U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# U.S. Department of Energy Hydrogen and Fuel Cell Perspectives


## Dr. Sunita Satyapal, Director, Fuel Cell Technologies Office


Fuel Cell Seminar

Long Beach, CA – November 06, 2019

# Guiding Legislation: Energy Policy Act (2005) Title VIII on Hydrogen

**Authorizes U.S. DOE to lead a comprehensive program to enable commercialization of hydrogen and fuel cells with industry.**

**Includes broad applications: Transportation, utility, industrial, portable, stationary, etc.**

## Program to date

**$100M to $250M per year**

**100 to 200+ projects per year**

**>100 organizations & extensive collaborations**

**Includes RD&D on:**

**$H_2$ production, delivery, storage, utilization (including fuel cells)**

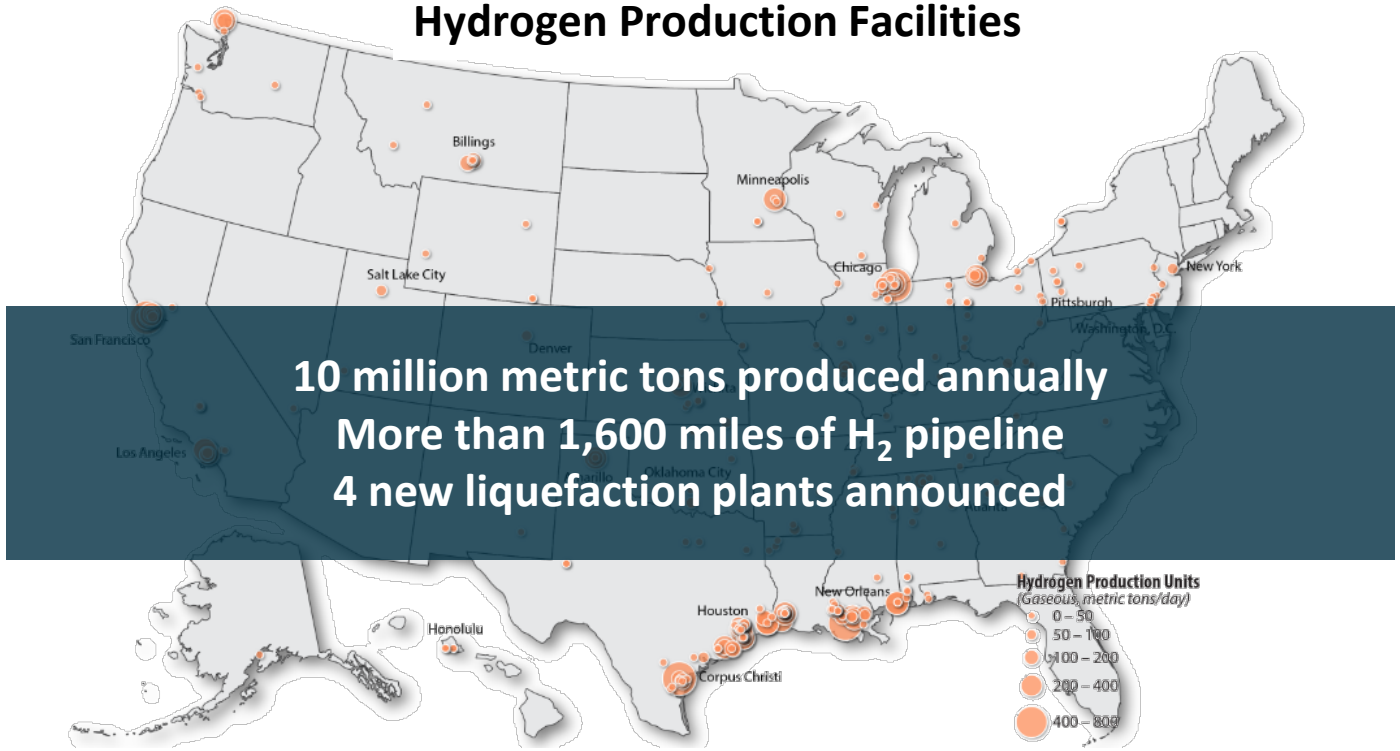
**Crosscutting: Analysis, systems development/integration, safety, codes and standards, education & outreach**

# U.S. Snapshot of Hydrogen and Fuel Cells Applications

## Examples of Applications in the United States

- **>500MW** Stationary Power
- **>30,000** Forklifts
- **>30** Fuel Cell Buses
- **>40** $H_2$ Retail Stations
- **>7,800** Fuel Cell Cars

## Hydrogen Production Facilities




**10 million metric tons produced annually**
**More than 1,600 miles of $H_2$ pipeline**
**4 new liquefaction plants announced**

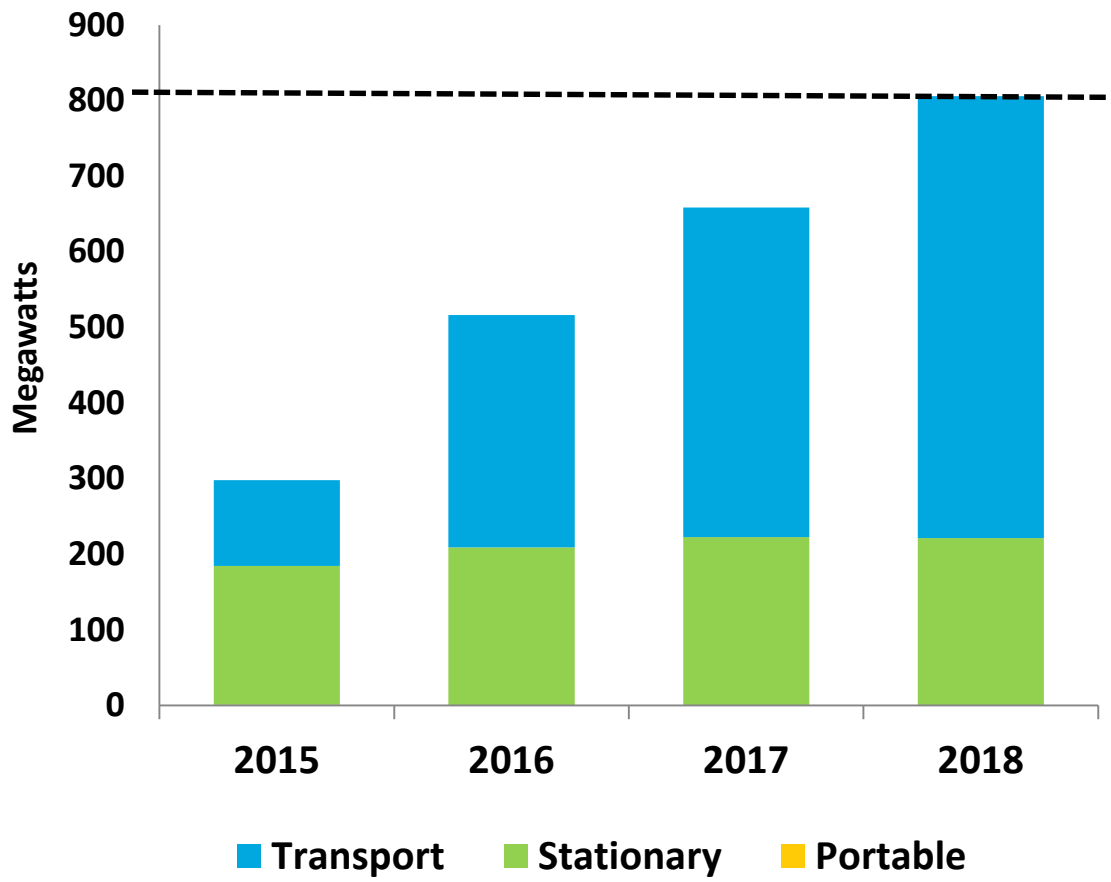
## Hydrogen Stations: Examples of Plans Across States

**California**
CaFCP roadmap: 1,000 stations by 2030

**Northeast**
12 – 20 stations planned

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

# Fuel Cell Market Growth Snapshot




**800 MW**
**fuel cell power**
shipped worldwide

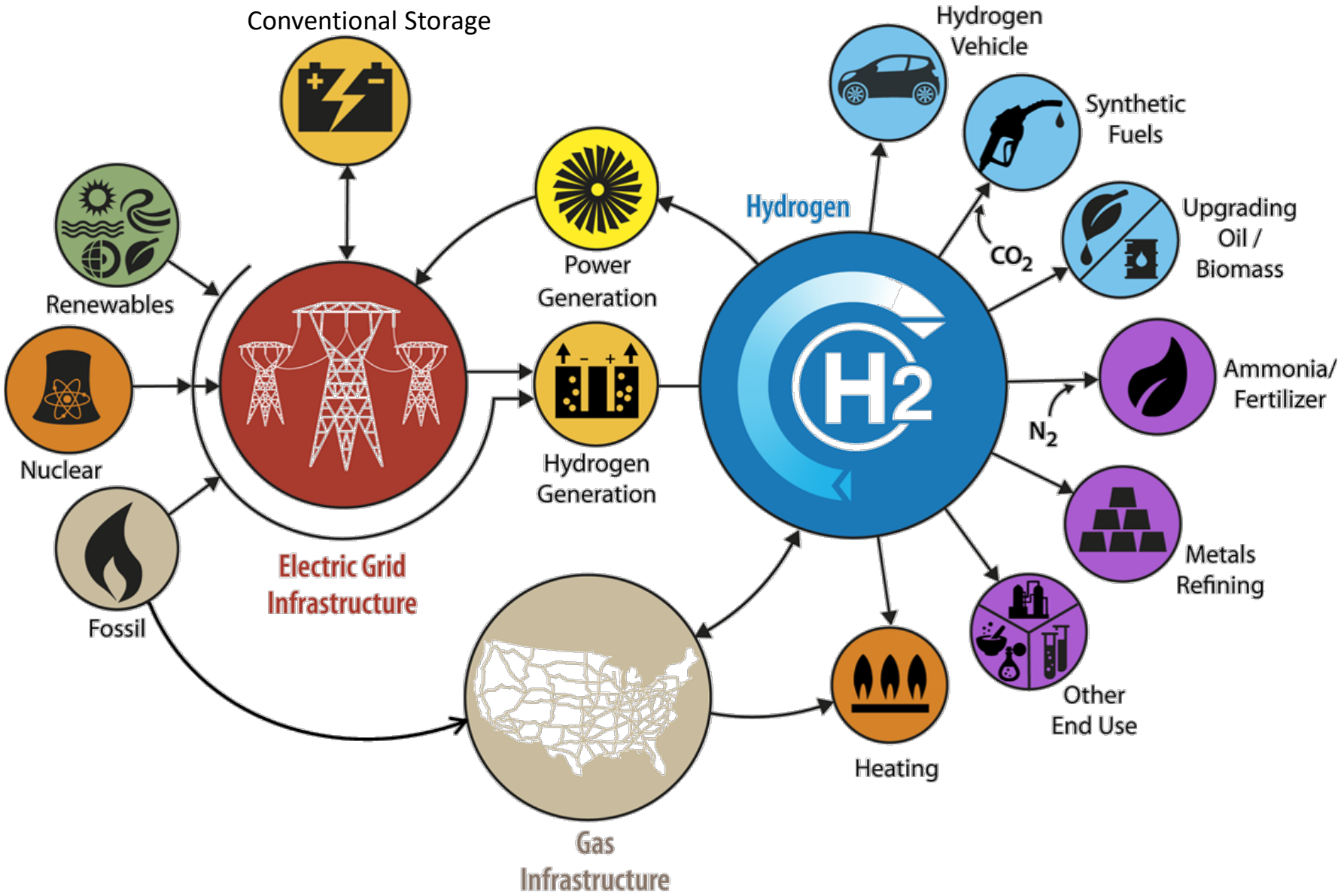
**68,500**
**fuel cell units**
shipped worldwide

Approximately
**$2.3 Billion**
**fuel cell revenue***

* Revenue from publicly available information

Source: DOE and E4Tech

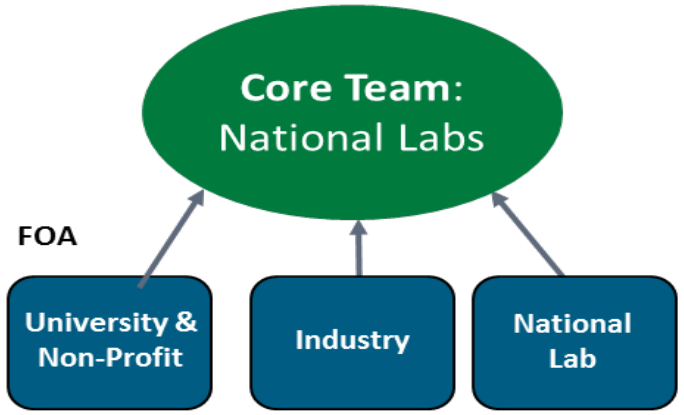
# Current Focus $H_2$@Scale: Enabling affordable, reliable, clean, and secure energy across sectors



# Consortia and National Lab Engagement Complements FOA Projects

## Early stage R&D:

National labs accelerate innovation and bring in new industry, university partners

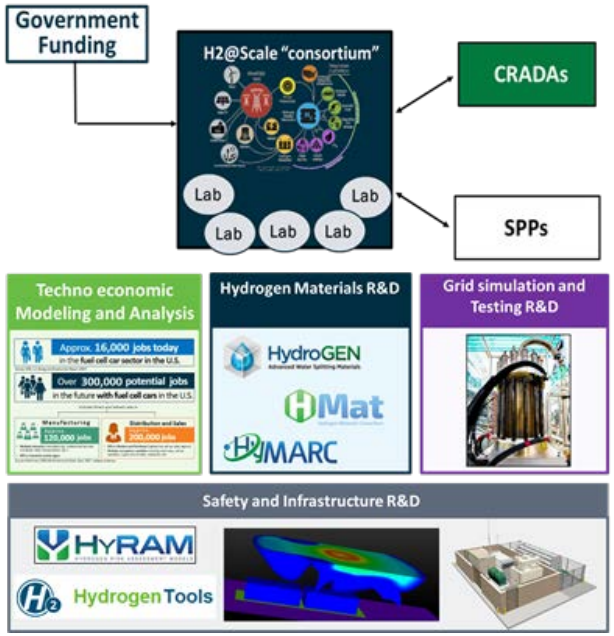



**Launched and addressing R&D needs:**

ElectroCat Electrocatalysis Consortium · HyMARC · HydroGEN Advanced Water Splitting Materials

**Part of:**

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




## Later stage RD&D:

Leverage private sector for large-scale demos

~25 Cooperative Research and Development Agreements (CRADAs) between industry and national labs

| Key Activity | FY 2018 ($ in thousands) | FY2019 ($ in thousands) |
|---|---|---|
| Fuel Cell R&D | 32,000 | 30,000 |
| Hydrogen Fuel R&D | 54,000 | 39,000 |
| Hydrogen Infrastructure R&D | - | 21,000 |
| Systems Analysis | 3,000 | 2,000 |
| Safety, Codes and Standards | 7,000 | 7,000 |
| Technology Acceleration | 19,000 | 21,000 |
| **Total** | **115,000** | **120,000** |

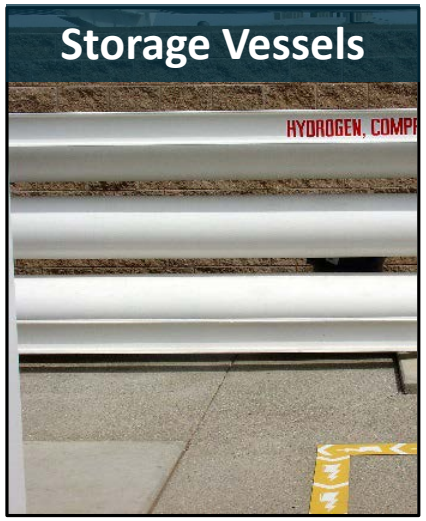
**FY 2020- House Mark: $144M**
**Senate Mark: $160M**

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

# R&D Consortium on Materials Compatibility

H-Mat SM Hydrogen Materials Compatibility Consortium

## H-Mat R&D addresses challenges with hydrogen-materials issues (polymers, metals, etc.)



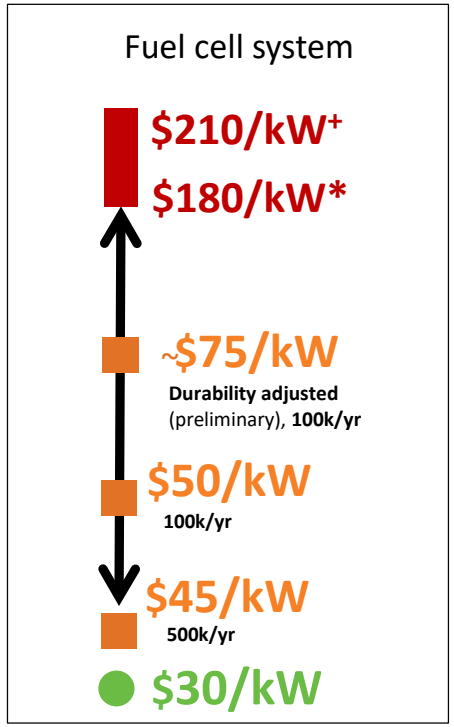

**Focuses of current activities include:**

1) Reducing expansion of seals in hydrogen by 50%.
2) Enhancing life of vessels by 50% through improved understanding of crack nucleation.
3) Enhancing fracture toughness of high-strength (>950 MPa) steels by 50%.

For more information, please visit https://www.energy.gov/eere/fuelcells/h-mat-hydrogen-materials-consortium
or contact h-matinfo@pnnl.gov

# Focus is on Affordability: DOE Targets Guide R&D

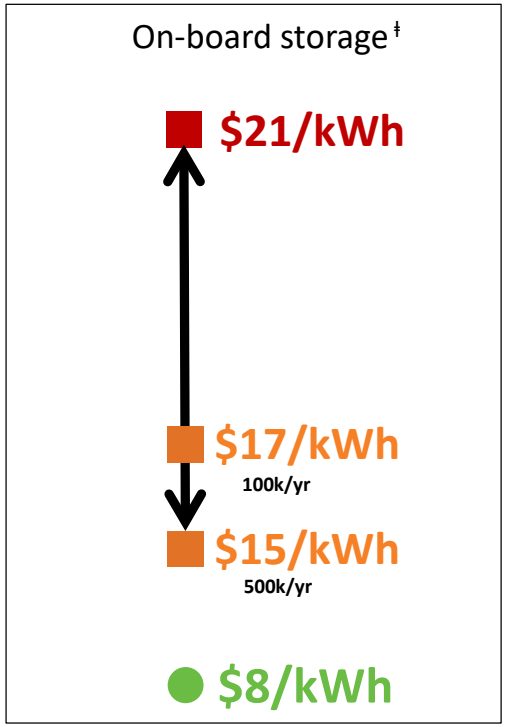
## Fuel Cell R&D



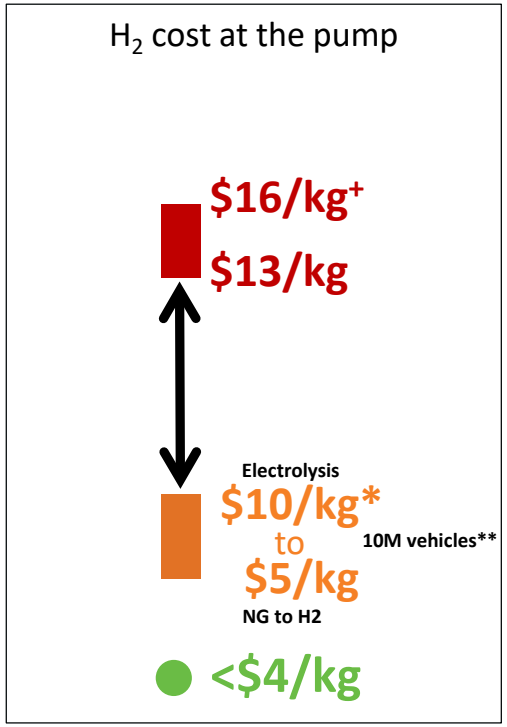

†Based on commercially available FCEVs

*Based on state of the art technology

## Hydrogen R&D




ǂStorage costs based on preliminary 2019 storage cost record





†For range: H2 production from natural gas (NG), delivered dispensed at today's (2018) stations (~180kg/d)

*For range: Assumes high volume manufacturing in 1) H2 production costs ranging from $2/kg (NG) to $5/kg (electrolysis manufactured at 700 MW/year), and 2) Delivery and dispensing costs ranging from $3/kg (advanced tube trailers) to $5/kg (liquid tanker or advanced pipeline technologies).

** Range assumes >10,000 stations at 1,000 kg/day capacity, to serve 10 million vehicles

# Establishing Long Haul Truck Targets for Hydrogen Fuel Cell Trucks – final Peer Review underway

***Technical targets under development for for Class 8 long haul tractor trailer trucks powered by hydrogen and fuel cells- durability is key focus area.***

| Characteristic | Units | Targets for Class 8 Tractors-Trailers | |
|---|---|---|---|
| | | Interim (2030) | Ultimate[4] |
| Fuel Cell System Lifetime[1] | [hours] | 25,000 | 30,000 |
| Fuel Cell System Cost[2,3] | [$/kW] | 80 | 60 |
| Fuel Cell Efficiency (peak) | [%] | 68 | 72 |
| Hydrogen Fill Rate | [kg $H_2$/min] | 8 | 10 |
| Storage System Cycle Life | [cycles] | 5,000 | 5,000 |
| Pressurized Storage System Cycle Life | [cycles] | 11,000 | 11,000 |
| Hydrogen Storage System Cost[3] | [$/kWh] ($/kg $H_2$ stored) | 9 (300) | 8 (266) |

*1. Corresponding vehicle lifetime range is 1M miles (Interim) and 1.2M miles (Ultimate) based on average speed of 40 mph.*
*2. Interim and ultimate cost targets assume 100,000 units per year production volumes*
*3. Costs are in 2016 dollars*
*4. Analysis based on 2050 simple cost of ownership assumptions and reflects anticipated timeframe for market penetration.*

Assuming trucks can be driven the maximum daily range (750 miles) between refueling

- Developed with input from the 21st Century Truck Partnership (21CTP), heavy duty workshop, cross-office (FCTO, VTO), Tech Teams
- Targets will be included in new Electrified Powertrain Roadmaps and will guide R&D

# Funding Opportunity Announcement (FOA) Updates

**FY18: $38M, 28 projects**
**FY19: $56M (H2@Scale and Truck FOA), 42 projects**

**FY19 H2@Scale FOA included 3 new projects for pilot scale H2@Scale demonstrations**

**Texas**
**Florida**
**Midwest**

**DOE Nuclear Energy FOA selection included hydrogen**

Installation of electrolysis unit at Davis-Besse Nuclear Power Station, and assessment of business case opportunities

**~$9M**

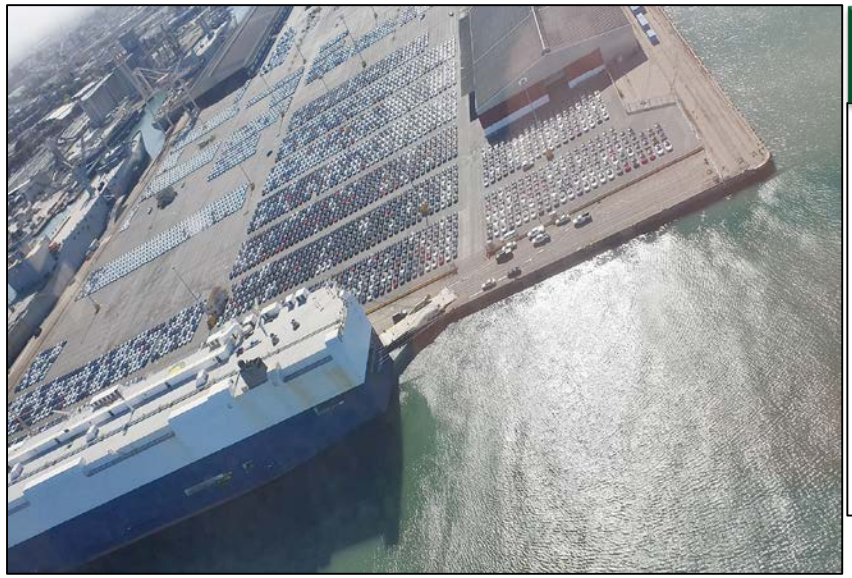
Blog at: www.energy.gov/ne/articles/could-hydrogen-help-save-nuclear

# Interest growing in

## End use applications across sectors

Heavy duty vehicles, steel manufacturing, ammonia, energy storage, liquid fuels, critical loads, natural gas blending, exports, and more

# DOE's H2@Ports, H2@Rail, H2@Datacenter Workshops



## H2@Datacenters

- Two breakout sessions for topics discussion
- Over 40 attendees
- R&D for techno-economic assessment of HFC
  - prime or backup power to critical loads of data centers.
  - Scenarios development to enable fuel cells for prime power supply to database

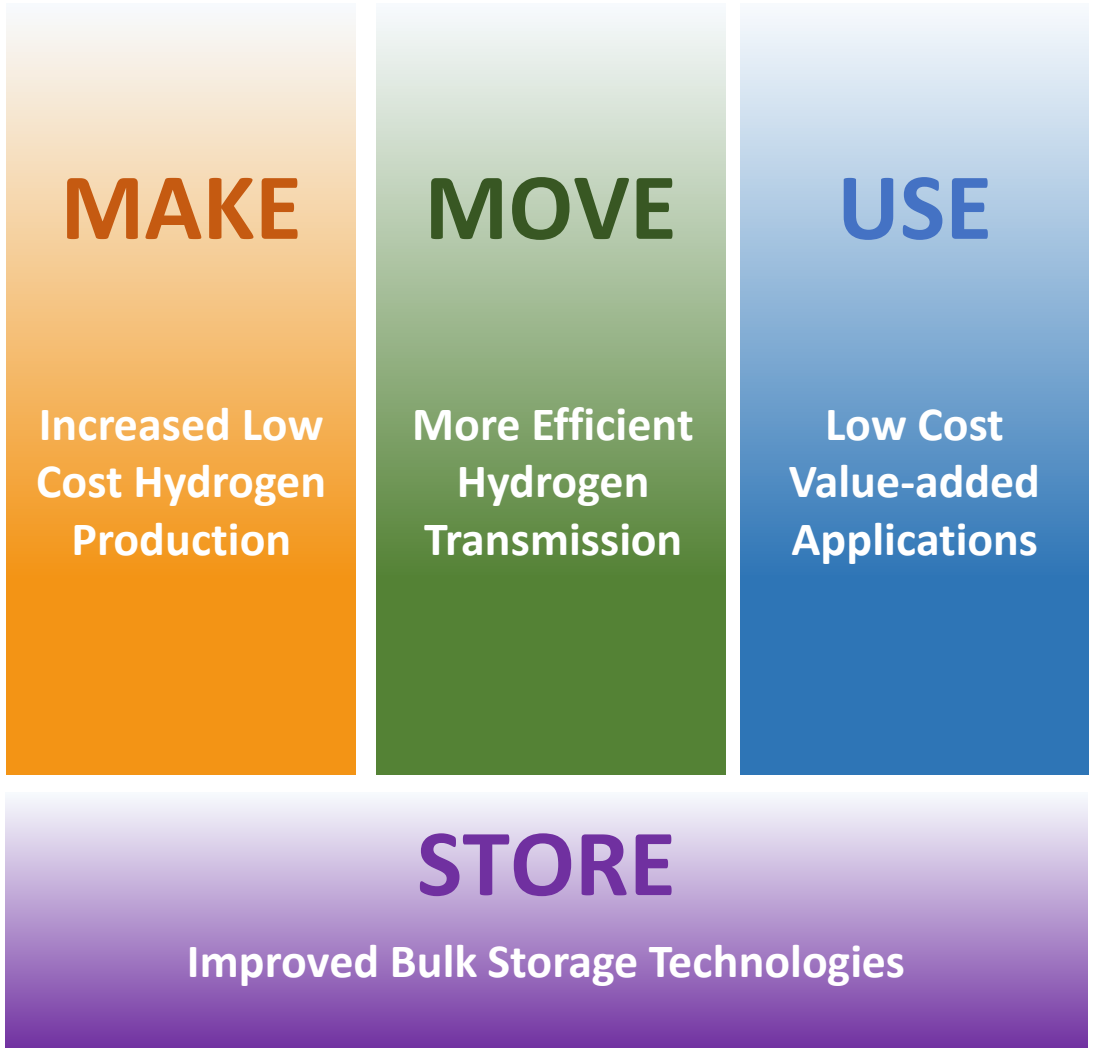
## H2@Ports

- In collaboration with U.S. Dept. of Transportation - Maritime Administration
- Eight panel sessions (35 speakers)
- 100 attendees
- R&D for techno-economic assessment of HFC
  - power system development
  - ship systems integration
  - regulations and standards.

## H2@Rail

- In collaboration with U.S. Dept. of Defense Federal Railroad Administration
- Four panel sessions (19 speakers)
- 60 attendees
- R&D for techno-economic assessment of HFC
  - Prime power system development
  - rail system operations
  - regulations and standards

# Key Focus Areas to Realize the $H_2$@Scale Vision




**FY2020 Plans**

Update of Hydrogen and Fuel Cells Program Plan to reflect H2@Scale vision and organized around MAKE, MOVE, USE, STORE

Update of Multi-year RD&D Plan including targets, status and analysis


Collaboration &
Resources

# International Collaborations

## The International Partnership for Hydrogen and Fuel Cells in the Economy

Enabling the global adoption of hydrogen and fuel cells in the economy

Elected Chair and Vice-Chair, 2018

**Working Groups: Education & Outreach**
**Regulations, Codes, Standards & Safety**

**Top Priorities**

- SHARE INFORMATION
- INFORM FUTURE GOVERNMENT RD&D
- FOSTER COLLABORATION

**Mission Innovation Hydrogen Challenge 2017**

**Clean Energy Ministerial New Hydrogen Initiative Launched 2019**

**Find IPHE on Facebook, Twitter and Linkedin**
Follow IPHE **@The_IPHE**

**www.iphe.net**

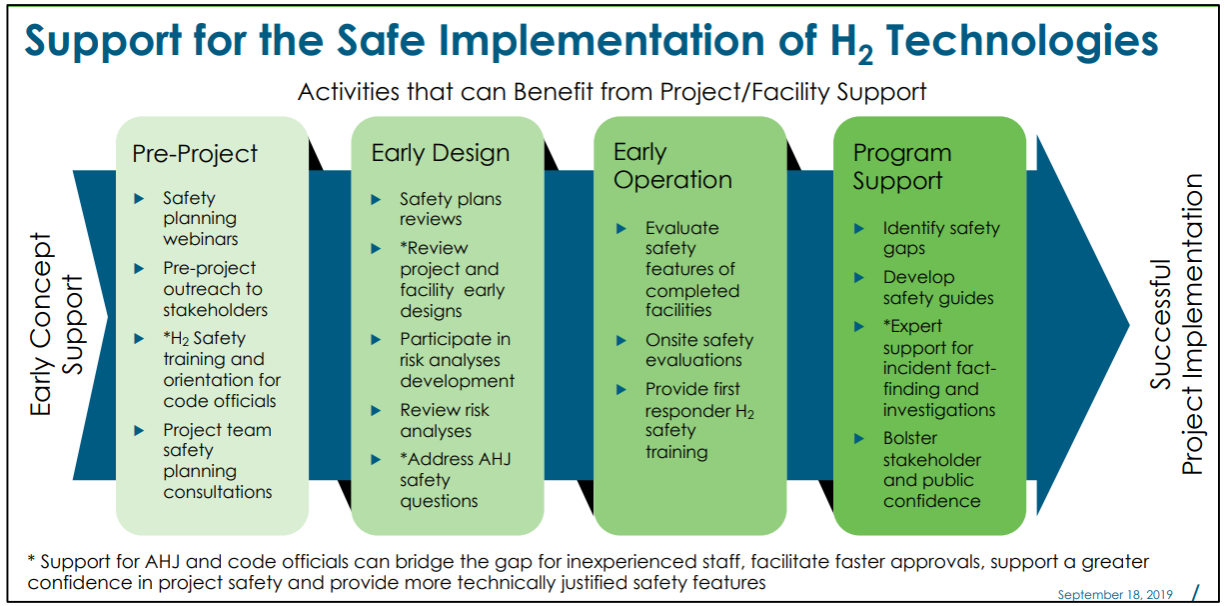
**Formed 2003**
**19 Countries and EC**

**Hydrogen Energy Ministerial (HEM)**

**International Energy Agency (IEA)**

# Center for Hydrogen Safety (CHS)

## Industry, governments partner: Access to 110 countries, 60,000 members through AIChE




MEMBERS

DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.
SCEJ The Society of Chemical Engineers, Japan
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ASTRA Rocket Company
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**www.aiche.org/CHS**

# Information and Resources

H2tools.org

INCREASE YOUR H2IQ

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

***Save the Date***
***May 19-22, 2020***
***DOE AMR***
***(Annual Merit Review)***
***Washington DC***

***www.hydrogen.energy.gov***

**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**

# DOE-wide STEM Initiative

# Join our Team!

## Roles Available:

- Fellows
- Contractors
- Interns

## Areas:

- Engineering
- Chemistry, Materials
- Project Management
- Communications
- Operations
- Safety, codes, standards

For more info: fuelcells@ee.doe.gov


# Bob Rose
# 1946 - 2018

## Pioneer and Founder of U.S. Fuel Cell Council

**The Fuel Cell Rose Education Award, led by the American Councils for International Education, will help prepare the global leaders of the future in the hydrogen and fuel cells community.**

http://roseaward.americancouncils.org/

**Pacific Northwest National Laboratory plans to host the first award recipient.**

RISE

# Thank You

**Dr. Sunita Satyapal**
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**energy.gov/eere/fuelcells or hydrogen.energy.gov**

# Additional Information

# FY19 FCTO FOA Selections: 29 Projects $40M DOE Funding
# (Note: Original selections below; award negotiations underway)

| Topic Area | Awardee | DOE Share |
|---|---|---|
| **Topic 1A: Novel Hydrogen Carrier Development** | Colorado School of Mines | $0.4M |
| | University of Hawaii | $0.9M |
| | University of Southern California | $1M |
| | Washington State University | $1M |
| **Topic 1B: H-Mat Materials Compatibility Consortium R&D: Hydrogen Effects in Materials for Fueling Infrastructure** | Clemson University | $1M |
| | Colorado School of Mines | $1.4M |
| | Hy-Performance Materials Testing, LLC | $0.6M |
| | Massachusetts Institute of Technology | $1M |
| | The University of Alabama | $1M |
| | University of Illinois at Urbana-Champaign | $2M |
| **Topic 2A: Advanced Water Splitting Materials Research (integrated with HydroGEN Consortium)** | Georgia Institute of Technology | $1M |
| | Nexceris, LLC | $1M |
| | Redox Power Systems, LLC | $1M |
| | The Chemours Company FC, LLC | $1M |
| | The University of Toledo | $0.7M |
| | University of California: Irvine | $1M |
| | University of California: San Diego | $1M |
| | University of Florida | $1M |
| | University of Oregon | $0.5M |
| | University of South Carolina | $1M |
| | William Marsh Rice University | $0.8M |
| **Topic 2B: Affordable Biological Hydrogen Production from Biomass Resources** | Oregon State University | $1M |
| **Topic 2C: Co-production of H2 and Value-add Byproducts** | C-Zero, LLC | $1M |
| | University of Colorado, Boulder | $1M |

# FY19 FCTO FOA Selections: 29 Projects $40M DOE Funding

**(Note: Original selections below; award negotiations underway)**

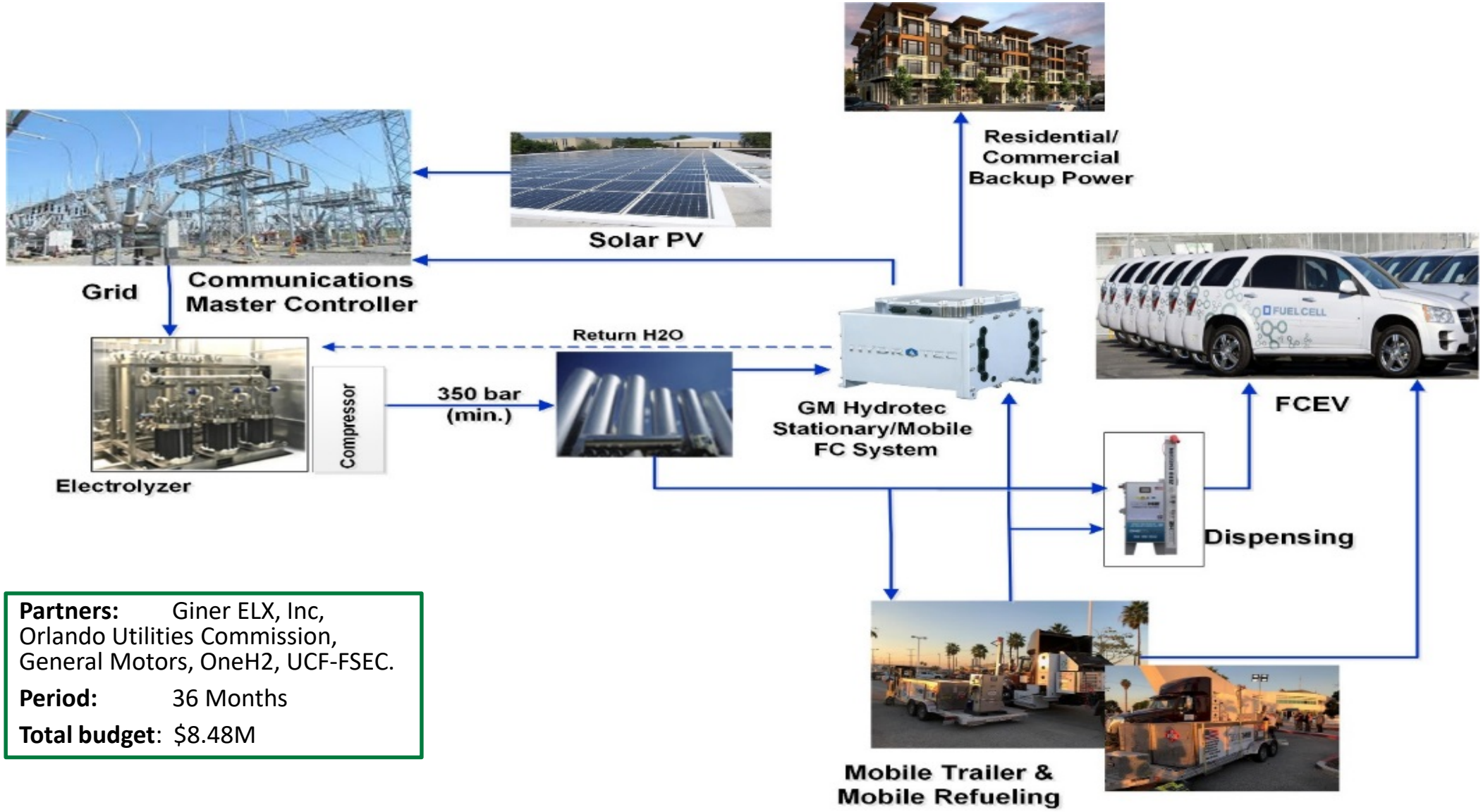
| Topic Area | Awardee | DOE Share |
|---|---|---|
| **Topic 2D: Reversible Fuel Cell Development and Validation** | FuelCell Energy, Inc | $2M |
| | Proton Energy Systems, Inc | $2M |
| **Topic 3: H2@Scale Pilot - Integrated Production, Storage, and Fueling System** | Exelon Corporation | $3.6M |
| | Frontier Energy, Inc. | $5.4M |
| | Giner ELX, Inc. | $4M |

# FY19 Commercial Trucks and Off-road Applications FOA Selections: 8 Hydrogen-based Projects ~$15M DOE Funding

**(Note: Original selections below; award negotiations underway)**

| Topic Area | Awardee | DOE Share |
|---|---|---|
| **1a – Advanced Storage for Gaseous Fuels** | Northwestern University | $1M |
| | University of South Florida | $0.8M |
| **3 - High Throughput Hydrogen Fueling Technologies for Medium- and Heavy-duty Transportation** | Air Products and Chemicals, Inc. | $1.7M |
| | NEL Hydrogen Inc. | $2M |
| | Electricore, Inc. | $3M |
| **4 – High-durability, Low Platinum Group Metal Membrane Electrode Assemblies (Meas) For Medium- And Heavy-duty Truck Applications** | General Motors LLC | $2M |
| | Nikola Motor Company | $1.7M |
| | Carnegie Mellon University | $2M |

# Integrated Hydrogen Production and Consumption for Improved Utility Operations – Orlando, FL

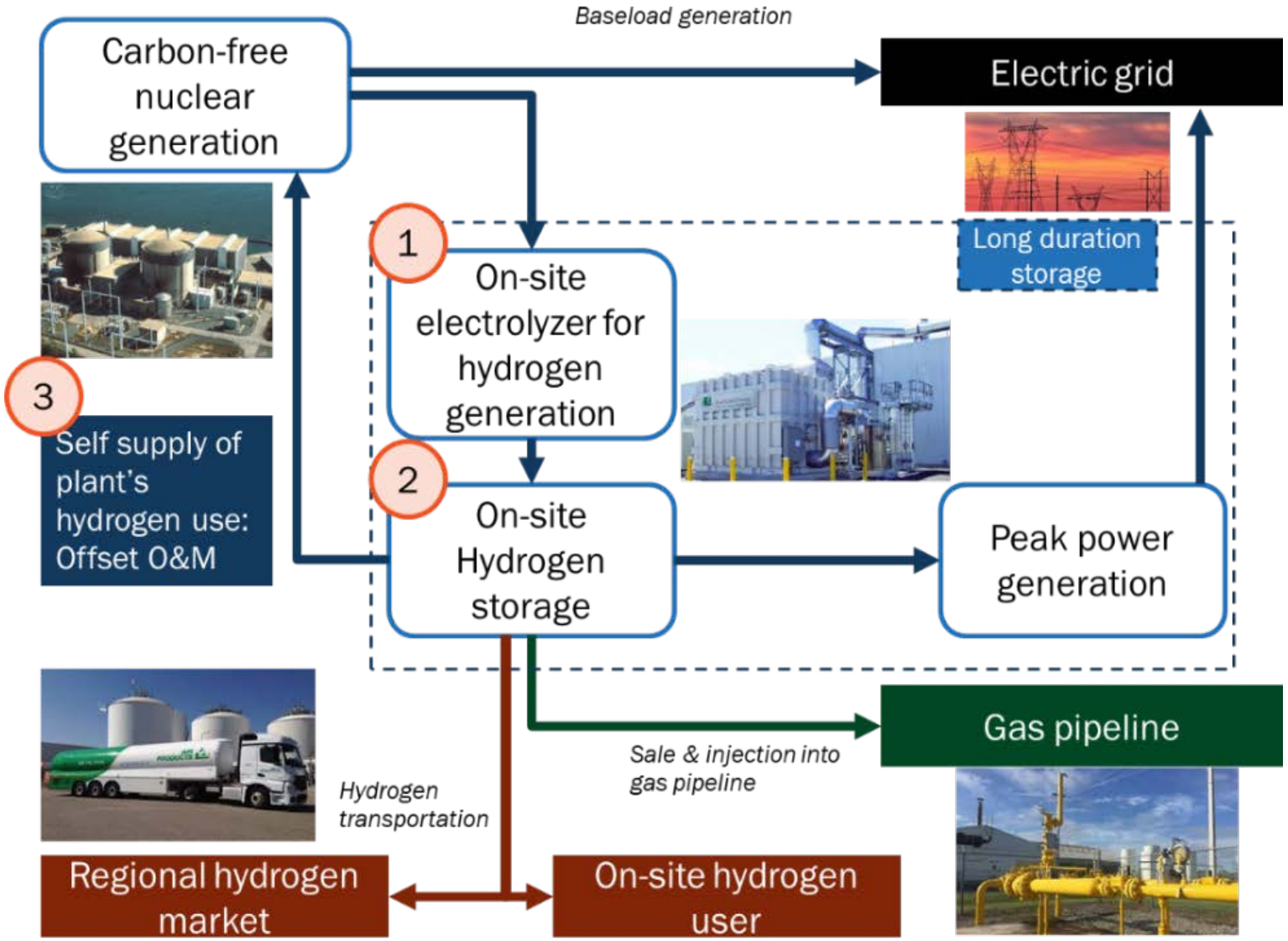



**Partners:** Giner ELX, Inc, Orlando Utilities Commission, General Motors, OneH2, UCF-FSEC.

**Period:** 36 Months

**Total budget**: $8.48M

# Electrolyzer Operation at Nuclear Plant and In-House Hydrogen Supply



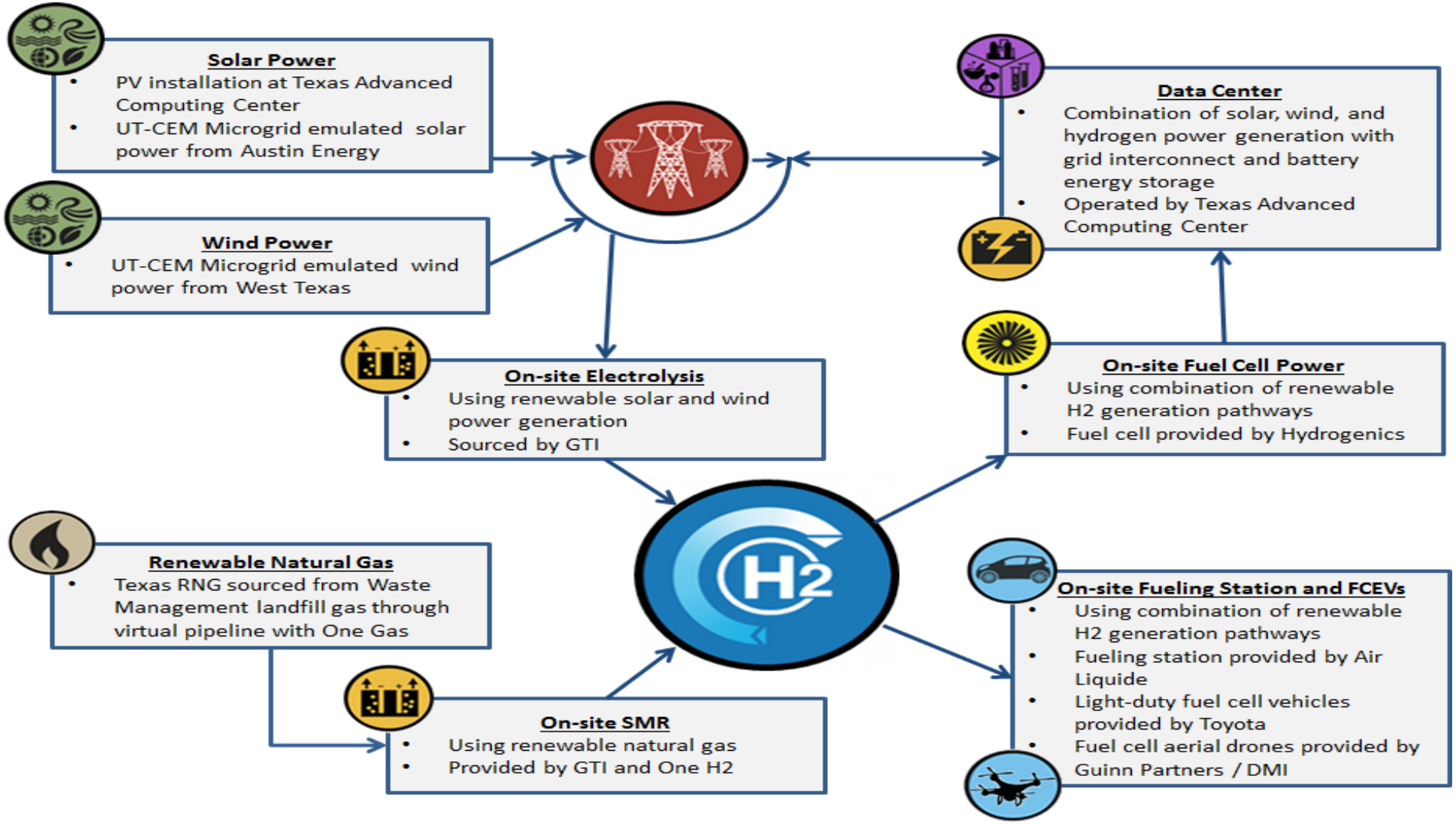

**Partners:** Exelon & Nel Hydrogen, INL, NREL, ANL

**Period:** 36 months

**Total budget:** $7,238,122

# Demonstration and Framework for H2@Scale in Texas and Beyond

***Integration Concepts Being Considered***

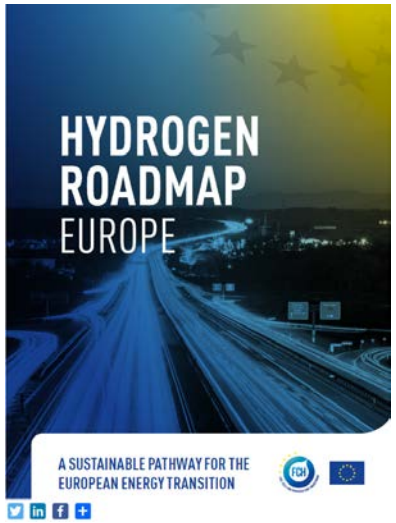



**Partners:** Frontier Energy, University of Texas at Austin, GTI, Toyota, Air Liquide, Waste Management, OneH2, Hydrogenics

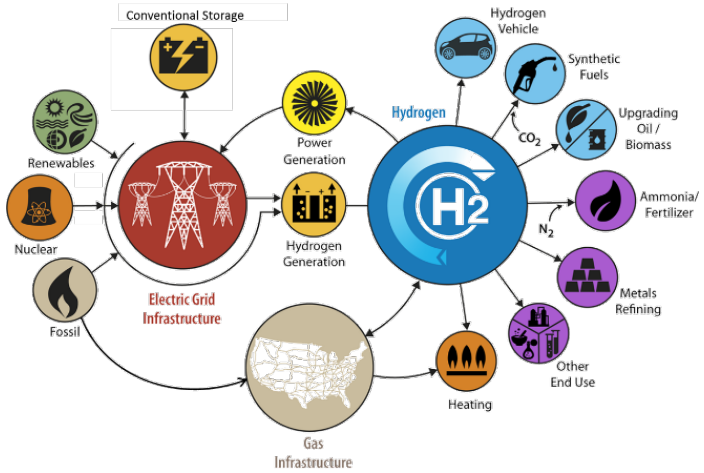
**Period:** 36 Months

**Total budget:** $12.7M

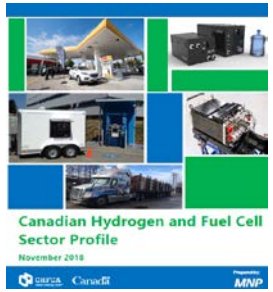
# "Hydrogen – at Scale and Sector Coupling" – A Common Vision Across Multiple Regions in the World



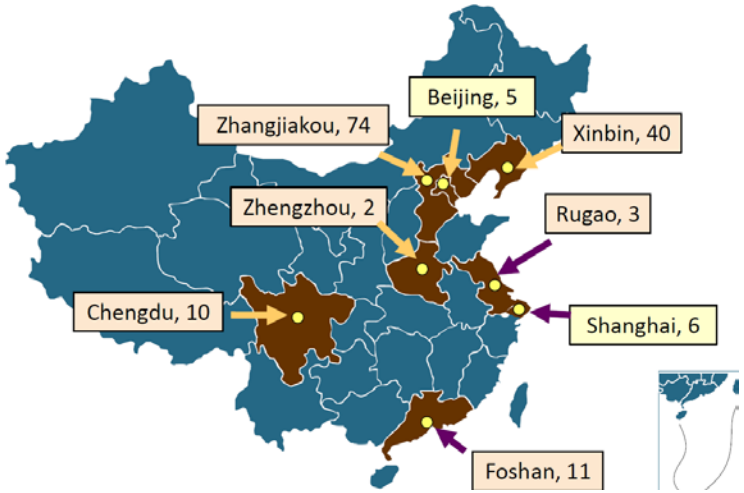





**Global Action Agenda released at Hydrogen Energy Ministerial, Tokyo (9/25/2019)**
**Aspirational Targets: "10, 10, 10"**
**10M systems, 10K stations, 10 years**








**High priority areas include: Global harmonization of codes and standards and addressing gaps, safety**
**From 10/19 IPHE meeting: Establish common definition of clean hydrogen to facilitate international trade**