

# Hydrogen and Fuel Cell Program Overview

**Dr. Sunita Satyapal, Director - Fuel Cell Technologies Office**

2018 Annual Merit Review

Washington D.C. - June 13, 2018

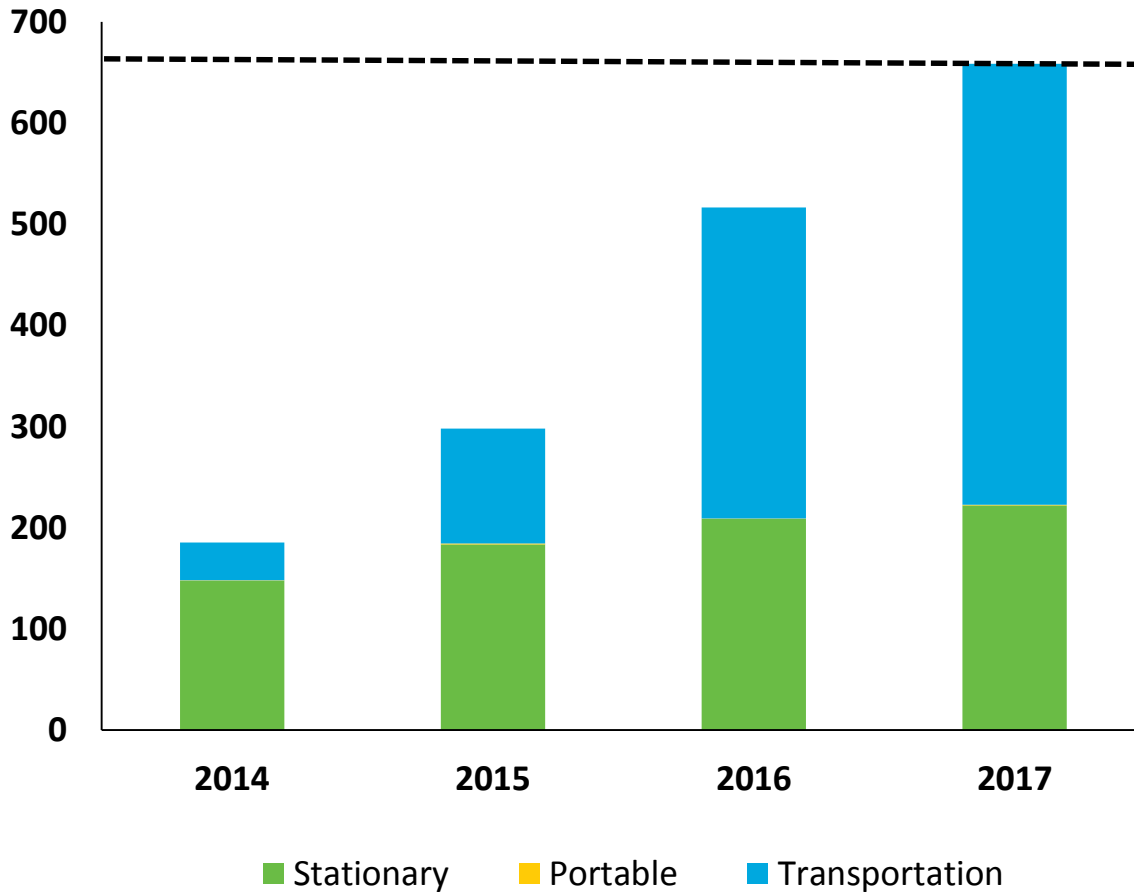



A photograph of two white hydrogen fuel cell vehicles (FCVs) parked at a hydrogen refueling station. The vehicles have blue and white graphics with the text "HYDROGEN FUEL CELL" on their sides. The refueling station is a tall, white and blue structure with a sign that says "HYDROGEN". The background shows a clear blue sky and some greenery. The overall scene is brightly lit, suggesting a sunny day.


# Exciting time for hydrogen & fuel cells


# Fuel Cell Shipments - Growth by Application

## Fuel Cell Power Shipped (MW)



 **650 MW**  
fuel cell power  
shipped worldwide

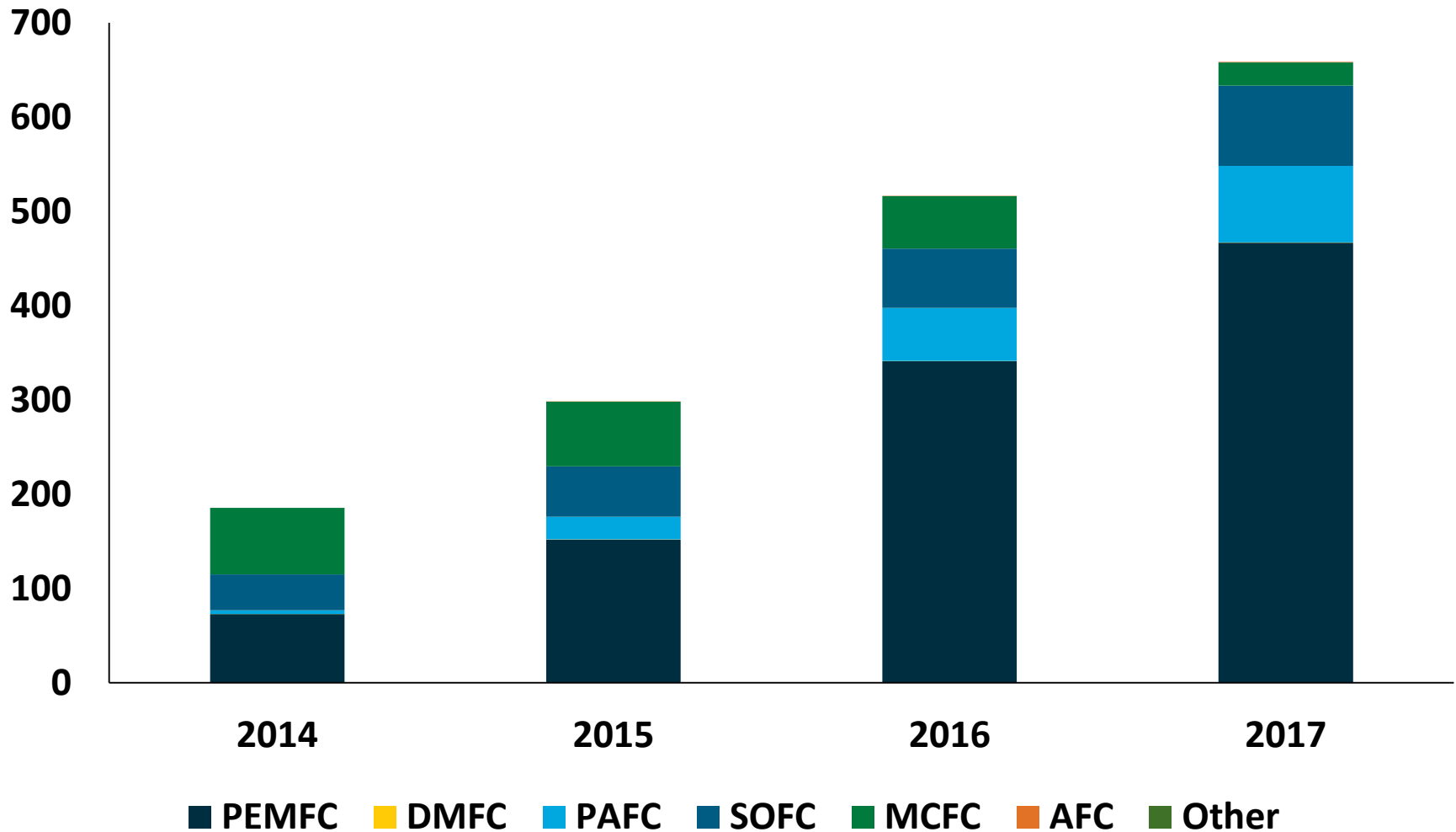
 **70,000**  
fuel cell units  
shipped worldwide

 Approximately  
**\$2 Billion**  
fuel cell revenue

Source: DOE and E4Tech

# Growth by Fuel Cell Type

## Fuel Cell Power Shipped (MW)



Source: E4Tech



Nearly 5,000 fuel cell cars  
in the U.S. since 2015

More than **20,000** forklifts

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Over **12 million** refuelings

**Over 30 buses in 4 states**

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**19 million passengers**

**35 retail stations open today**

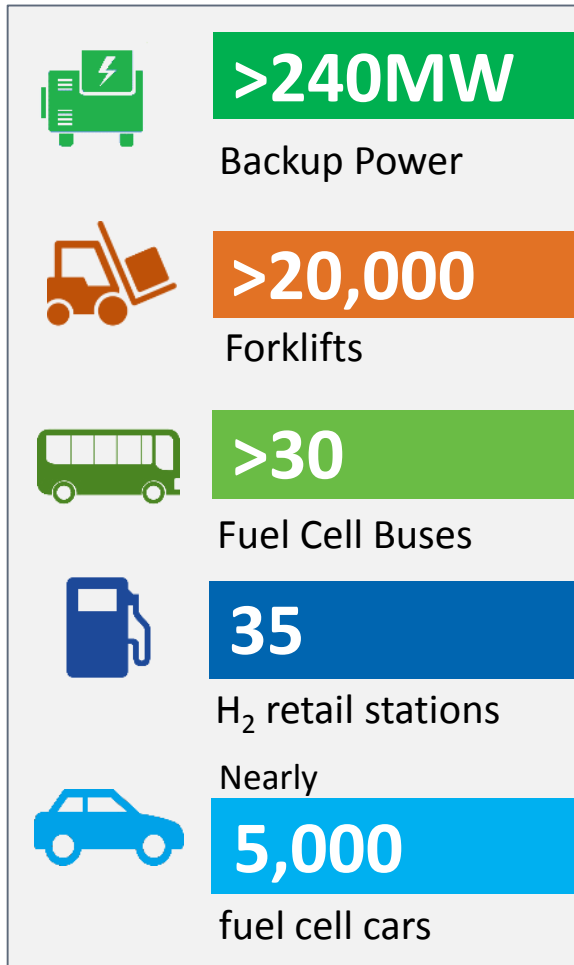
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**Over 200 planned**

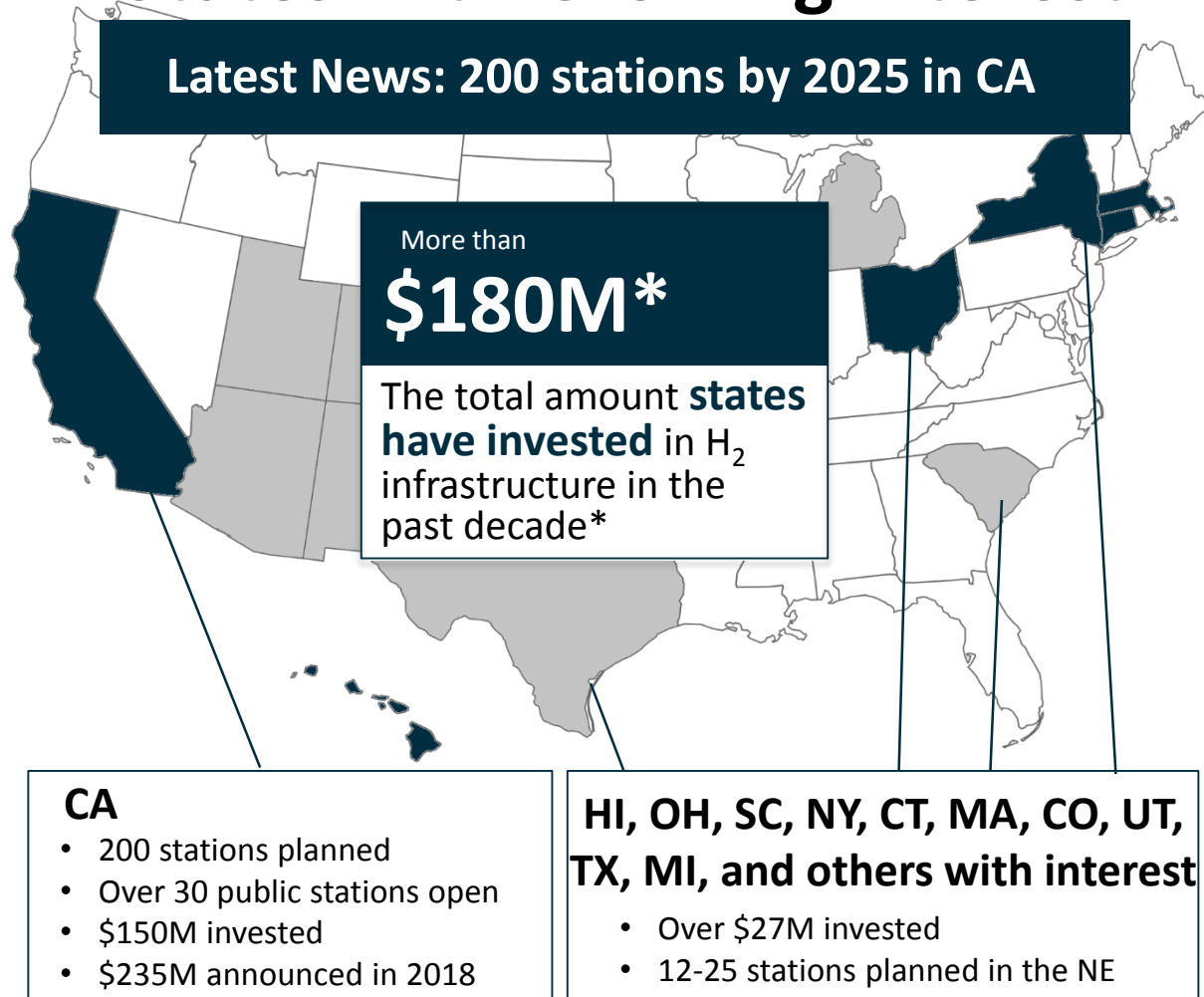


# Hydrogen and Fuel Cell Applications in the U.S.

## U.S. Snapshot



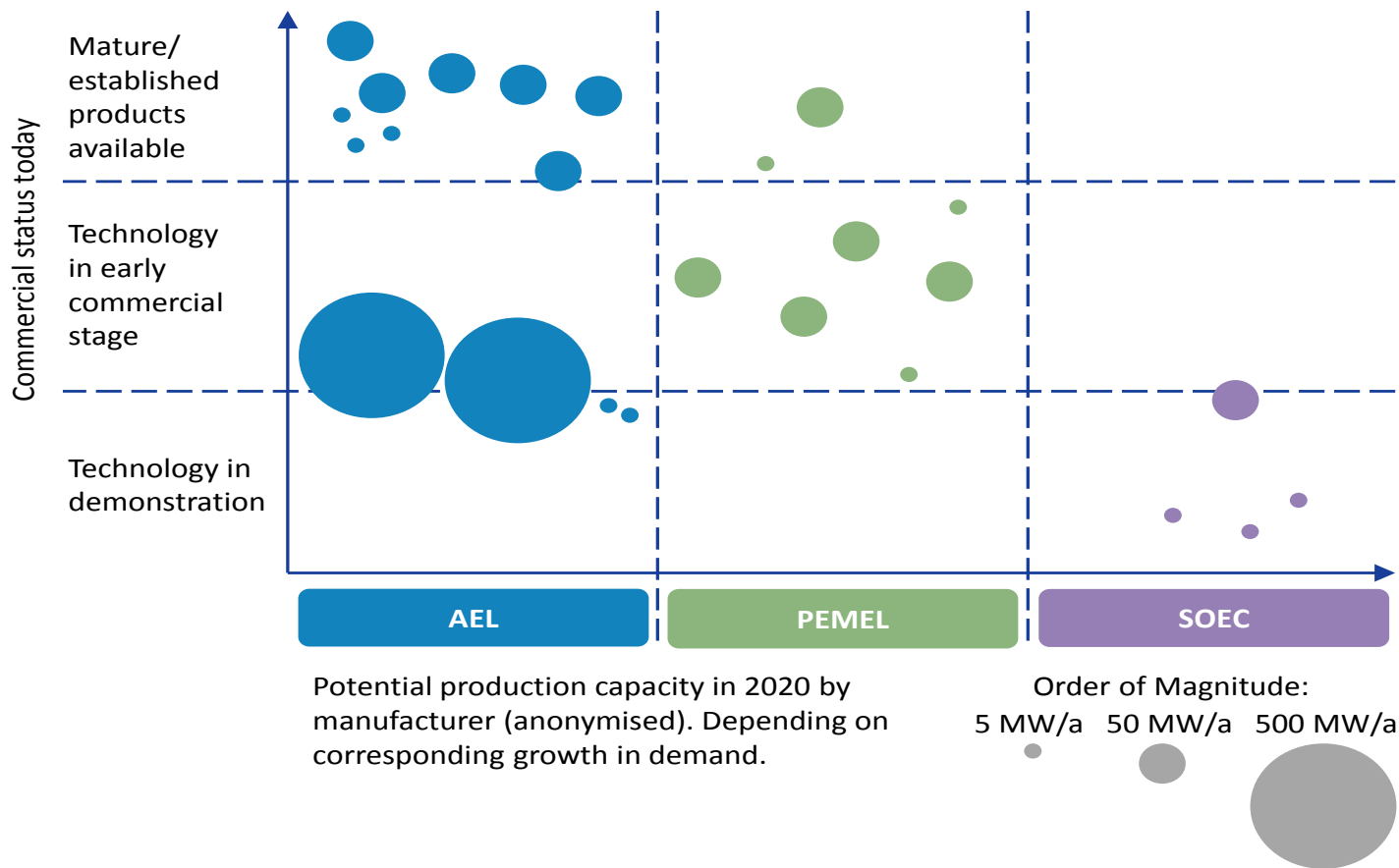
## States with Growing Interest



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

# Electrolyzers

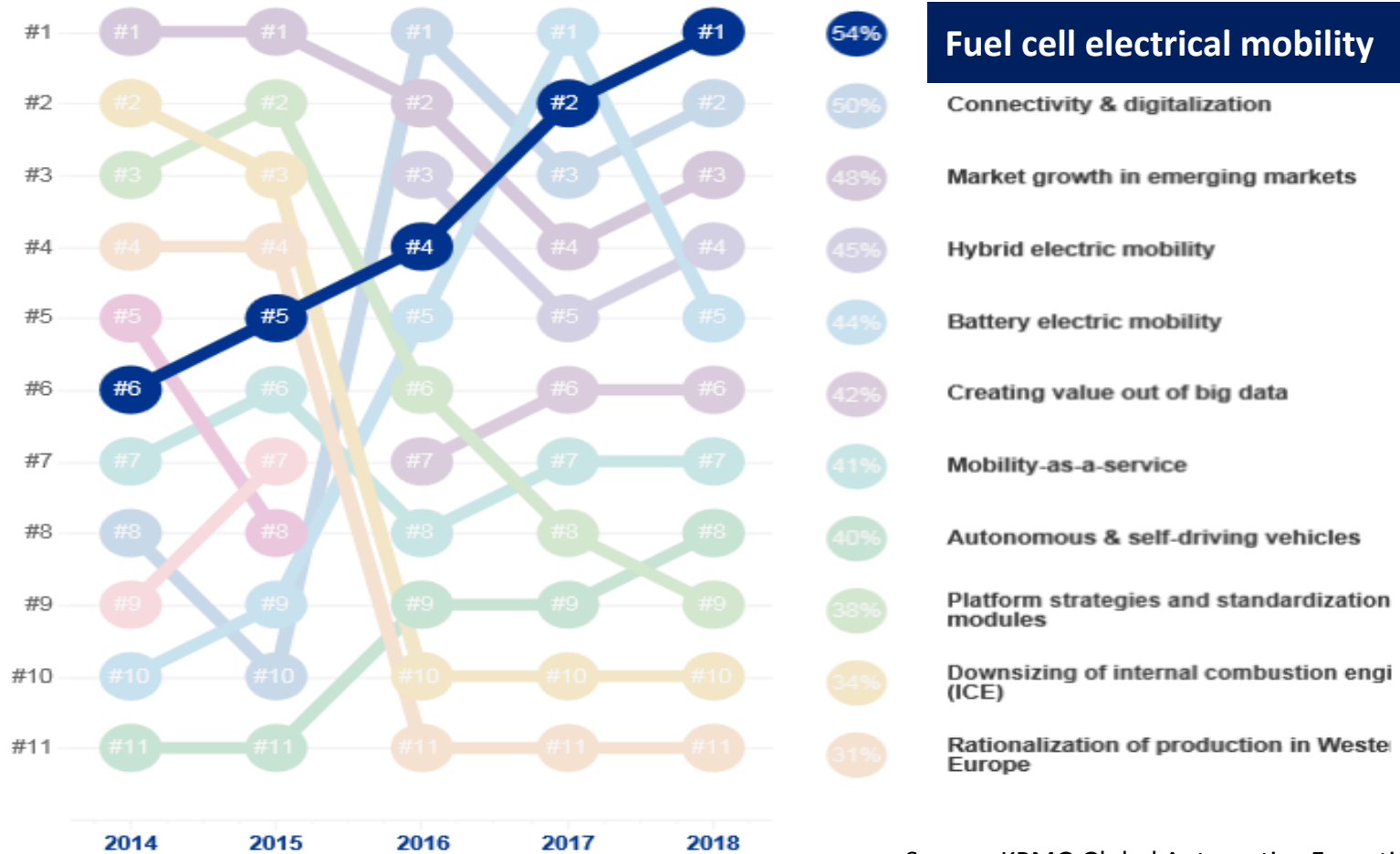
## Global sales estimated at 100 MW/year\*



\*Courtesy of NOW, E4tech and partners: A collaborative effort to assess electrolyzer market potential

# Automotive Executives Survey Results

## First time fuel cell electric mobility ranks #1 trend among automotive executives



Source: KPMG Global Automotive Executive Survey 2018



# Program Overview

# Strategy

**R&D and innovation to enable affordable and reliable hydrogen and fuel cell technologies.**

**Increase focus on infrastructure.**



# Targets Guide R&D

# DOE fuel cell system cost vs. targets

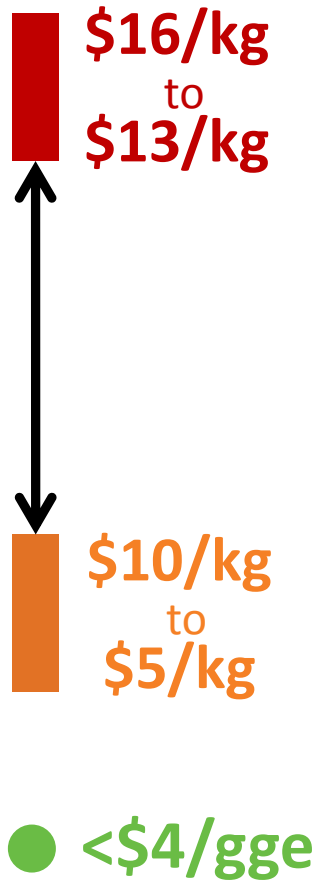


● **Targets**
■ **High-Volume Projection**
■ **Low-Volume Estimate**

<sup>†</sup>Based on commercially available FCEVs    <sup>†</sup>Based on state of the art technology    Note: Graphs not drawn to scale and are for illustration purposes only.

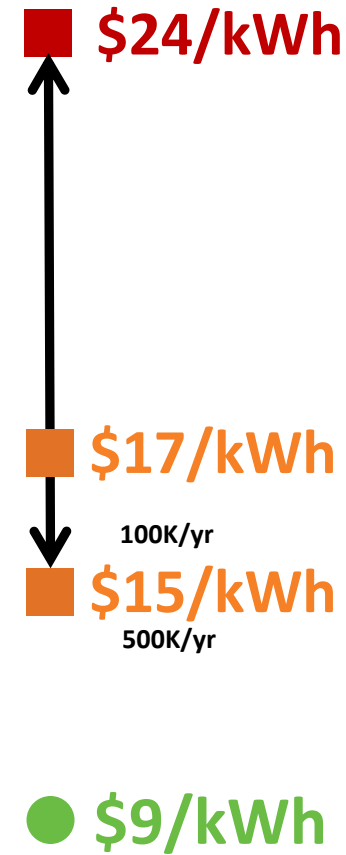
# Hydrogen fuel cost vs. targets

## Production, Delivery & Dispensing



## On-board Storage

(700-bar compressed system)



● Targets

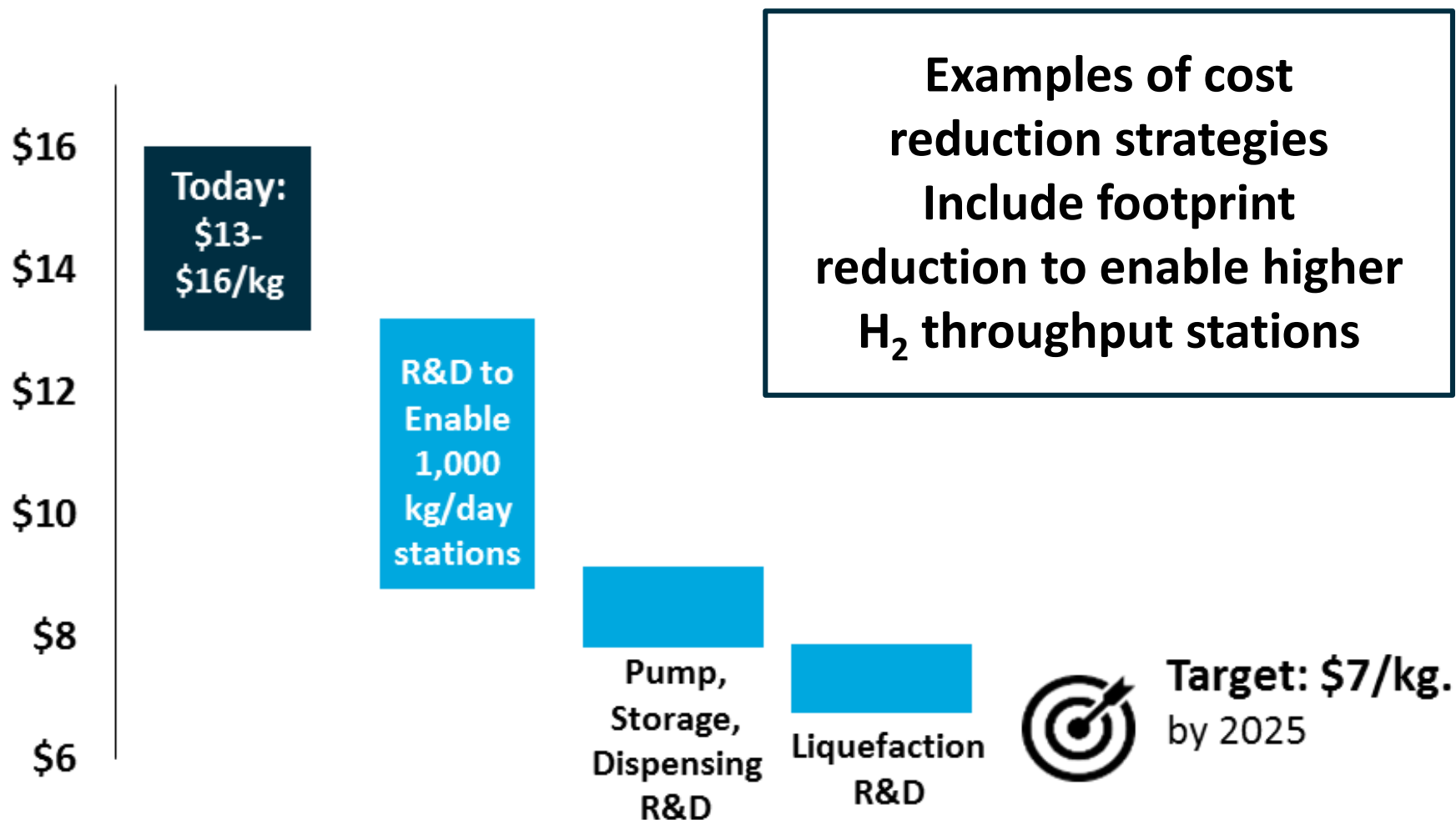
■ High-Volume Projection

■ Low-Volume Estimate

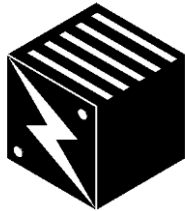
Note: Graphs not drawn to scale and are for illustration purposes only.



# Cost reduction strategies based on analysis



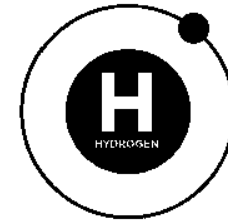
# Key Program Early R&D Focus Areas - FY18



## Fuel Cells

- PGM- free catalysts
- Durable MEAs
- Electrode performance

PGM = Platinum group metals  
MEA = Membrane Electrode Assembly



## Hydrogen Fuel

- Production
- Delivery (including dispensing)
- Storage

# Program Mission and Strategies

## Early R&D Focus

Applied research, development and innovation in 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 Fuel

- Production Pathways
- Advanced materials for storage



### Infrastructure R&D

- Safety
- Manufacturing
- Delivery components
- Others

PGM = Platinum group metals  
 MEA = Membrane Electrode Assembly

New in FY19 Budget Request

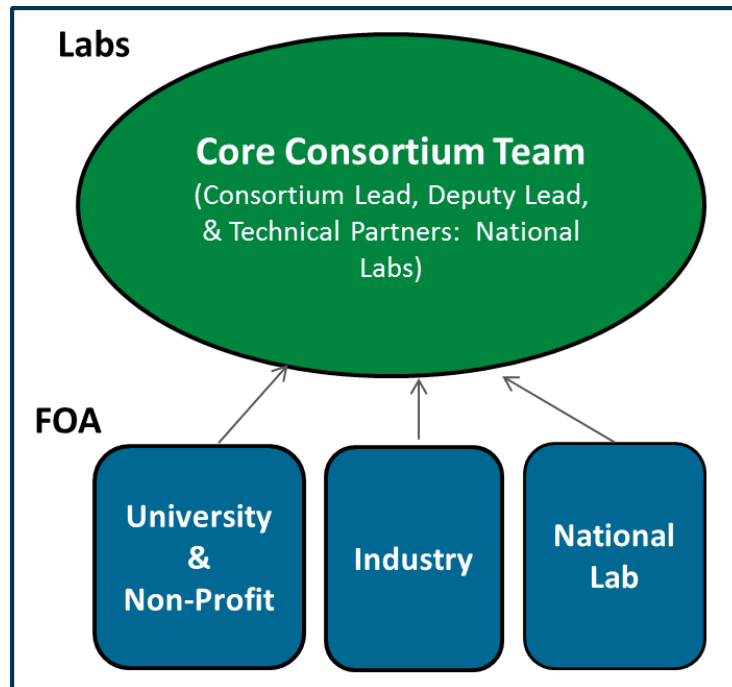
## Enabling



# Strategy: Leveraging National Labs and Partners

## 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



New Consortium: H-MAT

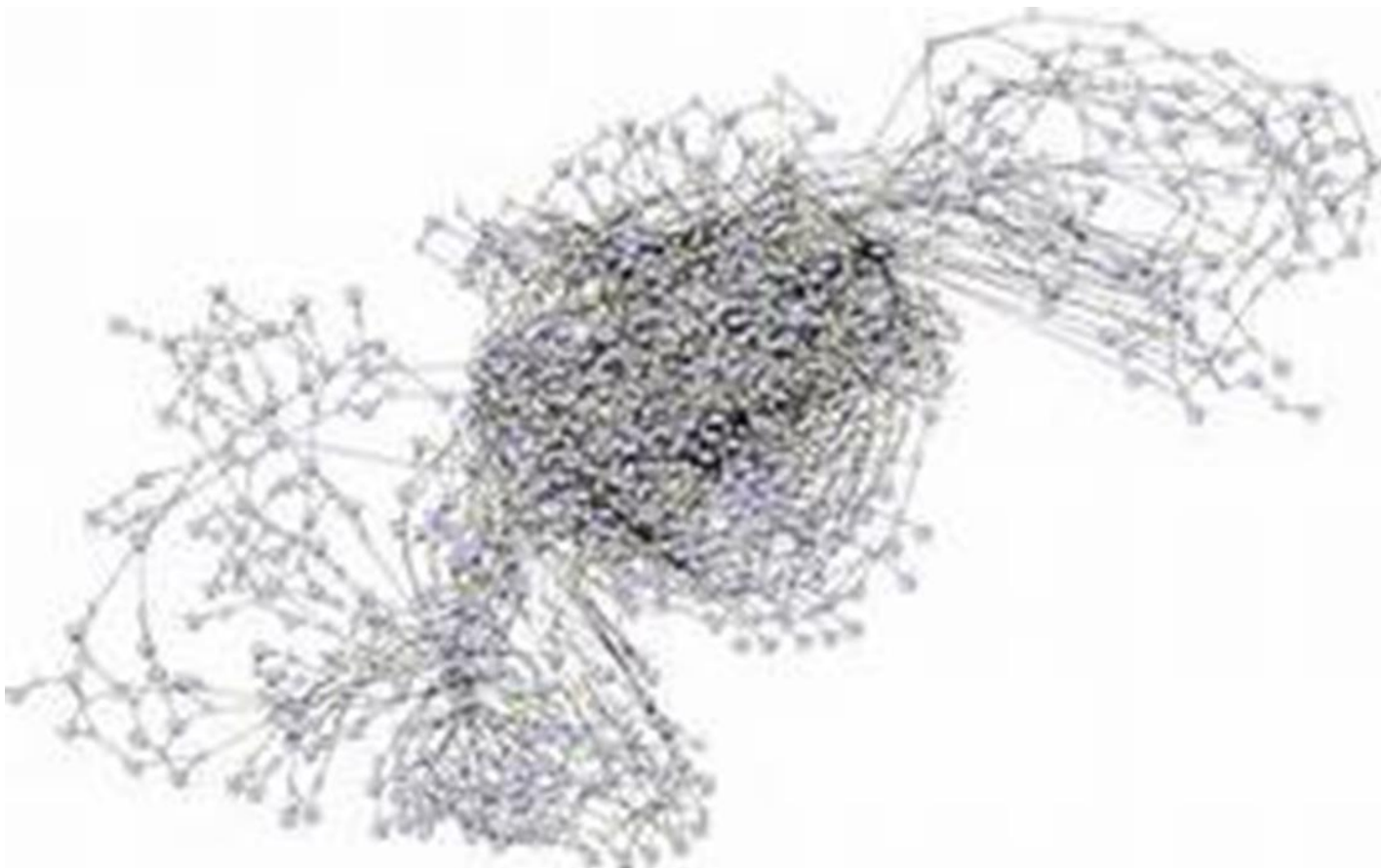


**A**



**B**

**A**



**B**

# EMN: A Platform for Accelerated Materials R&D



**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

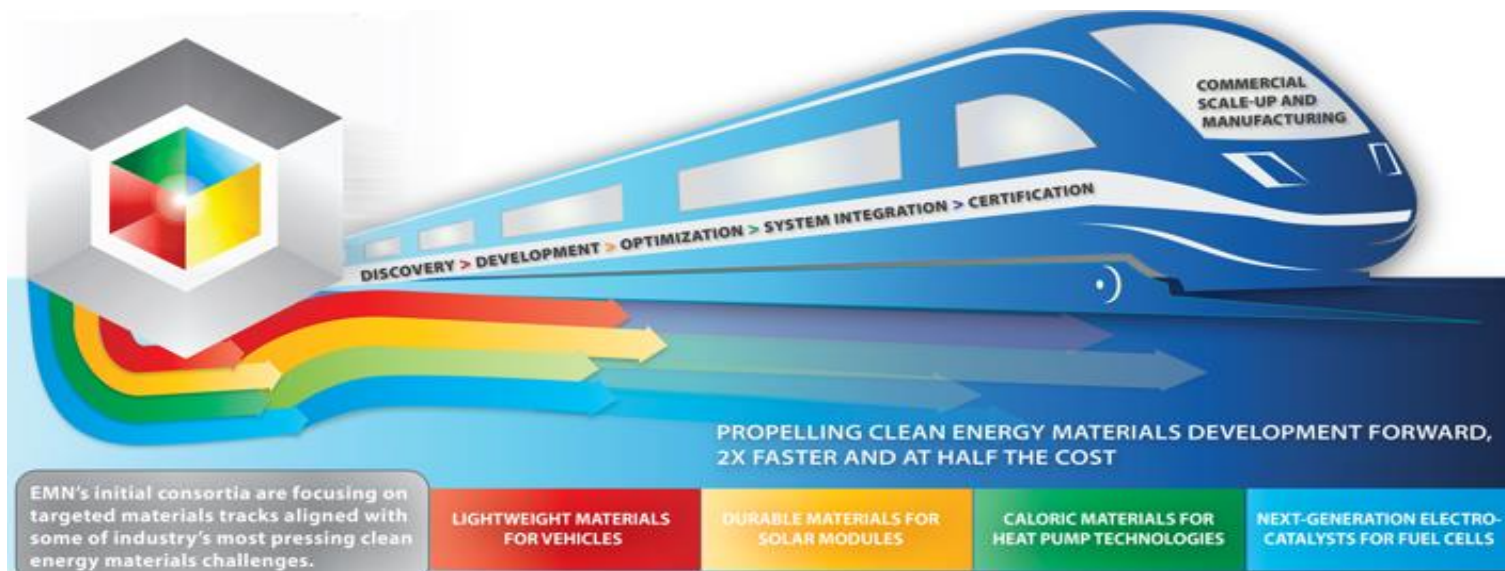
Process  
Scalability

Process  
Control

Real-time  
Characterization

Reliability  
Validation

Data Management & Informatics



EMN's initial consortia are focusing on targeted materials tracks aligned with some of industry's most pressing clean energy materials challenges.

LIGHTWEIGHT MATERIALS  
FOR VEHICLES

DURABLE MATERIALS FOR  
SOLAR MODULES

CALORIC MATERIALS FOR  
HEAT PUMP TECHNOLOGIES

NEXT-GENERATION ELECTRO-  
CATALYSTS FOR FUEL CELLS

# Technical Accomplishments



# DOE Program Impact - Examples

## Innovation



Approx. **730** H<sub>2</sub> and fuel cell **patents** enabled by FCTO funds

Approx. **35%** 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 **65** 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

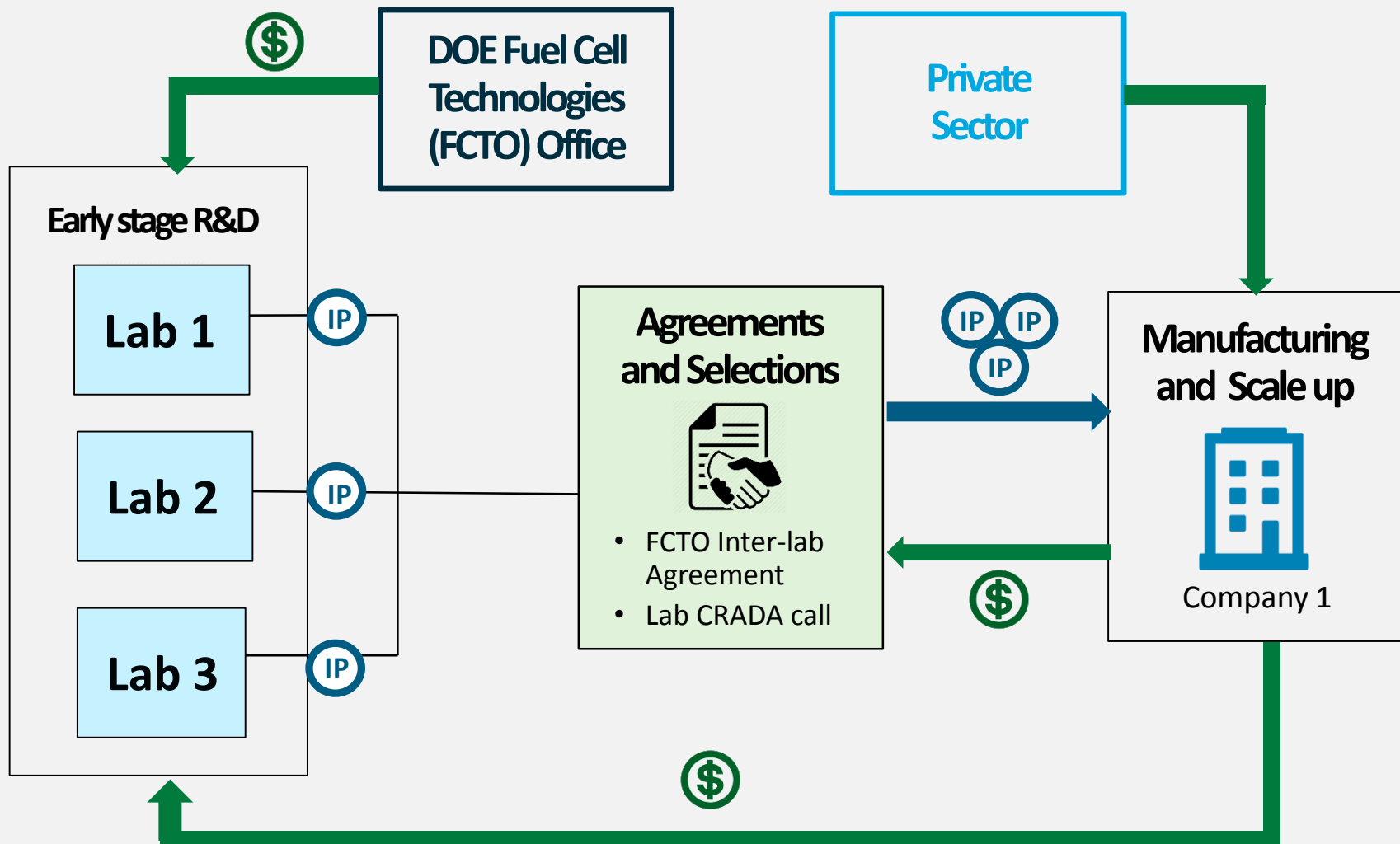


H<sub>2</sub> Production R&D

Cut electrolyzer costs 80%

# Leverage Private Sector to Accelerate Lab IP to Market

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



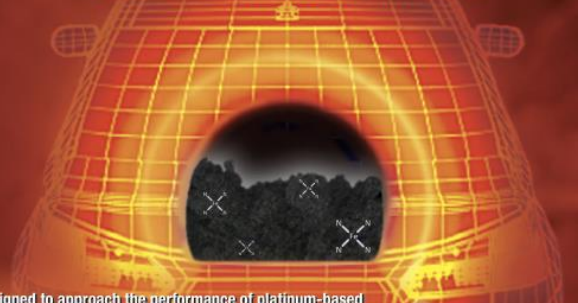
# Examples: R&D 100 Awards and more

2017 R&D 100 Joint Entry

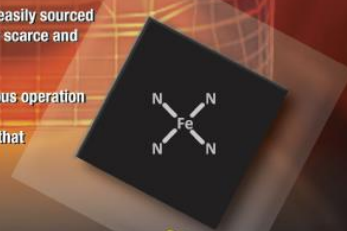
## Clean-Energy Electrocatalysts Without Precious Metals

Making Next-Generation Fuel Cells Cost-Effective

Los Alamos National Laboratory and Pajarito Powder, LLC

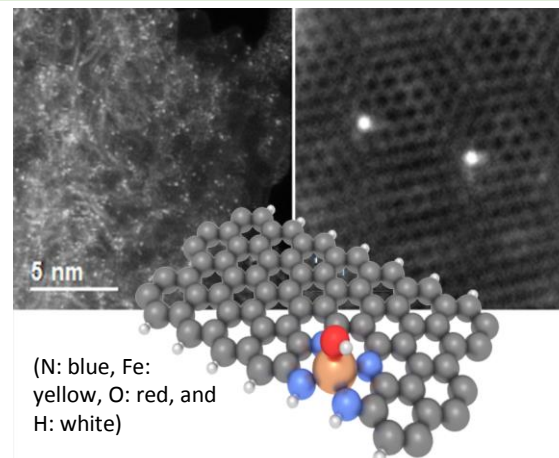


- Designed to approach the performance of platinum-based electrocatalysts but at a fraction of the cost
- Made using inexpensive, Earth-abundant, and easily sourced precursor materials that eliminate the need for scarce and costly precious materials
- Offer increased stability/durability for continuous operation
- Decrease the time-to-market for technologies that provide clean, reliable, and affordable energy

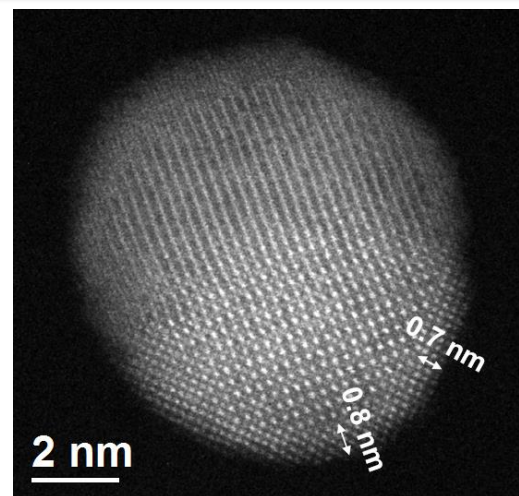


**Los Alamos**  
NATIONAL LABORATORY  
EST. 1943

**PAJARITO POWDER**  
FUEL CELL CATALYSTS



Science Paper  
(LANL, ORNL)  
Active site(s) in  
PGM-free Fe-N-C



Ordered core  
(PtCo) remains  
intact even  
after 30K  
cycles (AST)  
(LANL, Brown  
University,  
ORNL)

*Journal of the Electrochemical Society*: Focus Issue on PEM Fuel Cell Durability  
Guest Editors: Jean St-Pierre, Debbie Myers, Rod Borup, over 40 papers, many FC-PAD authors

# Focus Areas

**Emphasize high-throughput + modeling for catalyst R&D**

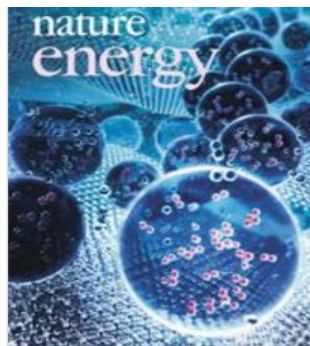
**Increase focus on innovative membranes**

# HydroGEN: High-Impact Computational Research in Catalysis

nature  
energy

ARTICLES

PUBLISHED: 31 JULY 2017 | VOLUME: 2 | ARTICLE NUMBER: 17127



## Self-optimizing, highly surface-active layered metal dichalcogenide catalysts for hydrogen evolution

Yuanyue Liu<sup>1†‡</sup>, Jingjie Wu<sup>1‡</sup>, Ken P. Hackenberg<sup>1‡</sup>, Jing Zhang<sup>1</sup>, Y. Morris Wang<sup>2</sup>, Yingchao Yang<sup>1</sup>, Kuntal Keyshar<sup>1</sup>, Jing Gu<sup>3</sup>, Tadashi Ogitsu<sup>2</sup>, Robert Vajtai<sup>1</sup>, Jun Lou<sup>1</sup>, Pulickel M. Ajayan<sup>1</sup>, Brandon C. Wood<sup>2\*</sup> and Boris I. Yakobson<sup>1\*</sup>

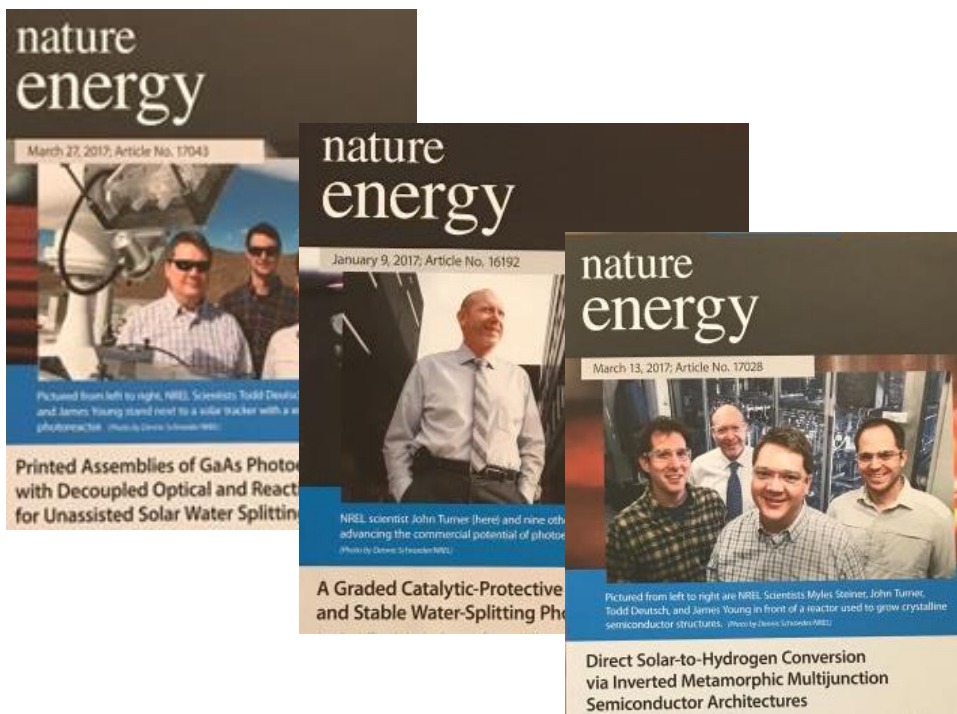


*Steering Committee Member (Tadashi) owns a FCEV and chooses a unique license plate*

# HydroGEN: High-Impact Research in Photoelectrochemistry

**Achieving Record Performance**  
NREL set new record with III-V semiconductor PEC tandem cell:  
3 *Nature Energy* publications.

**Addressing Benchmarking Needs**  
Technology advancement by  
publishing standards, protocols  
and reviews.



**PEC World Record Benchmarked at >16% STH**

**Technology Standards to Facilitate  
Research Progress**

# **Focus Areas**

## **Emphasis on water-splitting**

### **Raising the Tide: R&D Test Protocols for Water-Splitting**

# HyMARC Advanced Hydrogen Storage Materials

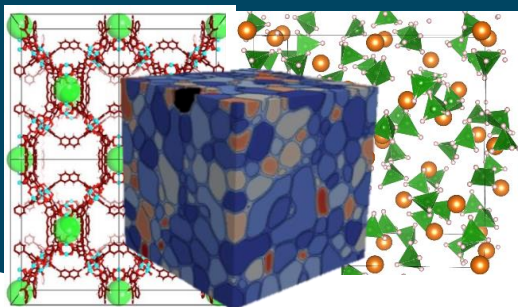


Provides **foundational understanding** of thermodynamics and kinetics to advance solid-state hydrogen storage materials

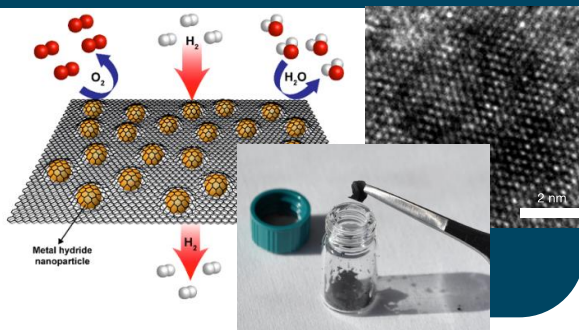
Delivers **community tools and capabilities:**

- High-throughput materials screening
- Surface, bulk, soft X-ray, synchrotron
- Probing nanoscale phenomena

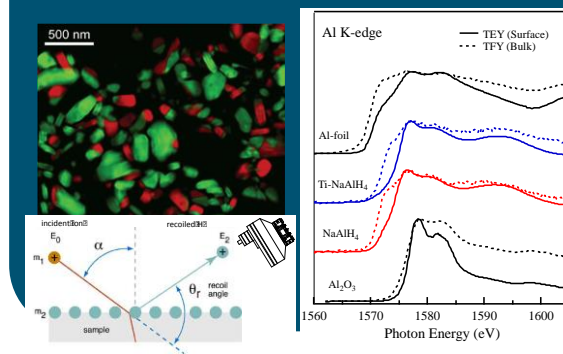
## Theory, simulation, & data



## Controlled synthesis



## *In situ* characterization



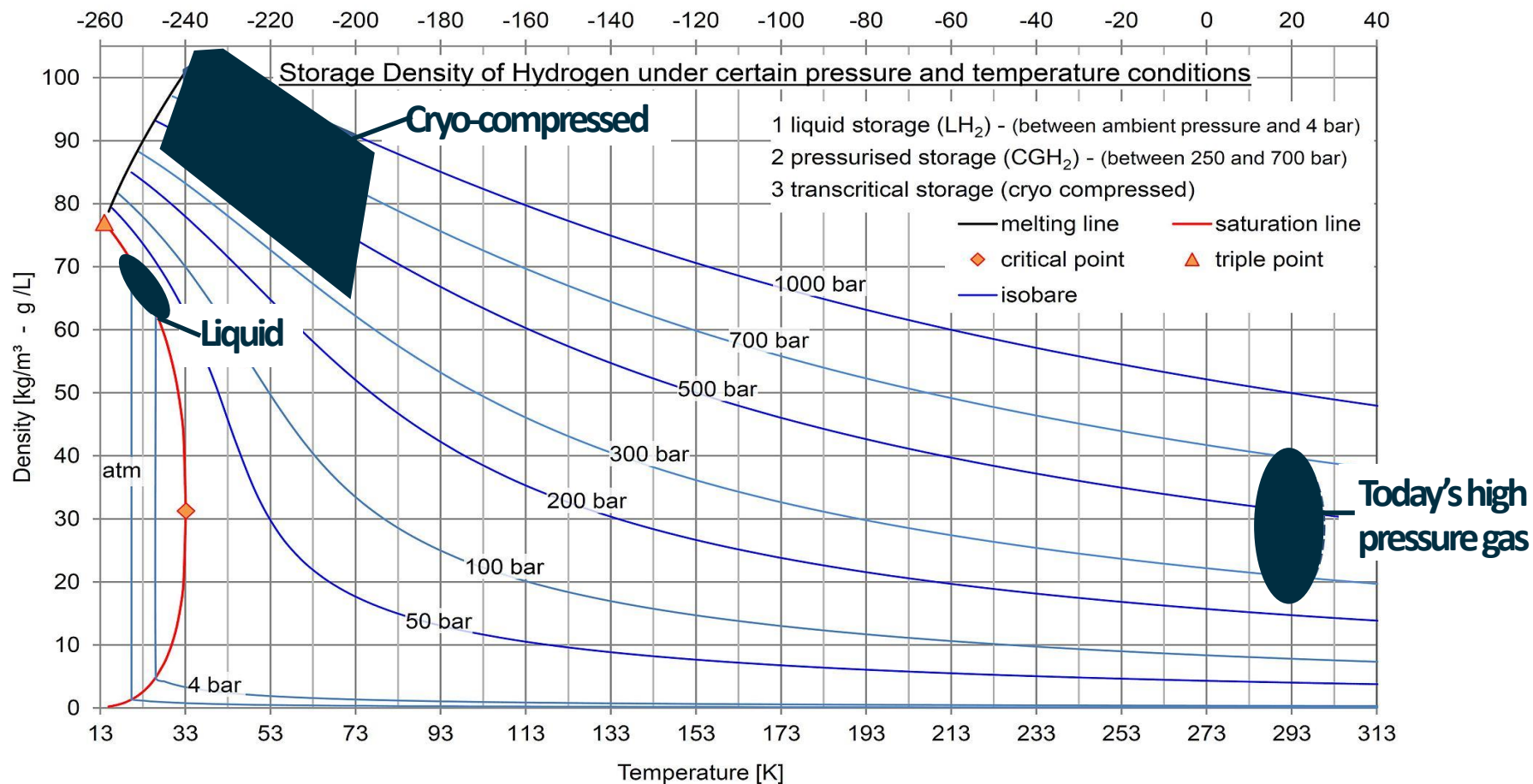


# Focus Areas

**Adding H<sub>2</sub> Carriers  
R&D to HyMARC**

# Example of Innovation- potential for heavy duty?

## Cryo-compression can offer densities higher than liquid hydrogen



**ANL analysis (preliminary) shows potential for:**

**90-200% storage capacity increase**

**25% less cost (at 5,000 units/yr)**

**46% less carbon fiber composite**

# Potential Opportunities for Larger Vehicles/Long Range

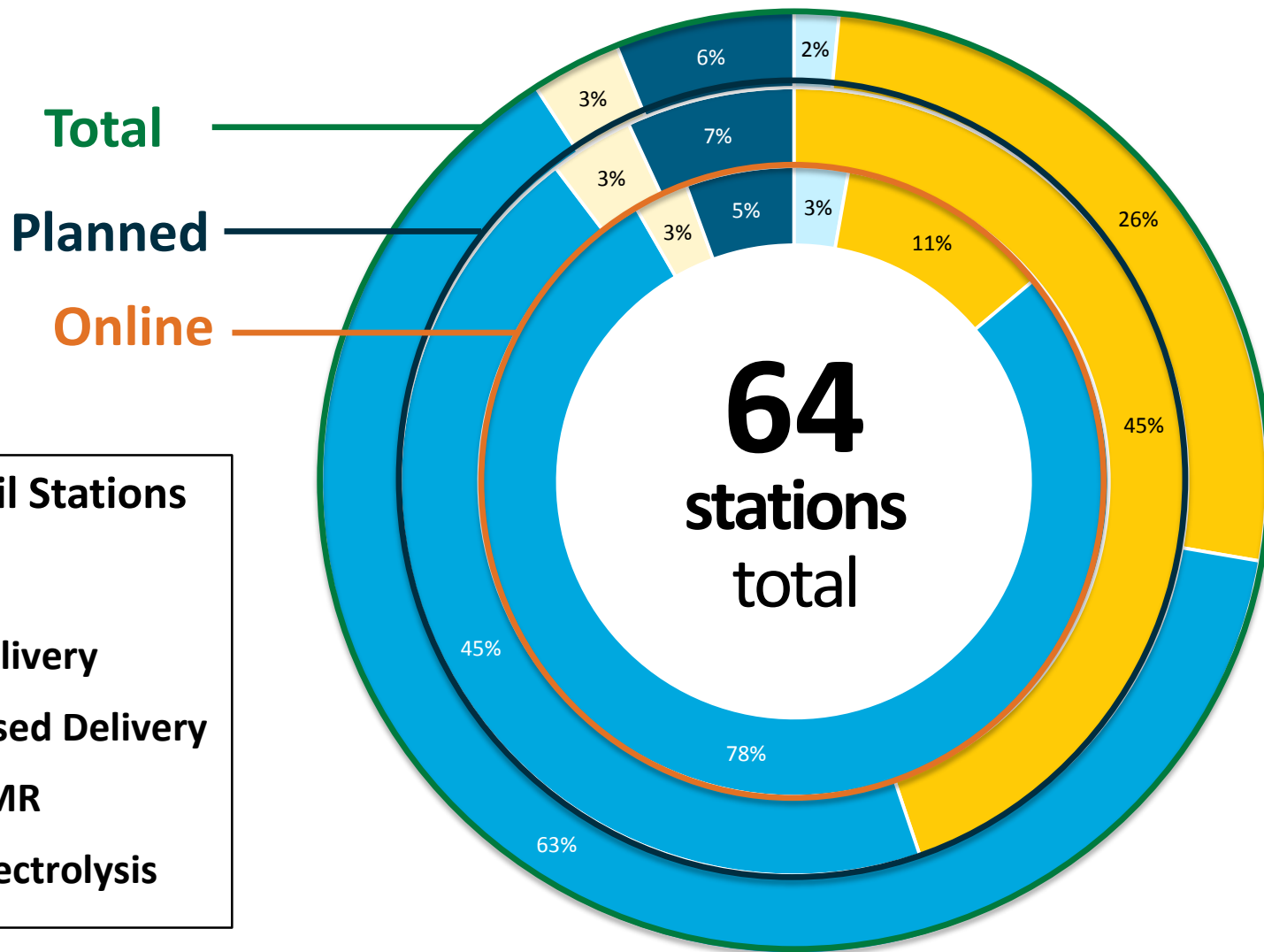
## FCEVs : Lower cost for large size classes and longer driving range

Year 2040: FCEV minus BEV-X Total Cost of Ownership  
Green shows where FCEVs are more cost effective

	50 mi.	100 mi.	150 mi.	200 mi.	250 mi.	300 mi.	350 mi.
Two-seaters	\$0.05	\$0.01	-\$0.03	-\$0.07	-\$0.11	-\$0.15	-\$0.19
Minicompacts	\$0.05	\$0.02	-\$0.01	-\$0.04	-\$0.07	-\$0.10	-\$0.13
Subcompacts	\$0.05	\$0.02	-\$0.01	-\$0.04	-\$0.07	-\$0.11	-\$0.14
Compacts	\$0.04	\$0.01	-\$0.02	-\$0.05	-\$0.09	-\$0.12	-\$0.15
Midsize Cars	\$0.05	\$0.01	-\$0.03	-\$0.06	-\$0.10	-\$0.13	-\$0.17
Large Cars	\$0.04	\$0.01	-\$0.02	-\$0.06	-\$0.09	-\$0.12	-\$0.16
Small Station Wagons	\$0.05	\$0.01	-\$0.03	-\$0.07	-\$0.11	-\$0.15	-\$0.19
Pass Van	\$0.03	-\$0.01	-\$0.06	-\$0.11	-\$0.15	-\$0.20	-\$0.24
SUV	\$0.03	-\$0.02	-\$0.08	-\$0.14	-\$0.19	-\$0.25	-\$0.30
Small Pickup	\$0.06	\$0.02	-\$0.02	-\$0.07	-\$0.11	-\$0.15	-\$0.19

Preliminary DOE Market Segmentation Study

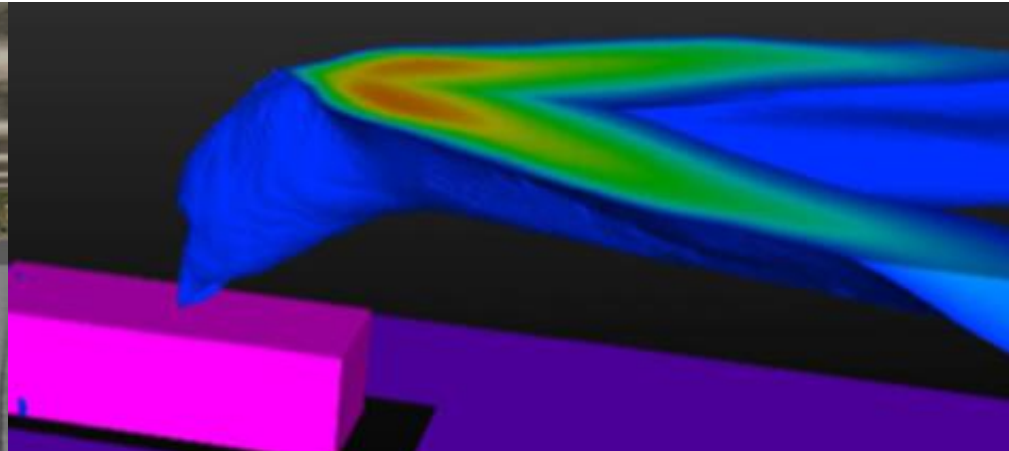
# More liquid stations planned



Based on data from NREL

# Safety R&D Accomplishments enabling Infrastructure

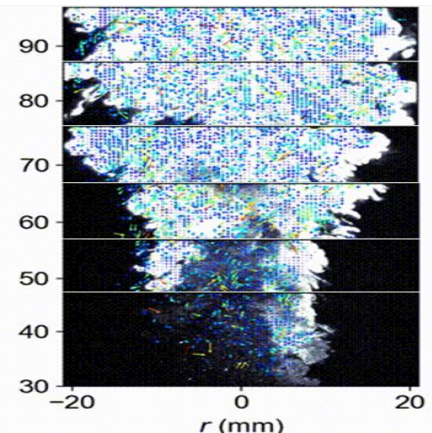
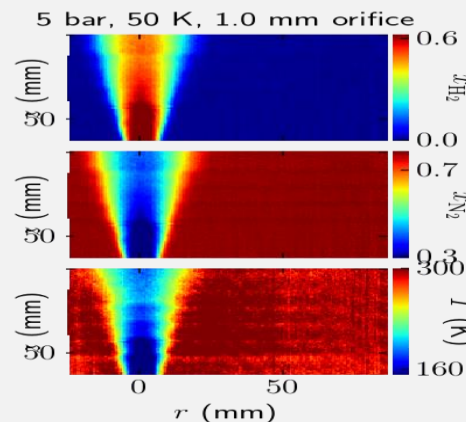
## Tunnel Safety R&D and Modeling



Relief vent fire doesn't have a significant impact on tunnel structure elements

## Validation of release models

First ever nearfield measurement and validation of temp., concentration and velocity of cryogenic plumes at 50K

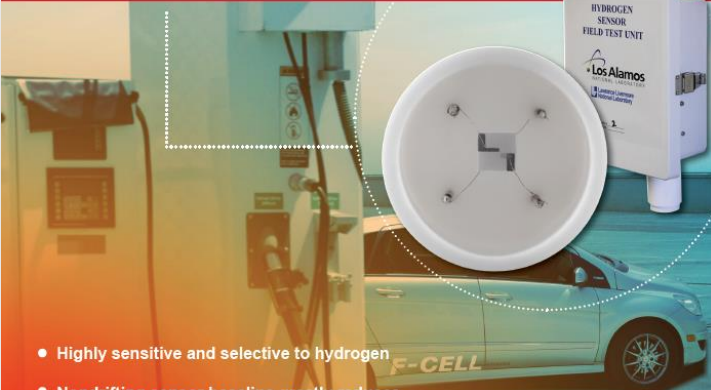


# Infrastructure R&D related progress- Examples

2017 Joint R&D 100 Entry  
Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Hydrogen Frontier, Inc.  
HYDROGEN FRONTIER INC.

## HYDROGEN SAFETY SENSOR:

Ready to Protect the New-Energy Economy  
*Filling Up Hydrogen-Fueled Vehicles Just Became a Lot Safer*



- Highly sensitive and selective to hydrogen
- Nondrifting sensor baseline greatly reduces the need for calibration and is intrinsically resistant to generating false alarms
- Insensitive to humidity, pressure, and temperature
- Made from ceramic sensor elements that are safe, durable, long-lasting, and inexpensive

Los Alamos NATIONAL LABORATORY  
Lawrence Livermore National Laboratory



LANL, LLNL, and H2Frontier R&D 100 award for H2 safety sensor (available for commercialization)



LANL contamination detector (HCD) to alert - in real time - fuel station operator if conditions for potential poor hydrogen fuel quality exist.



# H2@Scale

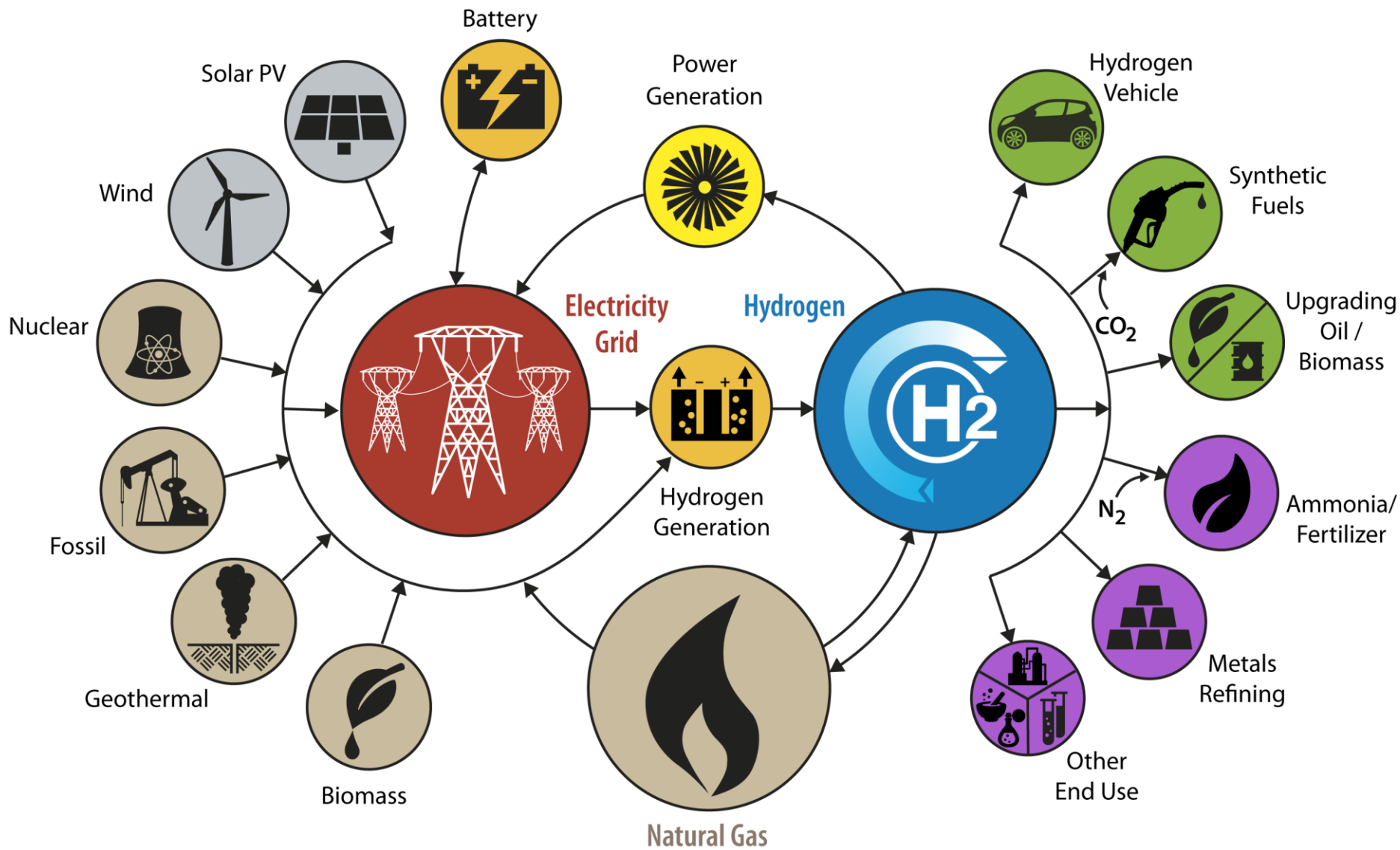
# Vision

**H2@Scale: Enabling  
affordable, reliable,  
clean and secure energy  
across sectors**





# H<sub>2</sub>@Scale: Linking Natural Gas, Electric and H<sub>2</sub> Grids

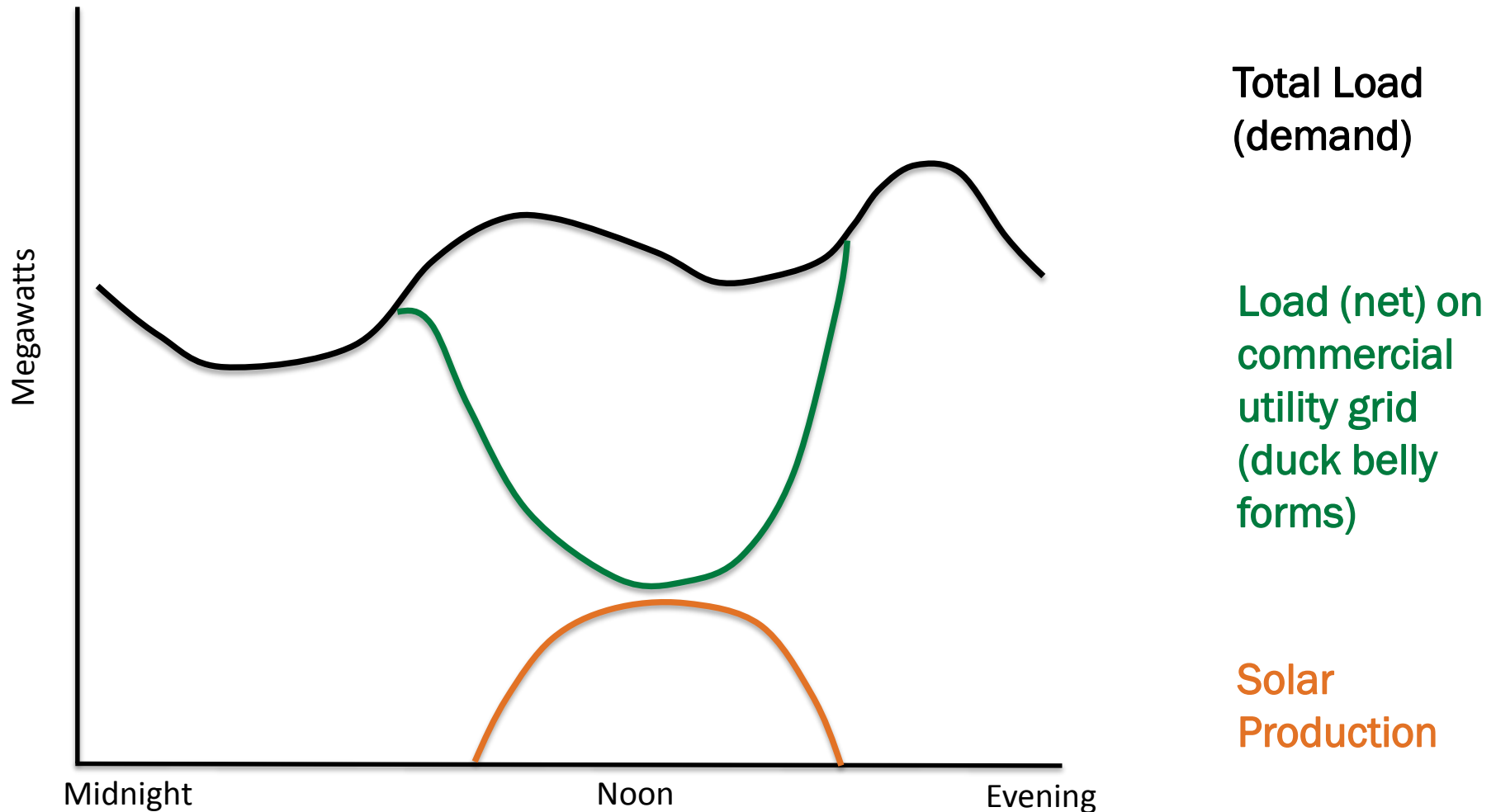


# Versatility

# Volume

# Value Proposition

# The Duck Curve 101 - Example

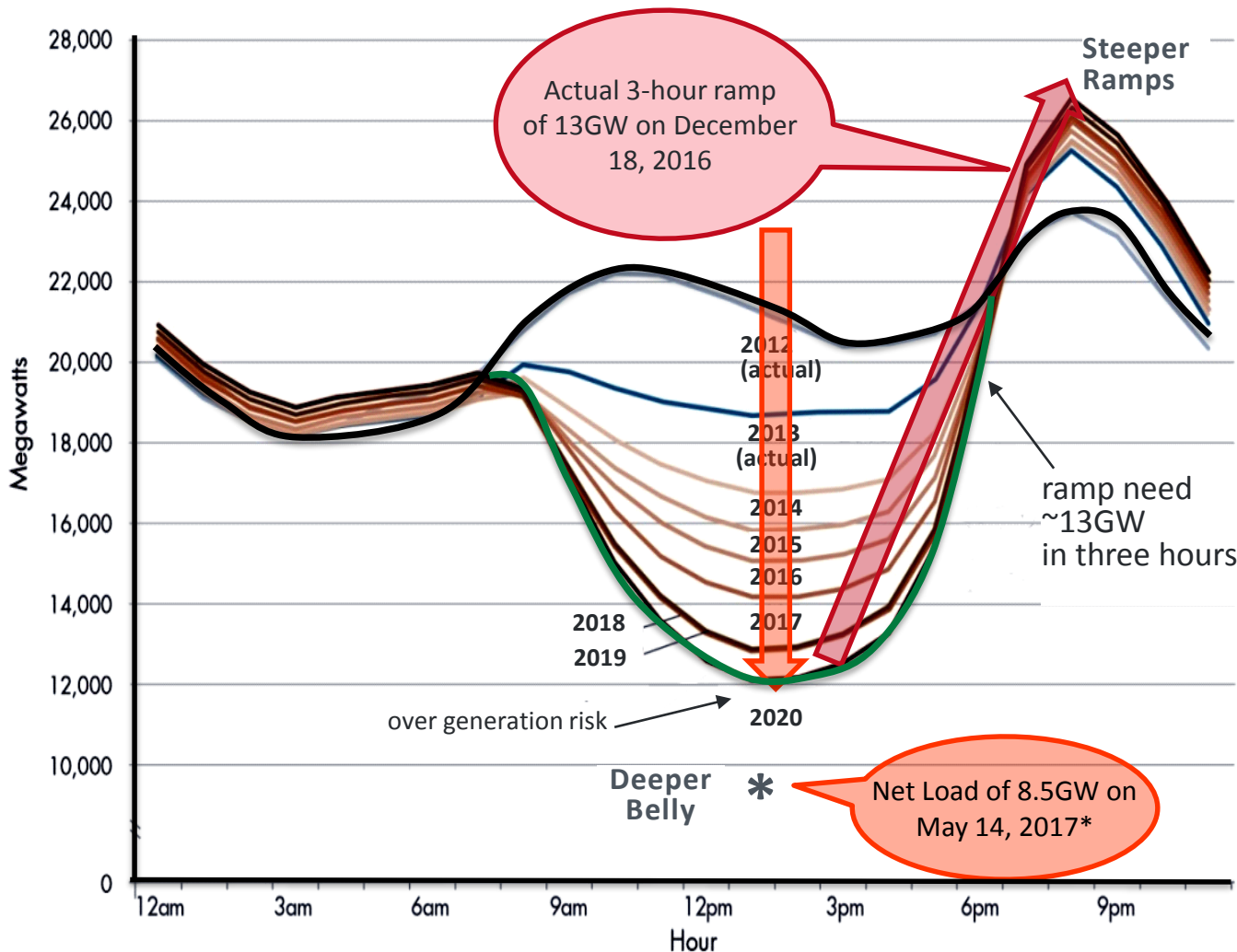


# The Duck's belly is getting bigger

## Two Concerns:

- **Low Net Load:** flexibility to reduce baseload generation resources is limited
- **High Ramp Rates in Evening:** flexibility of other generation to ramp up is limited

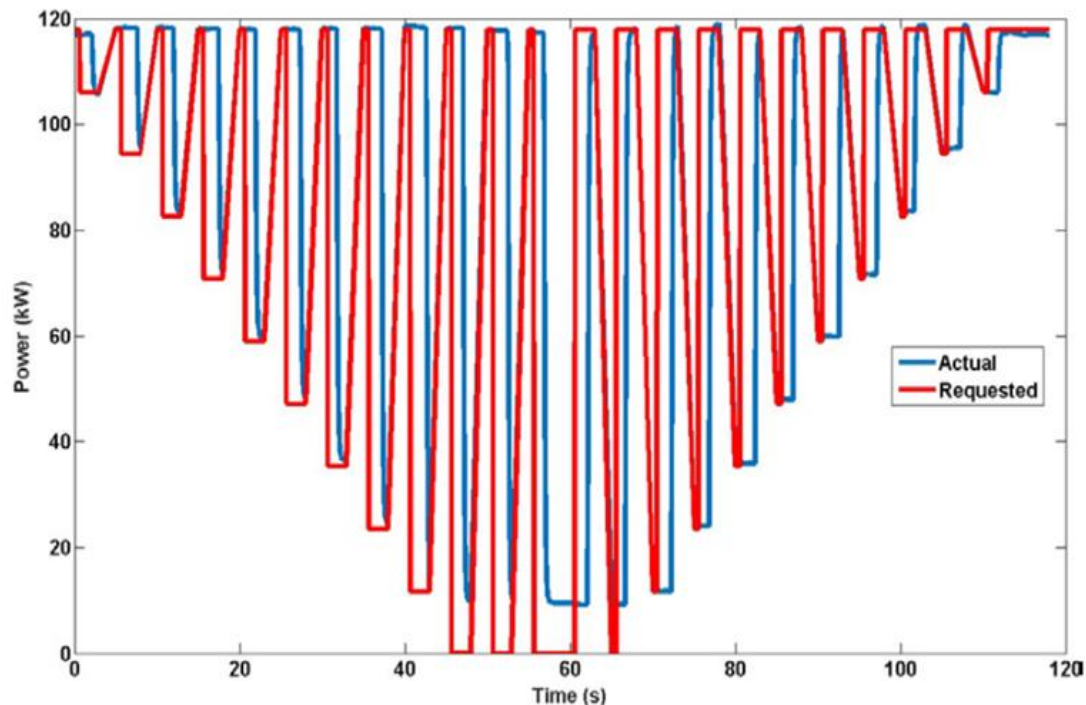
Can be addressed by



Source U.S. DOE Solar Energy Technologies Office \*Real example from California

# Lab testing shows value of electrolyzers for ancillary services

## First Ever Validation of Frequency Regulation with Electrolyzers

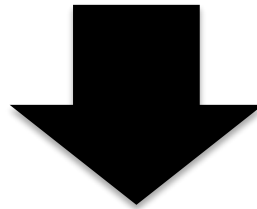


*Lab testing shows dynamic response within seconds and potential for grid services*



# Scale: Simple Example

## How much hydrogen for 1 car?

$$\frac{12,000 \text{ miles per year}}{60 \text{ miles per kilogram}} = 200 \text{ kg per year} \text{ or } 0.2 \text{ tonnes per year}$$



## How much hydrogen for many cars?

<b>100 M cars</b>   = 10M cars	<b>20M tons</b> H <sub>2</sub> per year <b>20 B kg</b> H <sub>2</sub> per year
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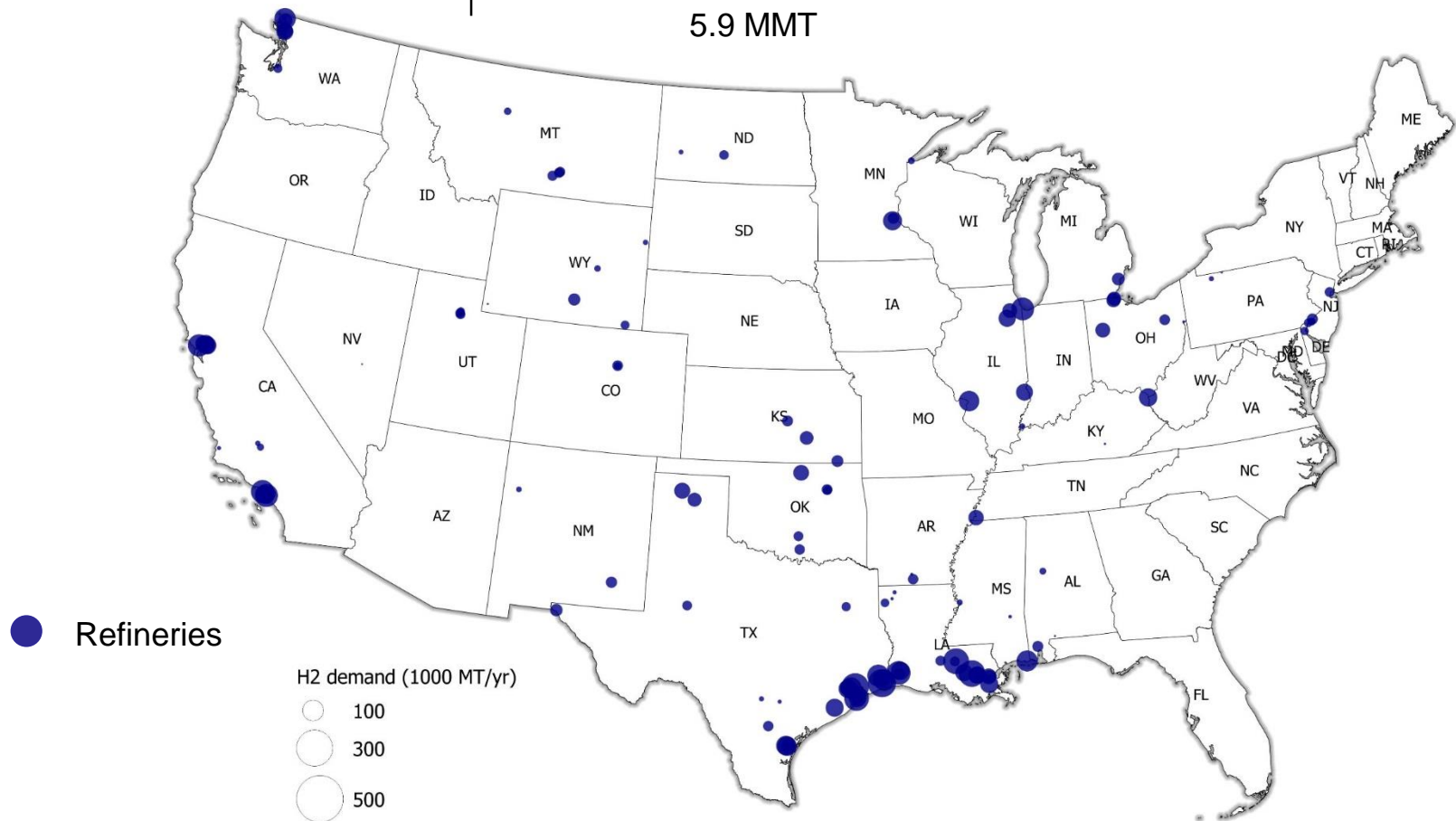
# Refineries: Where is the H<sub>2</sub> demand today?

2017

H<sub>2</sub> Demand



5.9 MMT



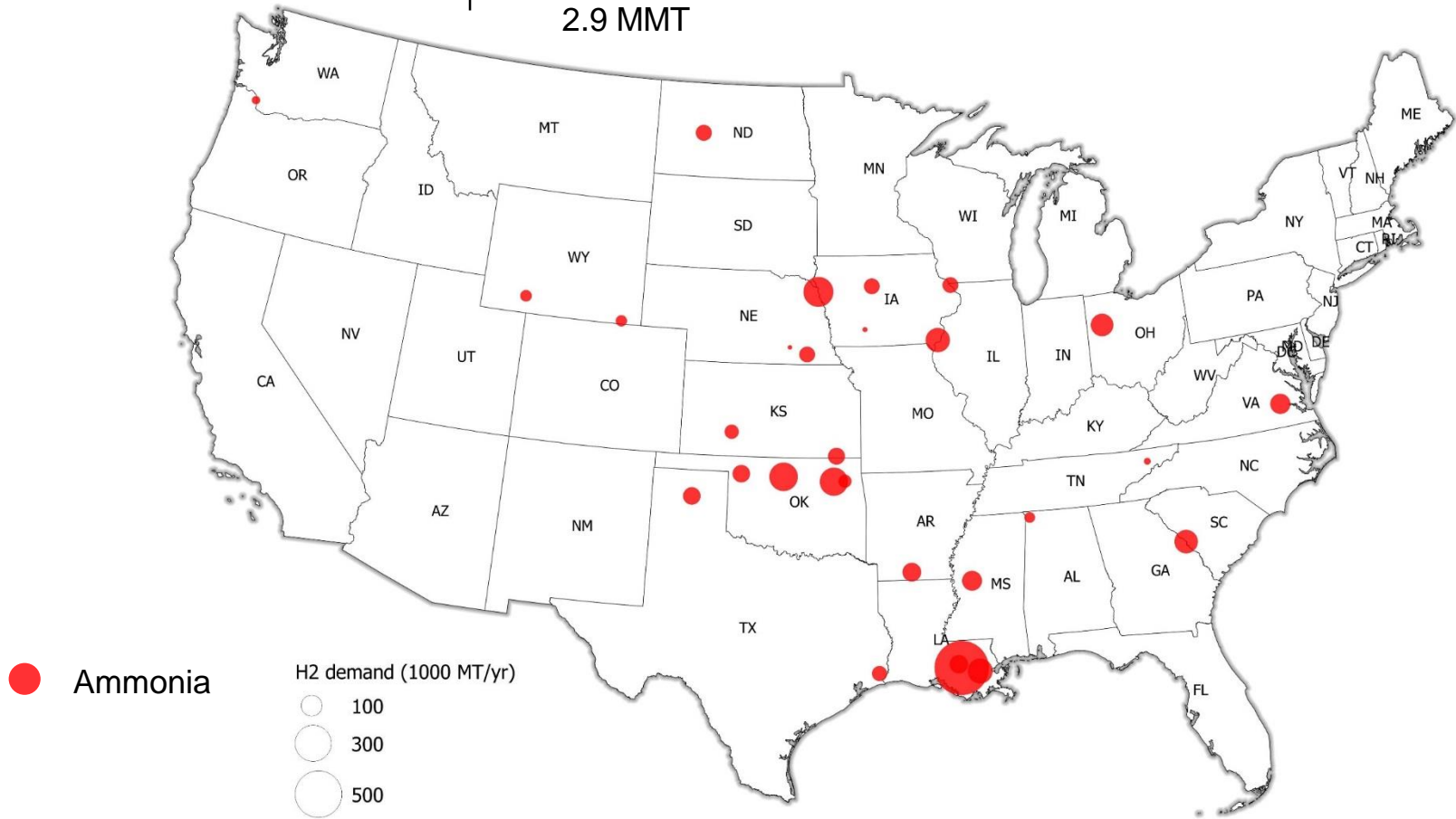
Source: Elgowainy, et al, ANL



# Ammonia: Where is the H<sub>2</sub> demand today?

2017

H<sub>2</sub> Demand  
2.9 MMT



Source: Elgowainy, et al, ANL

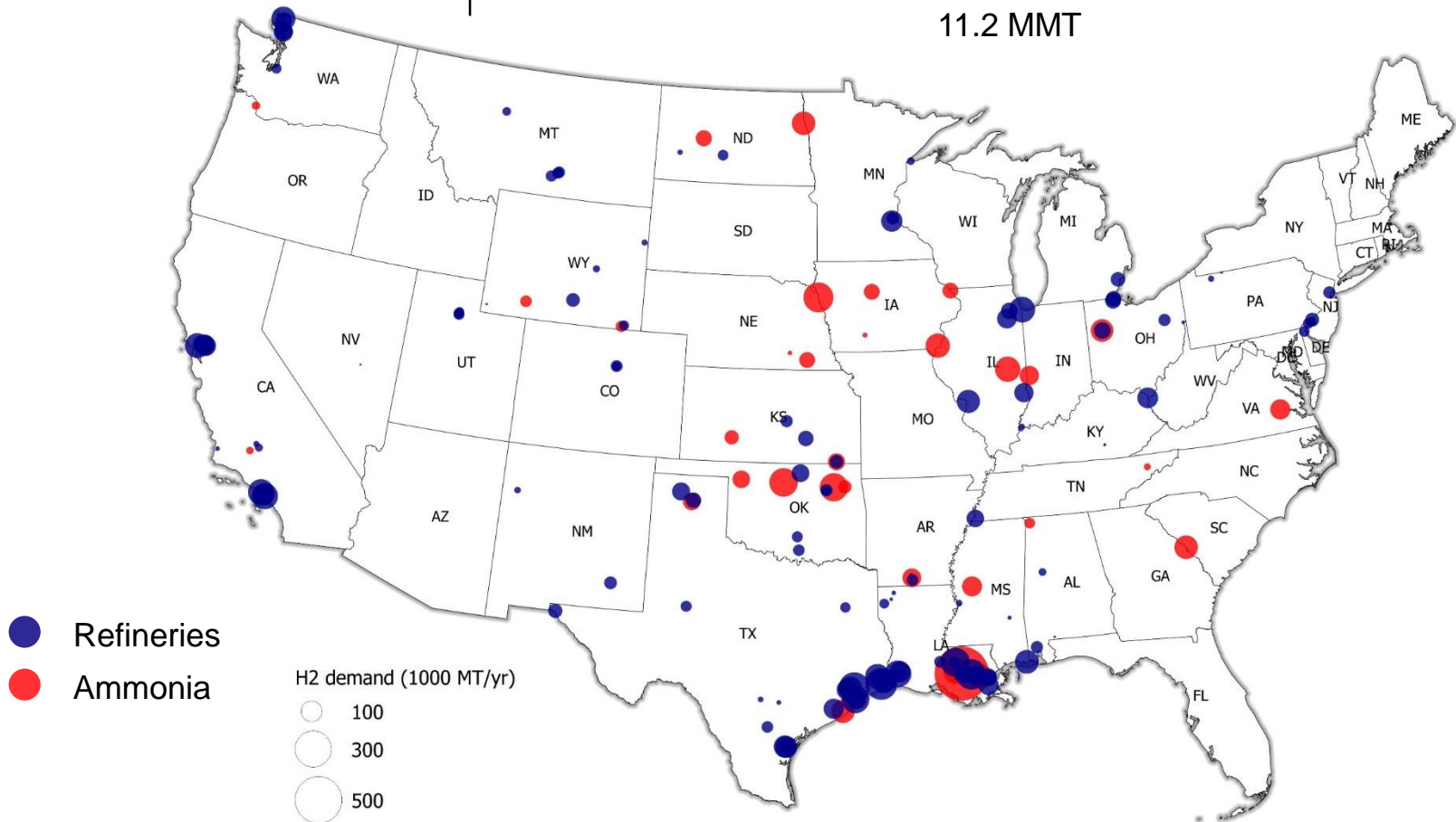
# Ammonia & Refineries and Potential H<sub>2</sub> Demand

2030

H<sub>2</sub> Demand



11.2 MMT



Source: Elgowainy, et al, ANL

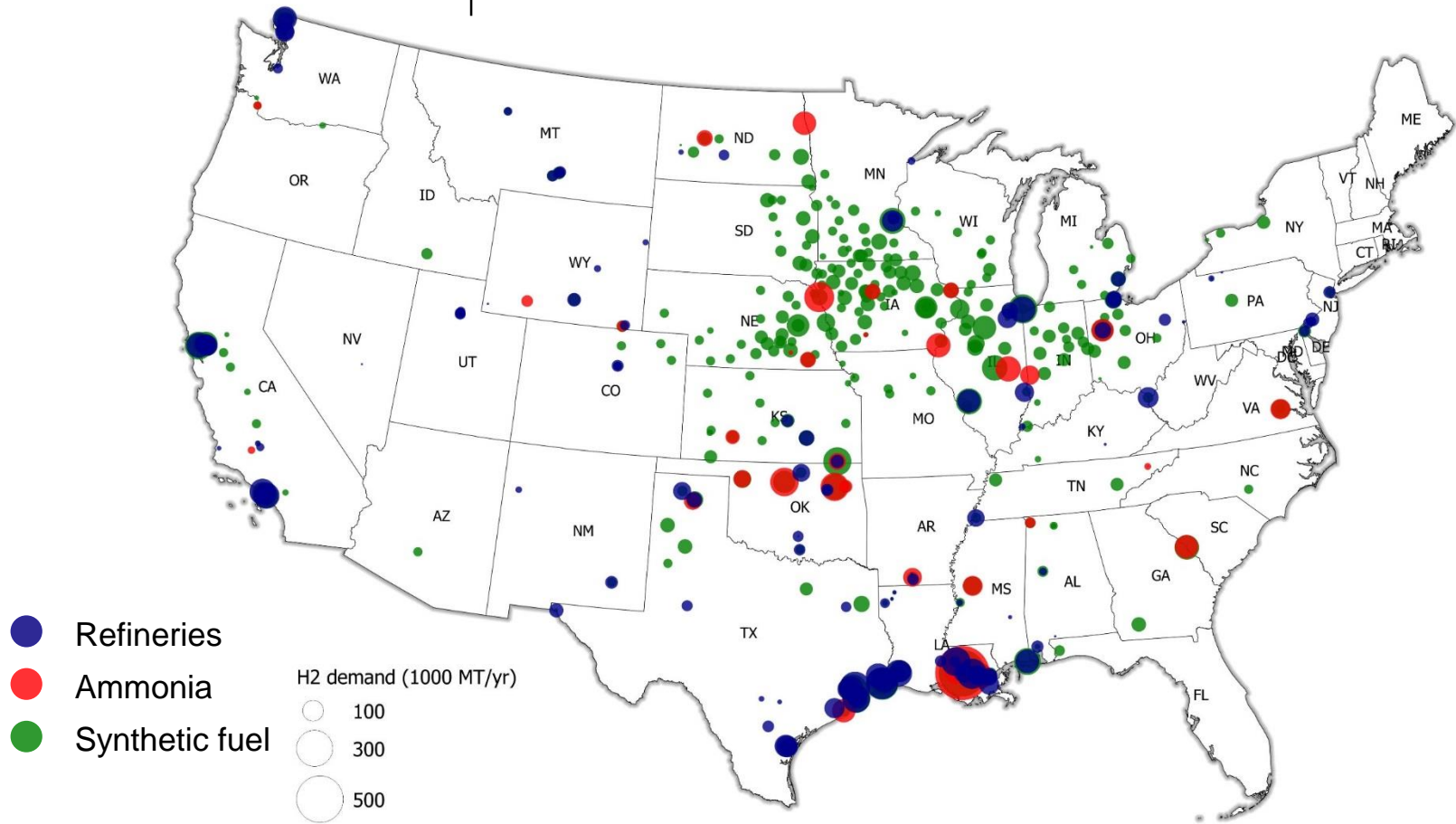
# Plus demand from synthetic fuel production...

2030

H<sub>2</sub> Demand



25.2 MMT



Source: Elgowainy, et al, ANL

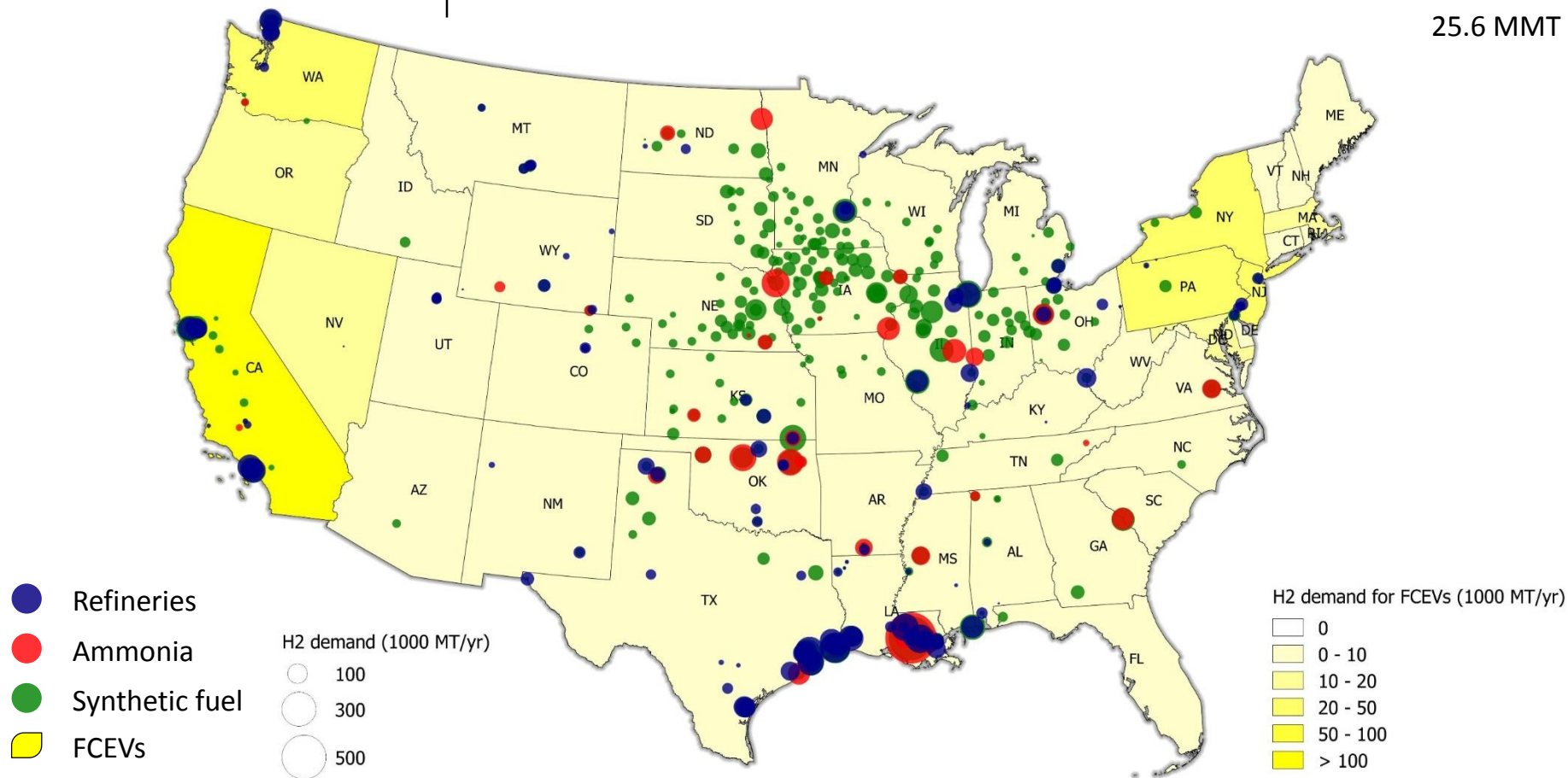
# Hydrogen Demand Potential

2030

H<sub>2</sub> Demand



25.6 MMT



**Nearly 30 million metric tons** of potential hydrogen demand in the U.S.

Source: Elgowainy, et al, ANL

# H<sub>2</sub>@Scale: Value to industrial processes?

## Electrical power plant cooling

- **Over 16,000 H<sub>2</sub> cooled generators worldwide**
- **Less delivery logistics, inventory management, 1-2 yr payback and improved efficiency**
- **Potential \$2B addressable market**

Source: Proton



## Iron Refining, Steel manufacturing

- **More energy efficient when hydrogen used as reductant at high temperatures**
- **Potential annual savings of over \$100,000 for a 100,000 ton/year plant**

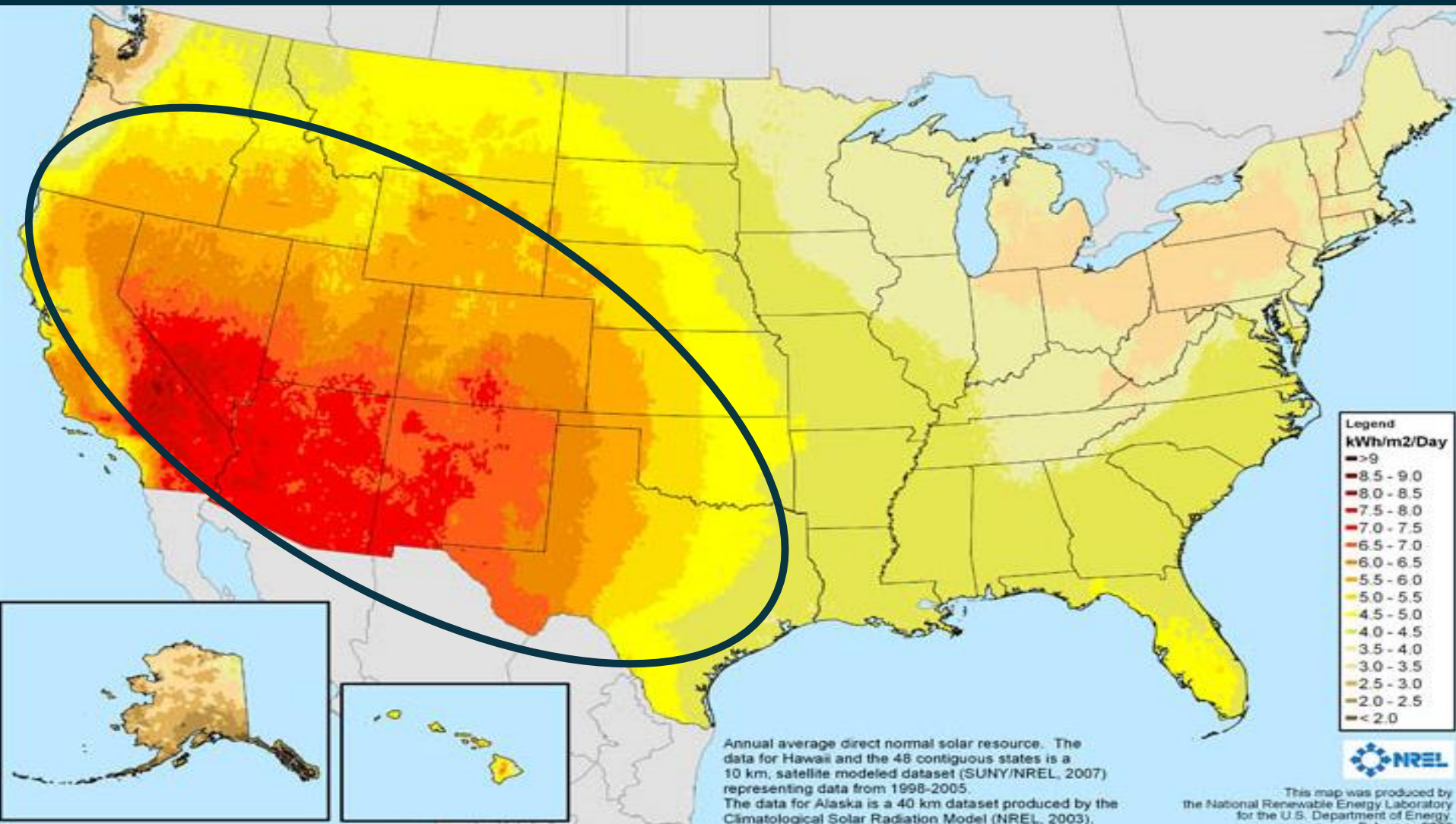
Source: EERE Advanced Manufacturing Office, Berry Metal



Image Credit: Berry Steel

# H<sub>2</sub>@Scale: Enabling renewable energy transport?

## Where we find abundant solar and wind energy



# H<sub>2</sub>@Scale: Enabling renewable energy transport?

Where we find abundant solar and wind energy



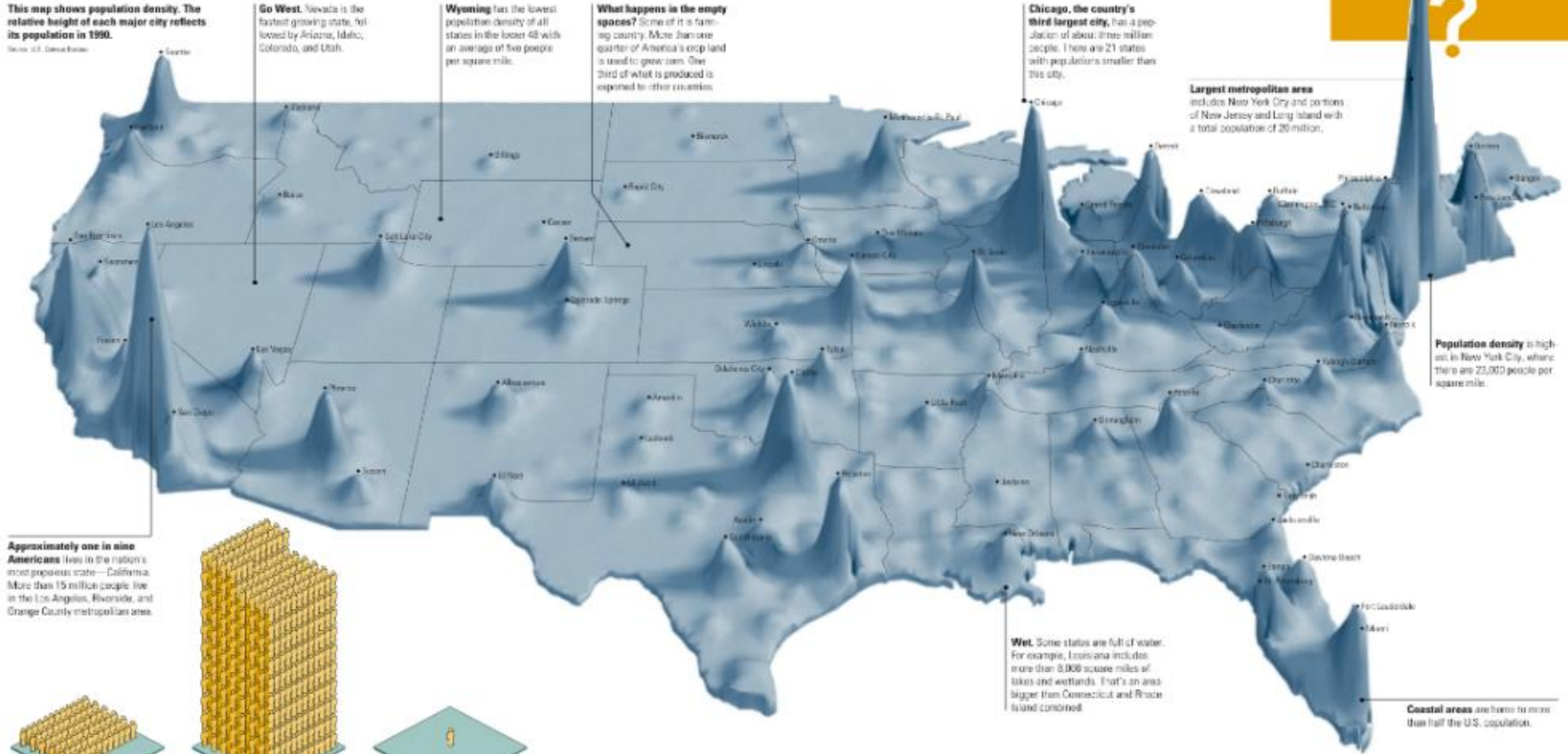
# ...and deliver it or co-locate distributed generation with demand for certain applications

The population of the United States is not distributed evenly. Instead, we tend to bunch up in communities, leaving the spaces in between more sparsely inhabited. Most Americans live in or near cities; today 53 percent live in the 20 largest cities, 75 percent of all Americans live in metropolitan areas.

## Where energy is consumed

This map shows population density. The relative height of each major city reflects its population in 1990.

Source: U.S. Census Bureau

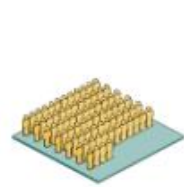


**Population Distribution**

*Where do we live?  
Where don't we live?*

?

Approximately one in nine Americans live in the nation's most populous state—California. More than 15 million people live in the Los Angeles, Riverside, and Orange County metropolitan area.



Distributing our population evenly would put an average of 75 people per square mile.



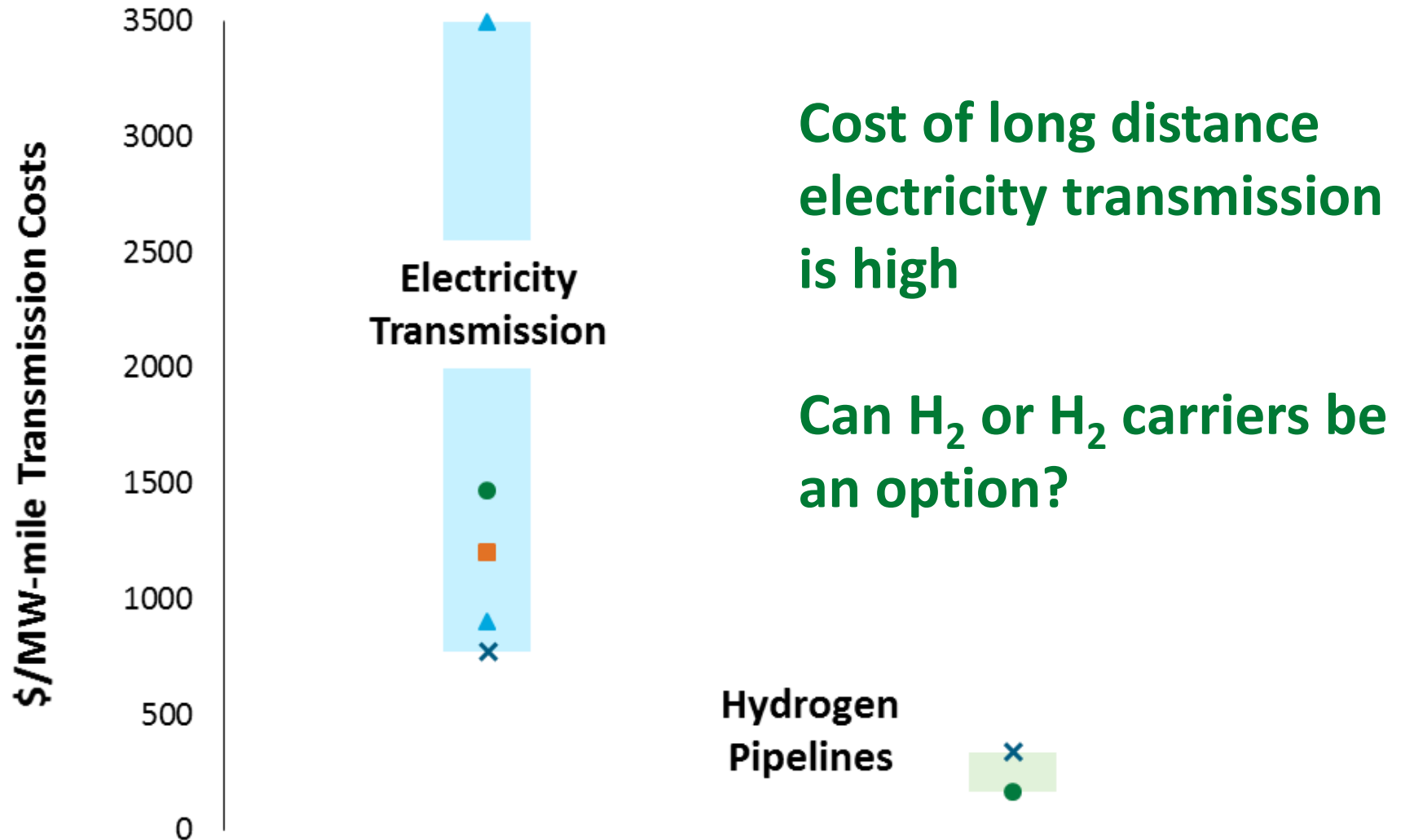
New Jersey is the most densely populated state with an average of more than 1,000 people per square mile.



Alaska is a sparsely populated state with an average of one person per square mile.



# Preliminary analysis underway to guide future plans



# Strategy: Partnerships to enable H<sub>2</sub>@Scale

## Early- Stage R&D

### Department of Energy

- Fuel Cells R&D
- H<sub>2</sub> Fuel R&D

### Other Federal Agencies



## Demonstration, Deployment & Commercialization

### Private Sector Industry, Other Agencies, States Partnerships

FCHEA (H2USA), CaFCP, OFCC, CT, HI, CO, NJ, etc.



# H<sub>2</sub>@Scale Consortium

# H<sub>2</sub>@Scale Stakeholder Feedback – Examples

Hundreds of stakeholders engaged  
6 DOE Offices engaged  
(EERE, FE, NE, OE, SC, ARPA-E)

Planned:  
2018 Kickoff  
Chicago, IL

2016 Session at  
Intermountain Energy  
Summit

Idaho Falls, ID

2017 Session at  
Fuel Cell Seminar  
Long Beach, CA

2017 Session at  
FCTO's Annual  
Merit Review  
Washington, D.C.

Examples of additional  
presentations:

- Utah (2017)
- Michigan (2017)
- Minnesota (2017)
- Germany (2017, 2018)
- Japan (2018)

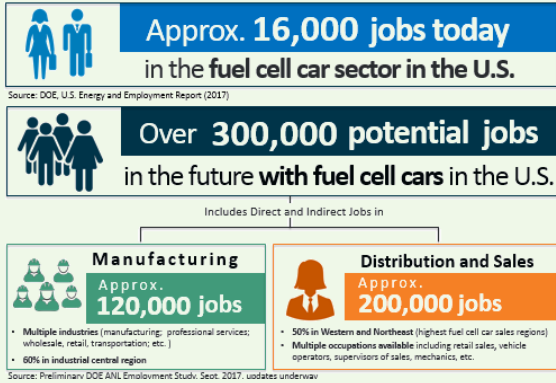
2017 Workshop  
Houston, TX

Planned: 2018  
AMR  
Washington, D.C.

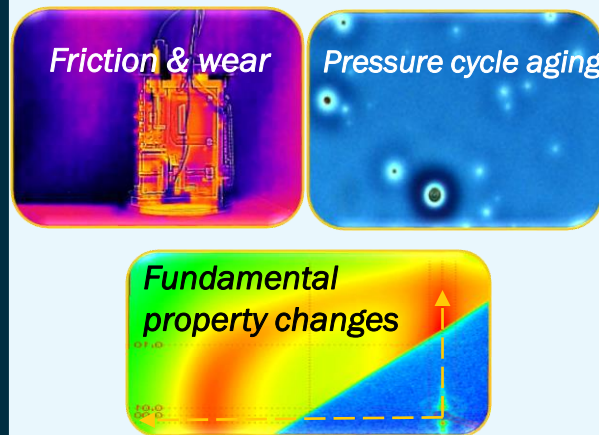
2016 Workshop  
Golden, CO

# H<sub>2</sub>@Scale R&D Lab Capabilities— Examples

## Techno economic Modeling and Analysis



## Hydrogen Materials R&D



## Grid simulation and Testing R&D



## Safety and Infrastructure R&D



Hydrogen\_Delivery\_Scenario\_Analysis

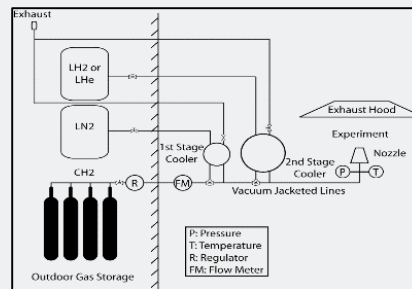
Refueling Station - Gaseous H<sub>2</sub>

Update Station Parameters

Calculation Outputs (Be sure ALL data is entered before checking)

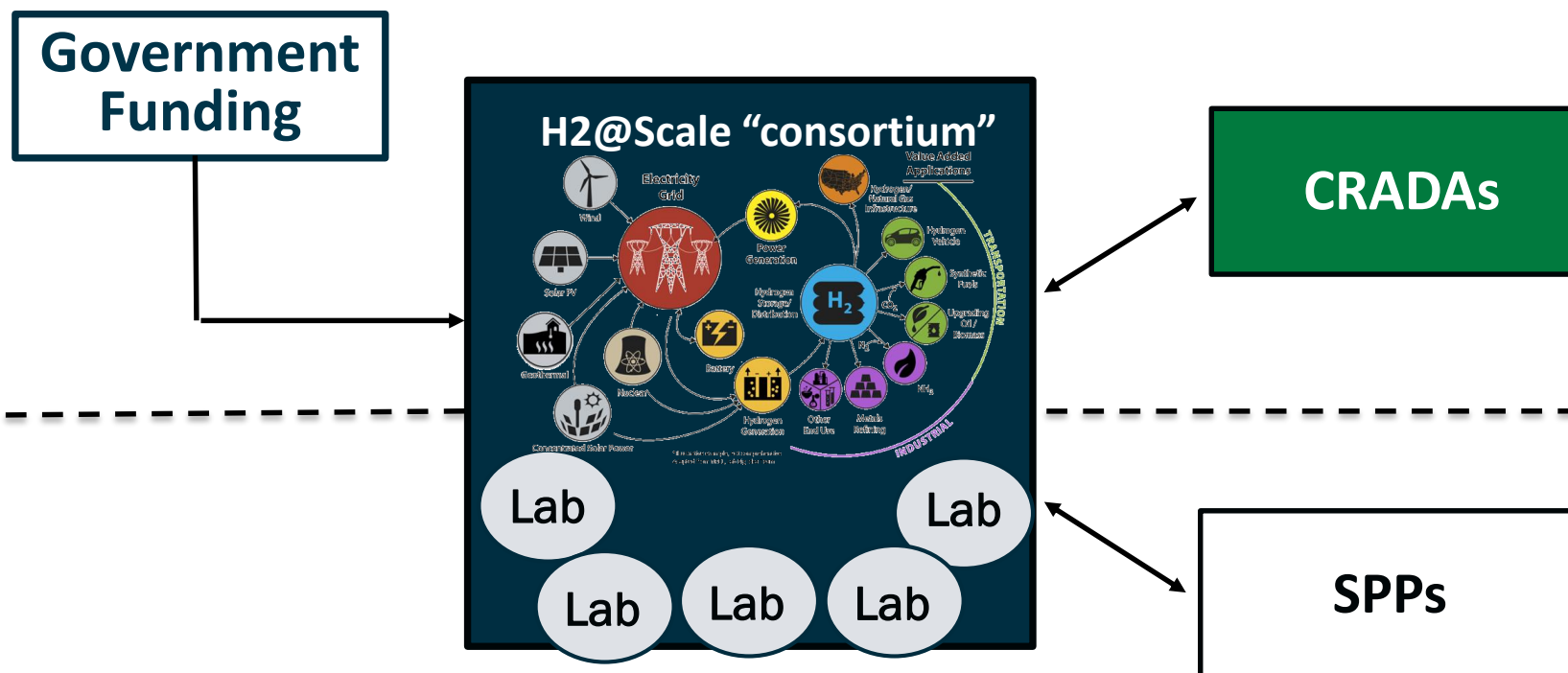
	Compressor (\$/D1H)	Storage (\$/D1H)	Dispenser (\$/D1H)	Refrigerant
	\$2.44	\$0.69	\$0.52	\$

Gaseous Refueling Station Number of the Year Leveraged Delivered Hydrogen Cost (\$/D1Hkg of Hydrogen)



# H<sub>2</sub>@Scale – Lab CRADAs

- Leverages Lab capabilities and expertise to address challenges- materials R&D, analysis, safety R&D, etc.
- Round 1 in 2017.



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

# H<sub>2</sub>@Scale 2017 CRADA call selections

## HYDROGEN QUANTITATIVE PERFORMANCE ANALYSIS AND OPERATION R&D

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



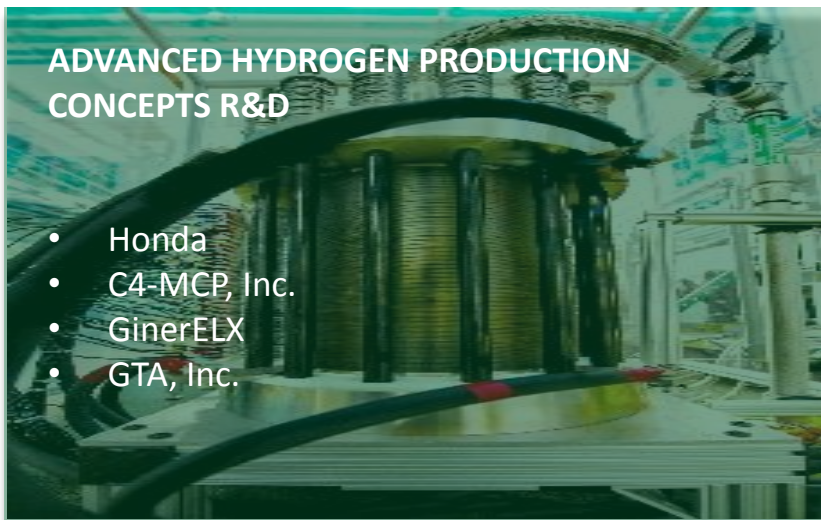
## HYDROGEN DISTRIBUTION COMPONENT DEVELOPMENT R&D

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



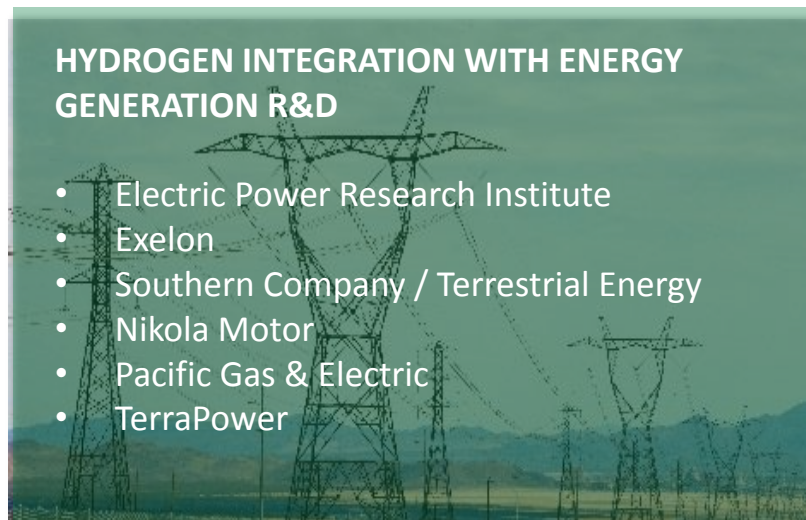
## ADVANCED HYDROGEN PRODUCTION CONCEPTS R&D

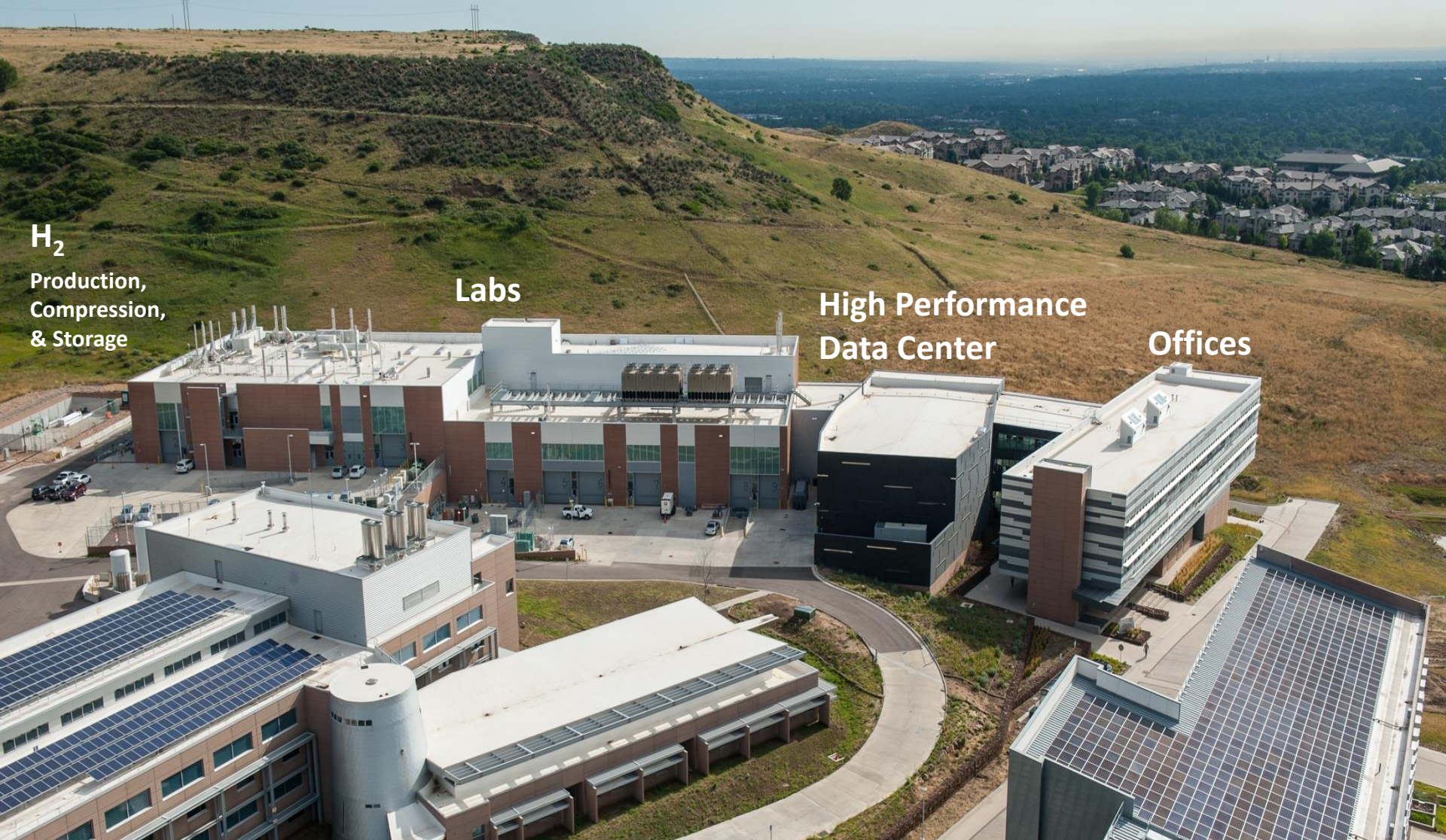
- Honda
- C4-MCP, Inc.
- GinerELX
- GTA, Inc.



## HYDROGEN INTEGRATION WITH ENERGY GENERATION R&D

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





**H<sub>2</sub>**

**Production,  
Compression,  
& Storage**

**Labs**

**High Performance  
Data Center**

**Offices**

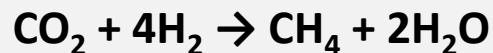
**Energy Systems Integration R&D, NREL  
Coordinating with INL, SNL and other labs  
For H2@Scale**

# Example of End Use & Industry Partnership with Labs

## Production of natural gas using H<sub>2</sub>

- Utilizes H<sub>2</sub>+ CO<sub>2</sub> and salts to generate pipeline quality natural gas (> 97% CH<sub>4</sub>)
- Biocatalyst used in the process - Methanothermobacter thermautotrophicus
- Industry and lab partners: Southern California Gas Company, NREL and Electrochaea

### Biomethanation Process:



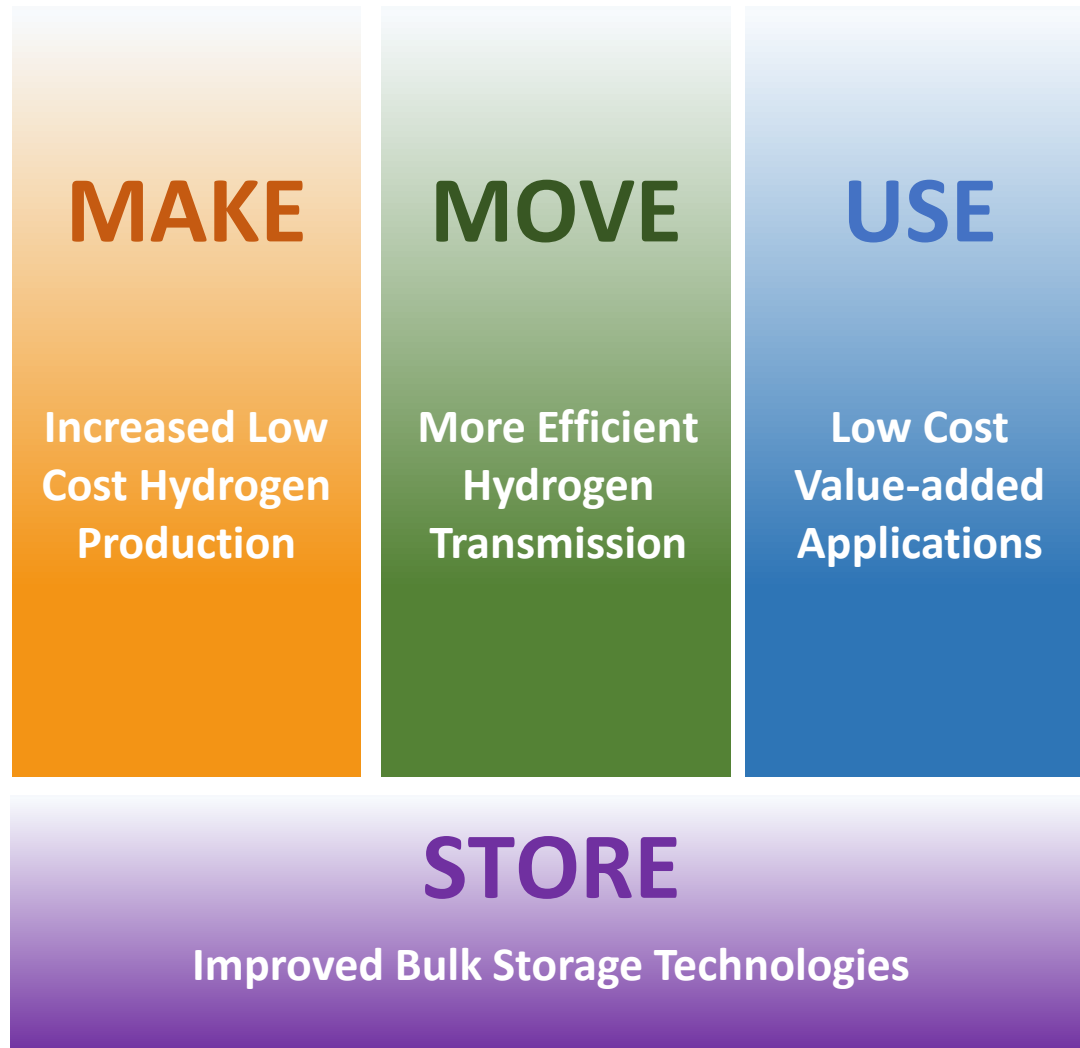


# NREL Fuel Cell Data Center



**First time automotive fuel cell is integrated to a data center**

# H<sub>2</sub>@Scale Future Plans: Focus Areas

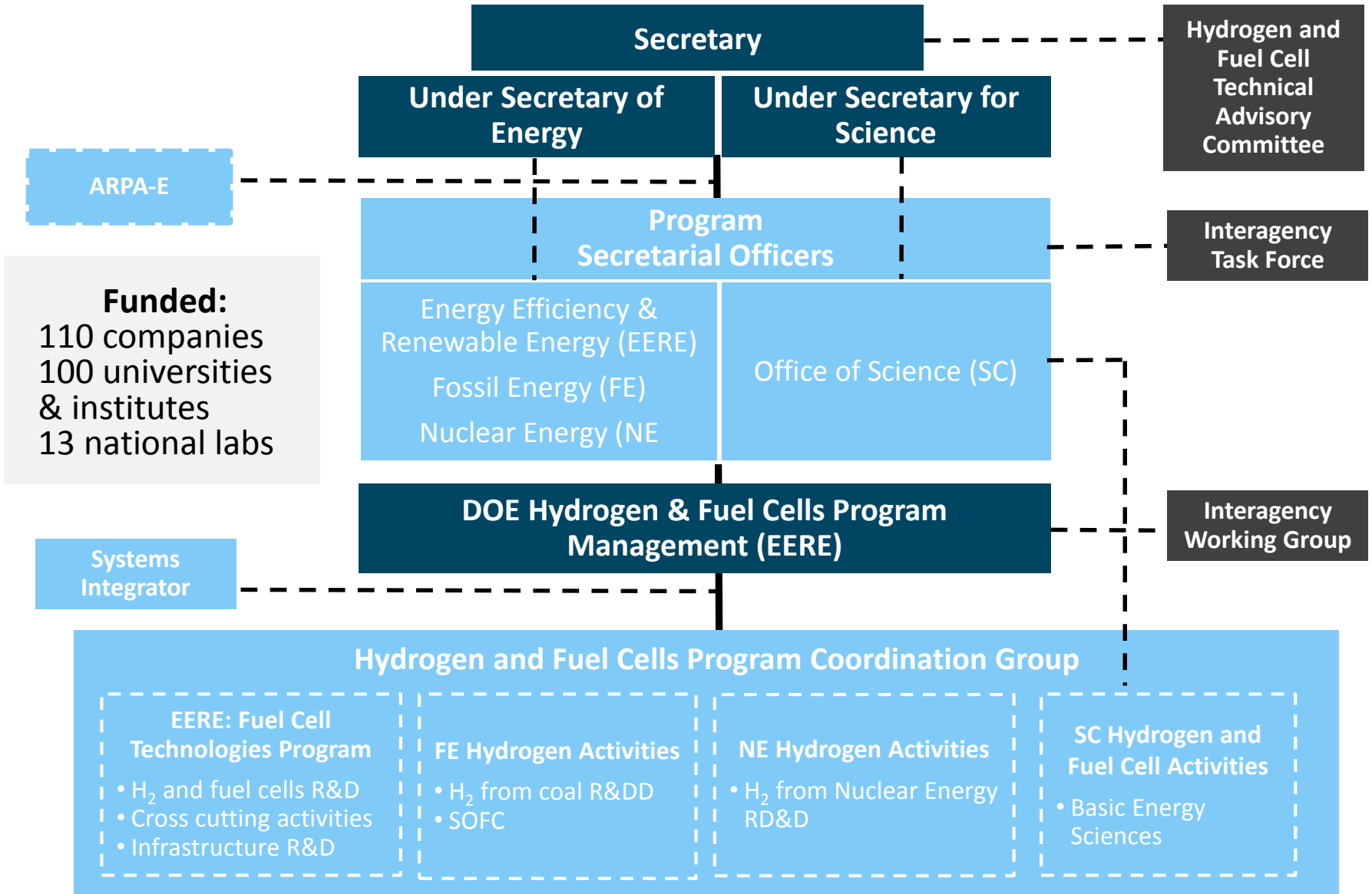


**August 1**  
**H2@Scale Kickoff**  
**Meeting Planned**  
**Chicago**  
**Roadmap Planned**



# Collaboration and Program Funding

# The H<sub>2</sub> and Fuel Cells Program spans other DOE offices



# DOE Program Funding

## DOE-wide Hydrogen and Fuel Cells Funding<sup>1</sup>

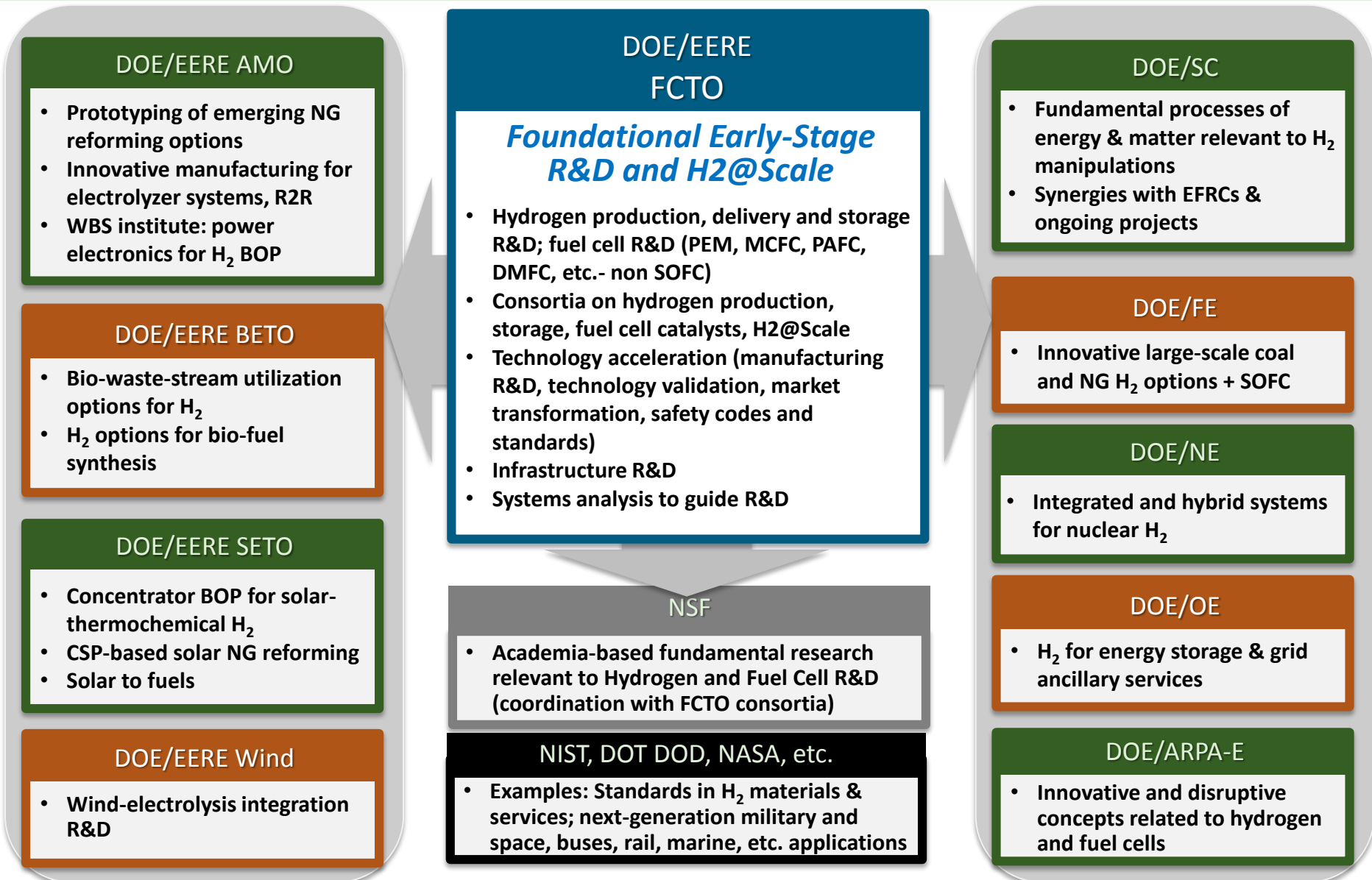
Office	FY 2017
	(\$ in thousands)
EERE	101,000
ARPA-E	47,000
Science	22,000
Fossil Energy	30,000
Nuclear	2,000
<b>Total</b>	<b>202,000</b>

## EERE – Fuel Cell Technologies Office

Key Activity	FY 2017	FY 2018
	(\$ in thousands)	
Fuel Cell R&D	32,000	32,000
Hydrogen Fuel R&D	41,000	54,000
Systems Analysis	3,000	3,000
Technology Acceleration	18,000	19,000
Safety, Codes and Standards	7,000	7,000
<b>Total</b>	<b>101,000</b>	<b>115,000</b>

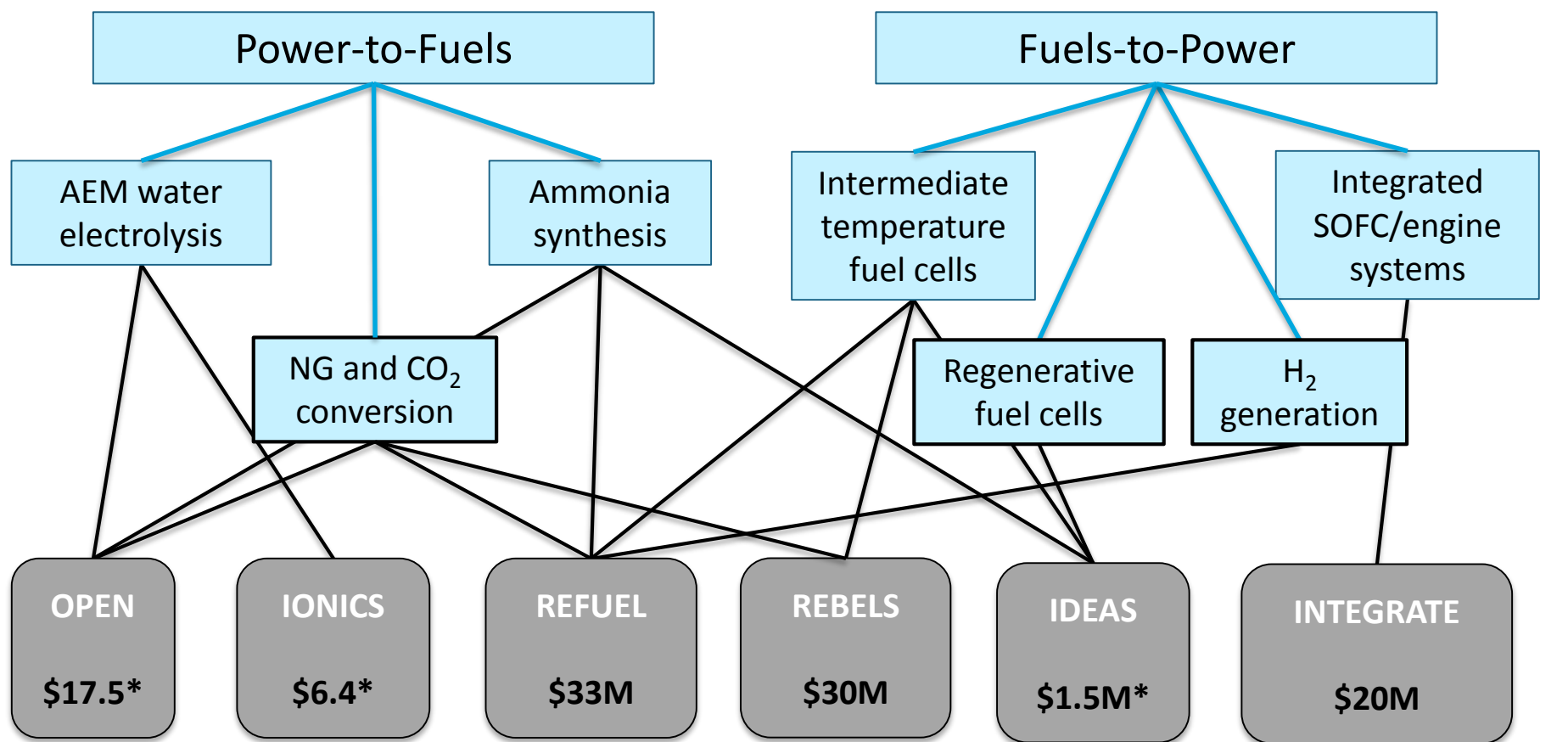
<sup>1</sup> 2017 DOE Hydrogen and Fuel Cells Program Annual Progress Report

# Coordination across Offices- Examples



# ARPA-E Hydrogen and Fuel Cells Activities

## ARPA-E Programs in Fuel Cells/Electrolyzers for Energy Conversion and Storage



Source: ARPA-E

\* - related to FC/electrolyzers/H<sub>2</sub>



# Online Resources - we need your help!

## Spread the word on **H<sub>2</sub> Safety Lessons Learned!**

Share at regular  
team meetings

Provide feedback to  
FCTO and  
stakeholders



Find lessons learned at **H2tools.org**

# Collaboration: Announcing New H<sub>2</sub> Safety Partnership

Leverages new partnership to promote collaboration on safety



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
**ENERGY EFFICIENCY &  
RENEWABLE ENERGY**

# IPHE: International Partnership for H<sub>2</sub> and Fuel Cells in the Economy

- **Share** information on H<sub>2</sub> and fuel cells, lessons learned, best practices
- **Increase** international **collaboration** to **accelerate progress**

**U.S. elected  
as Chair**

**May 2018**



Australia



Austria



Brazil



Canada



China



European Commission



France



Germany



Iceland



India



Italy



Japan



Republic of Korea



Norway



Russian Federation



South Africa



United Kingdom



United States

**Launched 2003 and includes 18 countries and the European Commission**

# 2019 Annual Merit Review

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April 29 - May 1, 2019

Washington, DC

# Thank You

**Dr. Sunita Satyapal**

Director

Fuel Cell Technologies Office

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

[energy.gov/eere/fuelcells](https://energy.gov/eere/fuelcells)

# DOE Collaboration: H<sub>2</sub> & Fuel Cell Working Group

DOE Program Managers collaborate on hydrogen and fuel cell activities

## Points of Contact for Member Offices

### Advanced Research Projects Agency – Energy (ARPA-E)

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**Grigorii Soloveichik** (REBELS, REFUEL)

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**David Tew** (INTEGRATE)

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