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

December 12, 2018 – Washington DC

Overview

- **HTAC Scope**
  - Membership
  - Energy Policy Act (EPACT) 2005 Title VIII
- **Program History and Updates**
  - H2@Scale
  - Budget and Progress
- **Next Steps**
  - Examples of outputs and recommendations

2018 HTAC Membership

HTAC Member and Affiliation	Expertise
Aszklar, Henry Independent Energy Consultant	**Energy Project Development & Financing**
Ayers, Katherine Nel Hydrogen (Proton OnSite)	**Hydrogen Production Companies**
Azevedo, Inês Carnegie Mellon University	**Behavioral/ Decision-Making Science**
Ffolkes, Marie Air Products and Chemicals, Inc.	**Hydrogen Production and Delivery**
Freese, Charles F. (Chair) General Motors Company	**Automotive Companies**
Irvin, Nick Southern Company	**Utilities/Advanced Energy Systems R&D**
Koyama, Harol H2 PowerTech	**Stationary Power and Markets**
Leggett, Paul Mithril Capital Management, LLC	**Venture Capital / Investment**
Leo, Anthony FuelCell Energy	**Stationary Fuel Cell and Hydrogen Production Technology Manufacturing**

New members as of July 2018

HTAC Member and Affiliation	Expertise
Markowitz, Morry Fuel Cell and Hydrogen Energy Association (FCHEA)	**Hydrogen and Fuel Cells Industry Association**
Marsh, Andrew Plug Power	**Stationary and Transportation Fuel Cell Technology Manufacturing**
Mizroch, John John F Mizroch, LLC	**Clean Energy Technology Exports and Investments**
Nocera, Daniel Harvard University	**Hydrogen Production R&D**
Novachek, Frank Xcel Energy	**Utilities (Electricity and Natural Gas)**
Powell, Joseph (Vice Chair) Shell Global Solutions	**Fuels Production and R&D**
Rogers, Paul US Army Tank-automotive and Armaments Command (TACOM)	**Department of Defense Hydrogen and Fuel Cell R&D**
Scott, Janea California Energy Commission	**State Energy Policies and Regulations**
Thompson, Levi University of Delaware	**Physical Sciences**

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**

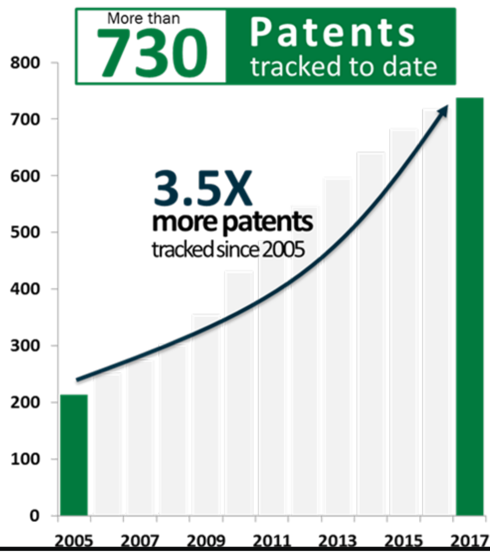
3. **The DOE Hydrogen & Fuel Cells Program Plan**

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**

DOE-funded Innovation Driving Impact

Innovation and Progress



- **Reduced fuel cell and electrolyzer cost by >60%**
- **Quadrupled fuel cell durability**
- **Achieved world's firsts: Tri-gen, PEC, liquefaction, etc.**

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 DOE R&D

Innovation to Market Technologies - Examples

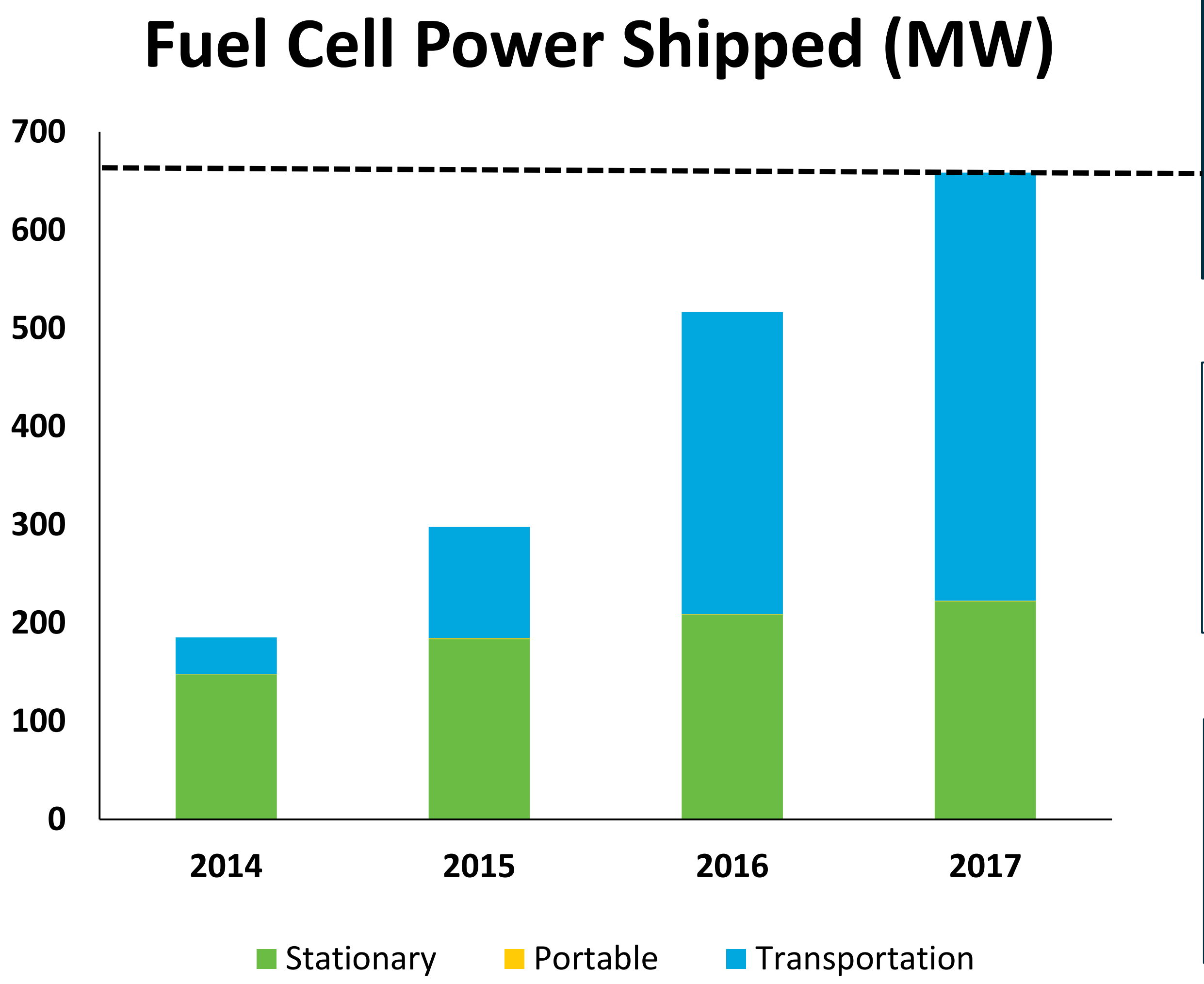
Electrolyzers - Giner

Fuel cell systems - Plug Power

Electrolyzers - Proton

Hydrogen Tube Trailers – Hexagon Lincoln

Fuel Cell Shipments - Growth by Application



650 MW
fuel cell power
shipped worldwide

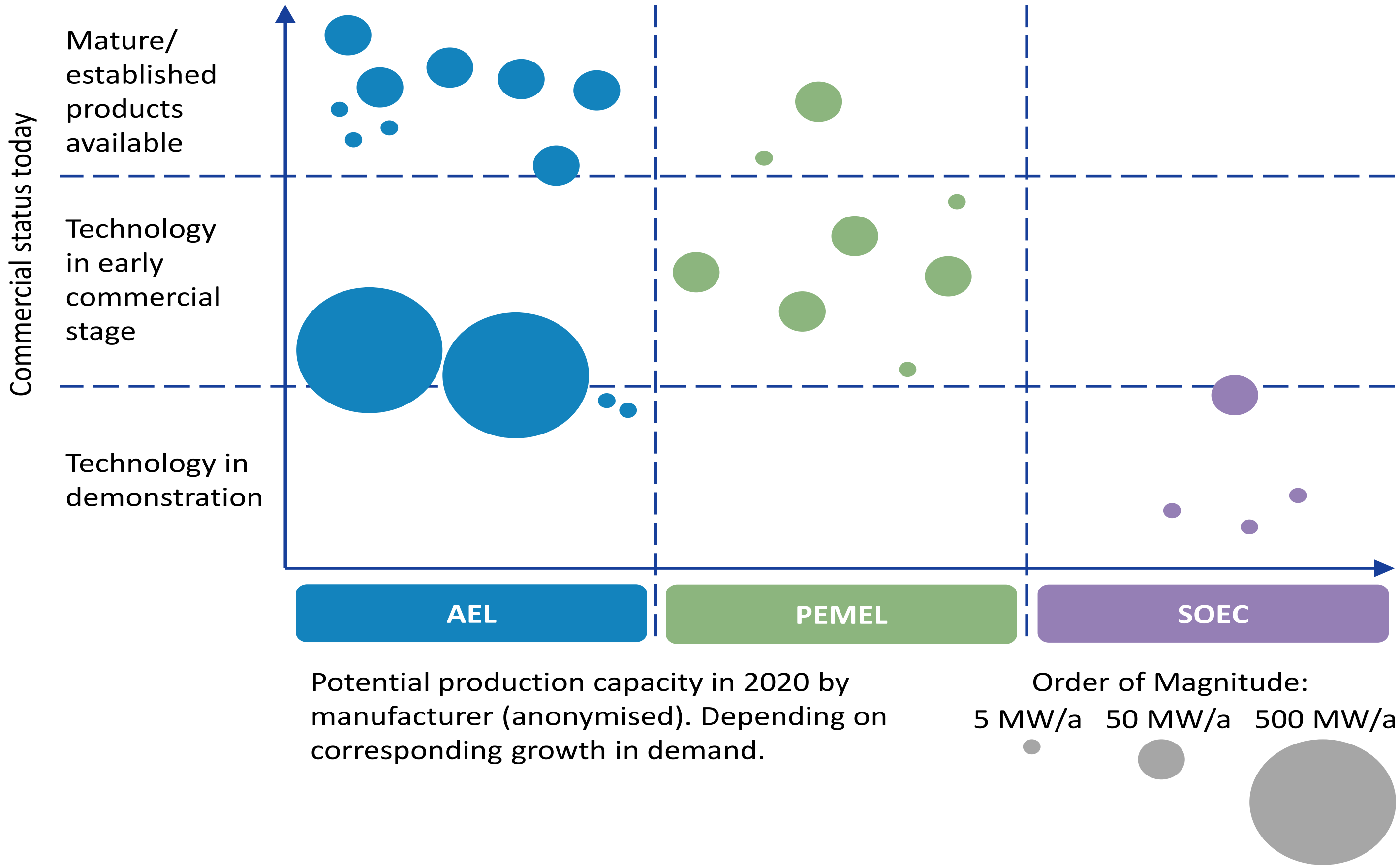
70,000
fuel cell units
shipped worldwide

Approximately
$2 Billion
fuel cell revenue

Source: DOE and E4Tech

Electrolyzers

Global sales estimated at 100 MW/year*



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

Bundesministerium für Verkehr und digitale Infrastruktur | PtJ Projektträger Jülich Forschungszentrum Jülich | NOW Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie | E4tech Strategy | Energy | Sustainability | Fraunhofer IPA | Fraunhofer ISE

Multiple H_2 and Fuel Cell Applications in the U.S.

U.S. Snapshot

Over
>240MW
Backup Power

More than
23,000
Forklifts

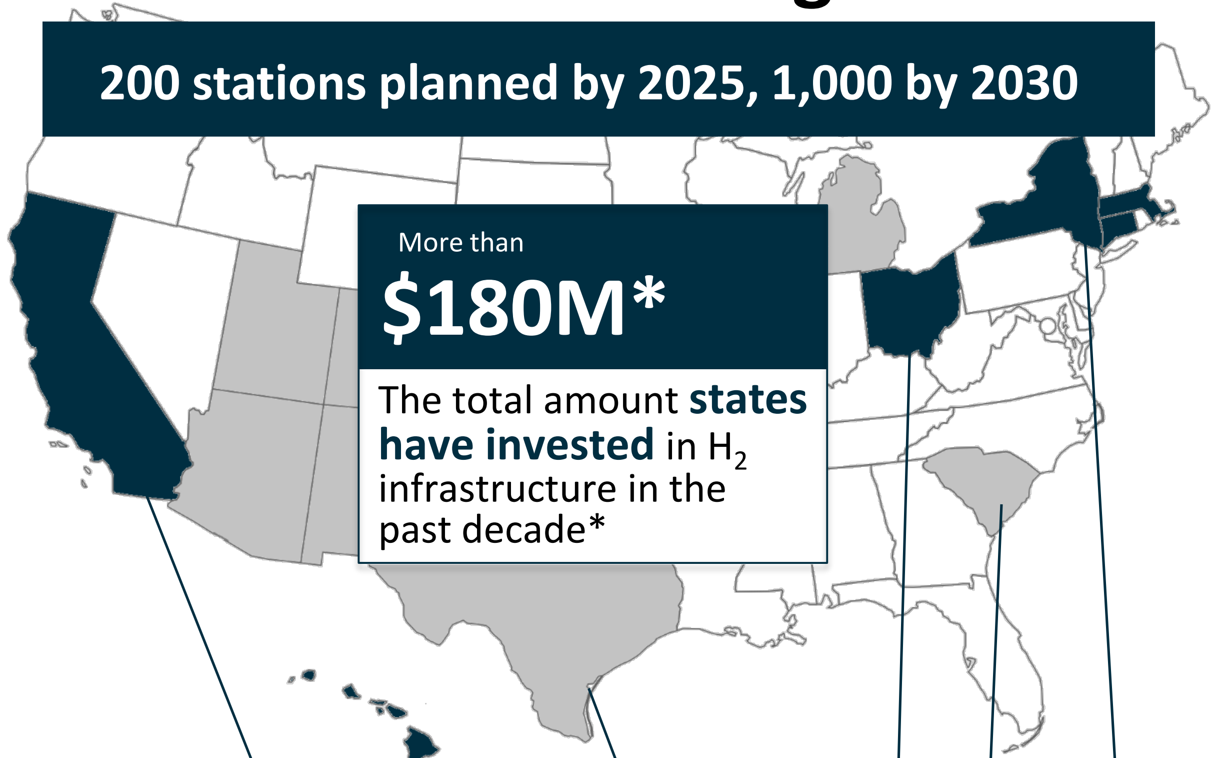
More than
30
Fuel Cell Buses

36
H_2 Retail Stations

Nearly
6,000
Fuel Cell Cars

States with Growing Interest

200 stations planned by 2025, 1,000 by 2030



More than
$180M*
The total amount **states have invested** in H_2 infrastructure in the past decade*

CA

- 1,000 stations by 2030
- Over 30 public stations open
- $150M invested
- $235M announced in 2018

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others with interest

- Over $27M invested
- 12-25 stations planned in the NE

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

Fuel Cell Technologies Office (FCTO) Overview

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
- Advanced materials for storage

Infrastructure

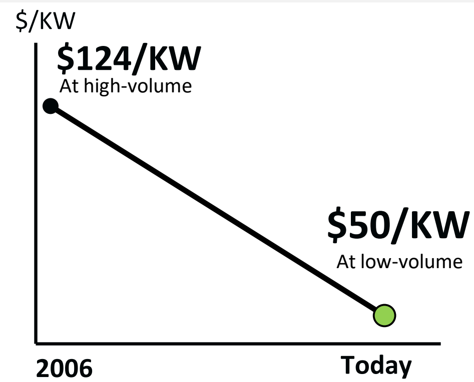
- Safety
- Manufacturing
- Delivery components
- Others

PGM = Platinum group metals

MEA = Membrane Electrode Assembly

Impact

60% Lower Fuel Cell Cost



Greater Fuel Cell Durability

4X more hours

of fuel cell durability since 2006

80% Lower Electrolyzer Cost

for H_2 production since 2002

Leverage private sector

Enabling

H2@Scale
U.S. Department of Energy

DOE Program Funding

DOE-wide Hydrogen and Fuel Cells Funding

Office	FY 2018 ($ in thousands)
EERE (FCTO)	115,000
Science (Basic/xcut)	19,000
Fossil Energy (SOFC)	30,000
Total	~164,000

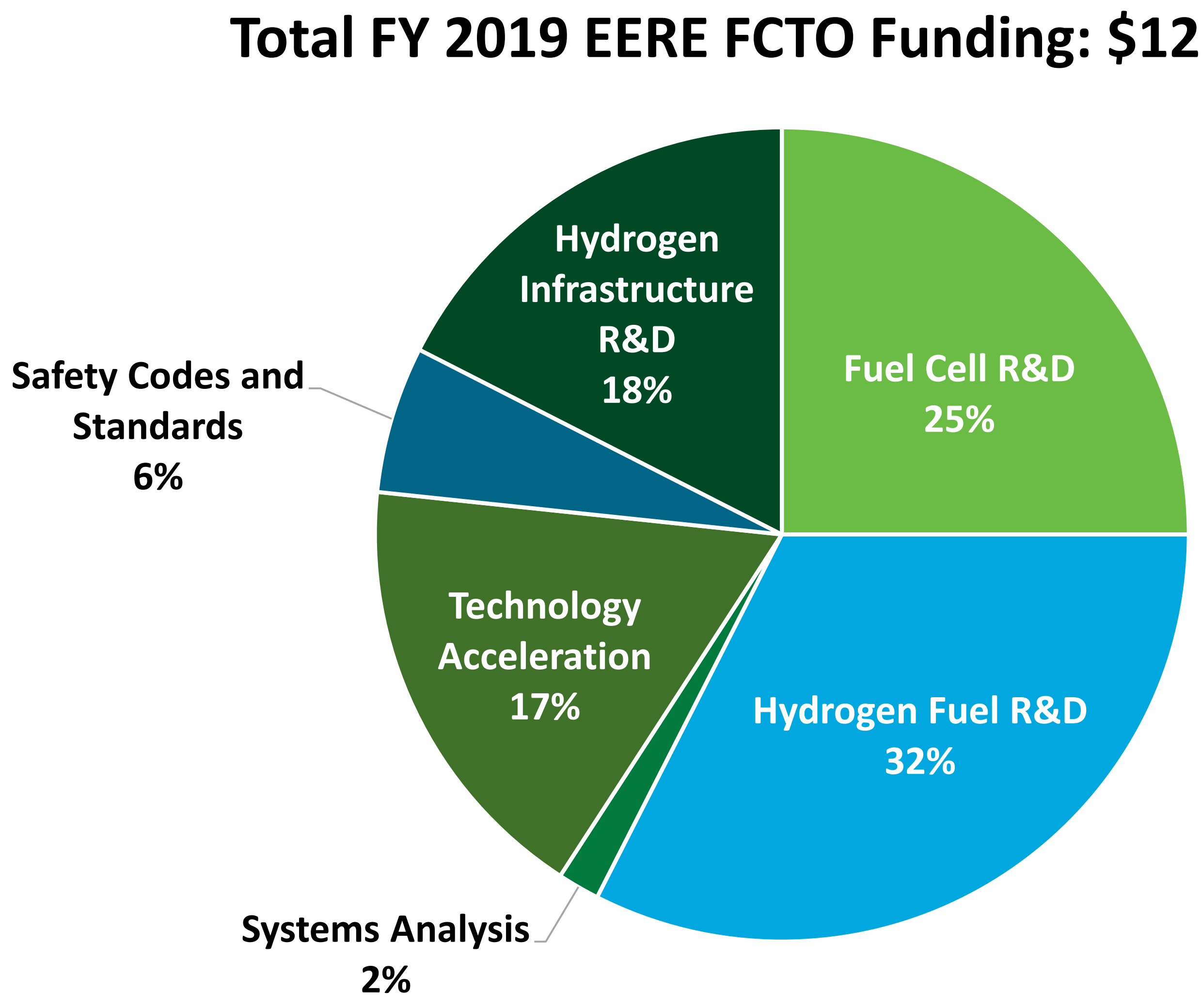
Note: ARPA-E funding dependent on program selected each fiscal year

EERE – Fuel Cell Technologies Office

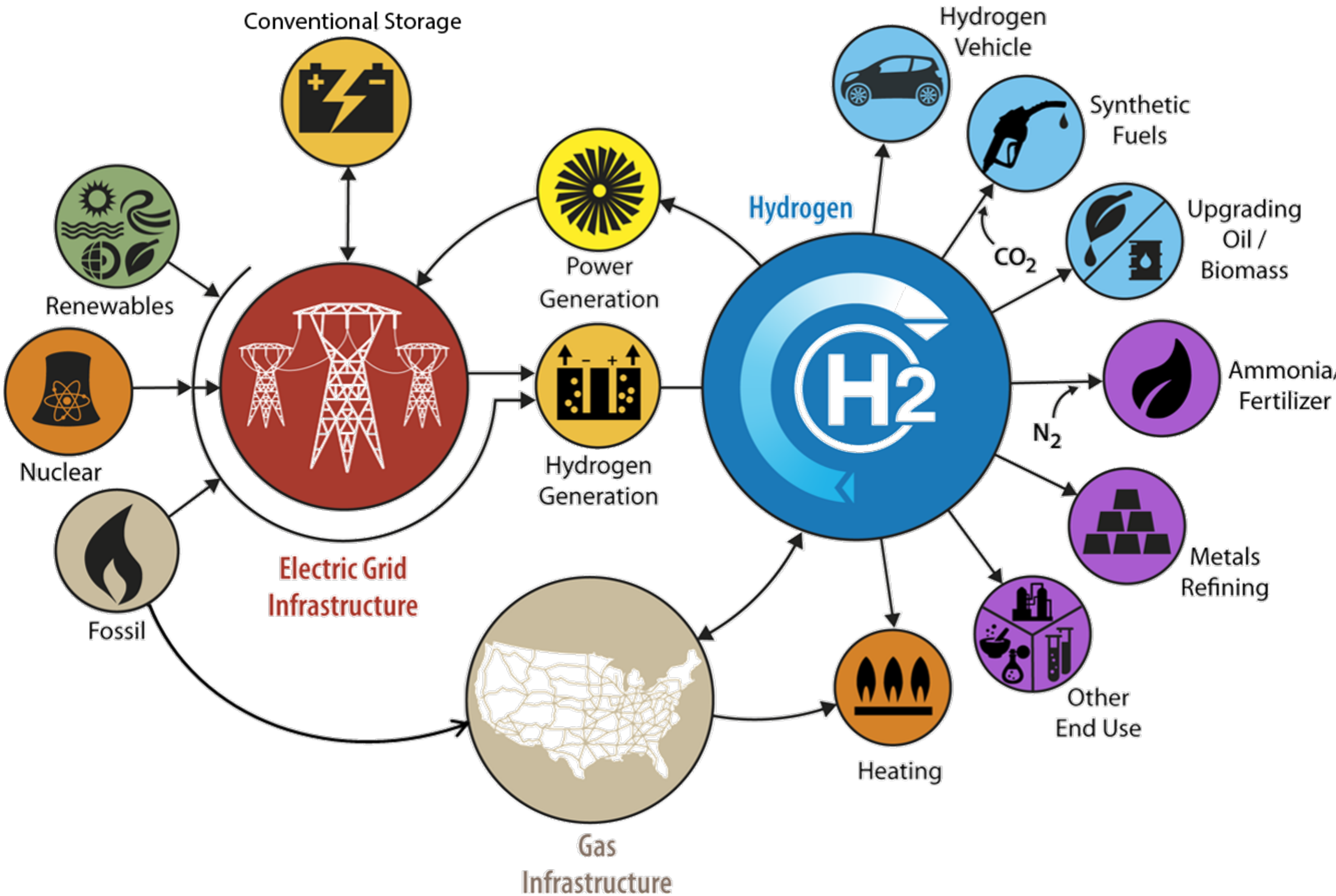
Key Activity	FY 2017	FY 2018	FY 2019
	($ in thousands)		
Fuel Cell R&D	32,000	32,000	30,000
Hydrogen Fuel R&D	41,000	54,000	39,000
Hydrogen Infrastructure R&D	-	-	21,000
Systems Analysis	3,000	3,000	2,000
Technology Acceleration	18,000	19,000	21,000
Safety, Codes and Standards	7,000	7,000	7,000
Total	101,000	115,000	120,000

EERE: Office of Energy Efficiency and Renewable Energy

Fuel Cell Technologies Office Funding - FY 2019



H_2@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



More information at: www.energy.gov/eere/fuelcells/h2-scale

Examples of Key Activities

Options to Scale up

- Opportunities to increase scale –
- Bundle supply & demand
- Rail, marine, heavy duty, industry (steel), etc.

H_2 Infrastructure

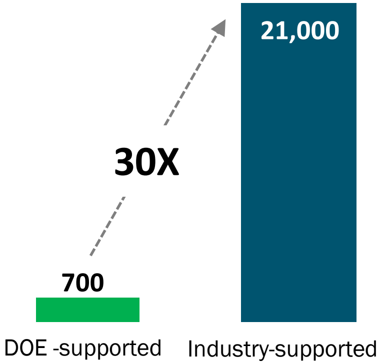
DC H_2 Station

Tri-Gen H_2 Station

Enablers

- HySTEP
- Mobile Fueler
- Tunnels
- Liquid Release
- Station footprints
- H-Prize

Recent Hydrogen and Fuel Cell Applications

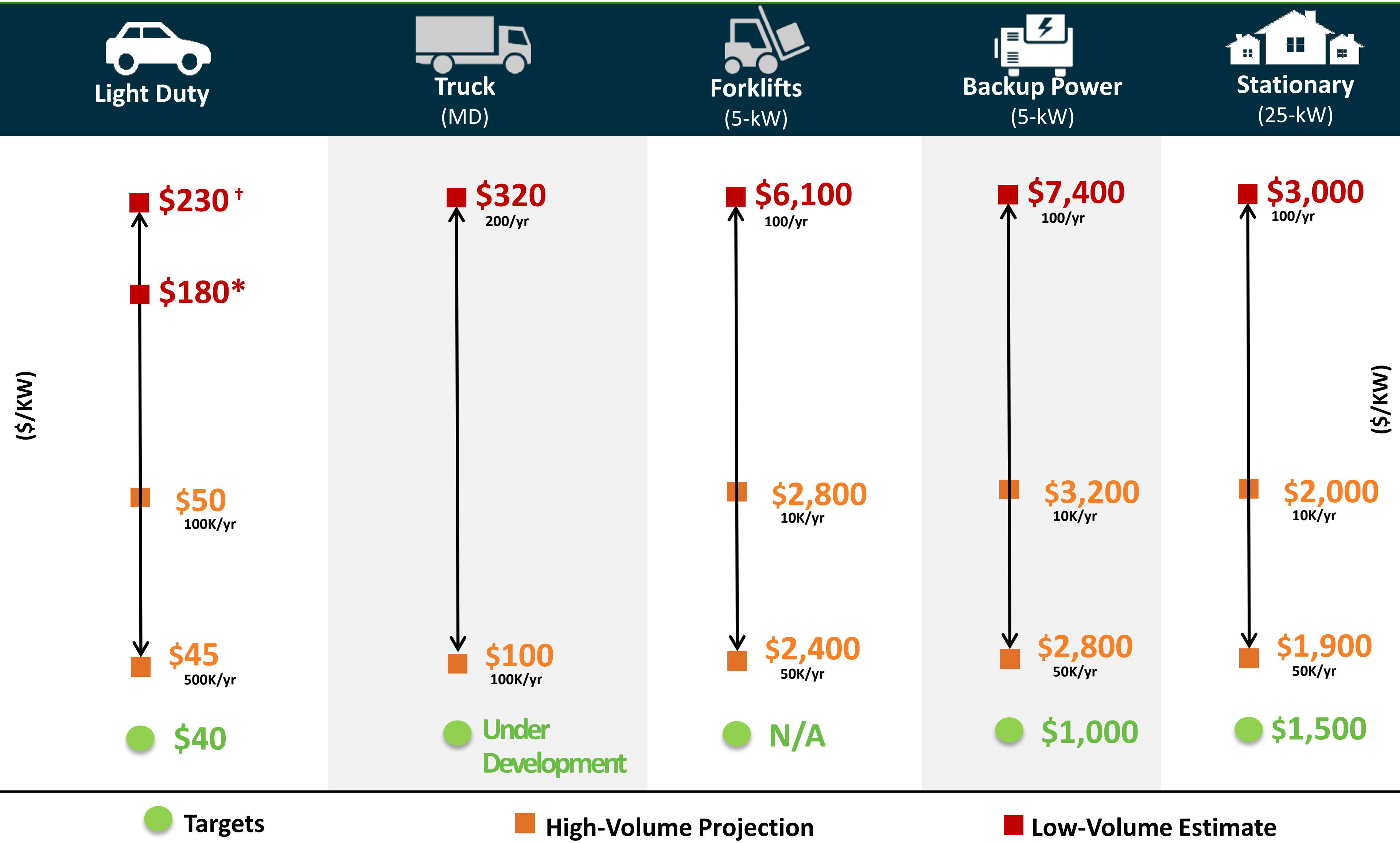


Lift Trucks

Parcel Delivery Vans

Ground Support Equip.

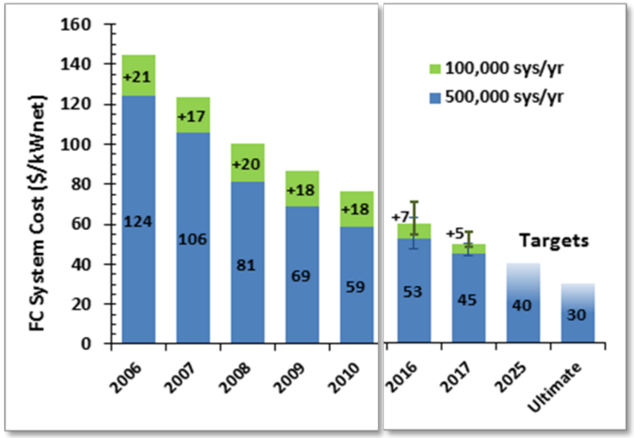
Cost remains a challenge: DOE fuel cell system cost vs. targets



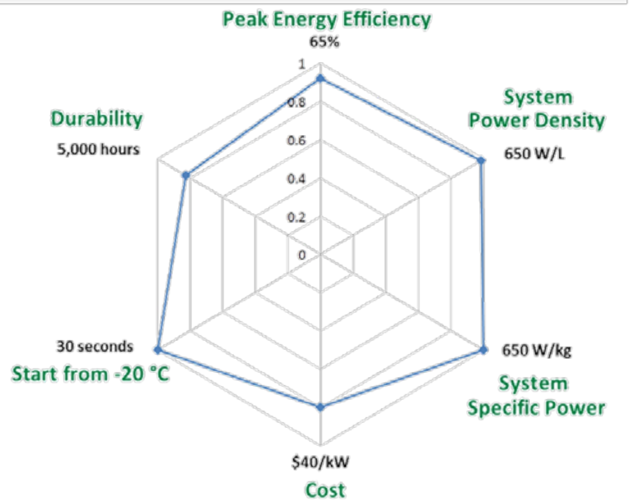
†Based on commercially available FCEVs †Based on state of the art technology Note: Graphs not drawn to scale and are for illustration purposes only.

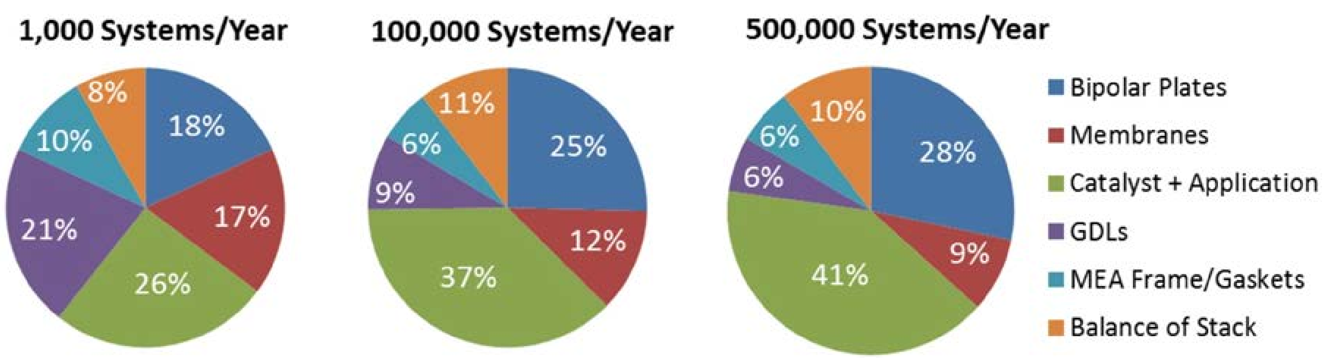
Fuel Cell Status vs. Targets

R&D has enabled > 60% cost reduction in the last decade



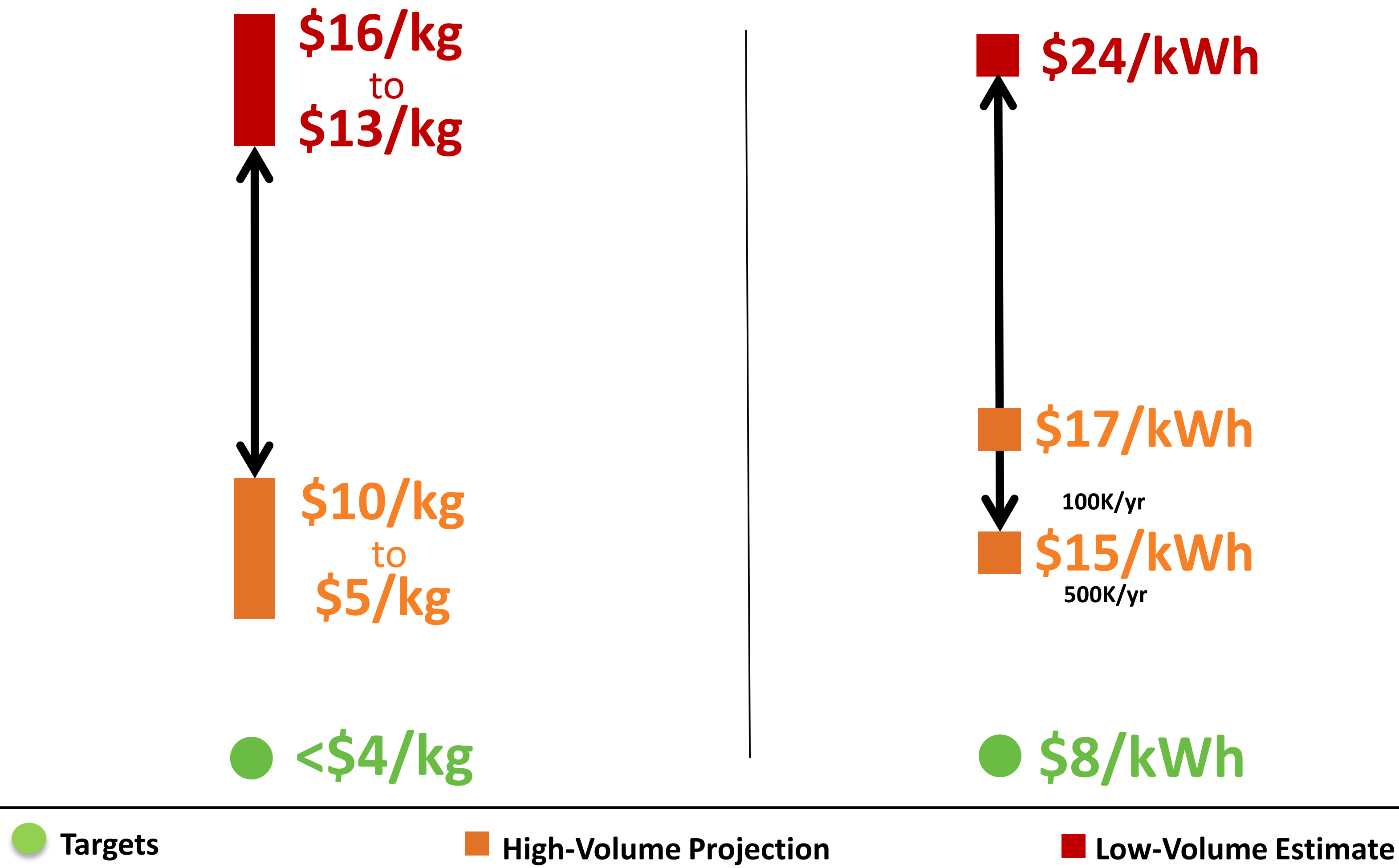
Some targets are met but fuel cell cost and durability must be addressed concurrently





Hydrogen fuel cost vs. targets

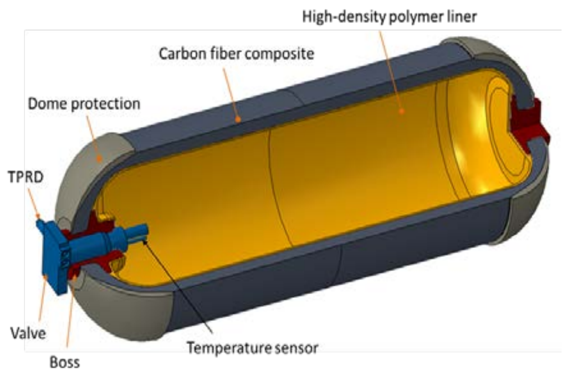
Production, Delivery & Dispensing	On-board Storage *(700-bar compressed system)*

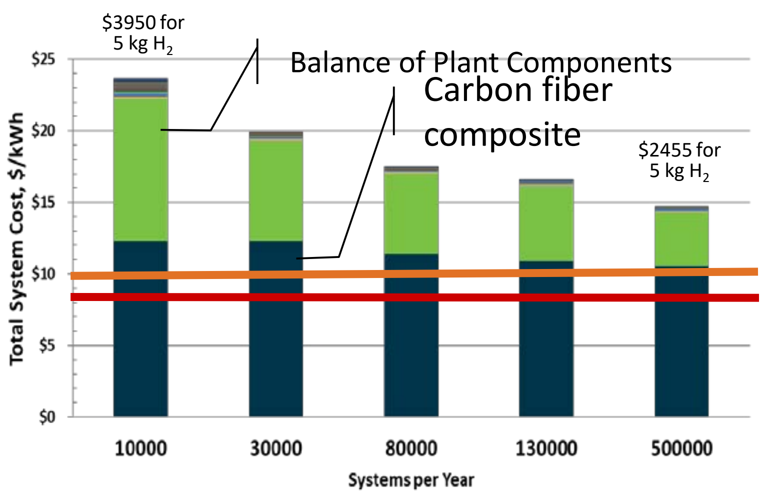


Note: Graphs not drawn to scale and are for illustration purposes only.

Hydrogen Storage and Delivery Costs

Hydrogen is currently stored in Composite Overwrapped Pressure Vessels at 700 bar (~10,000 psig) for LDVs



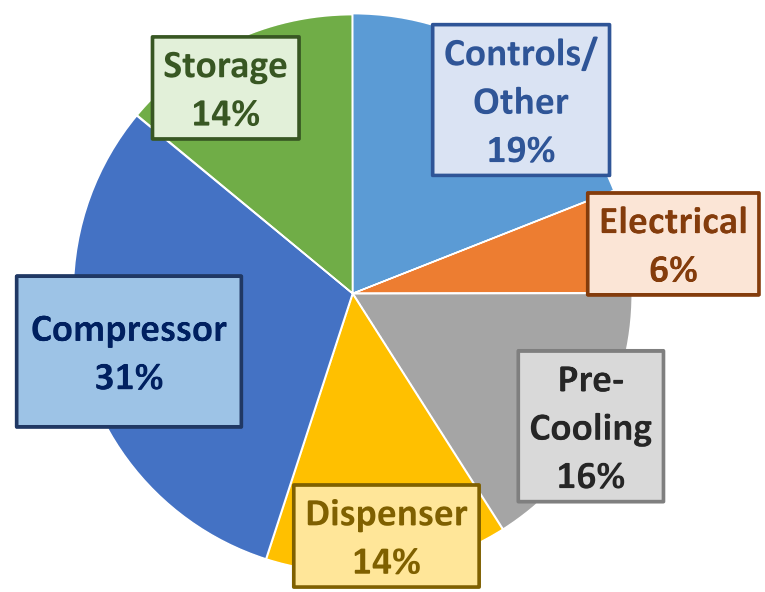


Analysis for a single tank design

- 2020 Target
- Ultimate Target

Delivery Cost by Component

Tube Trailer Delivery Example



https://www.hydrogen.energy.gov/pdfs/15013_onboard_storage_performance_cost.pdf

Key Strategies and Focus Areas- Examples

Challenge	Strategies	R&D Focus	Key Areas
Reduce the cost of hydrogen production, storage, and delivery in support of H2@Scale • **Materials issues** • **Feedstocks** • **Capital costs** • **O&M costs**	***Near-term*** **Applied R&D to enable 700 bar H_2 at refueling stations, reduce cost, address reliability** ***Longer-term*** **Improve performance and durability of materials & systems for production from sustainable sources**	• Techno-economics to guide applied R&D • Advanced materials and systems for H_2 delivery • Innovations in materials, devices and reactors for sustainable H_2 production • Reliability and cost of compression, storage and dispensing • Integrated/hybrid systems • Improved balance of plant	***Delivery & Storage*** • **Liquefaction technologies** • **Compression, materials R&D** • **H2 carriers, dispensing R&D** ***Production*** • **Advanced electrolysis** • **Waste and bio- conversion** • **Nuclear/hybrid approaches** • **Solar water splitting: PEC & STCH**

R&D Support Framework:

- FCTO FOA & Lab Calls
- SBIR/ STTR
- MOUs: NSF, DOD, etc
- Consortia (Seedlings)
- Crosscuts: Grid, etc.
- Prizes and Other

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**

→

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

↓

RD&D Plan and Solicitation Topics

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

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.

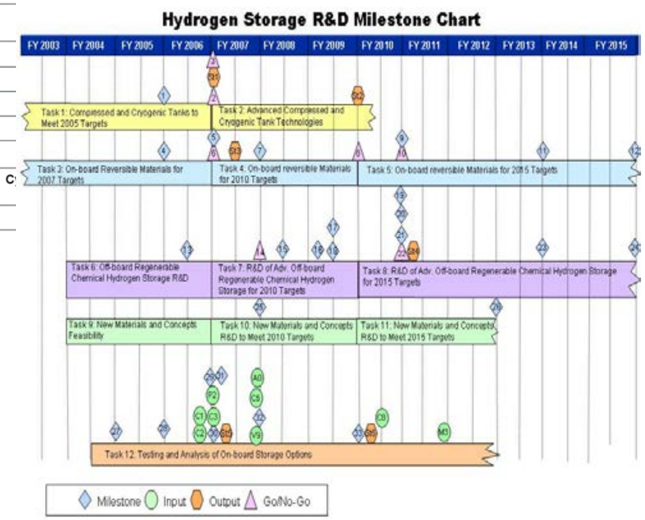
Reviewer comments for projects posted online annually. Projects discontinued/ work scope altered based on performance & likelihood of meeting goals.

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				

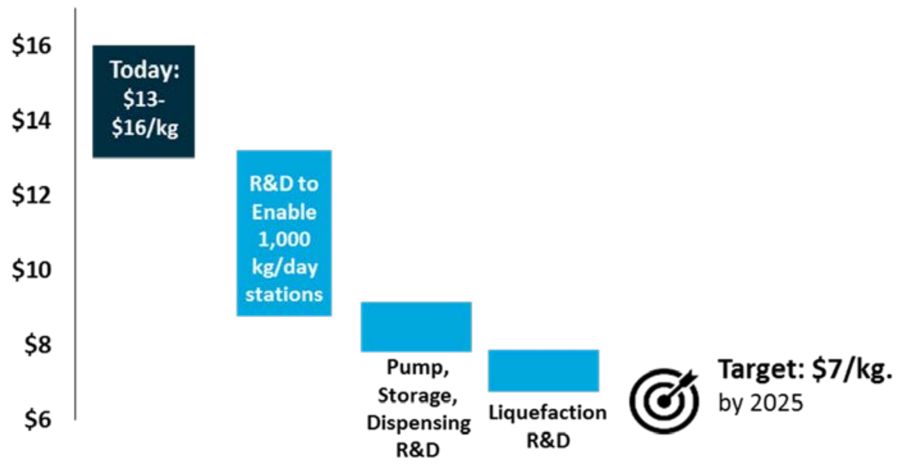
Technical targets help guide go/no-go decisions.

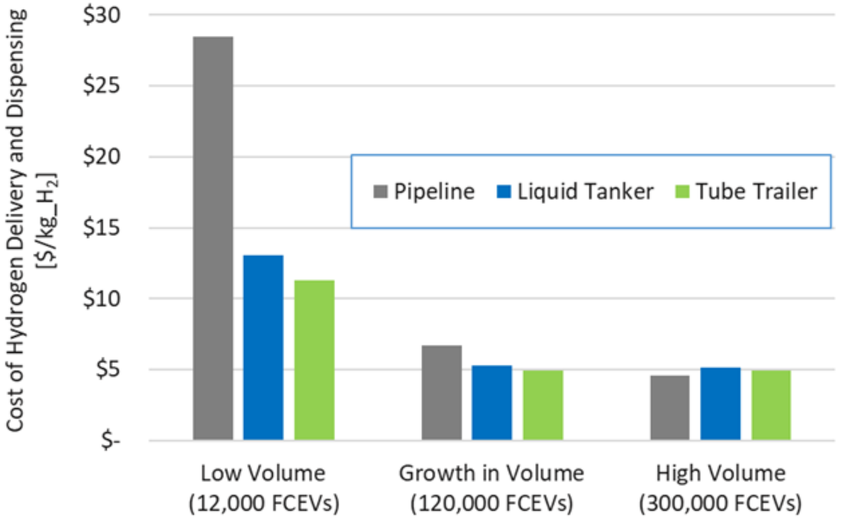


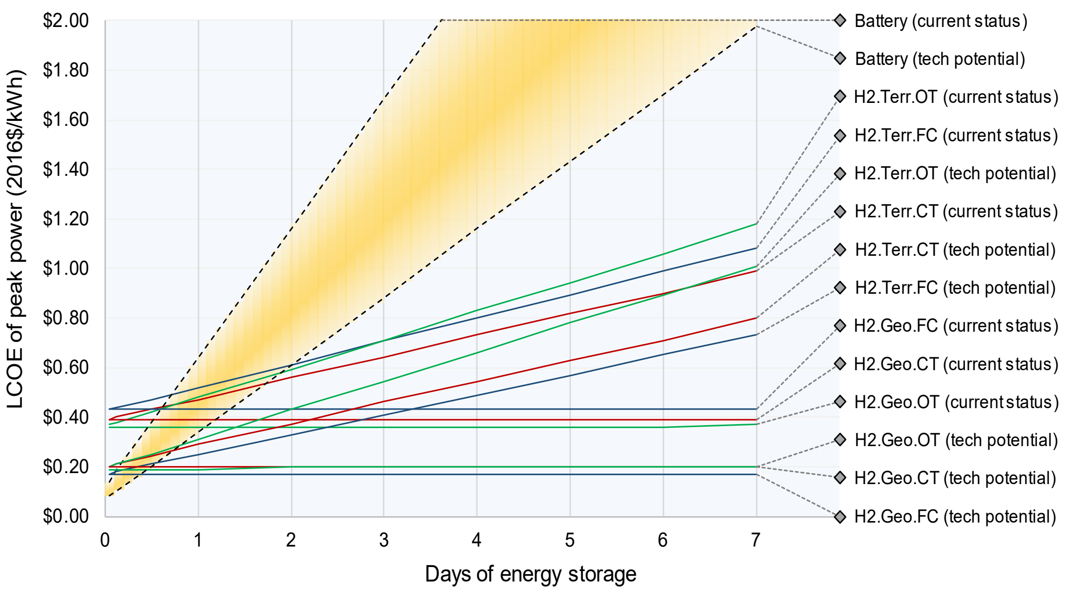
Update of Multiyear RD&D Plan and Targets in process

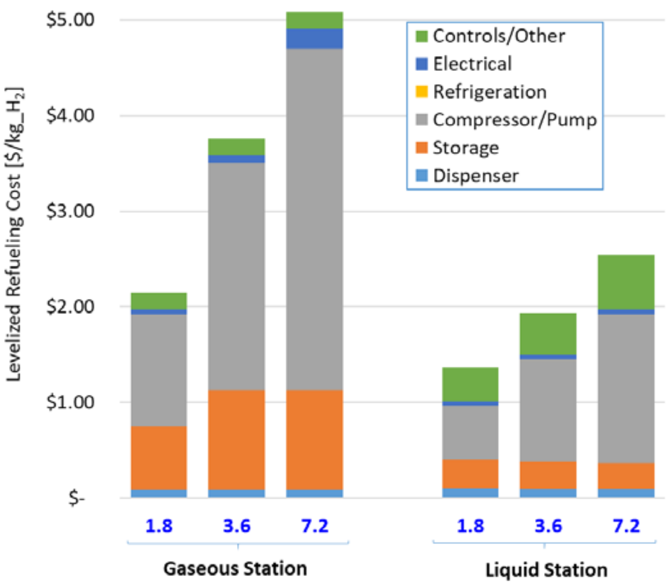
$16M saved from Active Project Management & Downselects from FY 2014 to FY 2018

Examples of Analysis Activities









Compatibility of Delivery & Storage Options

		Storage Options					
		700 Bar	Cold-compressed	Cryo-compressed	Cryo-sorbent	Near RT-sorbent	Metal Hydride
Delivery Options	Gaseous (Tube Trailer or Pipeline)	✓				✓	✓
	Liquid Trailer	✓	✓	✓	✓	✓	✓
	Cold Gas tube Trailer	✓	✓		✓	✓	✓
	H_2 Carrier	✓				✓	✓
Forecourt Implications		Pre-cooling (-40 °C)	Refrigeration (down to 150 K)	Supercritical H_2 (<< 150 K); requires high utilization to prevent boil-off	Liq H_2 or liq N_2 needed (down to 80 K) w/ recirculation	Pre-cooling; Heat rejection at forecourt	Heat rejection at forecourt

Decisions on H_2 delivery method and onboard storage technology can create limitations on the available choice for the other

Goal is to Optimize Both in Unison

Issues Arising from H_2 Infrastructure Data Collection

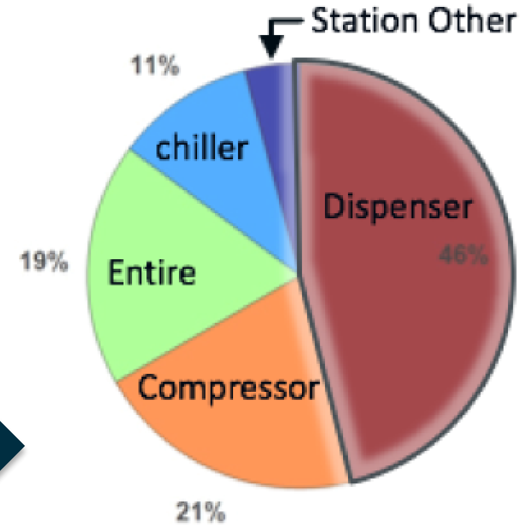
Through NREL's National Fuel Cell Technology Evaluation Center

To Participate

techval@nrel.gov

Need to address infrastructure component reliability

Example: Sources of H_2 Infrastructure Maintenance



Maintenance by Equipment Type
Retail Stations
Total Events: 4,663
Dispenser: 46% of Events

Most maintenance related to compressors and dispensers

- Visit: **energy.gov/eere/fuelcells/hydrogen-analysis-toolbox**

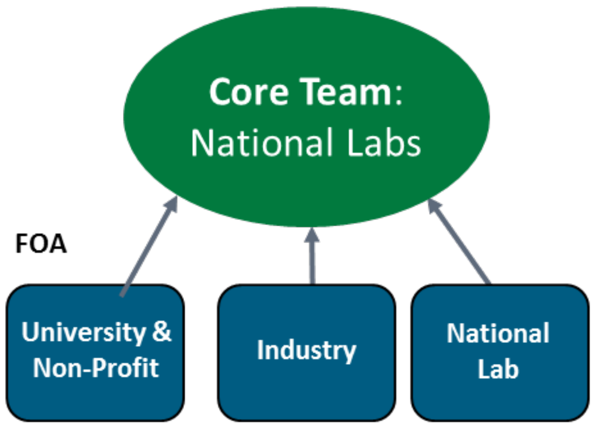
Source: U.S. DOE Fuel Cell Technologies Office

Program Strategy

Use Energy Materials Network (EMN) National Lab capabilities to accelerate innovation and address key technical challenges

Bring in new industry and university players on an ongoing basis

Consortium Approach



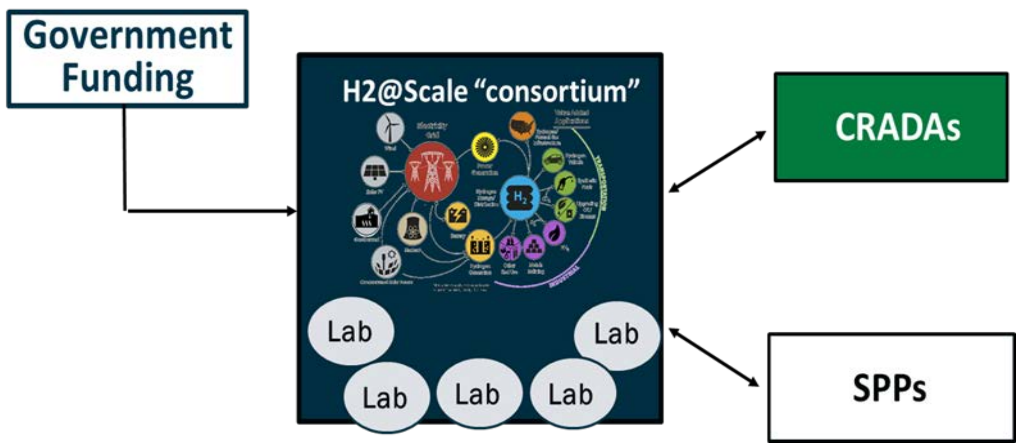
Launched and addressing R&D needs:

ElectroCat Electrocatalysis Consortium · HyMARC · HydroGEN Advanced Water Splitting Materials

Part of:

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

Leverage Private Sector for Demonstrations & Late Stage R&D



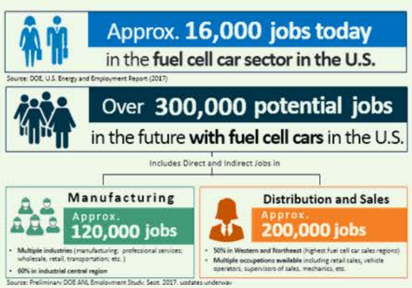
CRADA = Cooperative Research and Development Agreement
SPP- Strategic Partnership Project ('Work for Others')

Solicited Industry on Challenges and Needs

DOE held numerous workshops and issued requests on areas requiring assistance:

H2@Scale R&D Lab Capabilities– Examples

Techno economic Modeling and Analysis



Hydrogen Materials R&D

HydroGEN Advanced Water Splitting Materials

HMat Hydrogen Materials Consortium

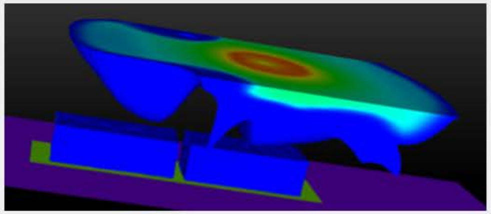
HyMARC

Grid simulation and Testing R&D

Safety and Infrastructure R&D

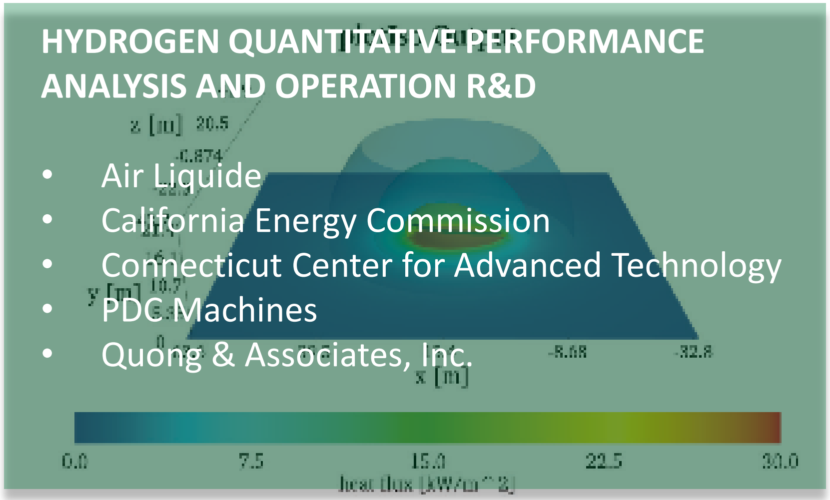
HyRAM HYDROGEN RISK ASSESSMENT MODELS

H2 Hydrogen Tools



Over 20 new CRADA projects initiated between industry and national labs

Current H_2@Scale CRADA Projects

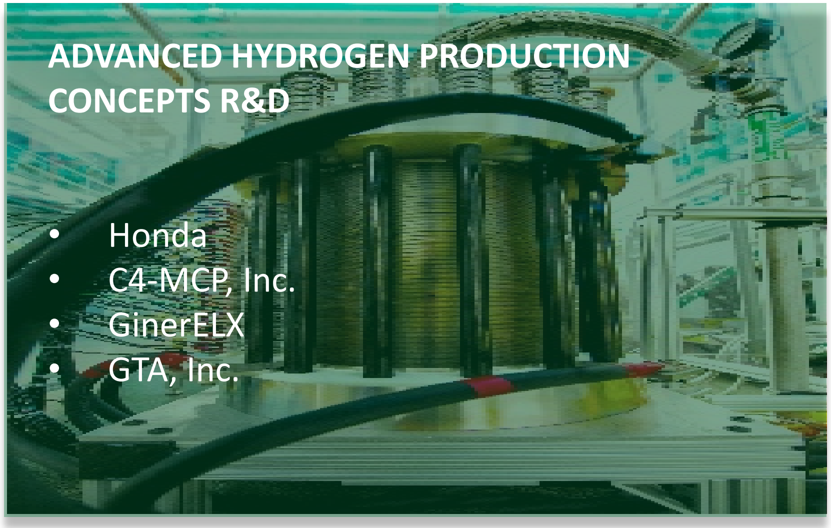


HYDROGEN QUANTITATIVE PERFORMANCE ANALYSIS AND OPERATION R&D

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

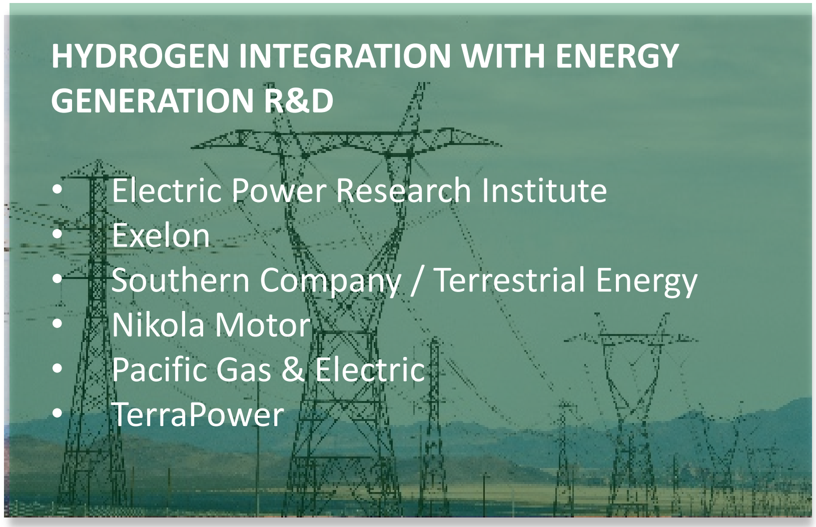
HYDROGEN DISTRIBUTION COMPONENT DEVELOPMENT R&D

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



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

Key focus areas to realize the H_2@Scale vision

MAKE

Increased Low Cost Hydrogen Production

MOVE

More Efficient Hydrogen Transmission

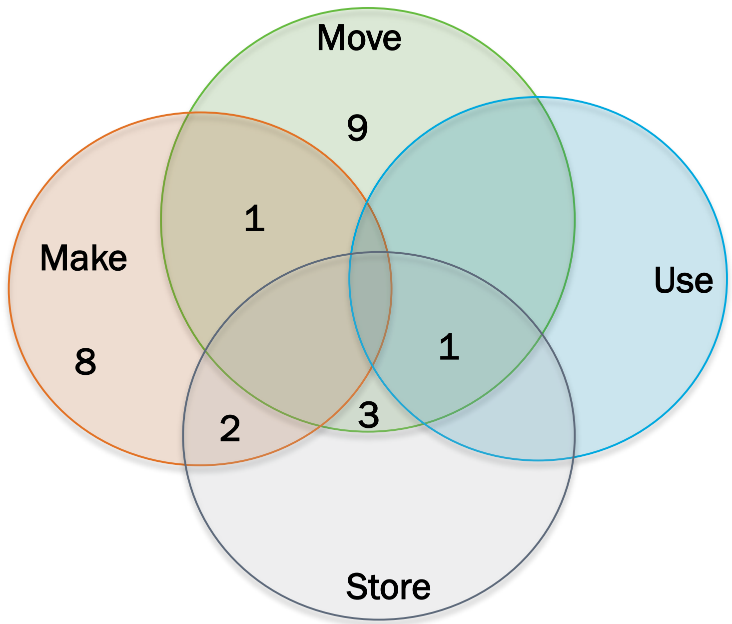
USE

Low Cost Value-added Applications

STORE

Flexible, Low-cost Bulk Storage Technologies

CRADA Project Distribution

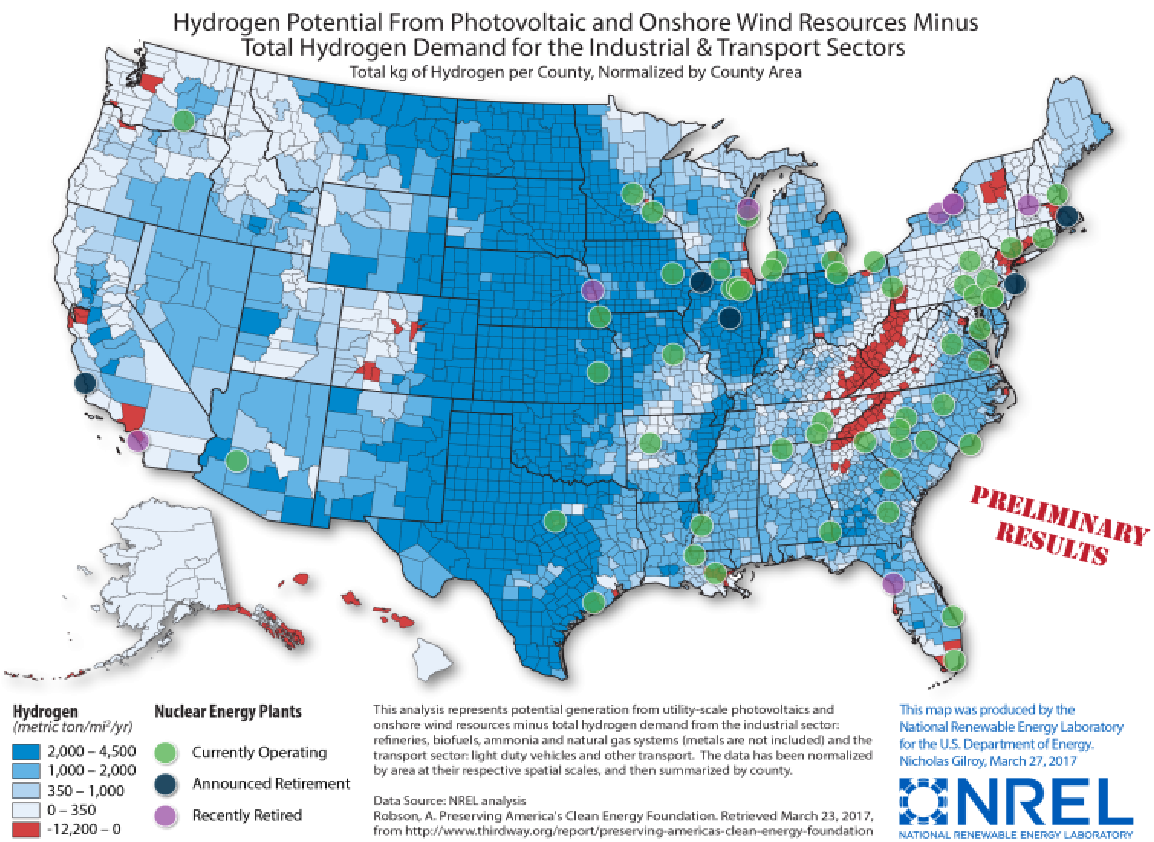


Make working group kick-off meeting December 2018

H_2@Scale: Nationwide Resource Assessment

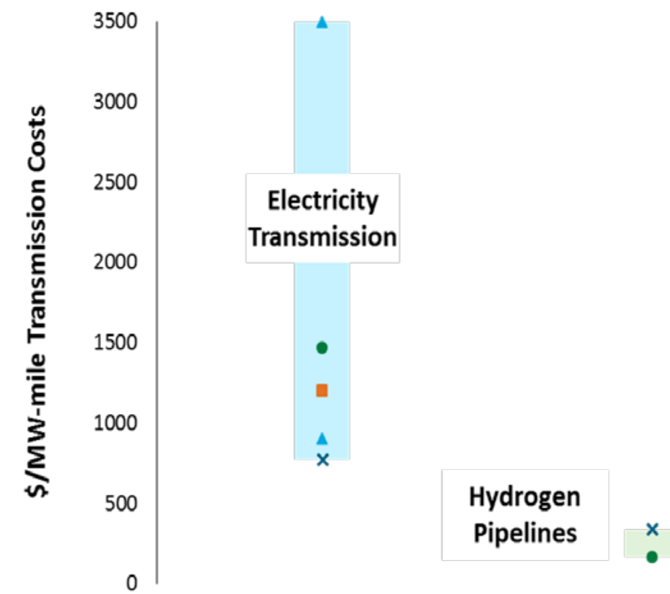
Assessing resource availability. Most regions have sufficient resources.

Red: Only regions where projected industrial & transportation demand exceeds supply.



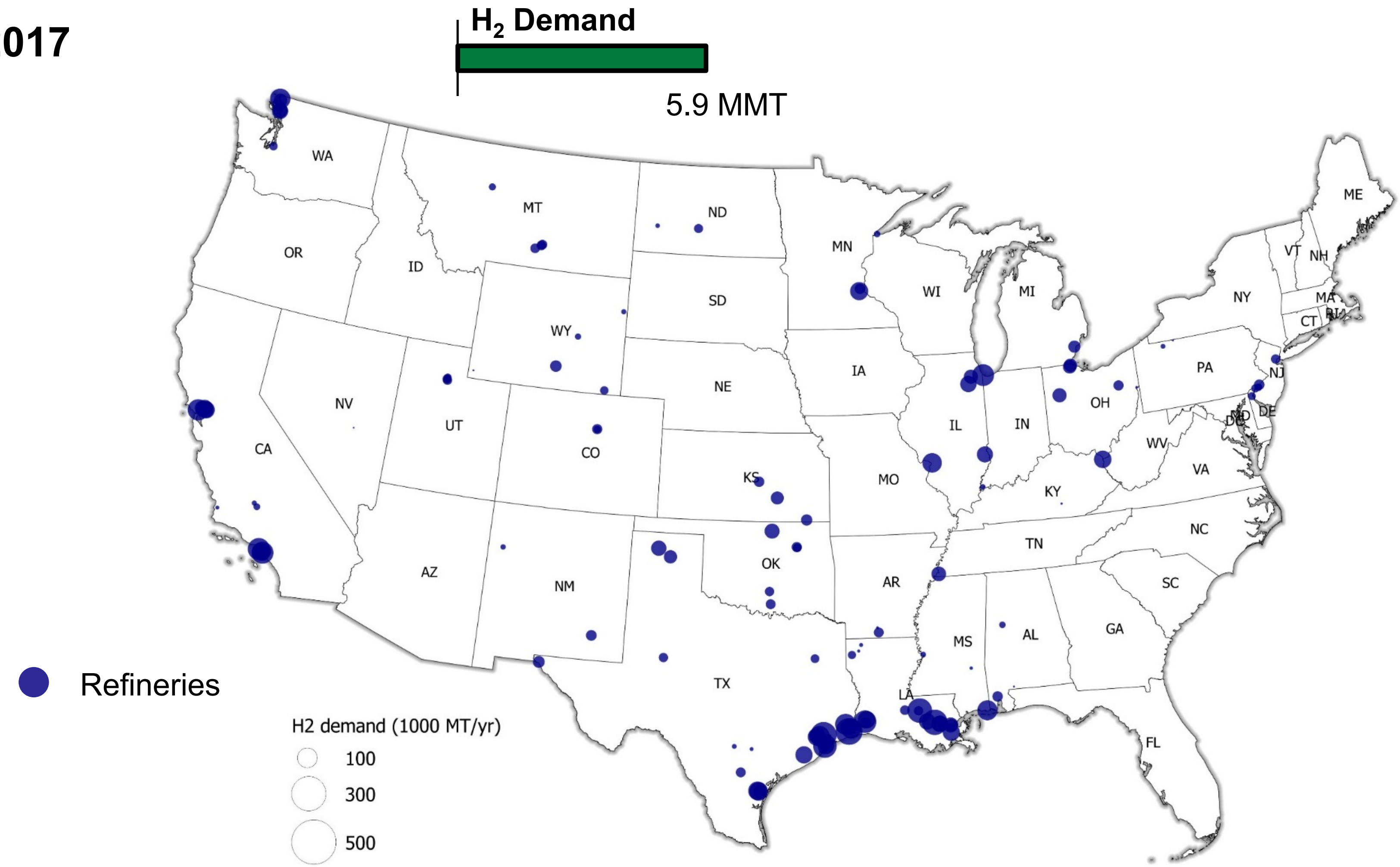
Assessing cost of H_2 vs electricity transmission

(in process)



Refineries: Where is the H_2 demand today?

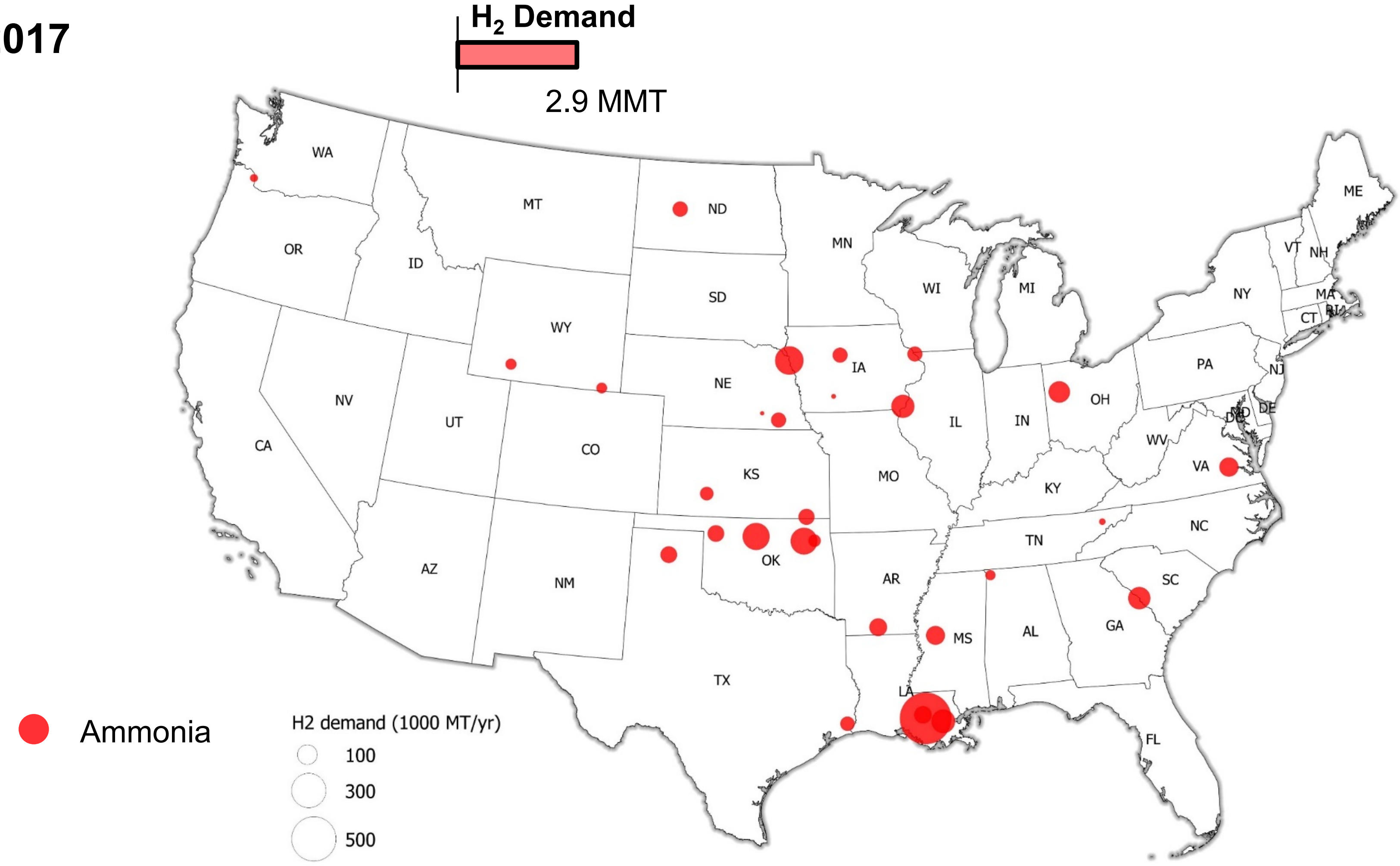
2017



Source: Elgowainy, et al, ANL

Ammonia: Where is the H_2 demand today?

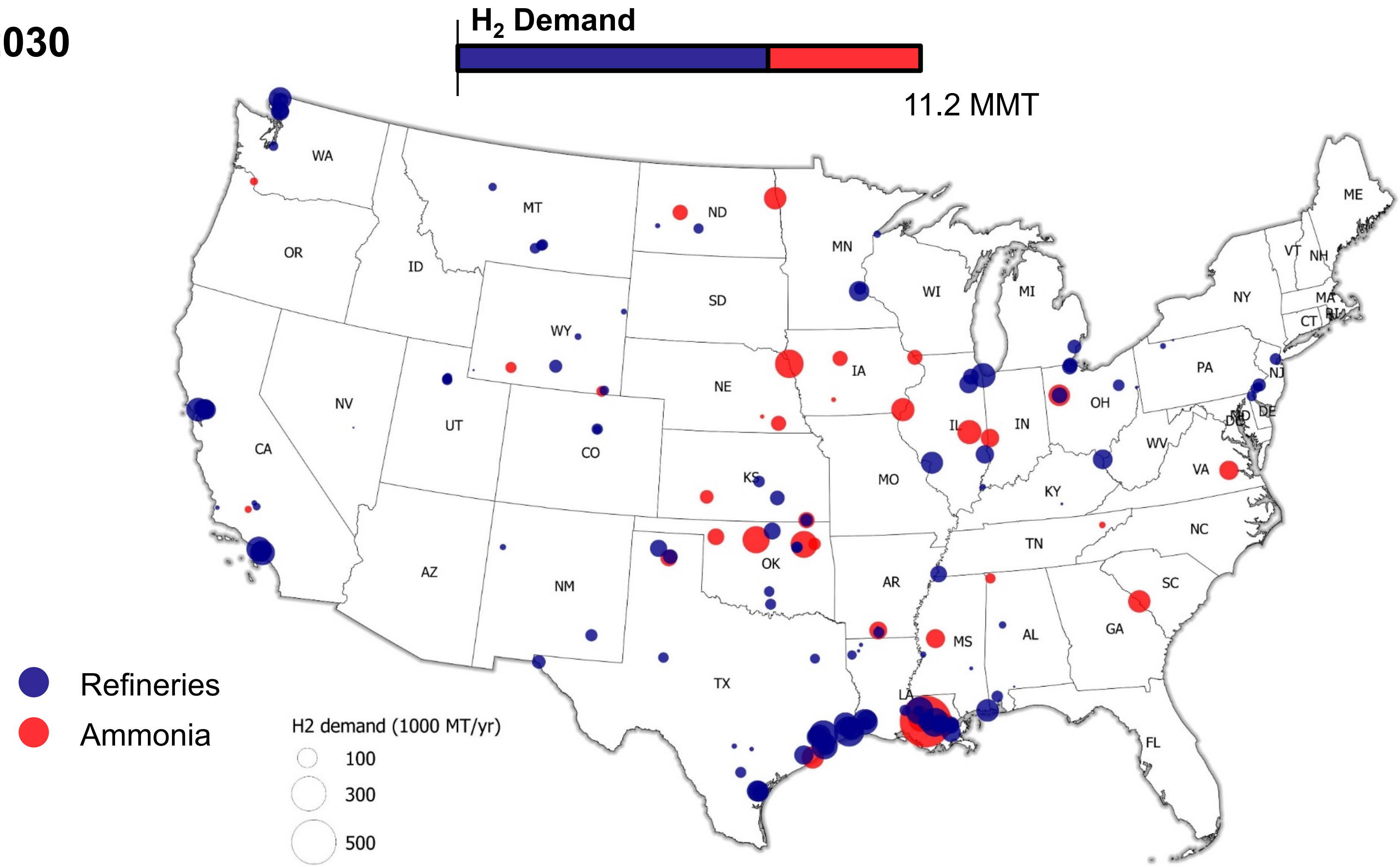
2017



Source: Elgowainy, et al, ANL

Ammonia & Refineries and Potential H_2 Demand

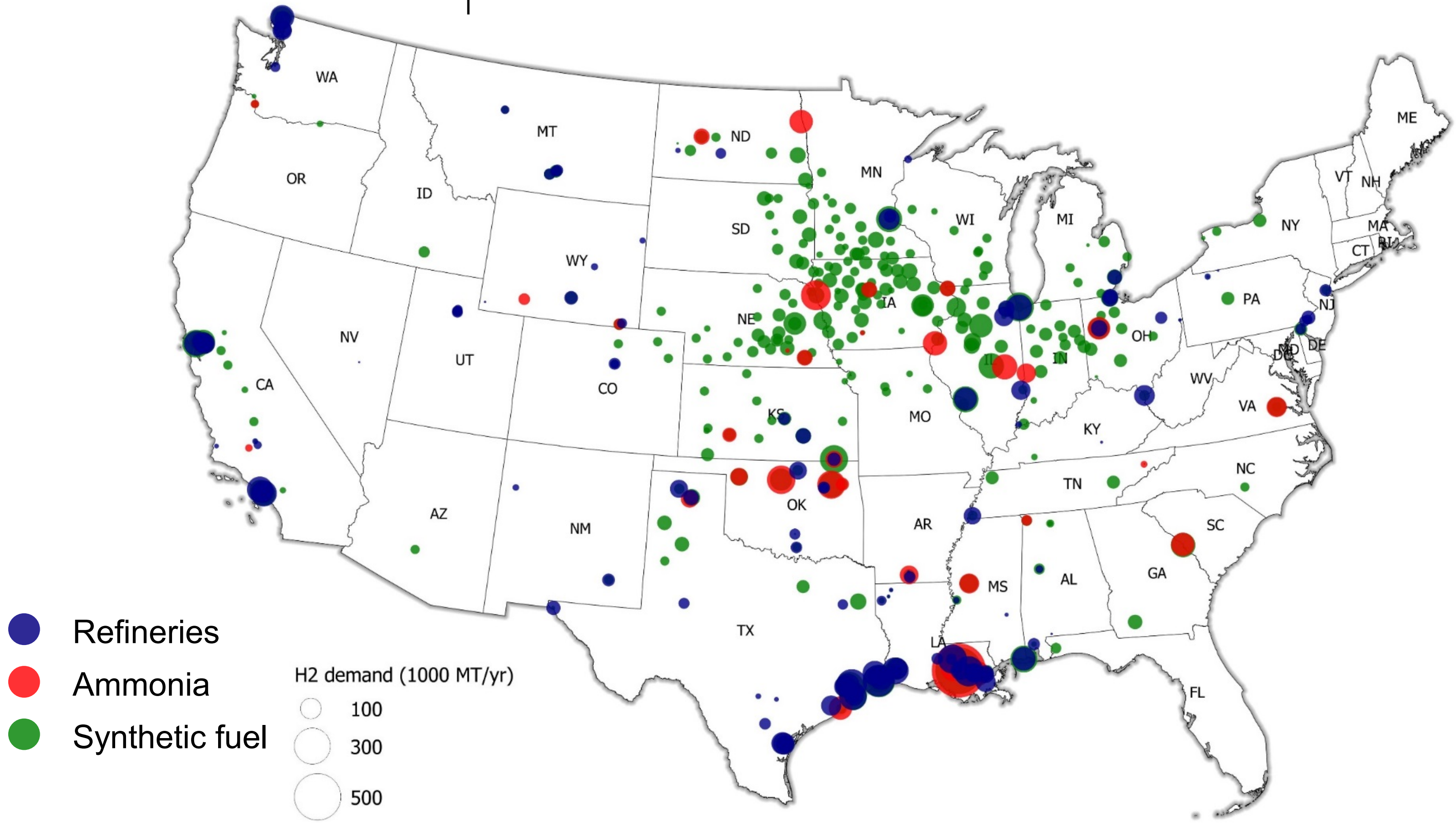
2030



Source: Elgowainy, et al, ANL

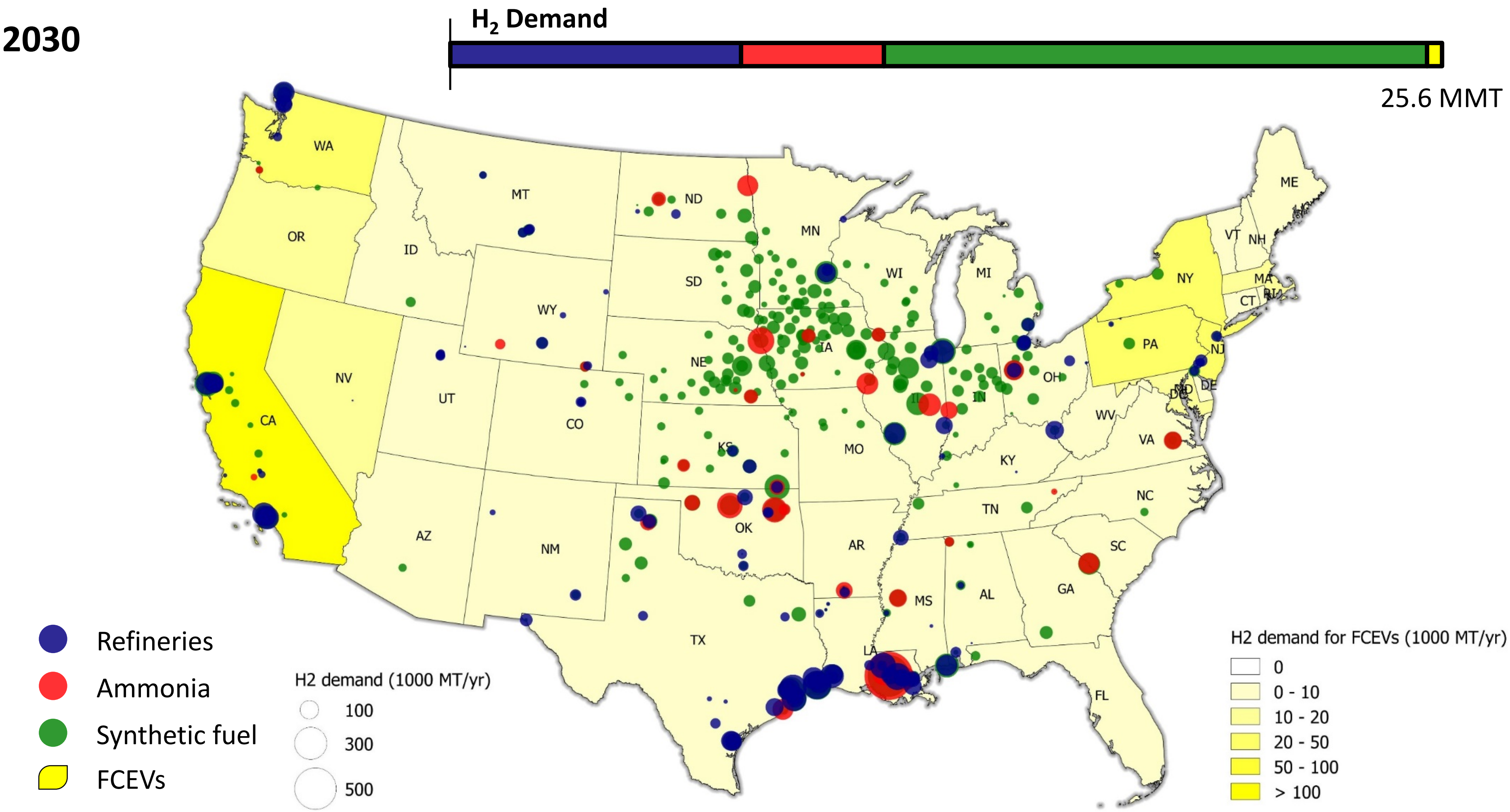
Plus demand from synthetic fuel production…

2030



Source: Elgowainy, et al, ANL

Hydrogen Demand Potential



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

Source: Elgowainy, et al, ANL

IPHE: International Partnership for Hydrogen and Fuel Cells in the Economy

- **Increase** international **collaboration to accelerate progress**
- **Working Groups:**
  - **Regulations, Codes and Standards, Safety**
  - **Education & Outreach**

U.S. elected Chair May 2018

Japan Vice Chair

EC, Germany, France, Canada support

Australia	France	Republic of Korea
Austria	Germany	Norway
Brazil	Iceland	Russian Federation
Canada	India	South Africa
China	Italy	United Kingdom
European Commission	Japan	United States

Launched 2003 and includes 18 countries and the European Commission

Coordination with IEA, Mission Innovation, and Energy Ministerials

Commitment from Ministers on H_2 and Fuel Cells

The U.S. Deputy Secretary of U.S. Dept. of Energy attended the Hydrogen Ministerial Meeting in Tokyo on Oct 23

Tokyo Statement
4 areas for collaboration

- **Harmonization of regulation**, codes and standards
- **Information sharing** on safety and infrastructure
- **Technical studies**
- **Communication, education and outreach**

Hydrogen Energy Ministerial Priorities: Summary

Action from Oct 23, 2018 Hydrogen Ministerial: Develop concrete actions that Agencies can undertake to address four priorities

Harmonization of Codes and Standards	Information Sharing, Safety, Infr. Supply Chain	Studies and Evaluations of Impact Potential	Communication and Outreach
• Coordinate with industry to enable harmonization of relevant regulations, codes and standards such as those for: • refueling stations, • heavy duty transportation, • energy storage • technologies supporting sectoral integration, • maritime • other	• Collaborate on relevant infrastructure R&D • Share safety lessons learned, best practices on hydrogen safety • Collaborate on R&D of risk assessment and mitigation to enable the safe and sustainable use of hydrogen technologies across applications.	• Collect, analyze and share data and conduct studies • Assess impact potential for sustainable production of H2 across pathways • Develop business cases and models across value chain and integrated systems analysis across scenarios	• Work together to promote appropriate outreach and awareness programs and initiatives to educate a broad range of stakeholder groups on H2 and fuel cell technologies • Develop 'train the trainer' programs, to build awareness of hydrogen solutions, especially on safety

HTAC Recommendations Being Addressed

Recently Published: Sixth Biennial Report to Congress
responding to HTAC Findings and Recommendations from FY16 – FY17

Recommendation	Actions Taken Since Last Meeting (Examples)
Ensuring positive retail hydrogen fueling experience	• **Issued RFIs on regulatory barriers to H_2 infrastructure and H2@scale**
Continue efforts in material and process integration and technology acceleration in order to meet the 2020 EPACT Title VIII goals	• **Launched H-Mat consortium to focus on materials compatibility** with hydrogen • **Funded over 20 projects** to enable H2@scale ($11M total including cost share)
Maximize the role of the Hydrogen Safety Panel (HSP)	• **Spearheaded formation of the Center for Hydrogen Safety (CHS)** to provide the hydrogen and fuel cell industries and its stakeholders with hydrogen safety guidance (Direct HTAC output).
Leverage the capabilities of public-private partnerships	• **Participated in hydrogen fuel R&D workshop with Industry and National Labs** to foster collaboration and identify R&D gaps
Identify and support other federal and state agencies	• **Signed DOD TARDEC MOU** to H_2 and fuel cell applications for military and civilian use

HTAC Impact – Examples

- **HTAC Annual Reports and Letters to DOE Secretary**
  - 2007 to 2017
- **Subcommittee Outputs**
  - Hydrogen Safety & Event Response (2017)
  - Communication & Outreach (2017)
  - Manufacturing (2014)
- **Other Examples**
  - Input on Hydrogen Safety Panel and affiliation with AIChE
  - Input on H-Prize – ***1st commercial system exported to Japan, manufactured in the US***
  - Peer review of H_2 cost target – ***published***
  - Input on R&D Plan
  - H2@Scale

Potential Areas of Input by HTAC

- **Plans and Roadmaps**
  - Program Plan (see next slide for brief update)
  - 2020 infrastructure goals in EPACT and Program Plan
- **Collaboration - Examples**
  - Tokyo Statement areas of collaboration and IPHE role
  - MOUs and concrete collaboration opportunities (e.g. TARDEC-FCTO MOU)
  - Center for Hydrogen Safety (see next slide and tomorrow's presentation at HTAC)
  - Prize concepts

Example of HTAC Impact: Expanding Safety Collaborations

Leverages new partnership to promote collaboration on H_2 safety

Pacific Northwest NATIONAL LABORATORY

AIChE

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

CENTER FOR Hydrogen SAFETY

HYDROGEN Safety Panel

HYDROGEN Emergency Response Training Resources

Modeled after Center on industrial Chemical Process Safety

200 industry members- access to 110 countries & 60,000 members

Direct result of HTAC input and recommendations:

- **Leverages private sector**
- **Expands impact of safety panel**
- **Transitions key areas to industry for sustainable business model**
- **Supports IPHE, Hydrogen Ministerial, etc.**

Hydrogen and Fuel Cell Technologies Program Plan

Completed outline. Preliminary draft underway.
Tentative complete date: End of 2018

1. Introduction

- **DOE Objectives**
- **Program Overview**
  - Mission
  - Vision
- **H2@Scale Goals**
  - Key targets
- **Program structure**
- **Program Accomplishments**
- **Program Impact**
  - Tracking Innovation
  - Tracking R&D Impact (e.g. patents)

2. Program Activities, Plans, and Milestones

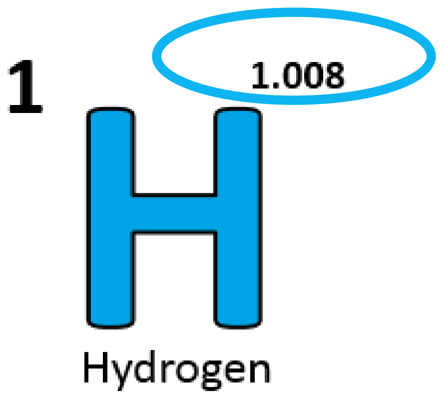
- **H2@Scale concept** (benefits of hydrogen/impacts of widespread utilization)
- **Barriers**
- **Make**
- **Move**
- **Use**
- **Store**
- **Overarching activities**

3. Program Implementation

- **Organizations and Partnerships**
- **Federal, State, and International Collaboration and Coordination**
- **Active Project Management**
- **Peer Review**
- **Stakeholder Input**

Stakeholder Engagement to support early stage R&D

Celebrate Hydrogen & Fuel Cell Day
October 8 or 10/8



Use Safety Information and Training Resources

H2tools.org

INCREASE YOUR H_2IQ

Download for free at:
energy.gov/eere/fuelcells/downloads/increase-your-h2iq-training-resource

Attend the 2019 Annual Merit Review

April 29 – May 1
Crystal City, VA
www.hydrogen.energy.gov

Includes participation from other federal agencies working on hydrogen and fuel cell technologies

Sign up to receive hydrogen and fuel cell updates

www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-newsletter

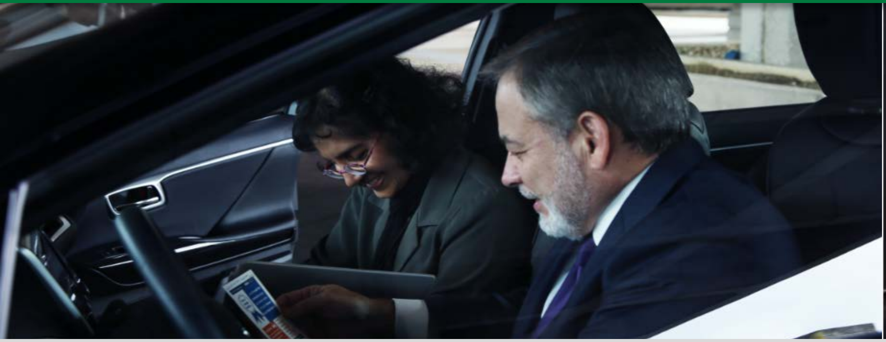
Learn more at: energy.gov/eere/fuelcells

Examples of Recent DOE Engagement

Driving a fuel cell car blog by Under Secretary of Energy Menezes

Sent to 20,000 people in distribution list

Reached 3,000 people through various outreach events



Reached over 30 different DOE offices

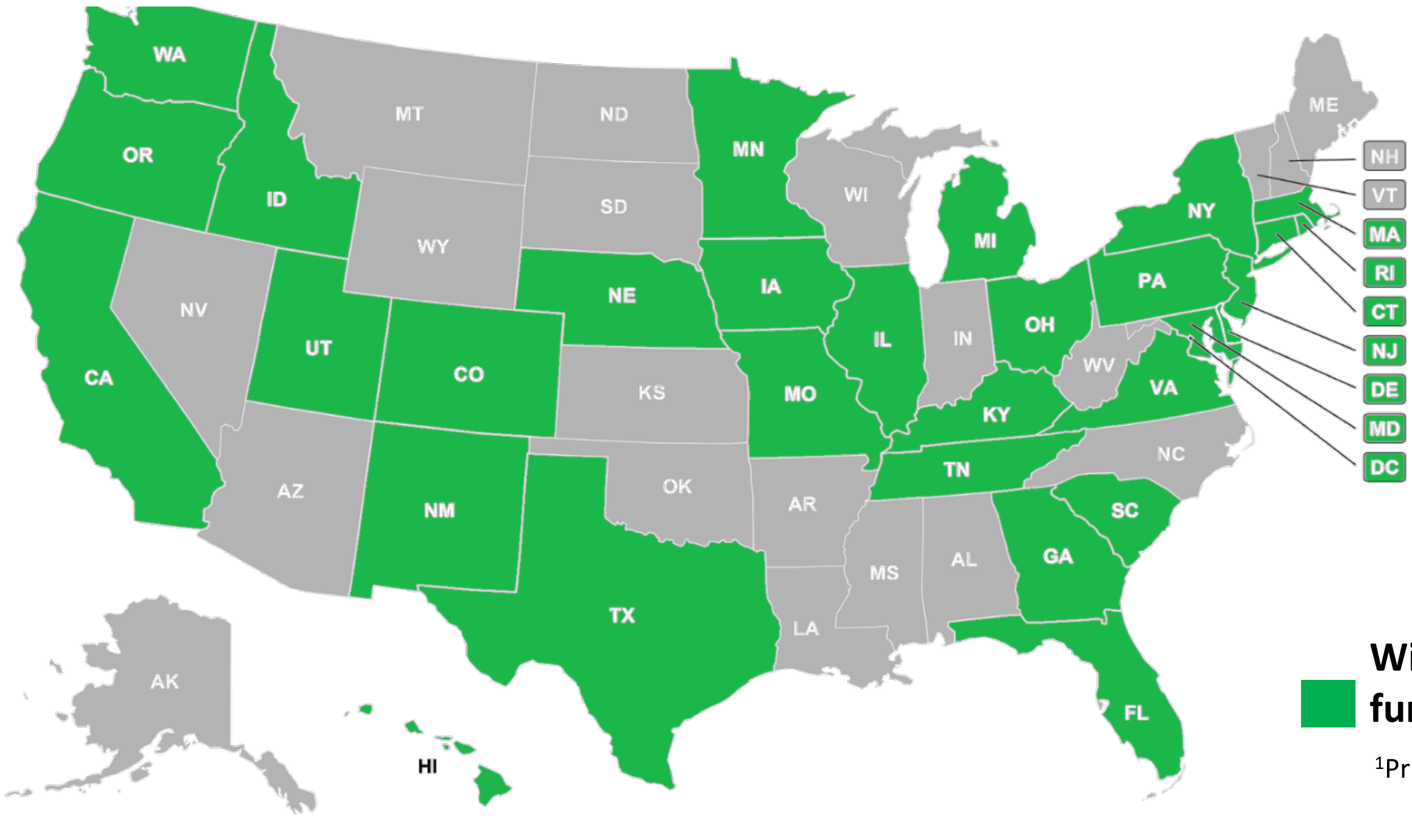
Thank You
&
Additional Information

Dr. Sunita Satyapal
Director
Fuel Cell Technologies Office
Sunita.Satyapal@ee.doe.gov

energy.gov/eere/fuelcells

DOE activities cover many states across the U.S.

EERE Fuel Cell Technologies Office Funding[1]
FY 2013 – FY 2017



With FCTO funding

[1]Prime recipients only

From 2013 to 2017		Covering H_2 and Fuel Cell Activities in
$429M	→	**30 states and DC**

FY 2019 Congressional Language

House	Senate	Conference
[No direction.]	The Committee recommends **$19,000,000** for Technology Acceleration activities, including **$3,000,000** for manufacturing R&D, and **$7,000,000** for industry-led efforts to demonstrate a hydrogen-focused integrated renewable energy production, storage, and transportation fuel distribution/retailing system. Regular consultation with industry is encouraged to avoid duplication of private-sector activities. The Committee encourages the Secretary to work with the Secretary of Transportation and industry on coordinating efforts to deploy hydrogen fueling infrastructure.	Within available funds, the agreement provides **$21,000,000** 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. *[Senate language stands.]*

FY 2019 Congressional Language

House	Senate	Conference
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** is to enable integrated energy systems using **high and low temperature electrolyzers** with the intent of **advancing the H2@Scale concept.**	**$39,000,000 for Hydrogen Fuel R&D** for efforts to reduce the cost and improve the performance of hydrogen generation and storage systems, hydrogen measurement devices for fueling stations, hydrogen compressor components, and hydrogen station dispensing components. The Department shall continue to **research novel onboard hydrogen tank systems, as well as trailer delivery systems to reduce cost of delivered hydrogen**. … directed to support R&D activities **that reduce the use of platinum group metals,** provide improvements in electrodes and membranes and balance-of-plant components and systems. …. **is directed to continue the H2@Scale Initiative**, which couples current research efforts within the program with new opportunities for using hydrogen to provide grid resiliency and advance a wide range of industrial processes for the production of fuels, chemicals, and materials.	**$39,000,000 for Hydrogen Fuel Research and Development** [Senate language stands.] Within available funds, the agreement provides **$4,000,000** for the EERE share of the integrated 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.

FY 2019 Congressional Language

House	Senate	Conference
The Committee recognizes the need to support the development of alternative fueling infrastructure for U.S. consumers. Accordingly, the Department is encouraged to collaborate with the National Institute of Standards and Technology to allow accurate measurement of hydrogen at fueling stations.	The Committee further recommends $7,000,000 for Safety, Codes, and Standards to maintain a robust program and engage regulatory and code officials to support their technical needs relative to infrastructure and vehicle safety.	**$7,000,000** for Safety, Codes, and Standards. *[House language stands. "Encouraged" is not considered congressional direction.]*
The Department is encouraged to work with the Department of Transportation on coordinating supporting hydrogen fueling infrastructure.	Within the amounts recommended, **$19,000,000** is recommended for Hydrogen Infrastructure R&D.	[Senate & House language stands. In both cases, 'encouraged' and 'recommended' are not considered congressional direction]

FY 2019 Congressional Language

House	Senate	Conference
The Committee recognizes the progress of the program and continues support for stationary, vehicle, motive, and portable power applications of this technology.	*[No direction.]*	*[House language stands. "Recognizes" is not considered congressional direction.]*
[No direction.]	The Committee recommends **$1,000,000** for Systems Analysis, including research on in-situ metrology for process control systems for manufacturing of key hydrogen system components.	*[Senate language stands. "recommends" is not considered congressional direction.]*

Example of HTAC "Dashboard" Recommendation

Technology Areas		EPACT 2005, Title VIII – HTAC Review Responsibilities						
		DOE Hydrogen & Fuel Cell Programs	Technology Consequences			Energy Secretary Coordinated Plan[i] for Hydrogen & Fuel Cells – Potential to Achieve Section 805 Program Goals		
			Safety	Economics	Environment	Vehicles[ii]	Hydrogen Energy and Energy Infrastructure[iii]	Fuel Cells[iv]
Hydrogen								
Production	Fossil Fuels, Hydrogen Carrier Fuels Renewables, Nuclear							
Delivery	Transmission by Pipelines, Surface Transport; Fueling (Central Refueling Stations, Distributed Onsite)							
Uses	Commercial, Industrial & Residential Power Generation							
Advanced Vehicle Technologies	Engine & Emission Control Systems, Energy Storage, Electric Propulsion, Hybrid Systems, Automotive Materials, Other							
Storage	Hydrogen & Hydrogen Carrier Fuels, Development of Materials for Storage in Gas, Liquid or Solid Form at Refueling Facilities and On-Board Vehicles							
Fuel Cells								
Power Systems	Safe, Durable, Affordable, Efficient, Fuel Flexible							
Hybrid Technologies	U.S. Produced, Commercially Available, Competitive							
Manufacturing	High Temperature Membranes, Cost Effective Stack & System Reliability,							

Program Impact on Hydrogen Delivery R&D - Example

"The DOE's contribution and support of the EERE and FCTO's testing and development of ASME B31.12 code gives operators and engineers the basis for employing FRP in spools, or in our case, site manufactured FRP in very long lengths. We appreciate all the hard work and dedication from the DOE team that has brought this project to such a successful conclusion."

- Gary Littlestar, CEO of Smart-Pipe Technologies

Continued Applied R&D Needs

- **New materials for H_2 service**
- **Non-mechanical FRP joints**
- **Weld performance for higher strength (X100) pipeline steel in H_2**
- **Advanced liquid transport technologies**

Pipeline Delivery

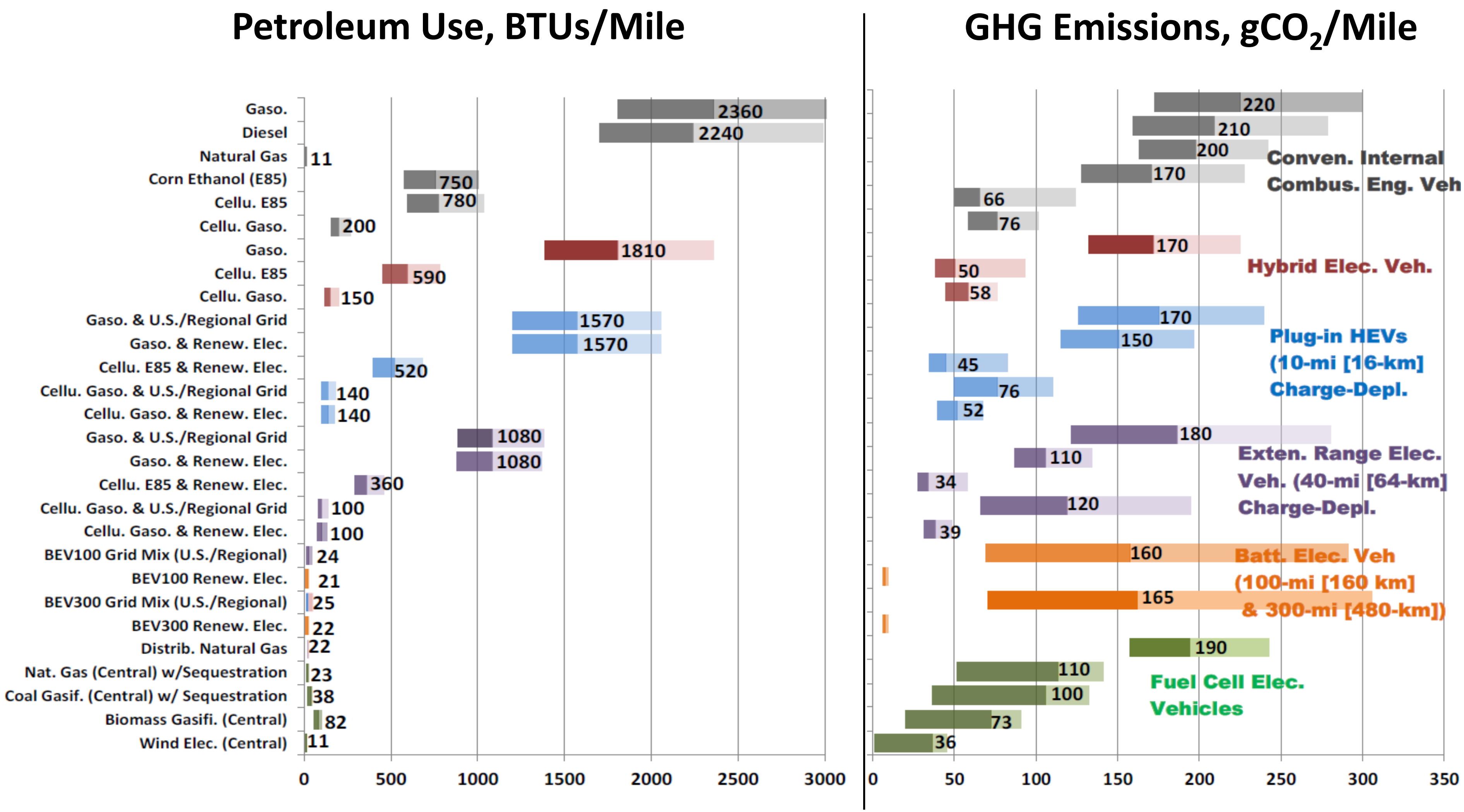
Vehicular Transport

Inclusion of FRP in ASME B31.12 Hydrogen Piping and Pipelines code, lowering cost of high-pressure transmission pipelines by ~25%. (SRNL)

Reduction of material performance factors for X70 steel in ASME B31.12 code, lowering cost of hydrogen pipelines construction by up to 30%. (SNL)

Reduction of cost of hydrogen tube trailers by > 20% from 2011 baseline, while increasing capacity by > 40%. (Hexagon Lincoln)

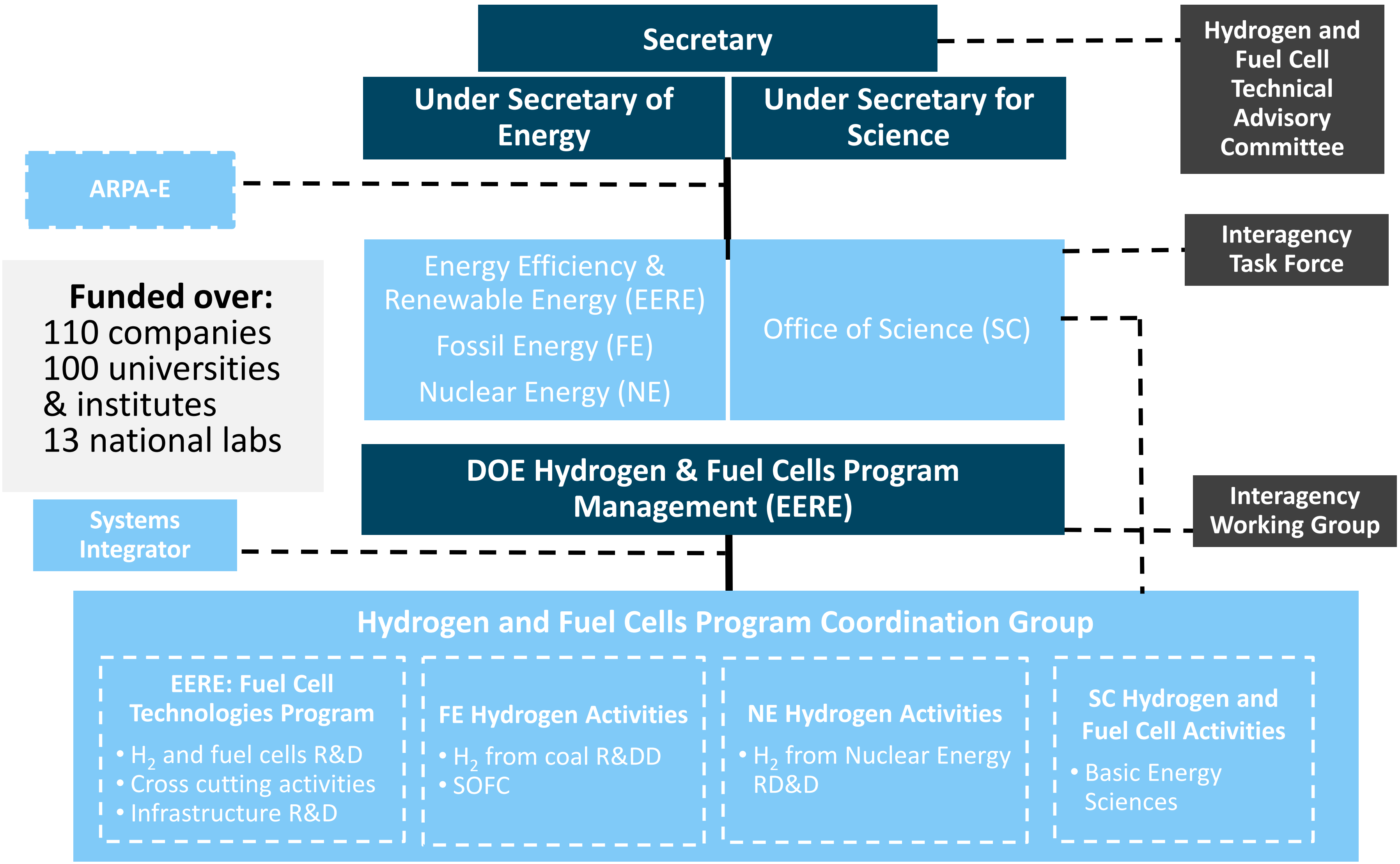
Well-to-Wheels Analysis:
Petroleum Use and Emissions



Program Record #13005: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

Cross-Office Updates

The H_2 and Fuel Cells Program spans other DOE offices



DOE-BES Overview

- FY 2018 Hydrogen and Fuel Cell crosscut spending level was approximately $19M
- Current solicitations are our "open" core FOA, Computational Materials Science and EPSCoR (https://science.energy.gov/bes/funding-opportunities/)
- BES coordinates with other DOE Offices through the internal working group, and with other Government Agencies through participation in the Interagency Working Group
- 2017 Basic Research Needs workshop on Catalysis Science report is available online. No upcoming workshops directly related to hydrogen or fuel cells.

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

Mission

Develop new disruptive technologies for efficient, cost-effective electrical storage and generation systems using renewable energy and natural gas with applications for transportation, commercial and industrial power customers across the economy, resulting in increased energy efficiency and security, significant fuel and energy savings, and emissions reduction

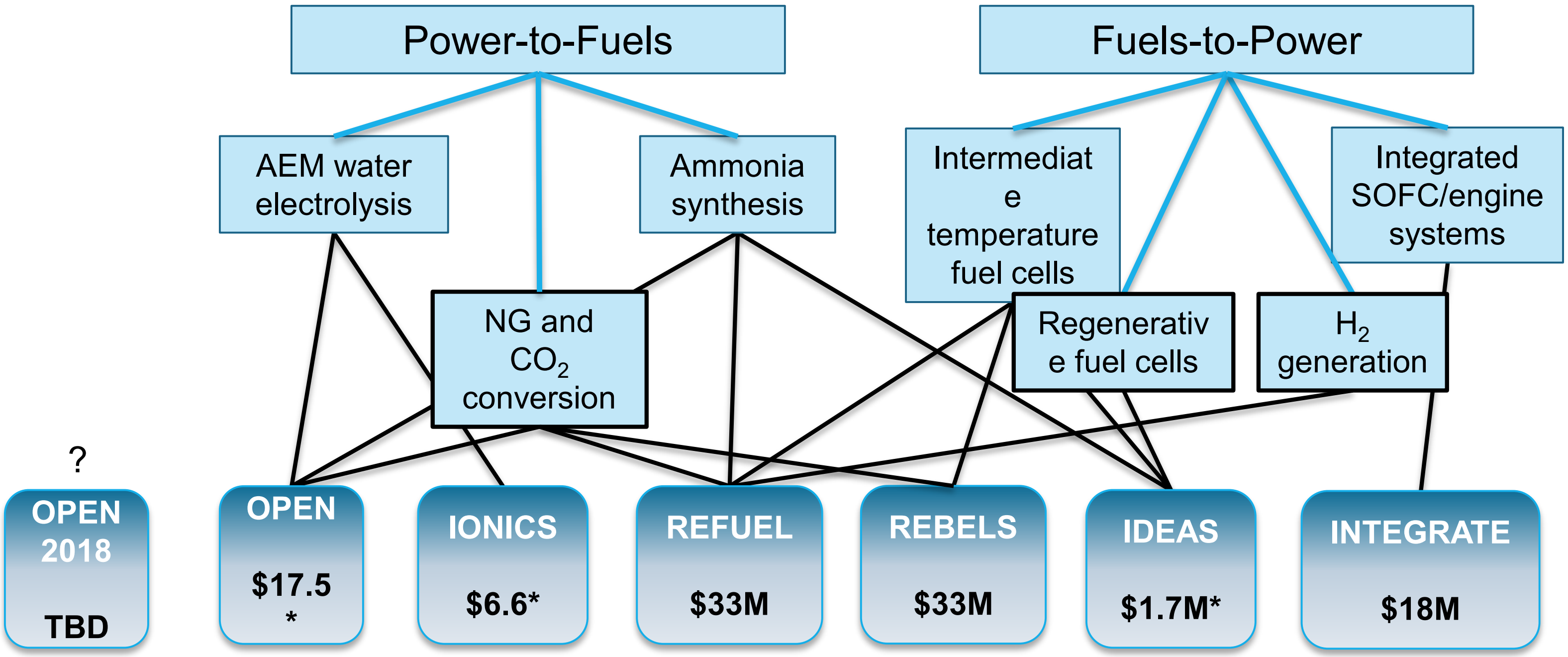
Drivers

- Growth of intermittent renewable energy, cheap and abundant natural gas
- Need for increased efficiency throughout the whole economy
- Increased demand for clean/electrified transportation
- Growth of microgrids and distributed energy generation

Coordination and cooperation with other DOE offices (FCTO, FE)

- Program development (workshops, common technical targets)
- Project evaluation (proposal reviewing, annual program reviews)
- Constant coordination via Fuel Cell and Hydrogen working group

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

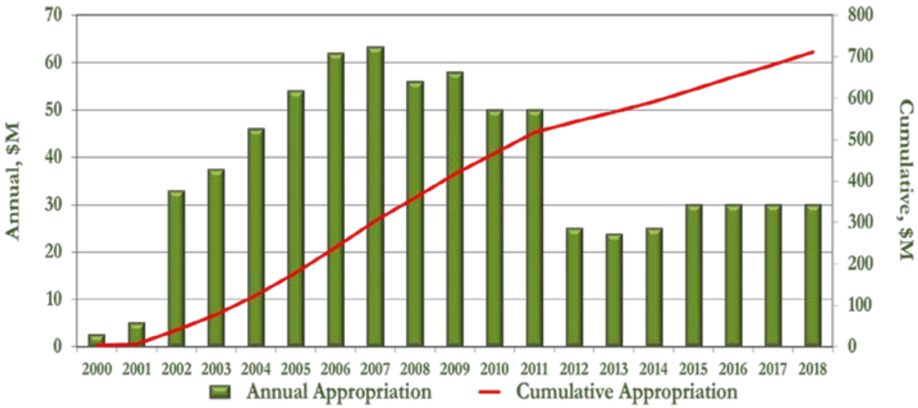


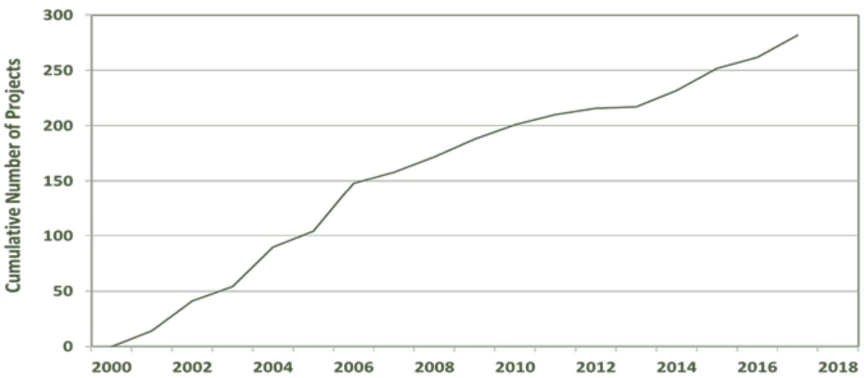
* - related to FC/electrolyzers/H_2

CHANGING WHAT'S POSSIBLE

SOFC Program
Funding History

- FY19 Appropriation: $30M
- Cumulative Funding (FY00 – FY18)
  - DOE ~$712M
  - Participant Cost Share ~$265M



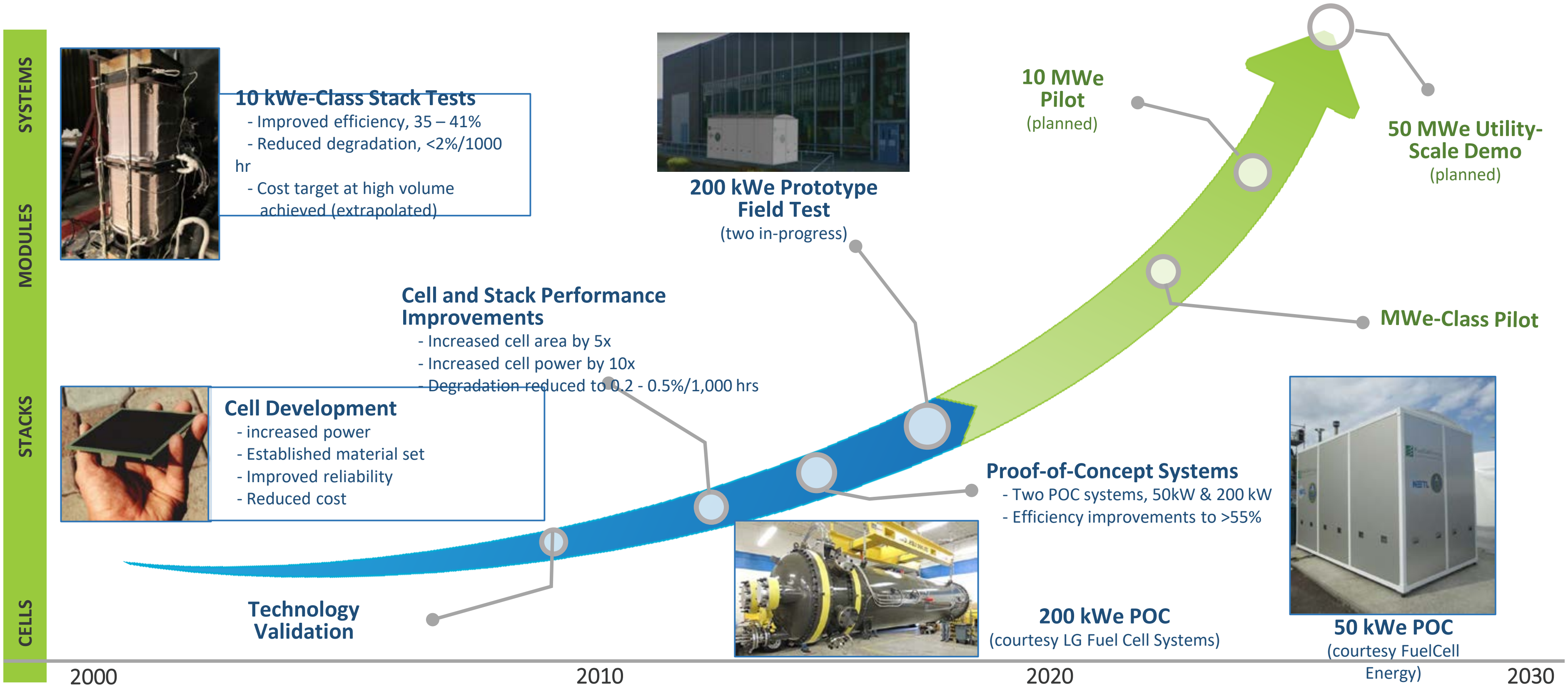


- Total Number of Awards >290
- Total Number of Participants 116
  - Industry 66
  - Academia 40
  - National Labs/Agencies 10

U.S. DEPARTMENT OF ENERGY

SOFC Program

How the technology has evolved



Cross-Office Activities Update

- Solar Fuels Research Initiative Strategic Plan
  - Addressed in FY 2019 congressional language

  *"The Committee directs the Department of Energy to submit a solar fuels research initiative strategic plan within 120 days after enactment of this act. The 10-year plan shall include **research challenges and opportunities, program goals and milestones to overcome scientific and technological impediments**, a description of **coordination between the Office of Science, EERE, and ARPA-E to leverage basic research and early-stage translational research in solar fuels** to accelerate the pace of innovation, an assessment of U.S. leadership in solar fuels research relative to international competition and the extent to which the Department's investments are sufficient to maintain U.S. leadership."*

  - **Basic Energy Sciences leading**
  - **Solar, ARPA-E and Fuel Cell Tech Offices contributing**