analysis Updates



Approx. **16,000** jobs today  
in the **fuel cell car sector** in the U.S.

Source: DOE, U.S. Energy and Employment Report (2017)



Over **200,000** potential jobs  
in the future **with fuel cell cars** in the U.S.

Includes Direct and Indirect Jobs in



## Manufacturing

Approx.  
**100,000** jobs

- **Multiple industries** (manufacturing; professional services; wholesale, retail, transportation; etc.)
- **60% in industrial central region**



## Distribution and Sales

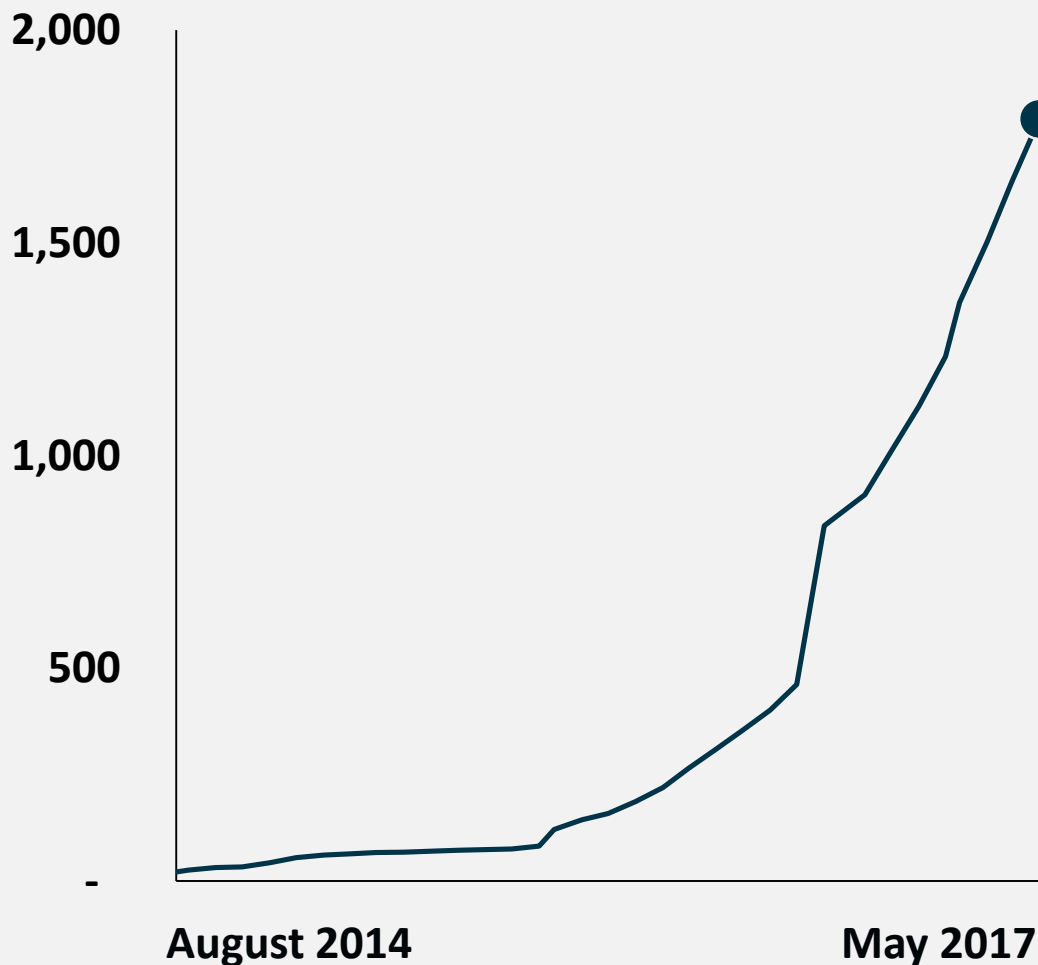
Approx.  
**150,000** jobs

- **50% in Western and Northeast** (highest fuel cell car sales regions)
- **Multiple occupations available** including retail sales, vehicle operators, supervisors of sales, mechanics, etc.

Source: Preliminary DOE ANL Employment Study, June 2017, updates underway

# U.S. Fuel Cell Car Sales and Expert Outlook

## Fuel Cell Car Sales Growing



Note: Cumulative number of vehicles sold/leased. Source: hybridcars.com



**1,800**  
fuel cell cars

**sold or leased in the U.S.**

**78%**  
of executives



**Absolutely or partly  
agree that**

**Fuel cell cars will be  
the real breakthrough  
for electric mobility**

Exceeded DOE-DOT 2016 Durability Target:  
**Nearly 25,000 hours (June 2017)**



Source: AC Transit

**By 2017: Served 17 million passengers**



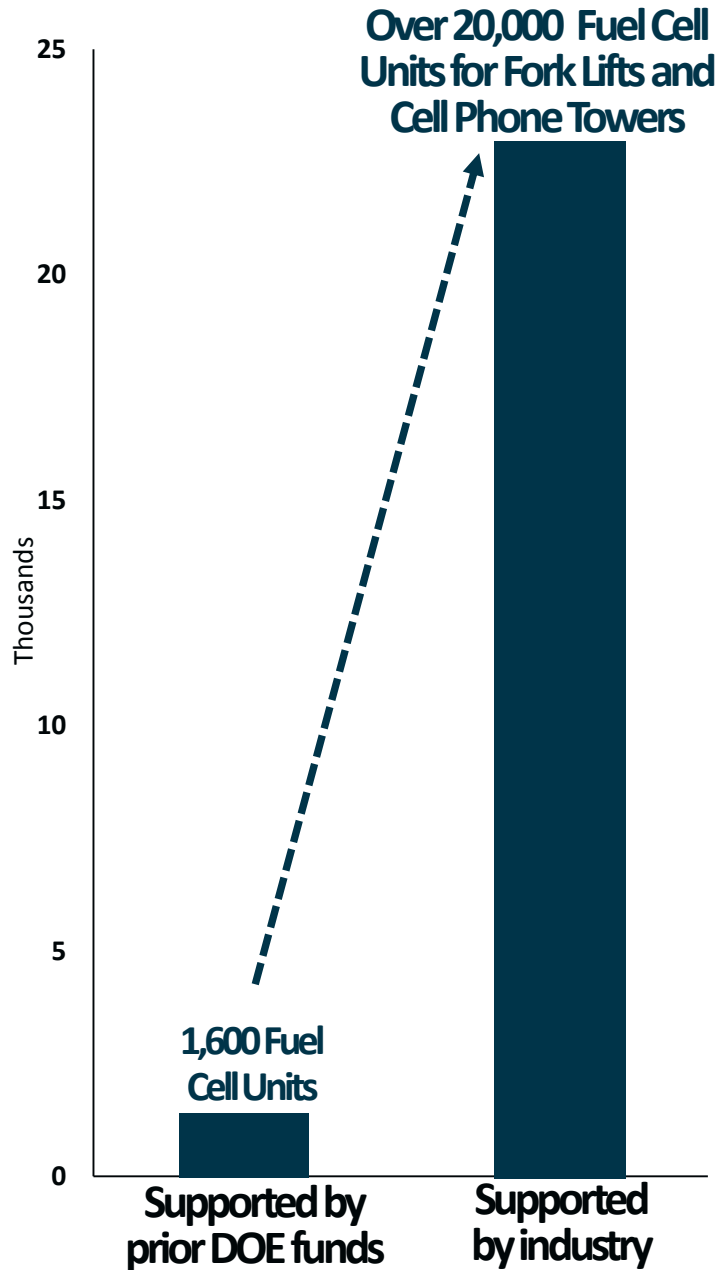
# Industry Orders for Fuel Cells on the Rise



BMW plant in Greer, South Carolina

**Over 15,000 fuel cell forklifts  
deployed or on order**

**Approx. 6 million hydrogen  
refuelings to date**



# Fuel Cells: New Applications Demonstrated



**World's first hydrogen fuel cell train  
in Germany**



**World's first 4-seater fuel cell plane  
takes off at German Airport**



**1<sup>st</sup> fuel cell cargo tow trucks at U.S. airport**



## Fuel Cell Electric Delivery and Parcel Trucks

First of its kind  
demonstration  
starting  
deliveries in  
the summer!



## Industry's first heavy duty fuel cell truck





**World's first fuel cell for maritime ports**



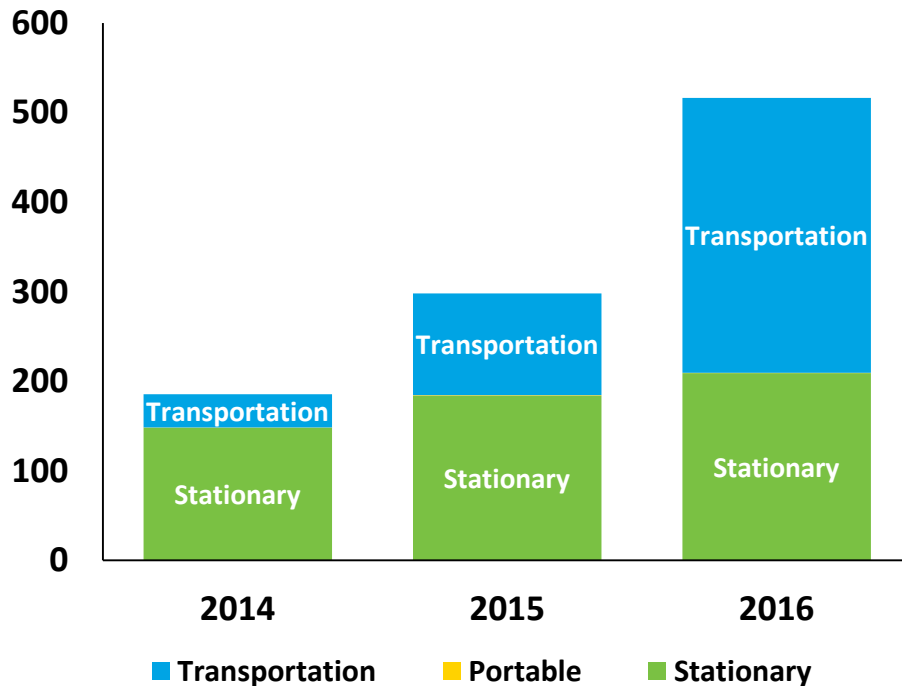
**ZH2: U.S. Army and GM collaboration  
First of its kind**



# 2016 Global Shipments – Trends

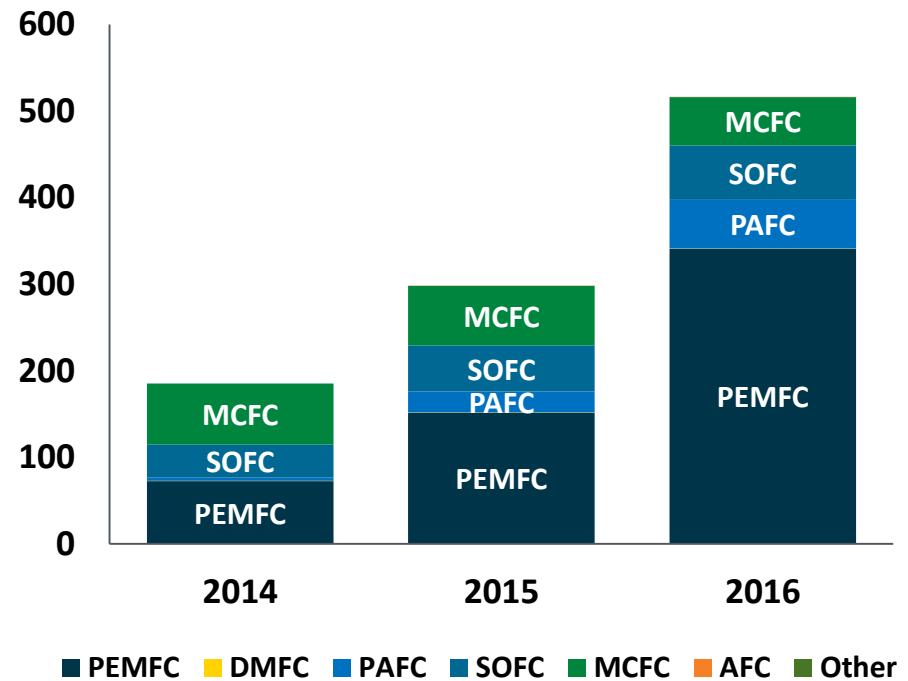
## Total power (in MW) shipped by application

### 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

# Hydrogen Stations – California and Northeast Area

## California

27 open retail

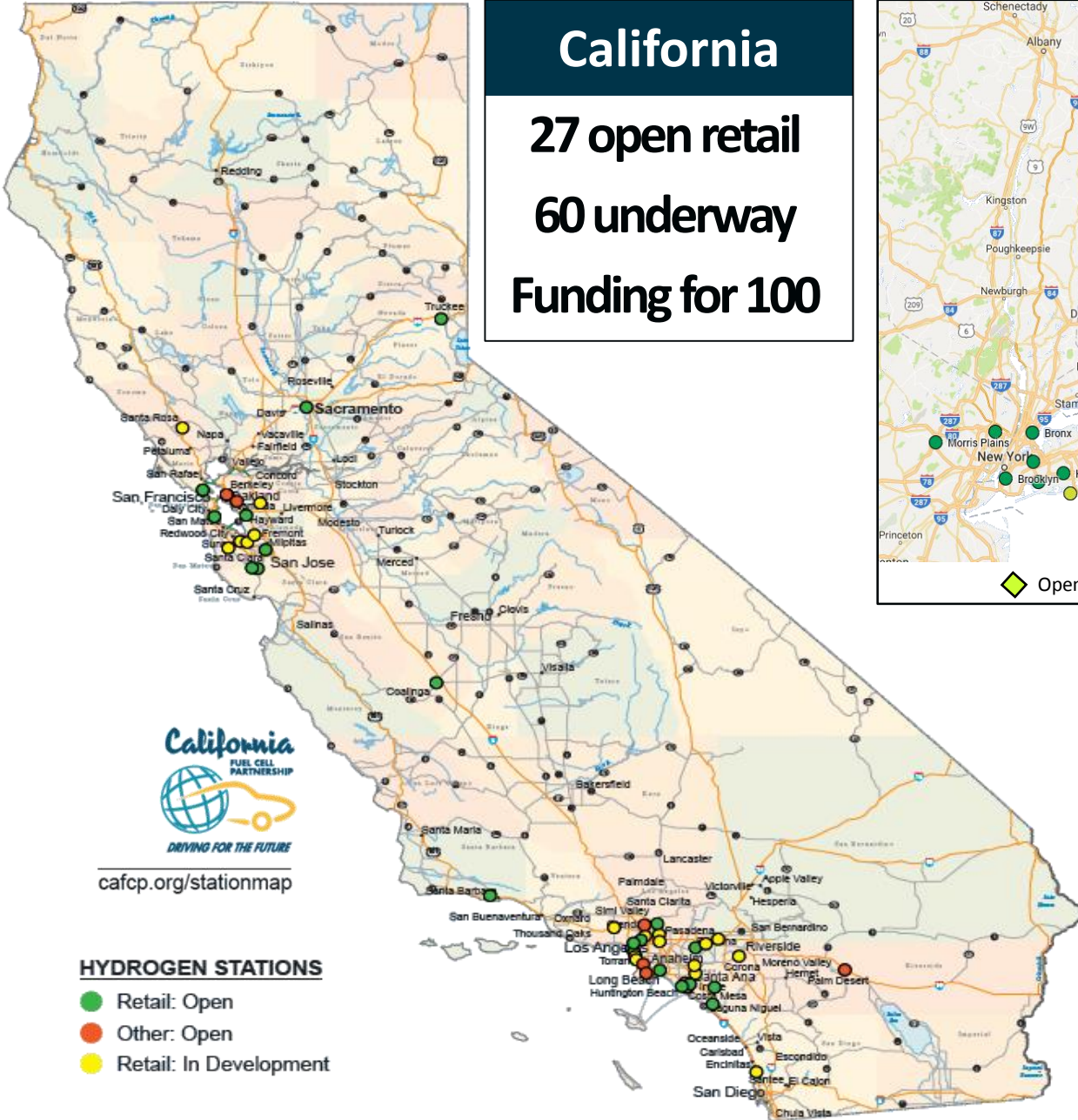
60 underway

Funding for 100



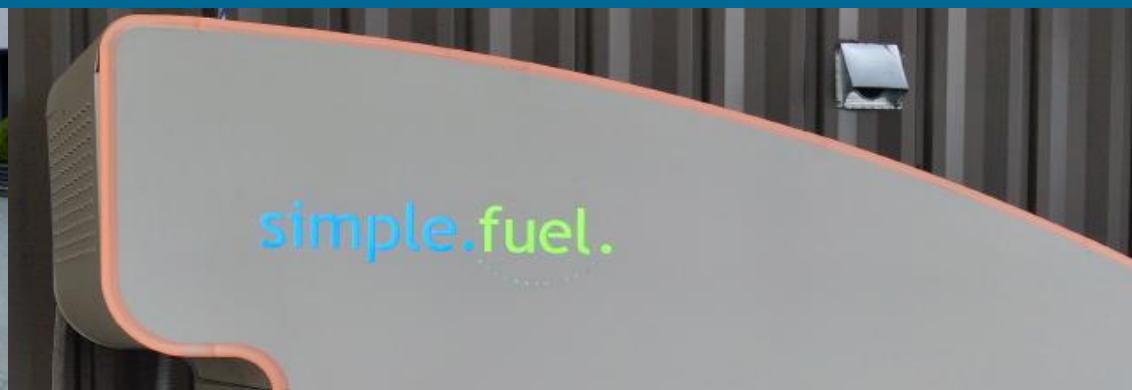
## Northeast

Approx. 12  
to 25 retail  
planned





## Hydrogen R&D demonstration station opens in Washington D.C. Data collection guides future R&D



## DOE awards \$1M H-Prize to Simple Fuel for winner small-scale H<sub>2</sub> fueling design



A photograph of a hydrogen fuel cell vehicle (FCV) at a station. The vehicle is white with blue accents and has "Hydrogen" written on its side. A worker in a white shirt and dark pants is standing near the vehicle. Several orange traffic cones are placed around the vehicle, and a white step ladder is visible. The background shows a clear blue sky and some trees.

**NIST revised Metering Standard from  
1.5% dispensing accuracy to 5%**  
**Example of CA, DOE, NIST, and global collaboration**

NIST HB 44 – Available at:

[www.nist.gov/sites/default/files/documents/2016/11/10/hb44-2017-web\\_final.pdf](http://www.nist.gov/sites/default/files/documents/2016/11/10/hb44-2017-web_final.pdf)

# Target and Status

## Target Updates

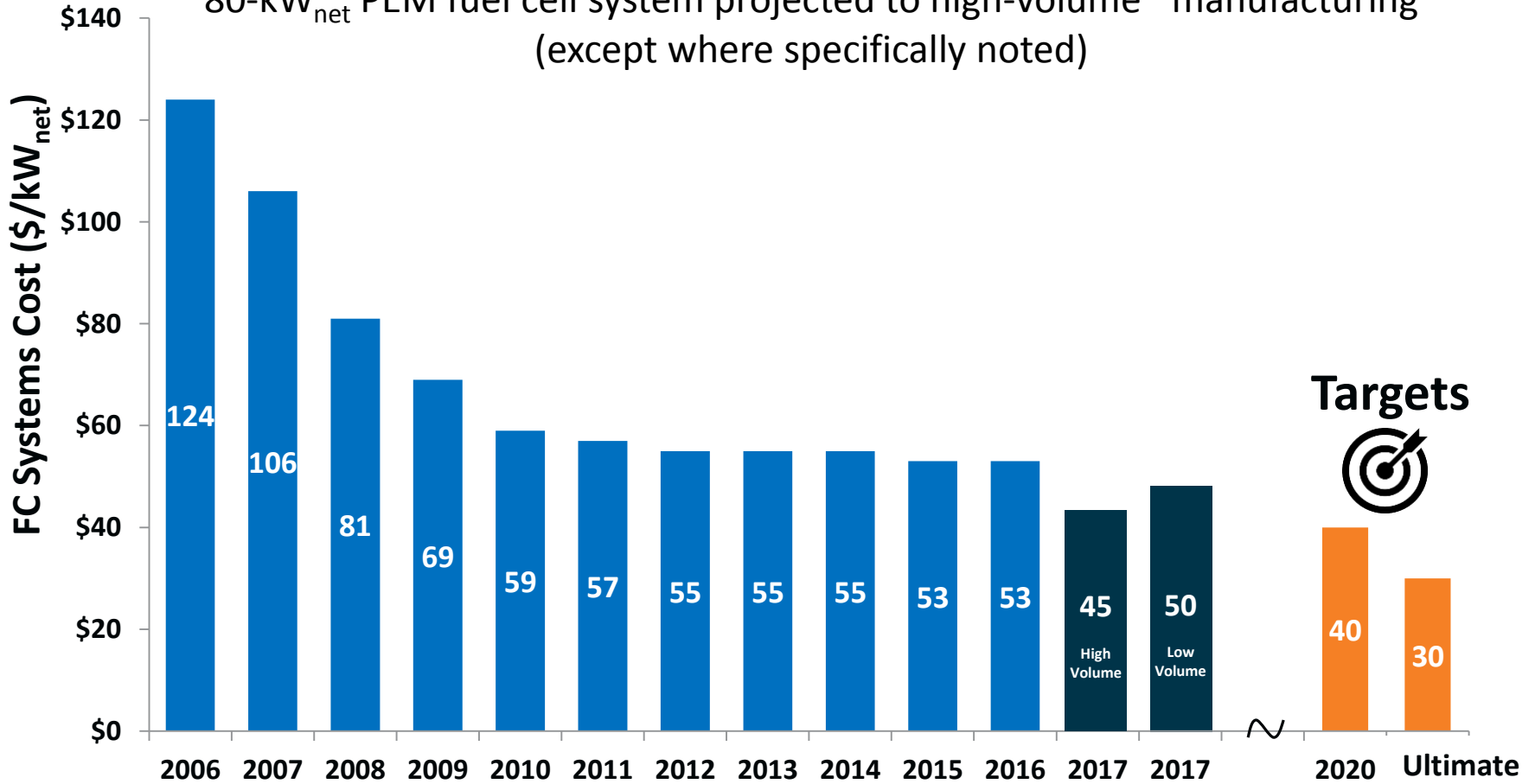
**Examples: Medium/Heavy Duty Trucks  
Hydrogen Storage**

(see backup slides- final publication coming soon)

# Projected Fuel Cell System Cost Reduction

## Modeled Cost of Fuel Cell System Over Time

80-kW<sub>net</sub> PEM fuel cell system projected to high-volume\* manufacturing  
 (except where specifically noted)

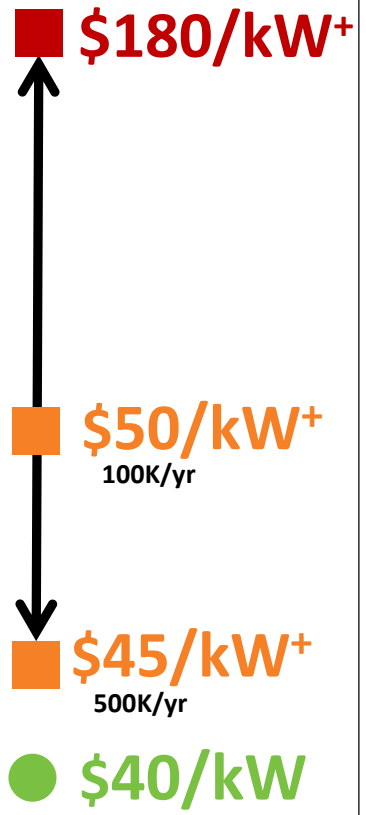


\*Preliminary 2017 cost status

**Advances in catalysts and MEAs  
 enabled major cost reductions in 2017**

## Fuel Cell R&D

### System

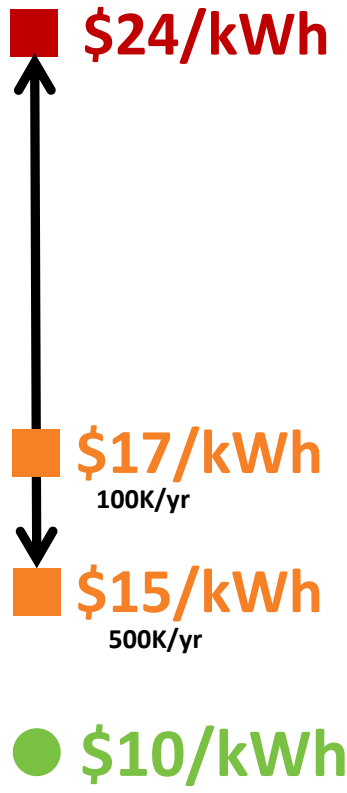


## Hydrogen R&D

### Production, Delivery & Dispensing



### Onboard Storage (700-bar compressed system)



● 2020 Targets      ■ High-Volume Projection      ■ Low-Volume Estimate

\*Based on Electrolysis \*\*Based on NG SMR †Preliminary, updates underway  
 Onboard storage cost status from DOE Program Record 15013

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



## Innovation



**650** H<sub>2</sub> and fuel cell  
**patents**  
enabled by FCTO funds

Approx.  
**40%** of H<sub>2</sub> 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



H<sub>2</sub> Production  
R&D

Cut electrolyzer  
costs 80%

# Hydrogen & Fuel Cells Budget (EERE FCTO)

Key Activity	FY 2016	FY 2017	FY 2018
	(\$ in thousands)		
	Approp.	Enacted	Request
Fuel Cell R&D	35,000	32,000	15,000
Hydrogen Fuel R&D <sup>1</sup>	41,050	41,000	29,000
Systems Analysis	3,000	3,000	1,000
Technology Acceleration	-		
Technology Validation	7,000	18,000	-
Manufacturing R&D	3,000		-
Market Transformation	3,000		-
Safety, Codes and Standards	7,000	7,000	-
NREL Site-wide Facilities Support	1,900	-	-
<b>Total</b>	<b>100,950</b>	<b>101,000</b>	<b>45,000</b>

## White House Budget Proposal Language FY 2018

- Increased reliance on the **private sector to fund later-stage research, development, and commercialization**
- Focuses resources toward **early-stage research and development**

DOE Basic Energy Sciences FY16 funding relevant to H<sub>2</sub> and fuel cells: \$24.7 M

<sup>1</sup>Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D

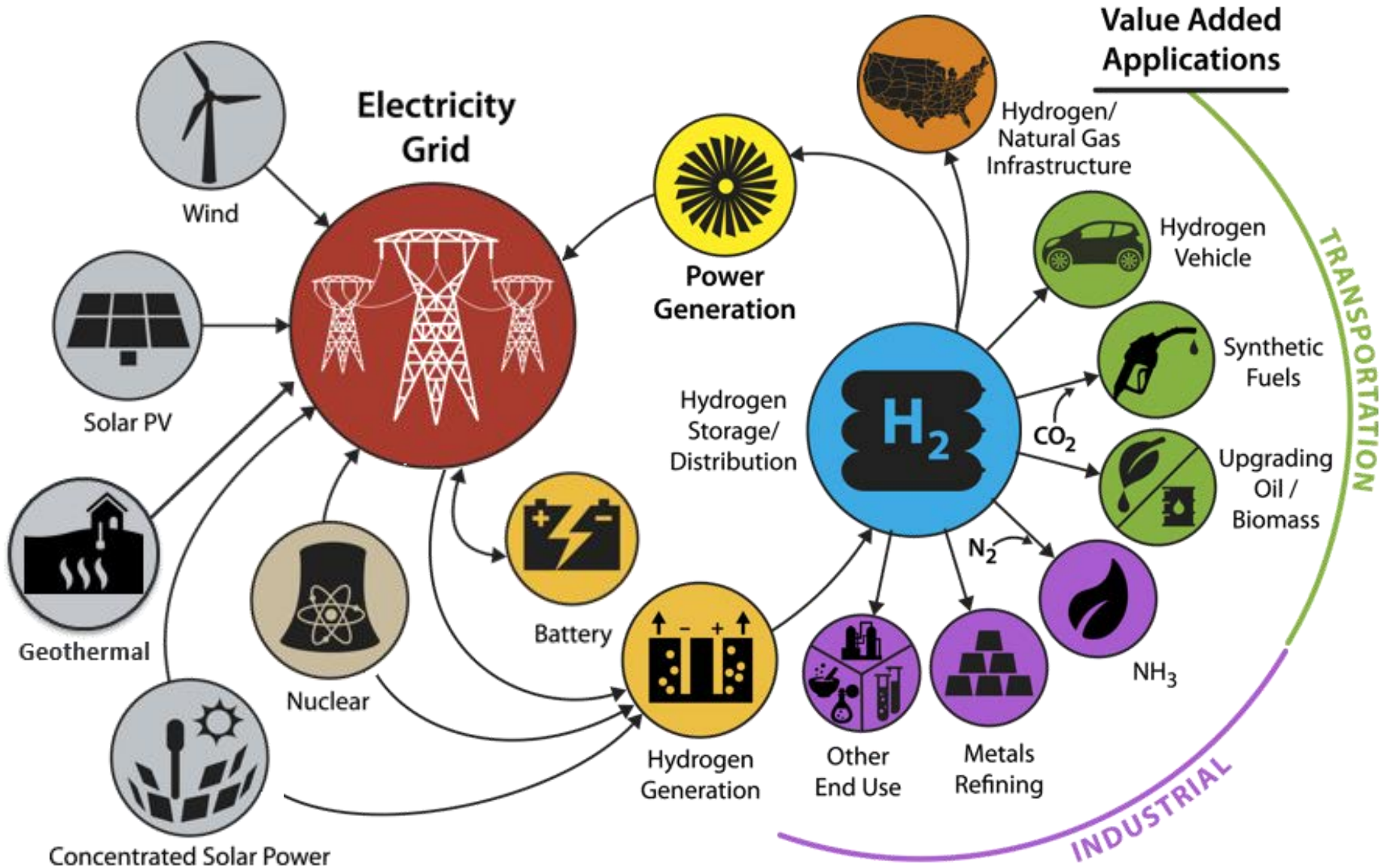
***Stronger emphasis on early R&D and relying on industry for later stage R&D***

# Strategy

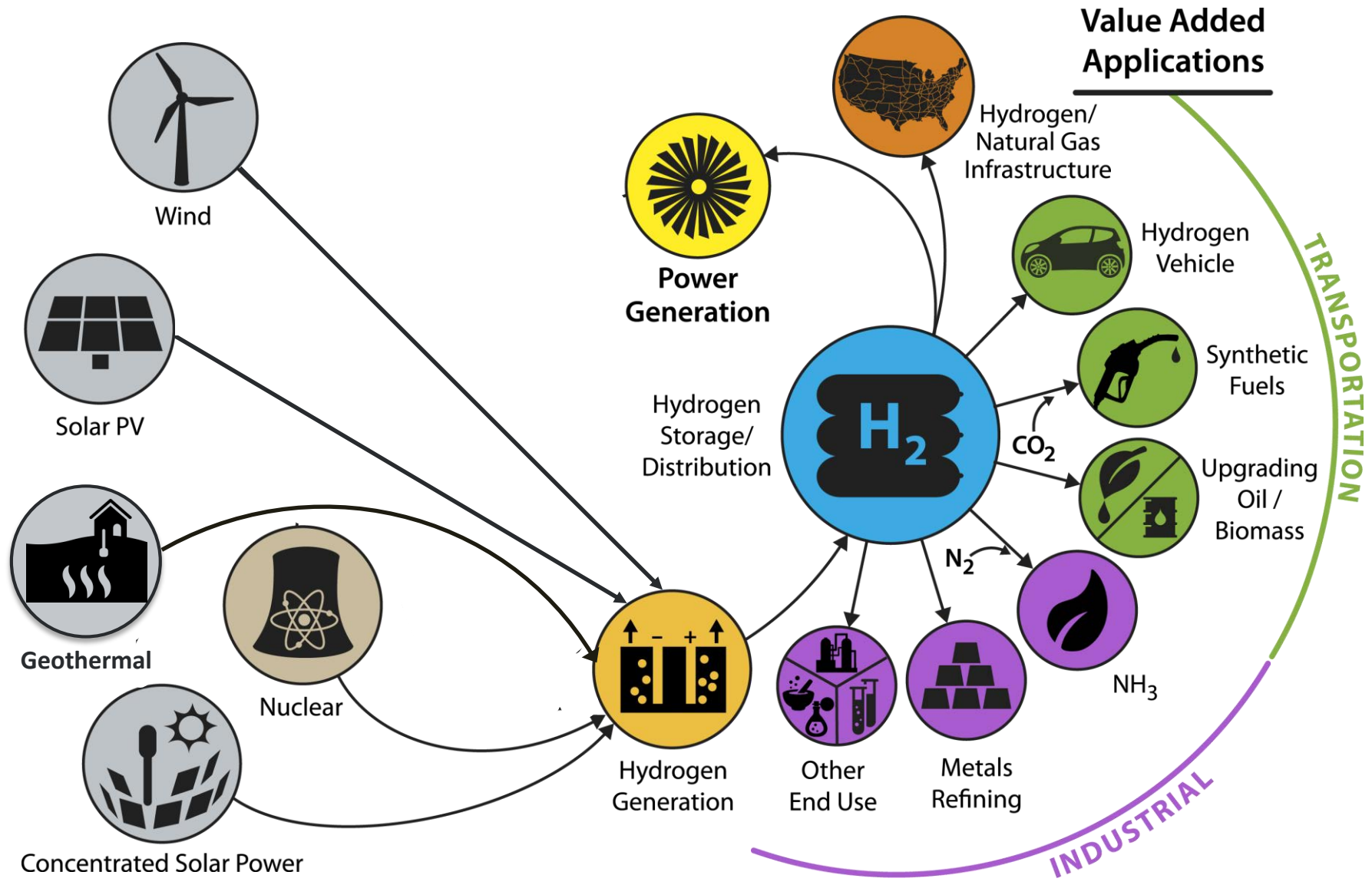
## Early stage R&D to enable innovation

- **Fuel Cells (\$15M):** Focus on PGM-free catalysts, electrodes, membranes
- **Hydrogen (\$29M):** Focus on materials R&D, advanced water-splitting, enablers for **H2@Scale** (materials, delivery and storage related technologies, liquefaction, etc.)

# H2@Scale Energy System



\*Illustrative example, not comprehensive  
Adapted from NREL, Lab Big Idea Team



**Collaboration**  
**is**  
**Critical**

## The Hydrogen Council formed Jan 2017



### Investment

**\$10.7B**

towards  
**hydrogen and  
fuel cells**



### Members

**13 companies**

representing  
**\$1T in revenues  
and 1.7M jobs**

# DOE National Lab System: A Reservoir of Talent for Science and Technology

Founded by DOE nearly 80 years ago

War effort motivated scientific breakthroughs:  
Manhattan project, radar development

A few \$M in **DOE investment** in the '40s  
Labs at ~ \$10B today

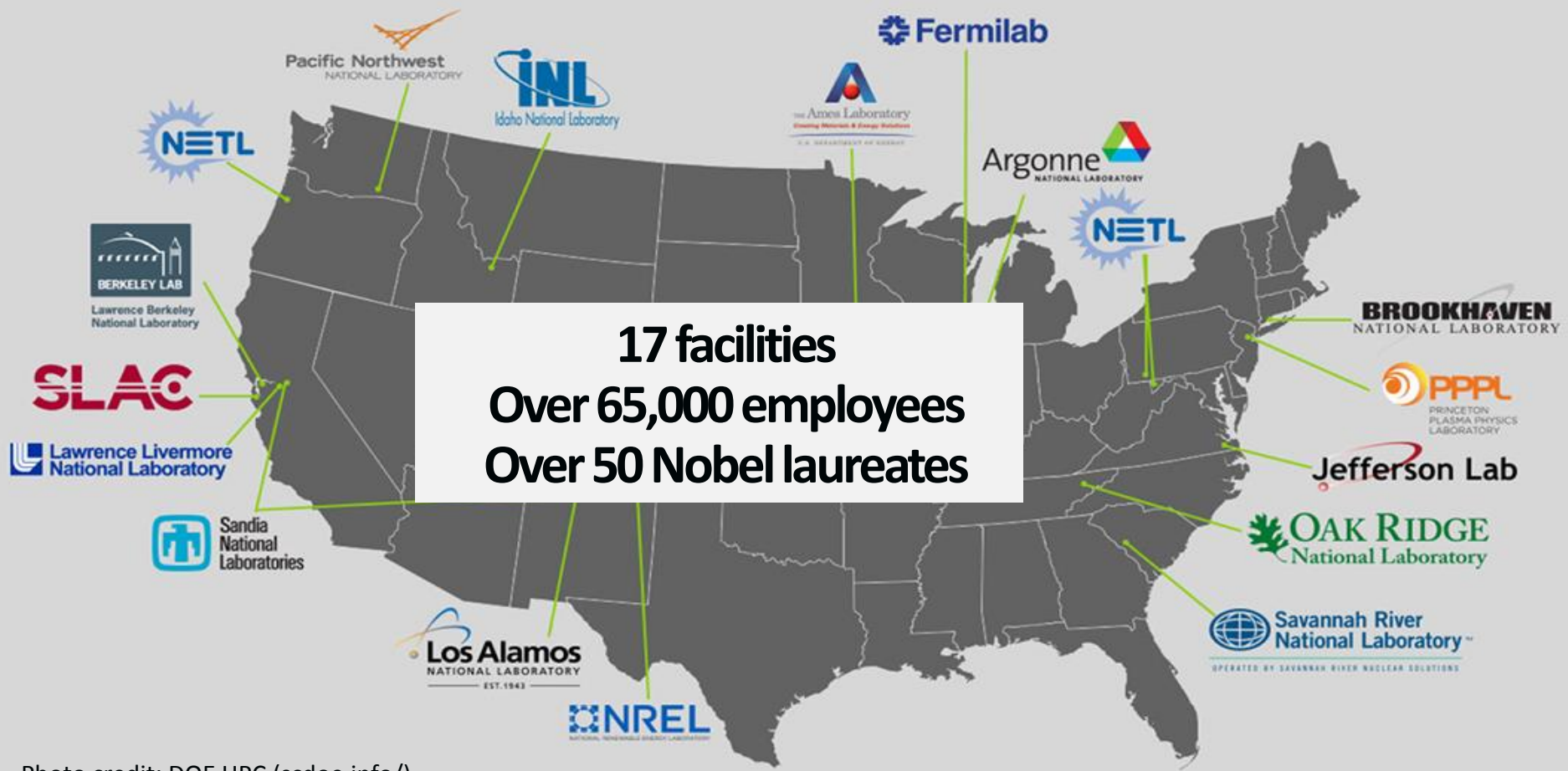
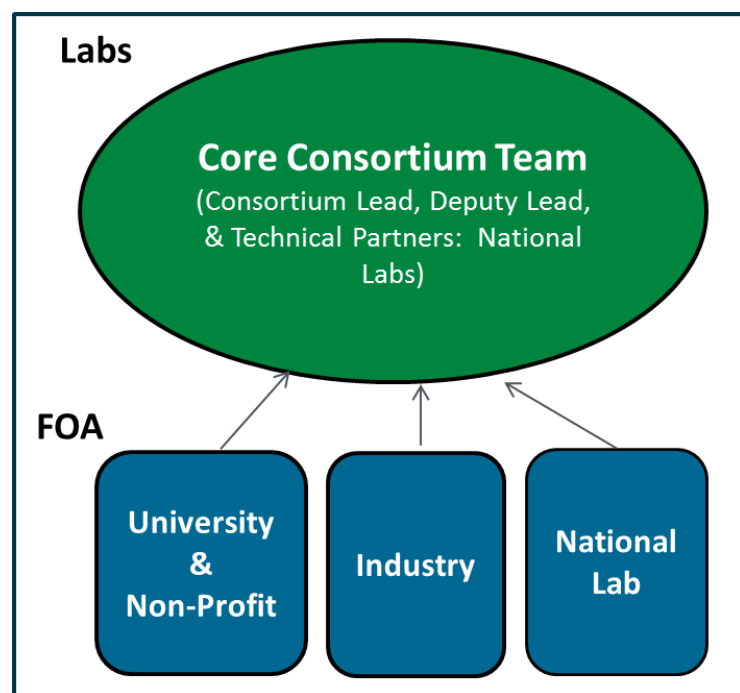


Photo credit: DOE HPC (scdoe.info/)



## Consortium Approach

Multi-lab core capabilities with steady influx of new partners



## Consortia Launched

Improved PEM fuel cells



PGM-free catalysts



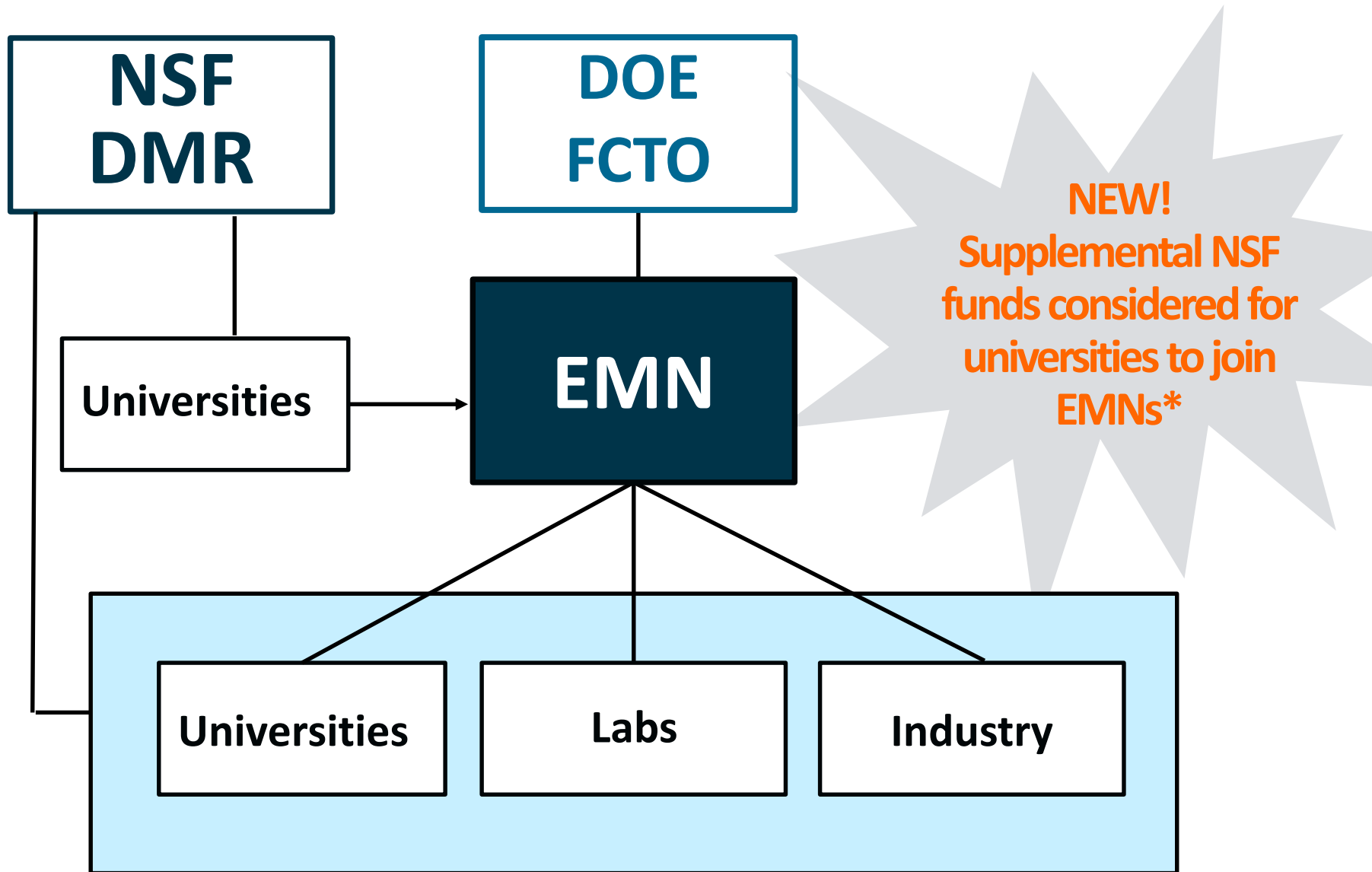
Advanced H<sub>2</sub> materials storage



Materials for renewable H<sub>2</sub> production



# Leveraging Funding- Example Pilot



## Four-Lab Consortium – Roll-to-Roll Processes

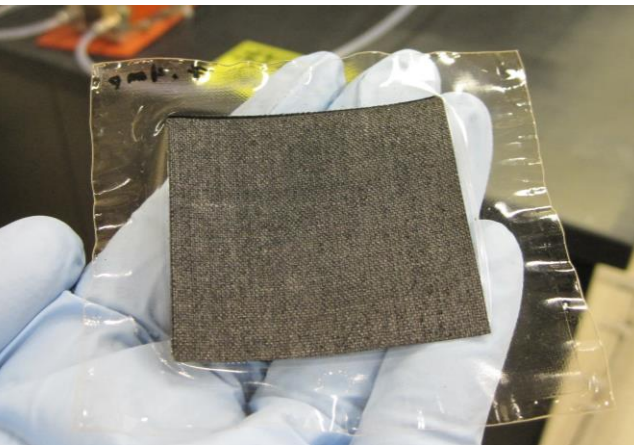
**DOE Offices:** AMO, FCTO and VTO

**Funding:** Over \$2M (\$1M from FCTO and \$1.3 from AMO)

**FCTO will cost share AMO funding on electrolyzer and fuel cell topics**

**Labs:** Oak Ridge, Argonne, Lawrence Berkeley and National Renewable Energy Labs

AMO: Advanced Manufacturing Office; VTO: Vehicle Technologies Office; FCTO: Fuel Cell Technologies Office



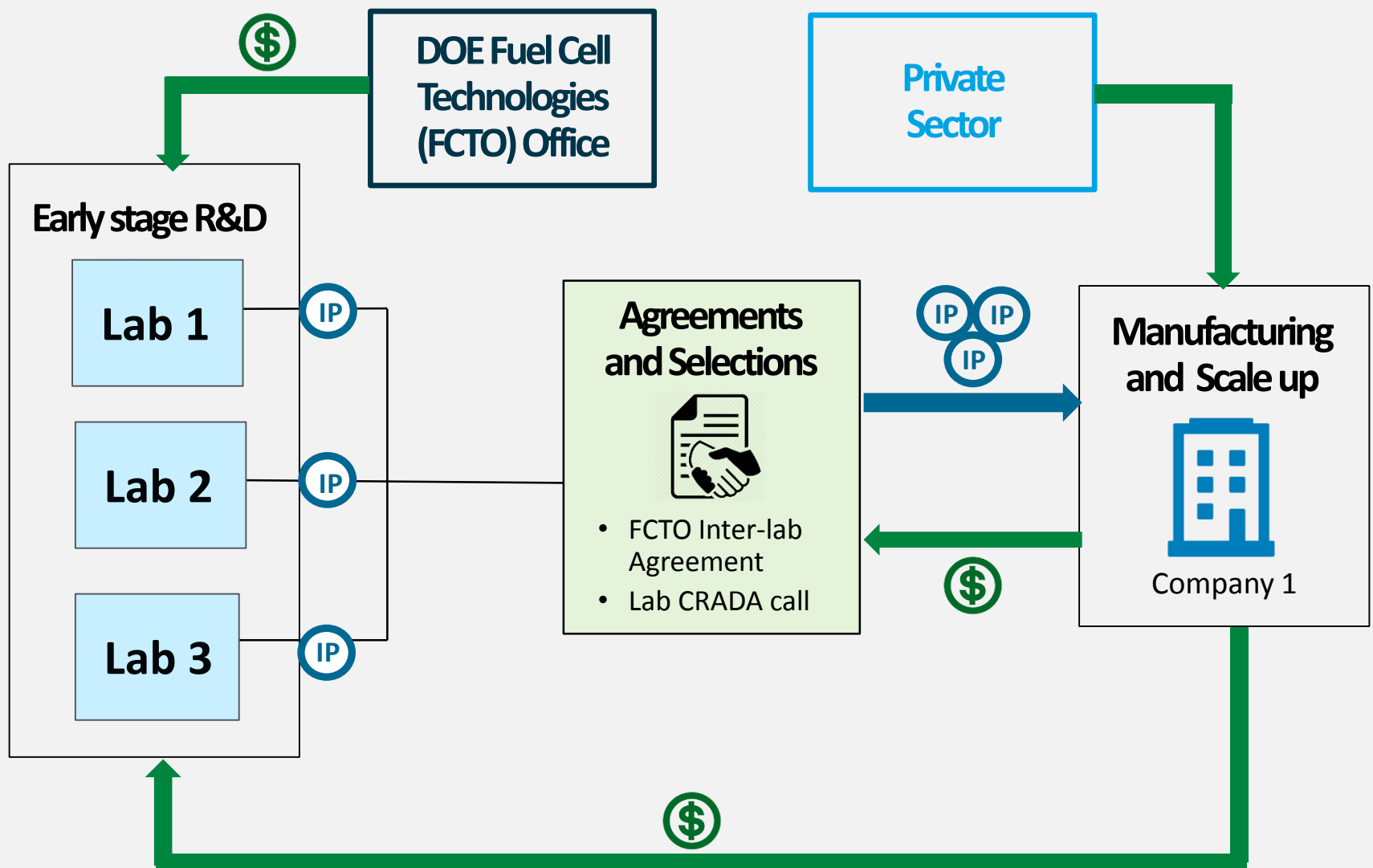
## CRADA Now Open to Proposals!

More info: [www.fbo.gov](http://www.fbo.gov)

Solicitation Number: ORNL-R2RAMM-2017-02-02

Questions? Email [R2RAMM@ornl.gov](mailto:R2RAMM@ornl.gov)

## L'Innovator= "Lab Innovator" FCTO Pilot



# **H2@Scale CRADA Call Planned**

(Cooperative Research & Development Agreement)

**to work with National Labs**

**Up to \$3M in FY17 Funds**

# Other Lab Capabilities (Examples- Draft)

## Modeling and Analysis

### Examples

- Value proposition
- Demand/market projection
- Cost/benefit, financial and application evaluation
- Scenario analysis
- Resource assessment

### Labs



## H<sub>2</sub> – Materials Compatibility R&D

### Examples

- H<sub>2</sub> materials exposure effects testing
- Materials selection and innovation

### Labs



## Simulation and Testing

### Examples

- Grid simulation
- Electrolyzer performance testing
- Model Validation

### Labs



## Safety R&D

### Examples

- Hydrogen behavior assessment
- Safety training and outreach
- Certification/permitting
- Quantitative risk assessment
- Safety testing and model validation
- Project/Facility safety review

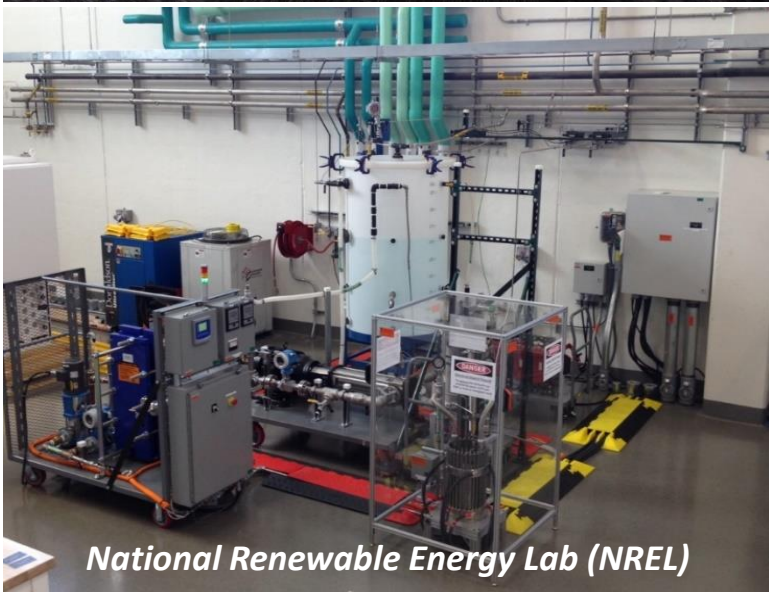
### Labs



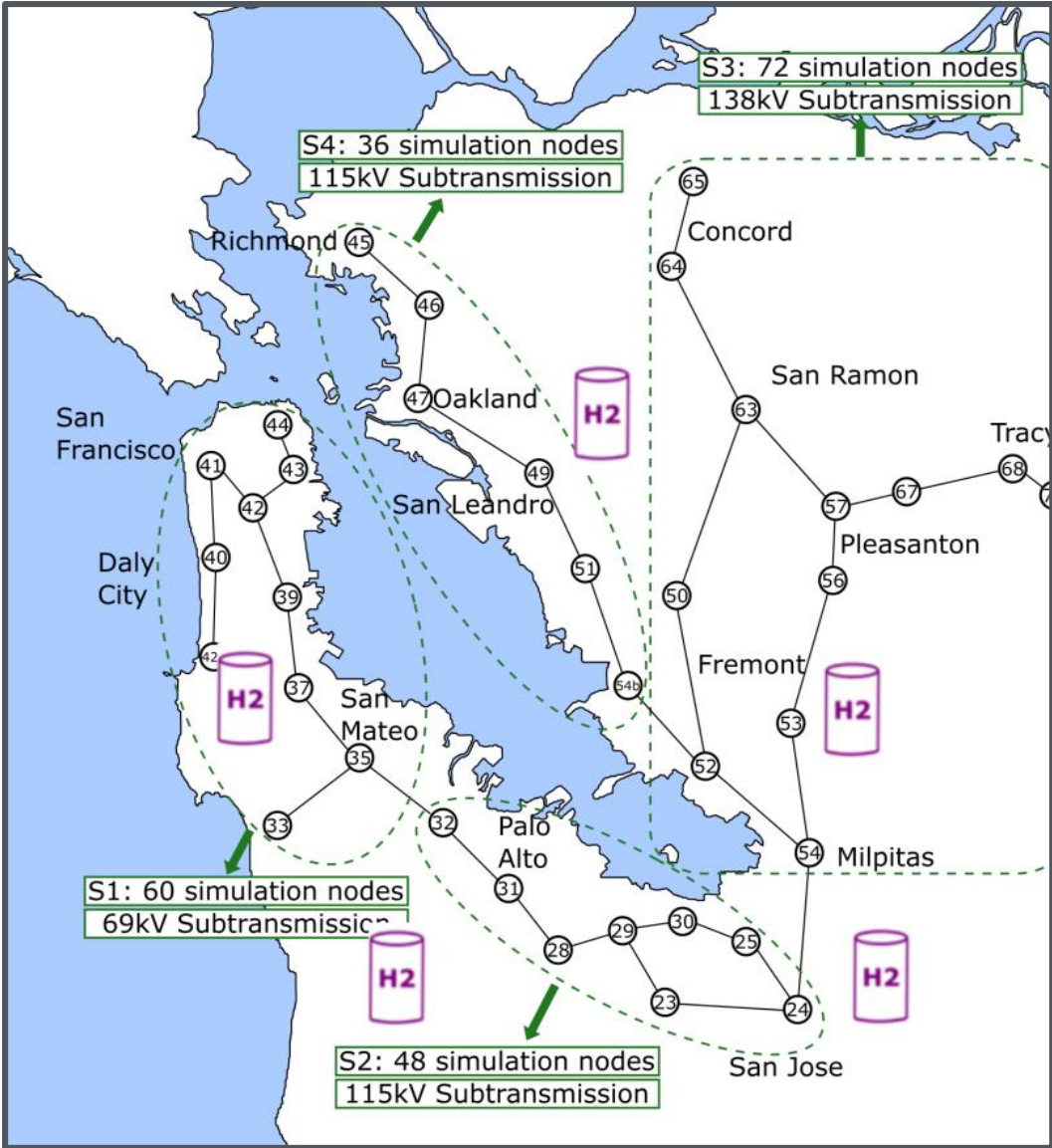
# Lab Testing: Electrolyzer Grid Integration



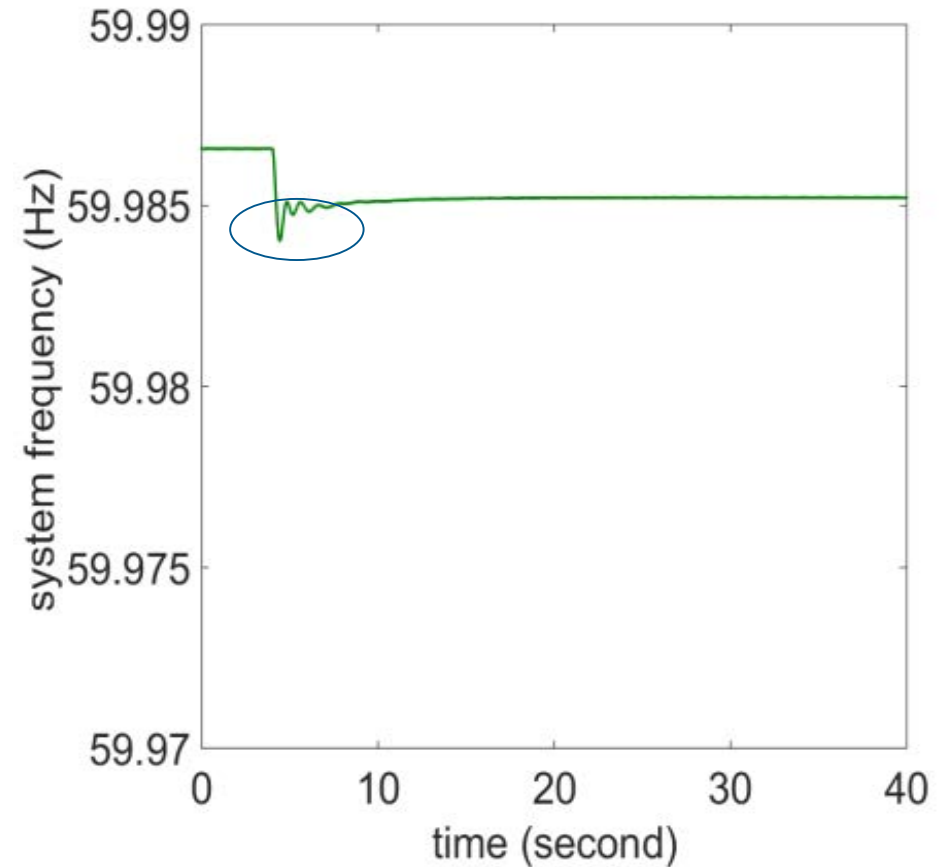
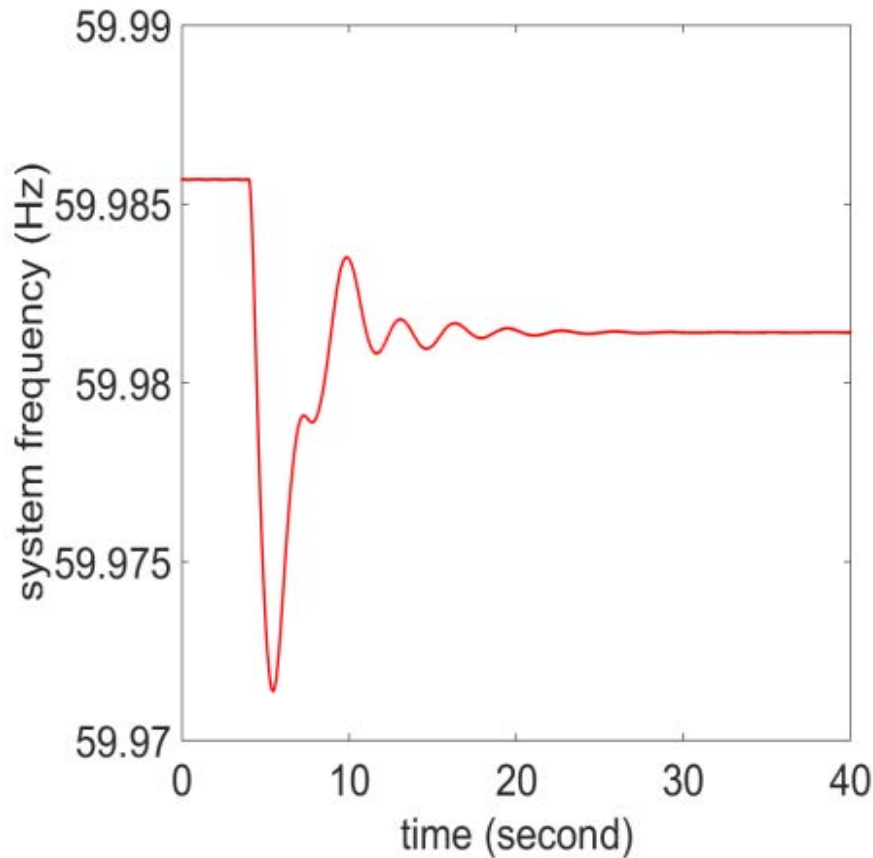
Idaho National Lab (INL)



National Renewable Energy Lab (NREL)



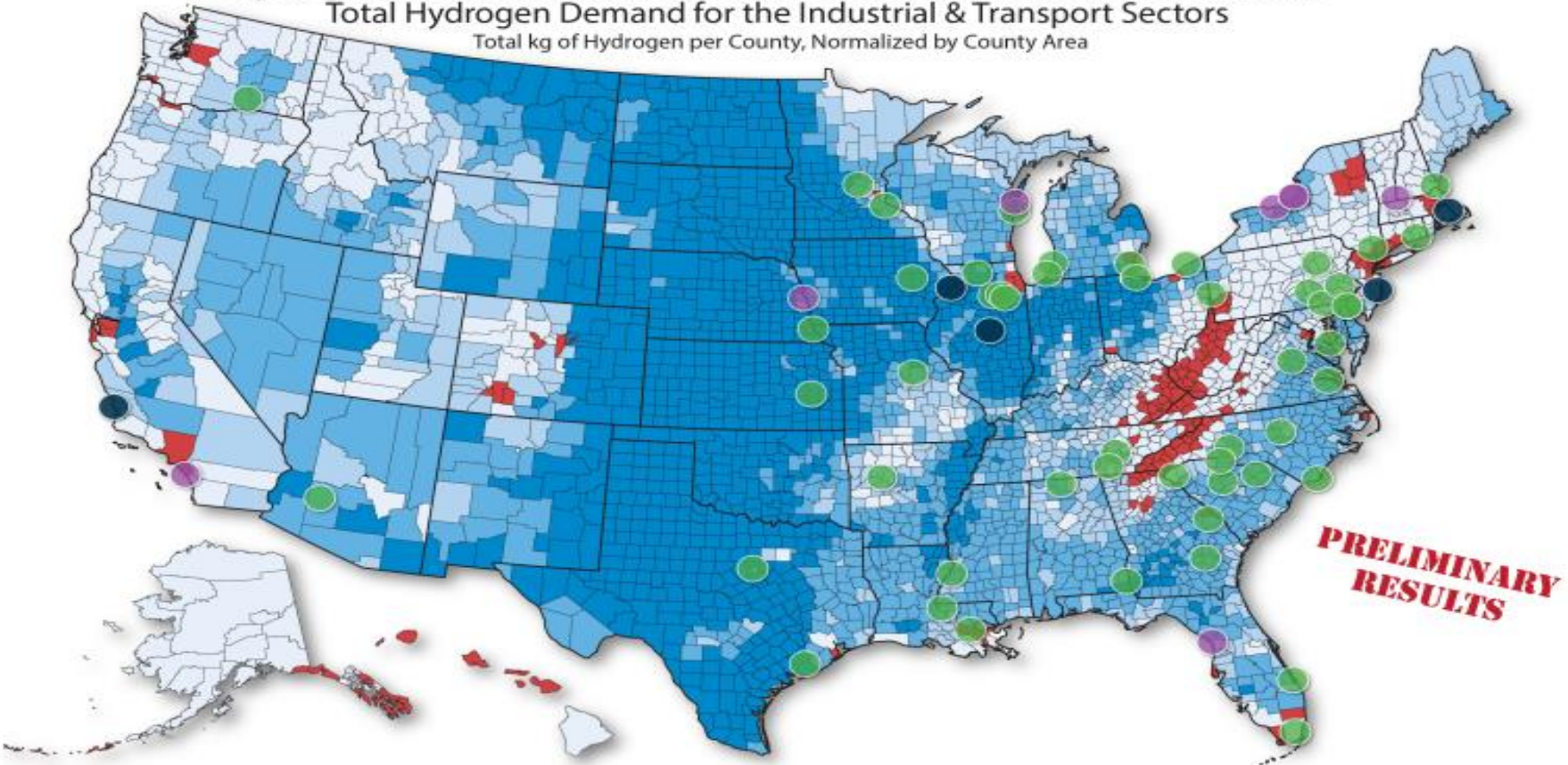
**First ever validation of real time grid simulation with electrolyzers**



*First independent validation of frequency regulation with electrolyzers and sub-second response times (INL, NREL)*



Hydrogen Potential From Photovoltaic and Onshore Wind Resources Minus Total Hydrogen Demand for the Industrial & Transport Sectors  
Total kg of Hydrogen per County, Normalized by County Area



**PRELIMINARY RESULTS**

**Hydrogen**  
(metric ton/m<sup>2</sup>/yr)

- 2,000 – 4,500
- 1,000 – 2,000
- 350 – 1,000
- 0 – 350
- 12,200 – 0

**Nuclear Energy Plants**

- Currently Operating
- Announced Retirement
- Recently Retired

This analysis represents potential generation from utility-scale photovoltaics and onshore wind resources minus total hydrogen demand from the industrial sector: refineries, biofuels, ammonia and natural gas systems (metals are not included) and the transport sector: light duty vehicles and other transport. The data has been normalized by area at their respective spatial scales, and then summarized by county.

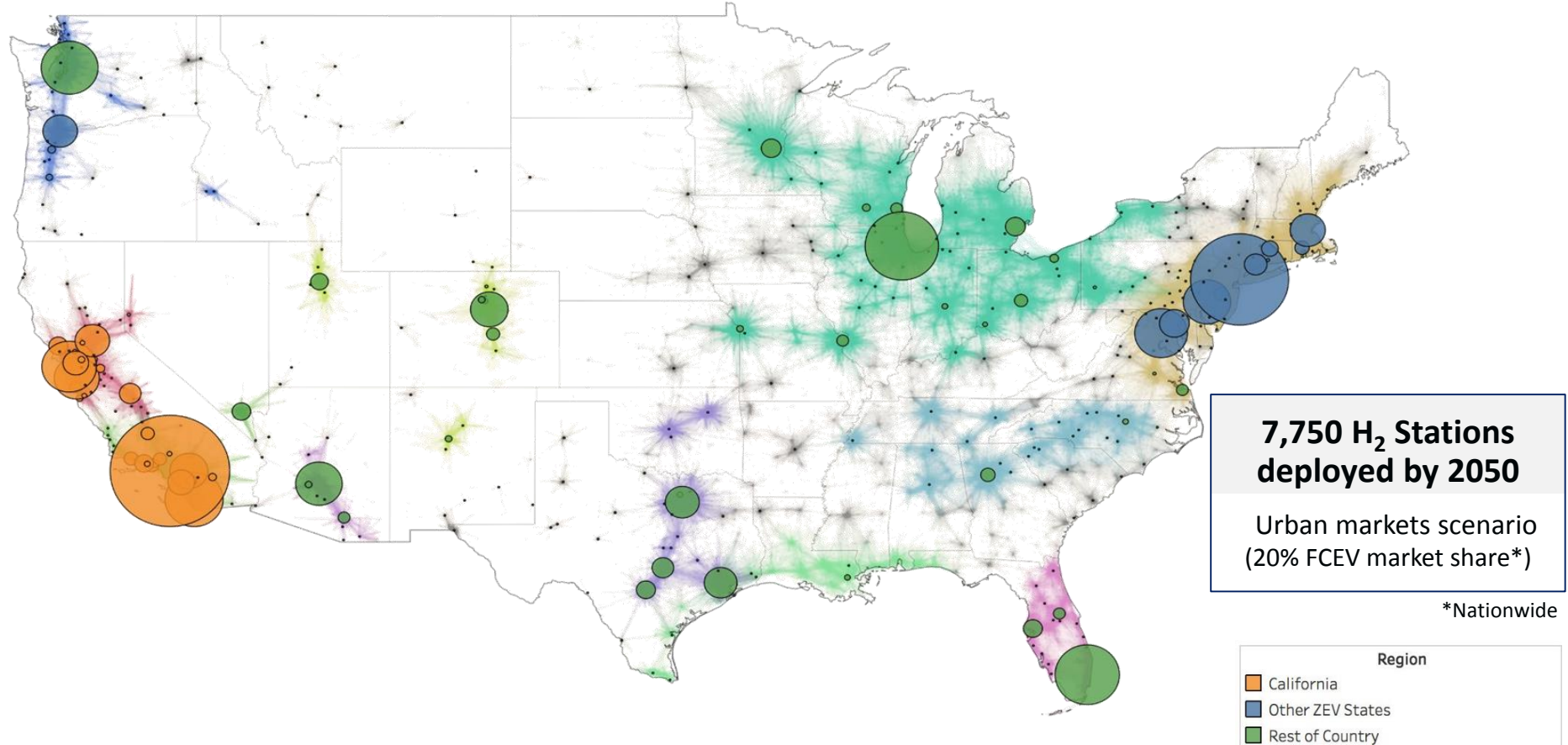
Data Source: NREL analysis  
Robson, A. Preserving America's Clean Energy Foundation. Retrieved March 23, 2017, from <http://www.thirdway.org/report/preserving-americas-clean-energy-foundation>  
Lab PIs: Mark Ruth, Bryan Pivovar, Richard Boardman, et al

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Nicholas Gilroy, March 27, 2017



**Labs assess resource availability. Most regions have sufficient resources.**  
Red: Only regions where projected industrial & transportation demand exceeds supply.

## NREL's Station Rollout Scenario Analysis in support of H<sub>2</sub>USA



### Examples of variables considered in scenarios:

- ✓ Consumer adoption
- ✓ Station Expansion Network

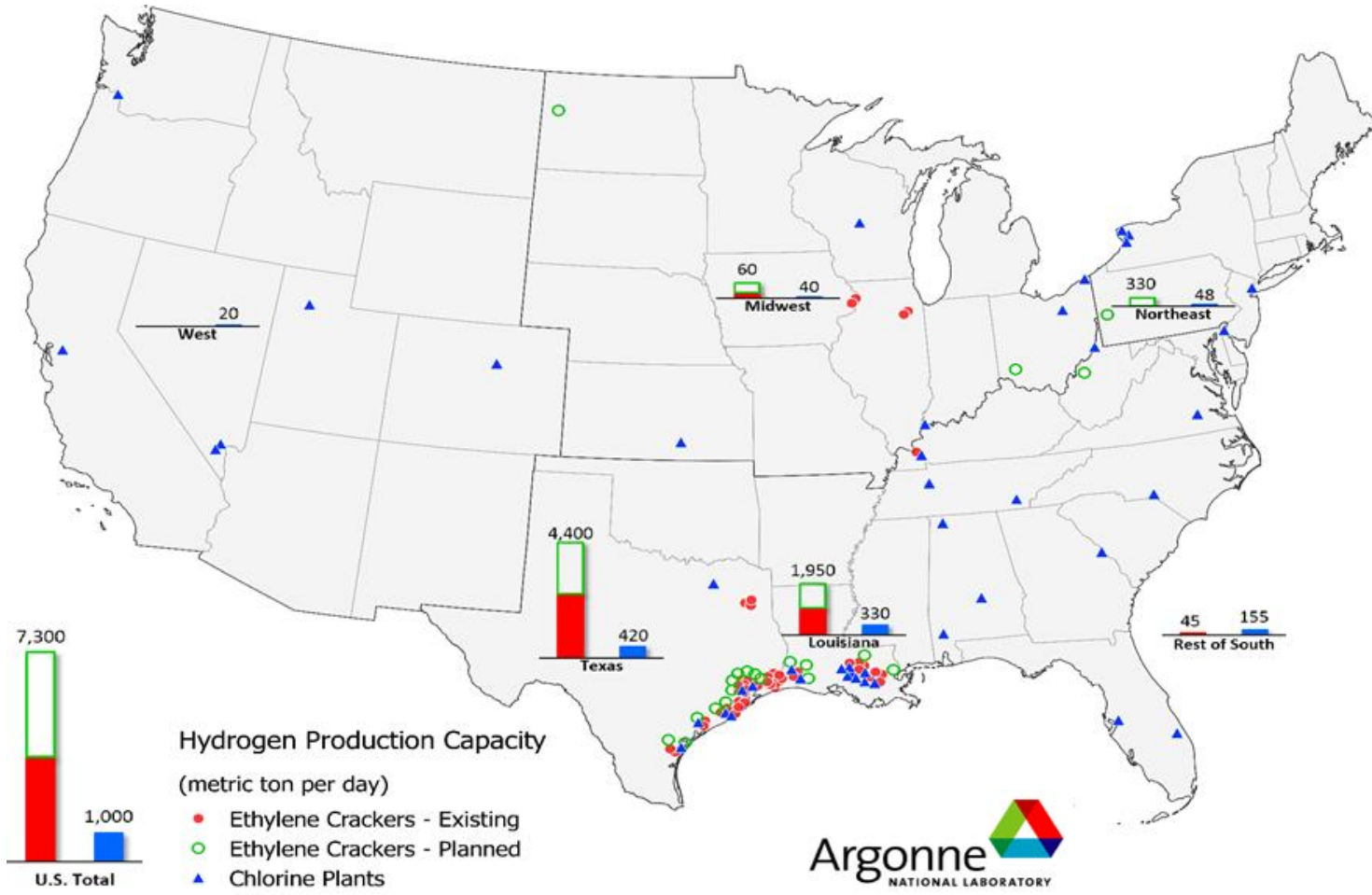
Source: Marc Melaina, et al, NREL

# Example Lab Analyses: Byproduct Hydrogen

More than 4,000 metric tons per day of H<sub>2</sub> byproduct from chlorine and ethylene cracker plants

Existing hydrogen byproduct production capacity can serve

**8 Million** hydrogen fuel cell cars



Source: Amgad Elgowainy, et al



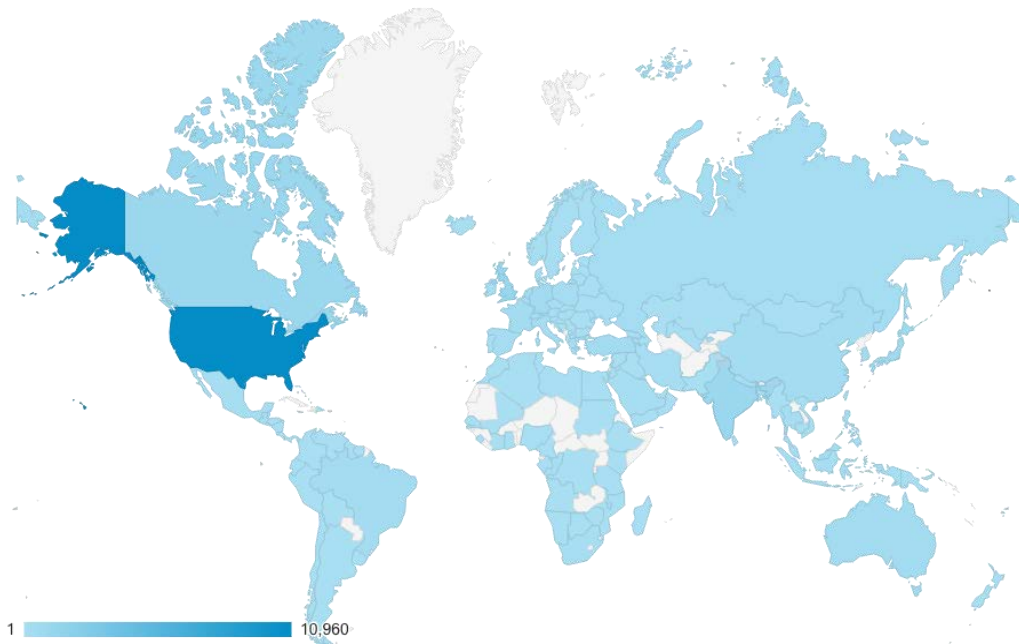
= 1M fuel cell cars

\*average FCEV needs approx. 0.5 kg of hydrogen per day

## H2Tools.org disseminates information on hydrogen safety

### A Global Resource

nearing 150,000 visits since 2015 - 50% are international  
Portions translated to Japanese, other languages underway



**Hydrogen Risk Assessment Models (HyRAM)** for risk analysis under various scenarios

**Hydrogen Safety Panel** with 400 years of collective safety expertise, collaborating worldwide to advance safety, codes & standards

**Nominations for experts now being accepted**

**Contact:**  
[hsp@h2tools.org](mailto:hsp@h2tools.org)

**HOT OFF THE PRESS**

**30 new FCTO awards totaling  
approx. \$16M in FY 2017 funding  
to be announced very soon**

**Stay Tuned**

# Active in Social Media?



Share your hydrogen and fuel cell thoughts this week

**#H2AMR**

**#H2IQ**



<https://energy.gov/eere/technology-to-market/videos/eeres-national-lab-summit-inspiring-innovation>

# Thank You

**Dr. Sunita Satyapal**

**Director**

**Fuel Cell Technologies Office**

**[Sunita.Satyapal@ee.doe.gov](mailto:Sunita.Satyapal@ee.doe.gov)**

**[hydrogenandfuelcells.energy.gov](https://hydrogenandfuelcells.energy.gov)**





## Save the Dates!



Participate in social media using  
**#HydrogenNow #FuelCellsNow**

## H2@Scale Session at the Fuel Cell Seminar

November  
Long Beach, LA

**AMR and Industry Expo**  
June 2018 (to be confirmed soon)  
Washington, DC