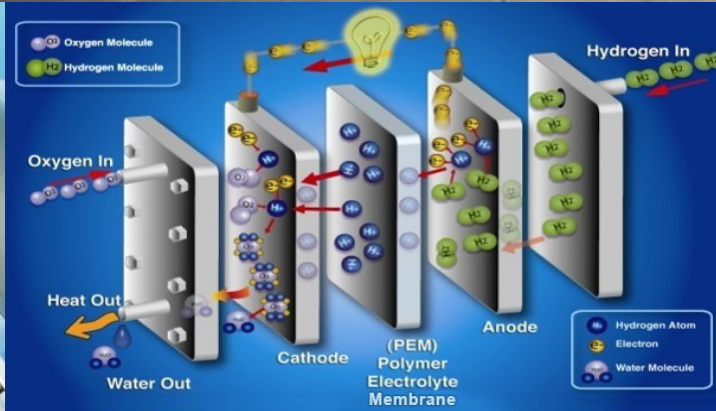


# U.S. Department of Energy Fuel Cell Technologies Office

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



## Hydrogen and Fuel Cell Technical Advisory Committee

Washington D.C.  
May 4, 2017

**Dr. Sunita Satyapal**

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

## 1970s

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



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

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



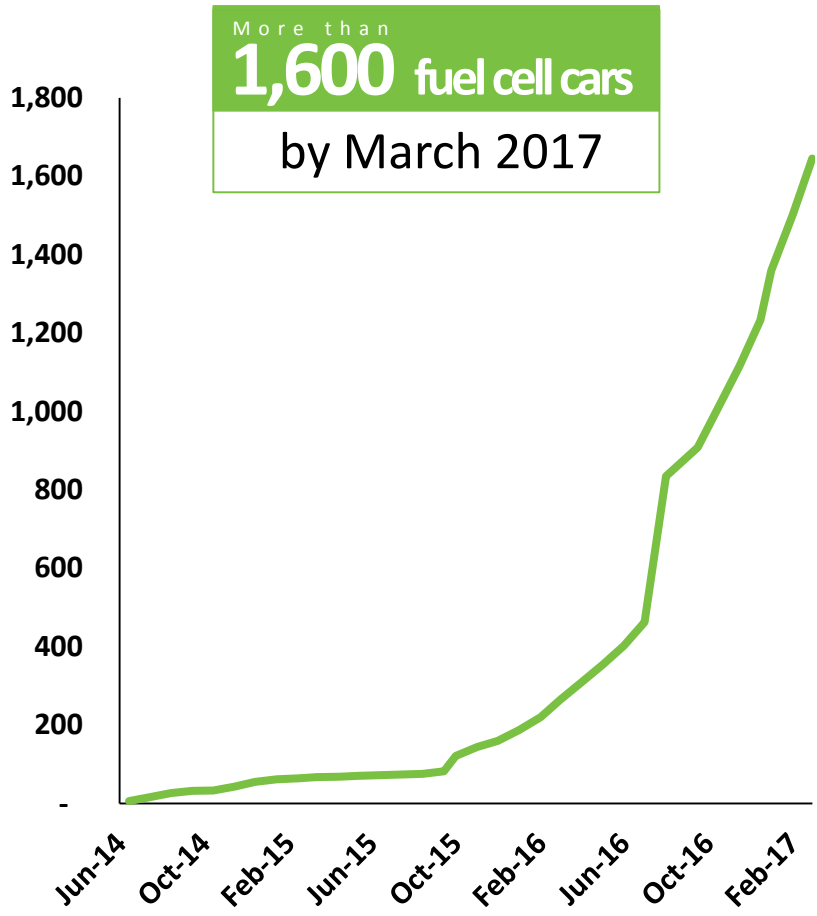
Commercial  
fuel cell electric  
cars are here!

Power, performance,  
petroleum-free, pollution-free

Refuels in minutes  
>360 mi driving range  
>60 mpgge



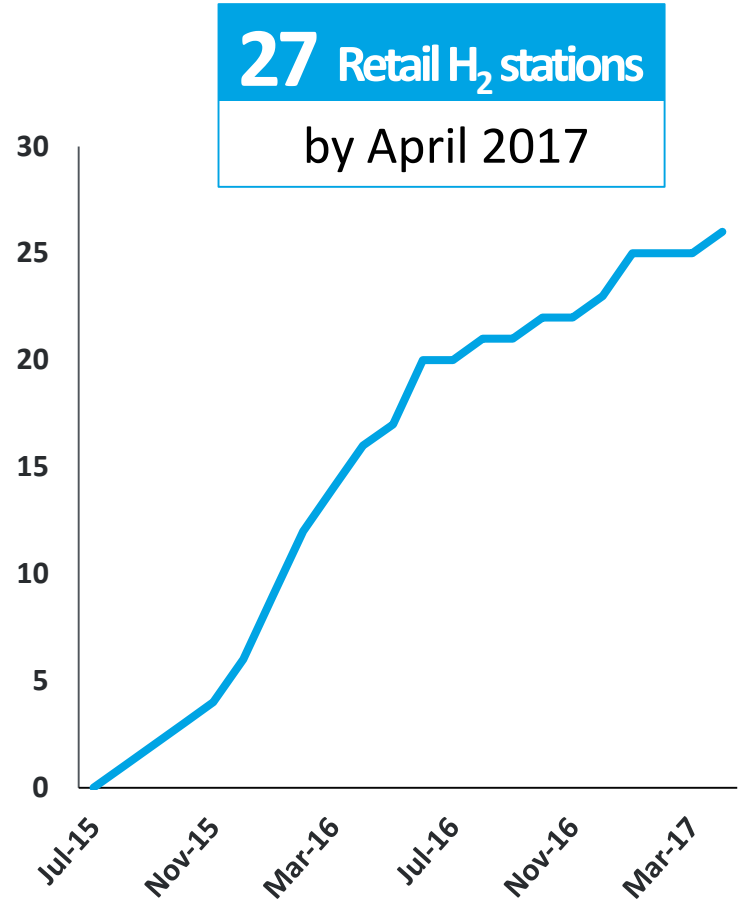
## U.S. Fuel Cell Car Sales Growing Exponentially



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



## Number of Retail H<sub>2</sub> Stations in CA Increasing

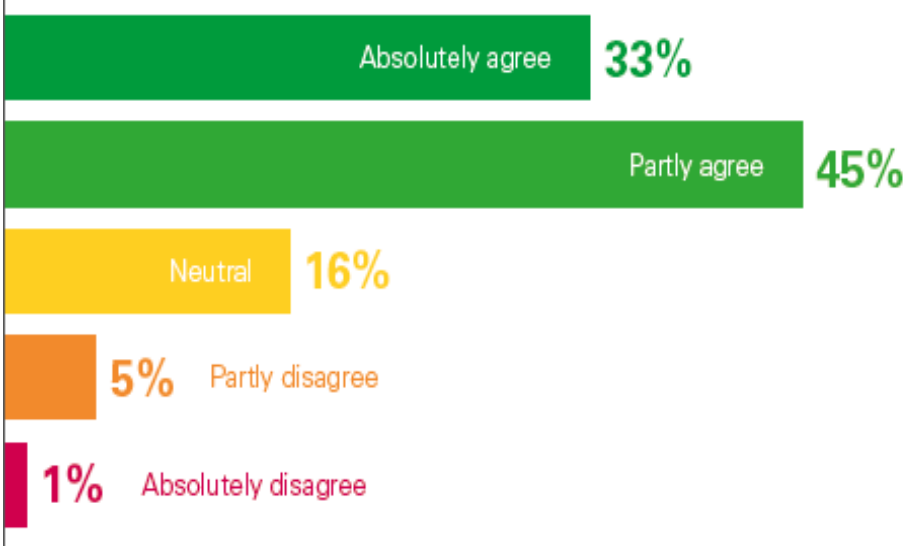


Sources: CaFCP

# Executive Opinions Worldwide- Jan 2017

## Fuel Cell Electric Vehicles (FCEVs)

**78%** of executives Absolutely or partly agree that **FCEVs will be the real breakthrough for electric mobility**



Source: KPMG, Global Automotive Executive Survey 2017 (Jan. 2017)

# Fuel Cells: Big leaps in the last couple of years

**ZH2: TARDEC and GM collaboration**  
First of its kind



**Over 10,000 fuel cell forklifts**  
~ 5 million H<sub>2</sub> refuelings

**Industry taking the lead- first heavy duty truck**



**Fuel cell buses surpass 15M passengers**



# Fuel Cells: Big leaps in the last couple of years

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



## First fuel cell cargo truck at U.S. airport



## Fuel cell powered lights at Super Bowl

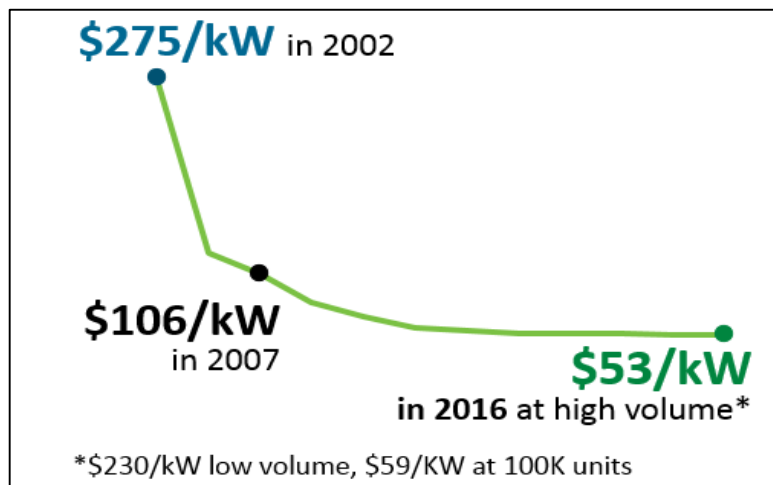


## World's first fuel cell for maritime ports



## Technology Innovation

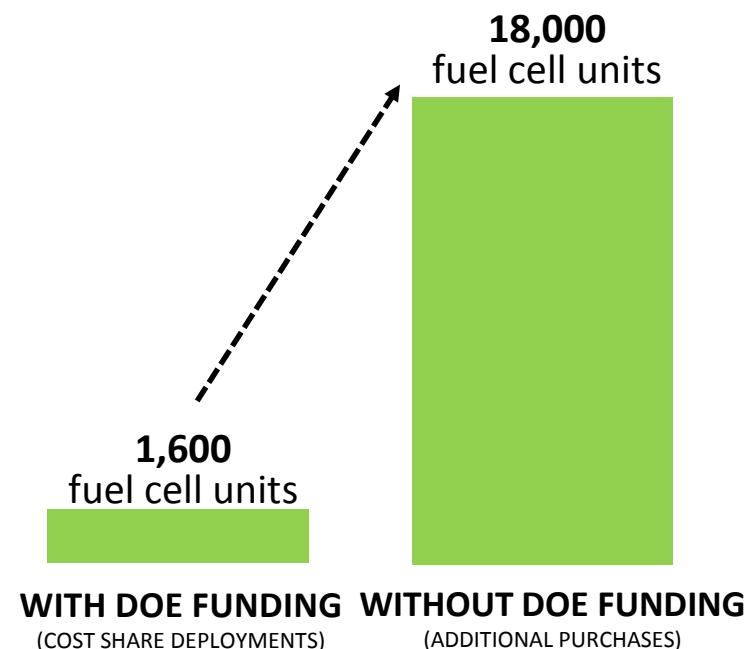
- Cut fuel cell cost by 80%



- Quadrupled fuel cell durability
- Enabled >580 patents and 30 technologies in today's market
- Validated research advances to guide R&D
  - >360 mi range, >2X efficiency of gasoline vehicles

## Market Impact

- Jumpstarted **early markets** by more than 11X



- Catalyzed additional private investment
- Over 16,000 jobs in the fuel cell vehicle sector\*



# The Hydrogen Council: A Global Initiative

## Launched in 2017

Position hydrogen among the key solutions of the energy transition at a global level by:

- Showcase hydrogen technology and benefits to the world
- Accelerate investment in the industry
- Engage key stakeholders

## Commitment

**\$10.7 Billion**  
in the hydrogen and fuel cells

## Formed by 13 companies

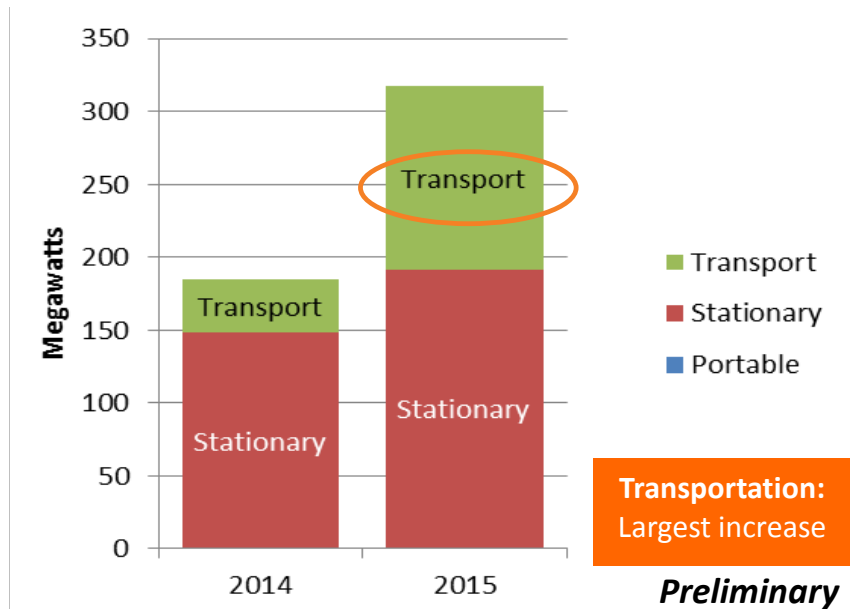


More information: [Hydrogen Empowers the Energy Transition- 2017 Report](http://hydrogeneurope.eu/) (<http://hydrogeneurope.eu/>)

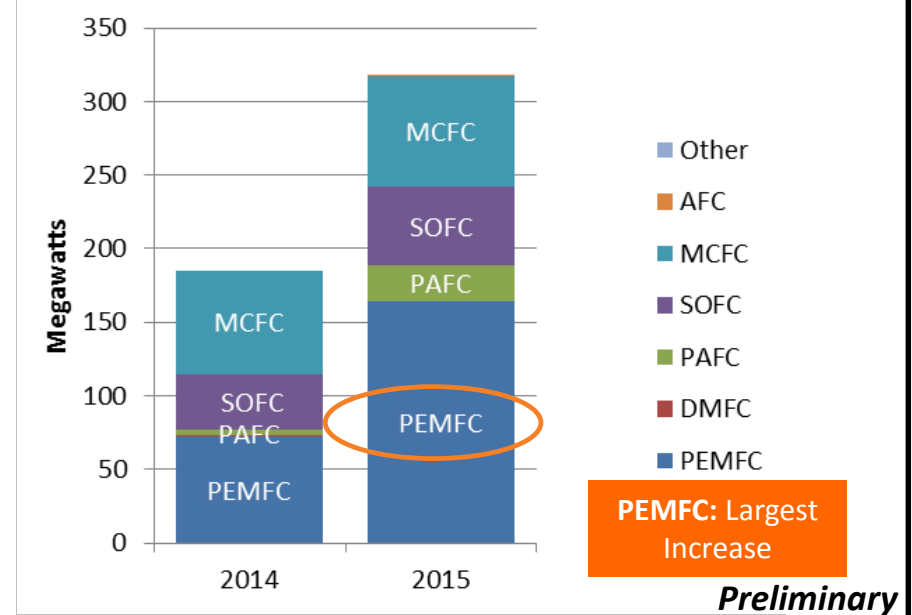
\* Indicates total number of employees working at member companies.

# Global Landscape: Recent Trends

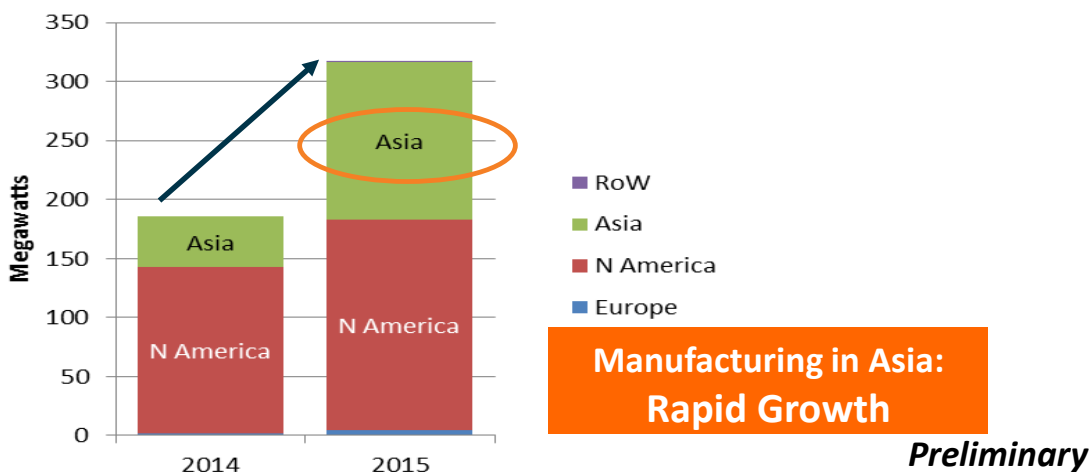
## Worldwide Shipments by Application



## Worldwide Shipments by Fuel Cell Type



## Worldwide Shipments by Region of Manufacture



## International RD&D Commitments in H<sub>2</sub> and Fuel Cells- Examples

- **Japan:** \$500M & \$350M to showcase H<sub>2</sub> and FCs at the 2020 Olympics
- **EU:** \$800M and industry-led H<sub>2</sub>Mobility partnership with a ~\$445M budget

## Formation of HTAC- Energy Policy Act of 2005 (EPACT):

### To advise the Secretary of Energy on:

1. The implementation of programs and activities under Title VIII of EPAC
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<sub>2</sub> 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<sub>2</sub> 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**

# Examples of HTAC Activities & Feedback

- Annual Report and annual letter with recommendations

## Strategic and Programmatic

- Manufacturing subcommittee
- Program Plan revision (previous update 2011)
- Safety Response subcommittee
- H<sub>2</sub> energy storage/H2@Scale feedback
- Communications/outreach

## Technical

- H<sub>2</sub> cost target revision review
- H<sub>2</sub> Production Expert Panel R&D review
  - Technology deep dive by experts
- Feedback on H-Prize
  - Topics, criteria, etc.

## Additional and Ongoing Needs:

- Strategies for leveraging (e.g. industry, states, other agencies, investors, etc.)
- Input on revised program plan (planned FY17-18)
- Communication and outreach

- **Recommendation:** Clean Cities program emphasis must actively promote and educate consumers on FCEV technology.
- **Response:** The AFDC has been updated with H<sub>2</sub> station language and counts.

The screenshot shows the Alternative Fuels Data Center (AFDC) website. At the top, it features the U.S. Department of Energy logo and navigation links for EERE Home, Programs & Offices, and Consumer Information. Below the header is a search bar for the AFDC and a menu with categories: FUELS & VEHICLES, CONSERVE FUEL, LOCATE STATIONS, LAWS & INCENTIVES, Maps & Data, Case Studies, Publications, Tools, About, and Home. The main content area displays six fuel types with their respective icons, descriptions, and vehicle categories:

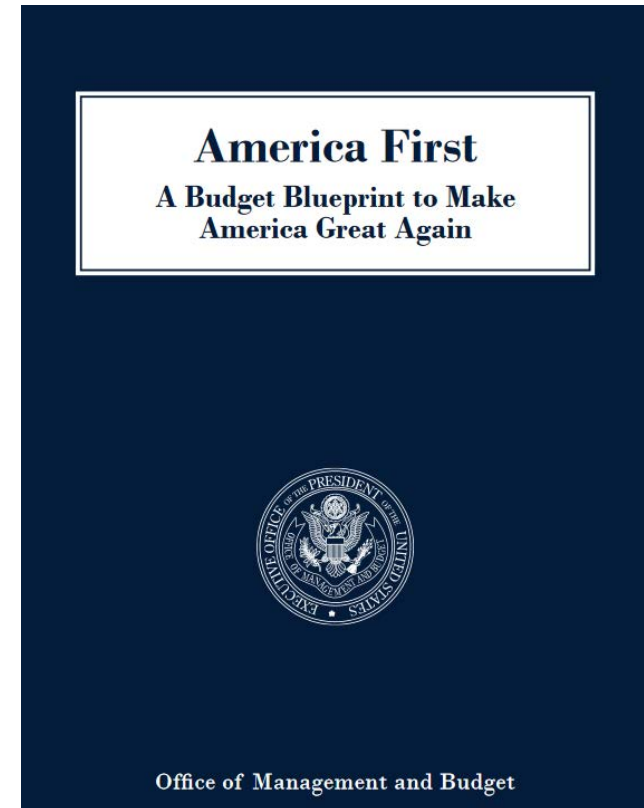
- Biodiesel**: Biodiesel is a renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled cooking grease for use in diesel vehicles. Diesel Vehicles
- Electricity**: Electricity can be used to power plug-in electric vehicles, which are increasingly available. Hybrids use electricity to boost efficiency. Hybrid & Plug-In Vehicles
- Ethanol**: Ethanol is a widely used renewable fuel made from corn and other plant materials. It is blended with gasoline for use in vehicles. Flexible Fuel Vehicles
- Hydrogen**: Hydrogen is a potentially emissions-free alternative fuel that can be produced from domestic resources for use in fuel cell vehicles. Fuel Cell Vehicles
- Natural Gas**: Natural gas is a domestically abundant gaseous fuel that can have significant fuel cost advantages over gasoline and diesel fuel. Natural Gas Vehicles
- Propane**: Propane is a readily available gaseous fuel that has been widely used in vehicles throughout the world for decades. Propane Vehicles

The Hydrogen section is highlighted with an orange border, indicating the focus of the recommendation and response.

More at: [afdc.energy.gov](https://afdc.energy.gov)

Recommendation	Response
<b>Maximize the Role of the Hydrogen Safety Panel (HSP)</b>	Developed draft <b>HSP Strategic Plan focusing on broadening the impact of the Panel</b> and setting it up as resource to state and regional entities.
<b>Leverage the Capabilities of Public–Private Partnerships</b>	The Hydrogen Safety Program at PNNL developed <b>draft outreach plan which leverages the capabilities and network of key stakeholder groups.</b>
<b>Take Steps to Support Reopening Hydrogen Stations in a Timely Fashion after a Safety-Related Incident</b>	The HSP Strategic Plan covers stakeholder groups and how to leverage them to <b>establish working relationships at the local level</b> for fast incident response.
<b>Identify and Support Other Federal and State Agencies that Need to Incorporate Hydrogen into Their Programs</b>	Ongoing collaboration with <b>Federal Energy Management Program (FEMP)</b> on safety and with <b>multiple states on H2 infrastructure (CA, MA, CT, NY, etc. )</b>

- Former Governor of Texas **Rick Perry** sworn in as the **Energy Secretary** on March 2
- White House **budget proposal** released
  - “...reflects an **increased reliance on the private sector to fund later-stage research, development, and commercialization** of energy technologies...”
  - “... **focuses resources toward early-stage research and development.**”

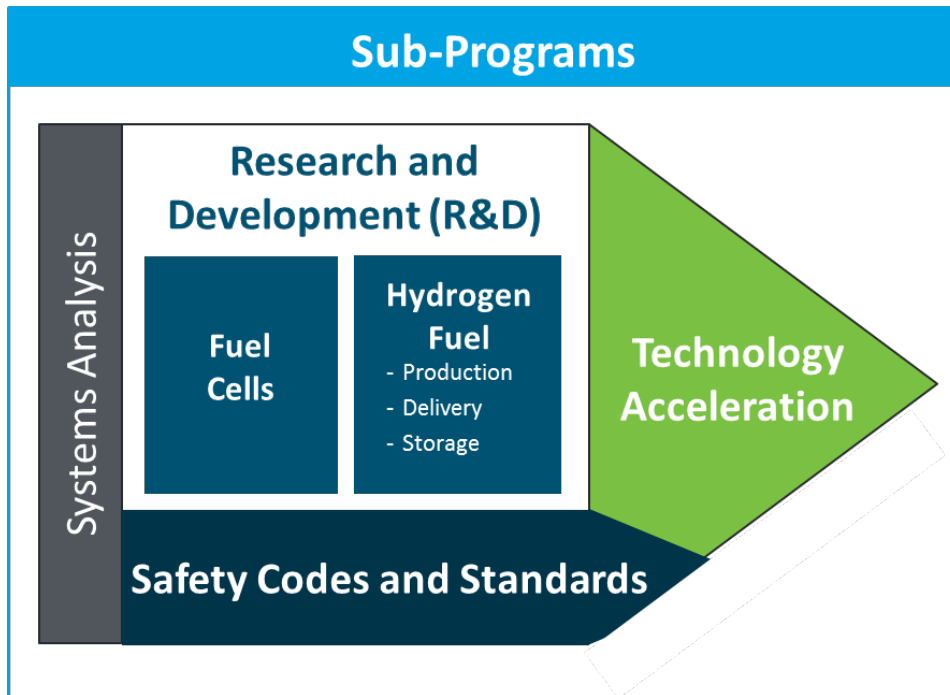


**WH Budget Blueprint released on  
March 16**

# DOE Hydrogen and Fuel Cells Program

## Focus

Applied research, development and innovation of hydrogen and fuel cell technologies that enable energy security, resiliency, and a strong domestic economy in emerging markets.



## 2020 Targets by Application



Fuel Cell Cost	<b>\$40/kW</b>	<b>\$1,000/kW*</b> <b>\$1,500/kW**</b>
Durability	<b>5,000 hrs</b>	<b>80,000 hrs</b>

H <sub>2</sub> Storage Cost (On-Board)	<b>\$10/kWh</b> 1.8 kWh/L, 1.3 kWh/kg
----------------------------------------	------------------------------------------

H <sub>2</sub> Cost at Pump	<b>&lt;\$4/gge</b> <b>&lt;\$7/gge</b> (early market)
-----------------------------	---------------------------------------------------------

\*For Natural Gas  
 \*\*For Biogas

*Strengthening U.S. energy security and the economy through R&D on hydrogen and fuel cells*



# DOE Cost Status and Targets

## Fuel Cell System

■ **\$230/kW**



■ **\$59/kW**  
100K/yr



■ **\$53/kW**  
500K/yr

● **\$40/kW**

## H<sub>2</sub> Production, Delivery & Dispensing

■ **\$16/gge<sup>+</sup>**  
to  
**\$10/gge**



■ **\$7.5\*/gge**  
to  
**\$5\*\*/gge**



● **<\$4/gge**

## Onboard H<sub>2</sub> Storage (700-bar compressed system)

■ **\$33/kWh**



■ **\$17/kWh**  
100K/yr



■ **\$15/kWh**  
500K/yr

● **\$10/kWh**

● 2020 Targets

■ High-Volume Projection

■ Low-Volume Estimate

\*Based on Electrolysis \*\*Based on NG SMR + Preliminary, updates underway

\*For illustration purposes only, not drawn to scale

Fuel Cells

- Bipolar Plates
- Membranes
- BOP
- MEA
- Frames/Gaskets
- GDLs



Focusing on...



**Low and Non PGM Catalysts,  
Alkaline Membranes**

H<sub>2</sub> Station

- Storage
- Cooling
- Dispensing
- Other



**Advanced Compression  
Alternate Approaches**

H<sub>2</sub> Storage

- BOP/Assembly
- Other processing
- Resin



**Low Cost Carbon Fiber (CF)  
Long term Materials Approaches**

# Leveraging National Labs

## Consortia Launched

### Improved PEM fuel cells



### PGM-free catalysts



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

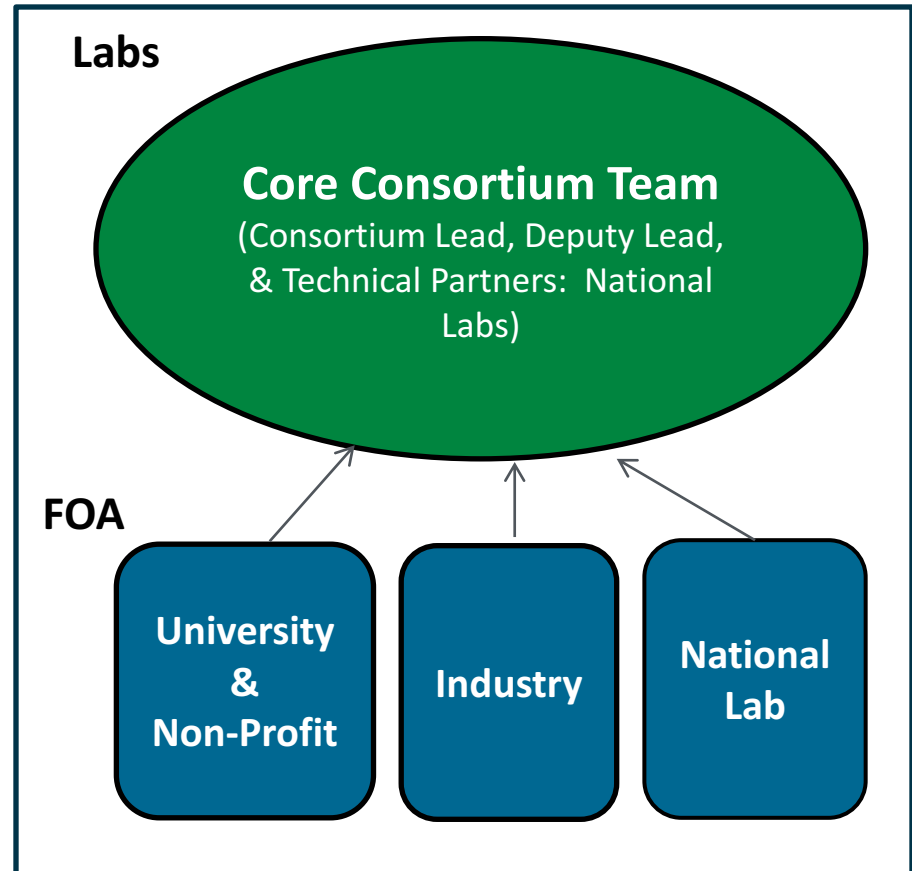


### Materials for renewable H<sub>2</sub> production



## Consortium Approach

Multi-lab core capabilities with steady influx of new partners





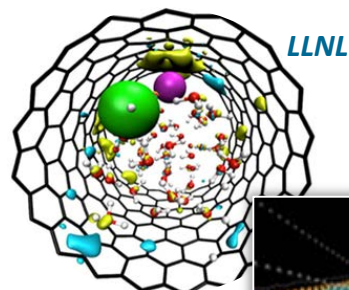
➤ Accelerating the discovery & development of innovative materials critical to advanced technologies for sustainable H<sub>2</sub> production, including:

- *Advanced high- and low-temperature electrochemical conversion*
- *Direct photoelectrochemical solar water splitting*
- *Direct solar thermochemical water splitting*

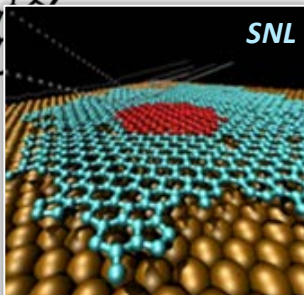
➤ Comprising more than 80 unique, world-class capabilities/expertise in materials theory/computation, synthesis, characterization & analysis:



## Materials Theory/Computation

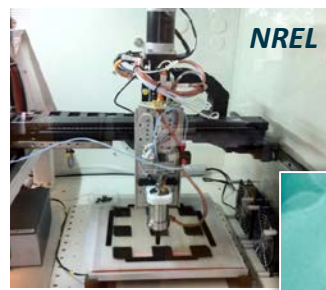


Bulk & interfacial models of aqueous electrolytes

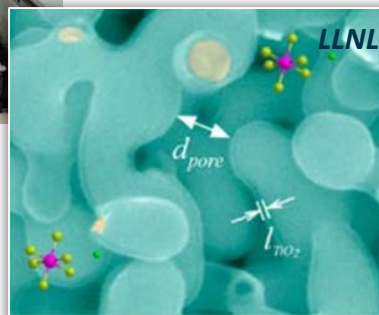


LAMMPS classic molecular dynamics modeling relevant to H<sub>2</sub>O splitting

## Advanced Materials Synthesis



High-throughput spray pyrolysis system for electrode fabrication

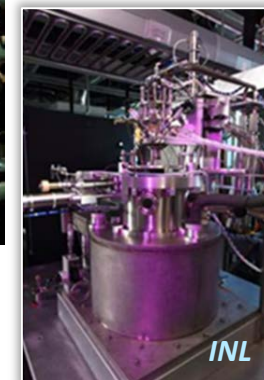


Conformal ultrathin TiO<sub>2</sub> ALD coating on bulk nanoporous gold

## Characterization & Analytics



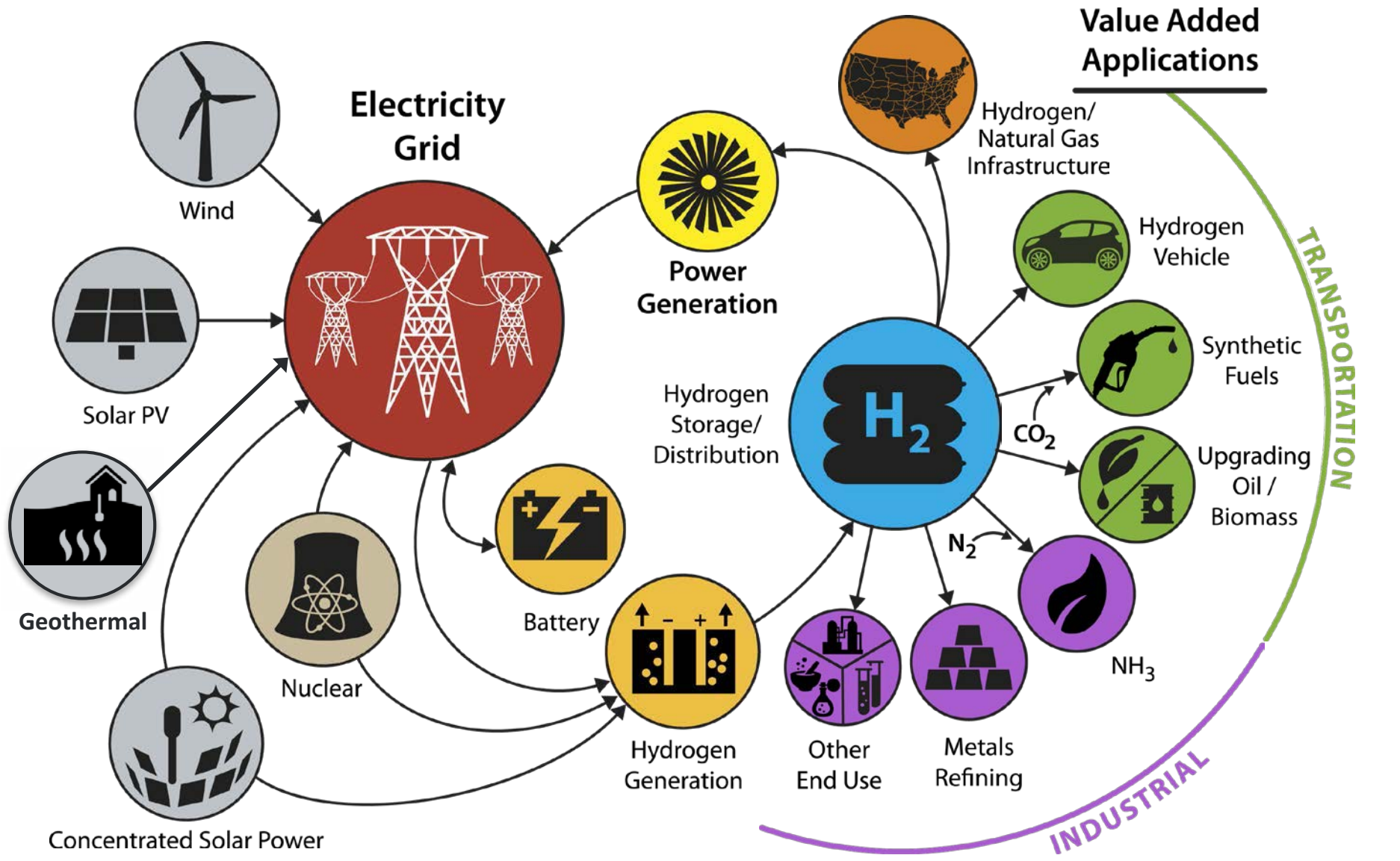
Stagnation flow reactor to evaluate kinetics of redox material at high-T



TAP reactor for extracting quantitative kinetic data

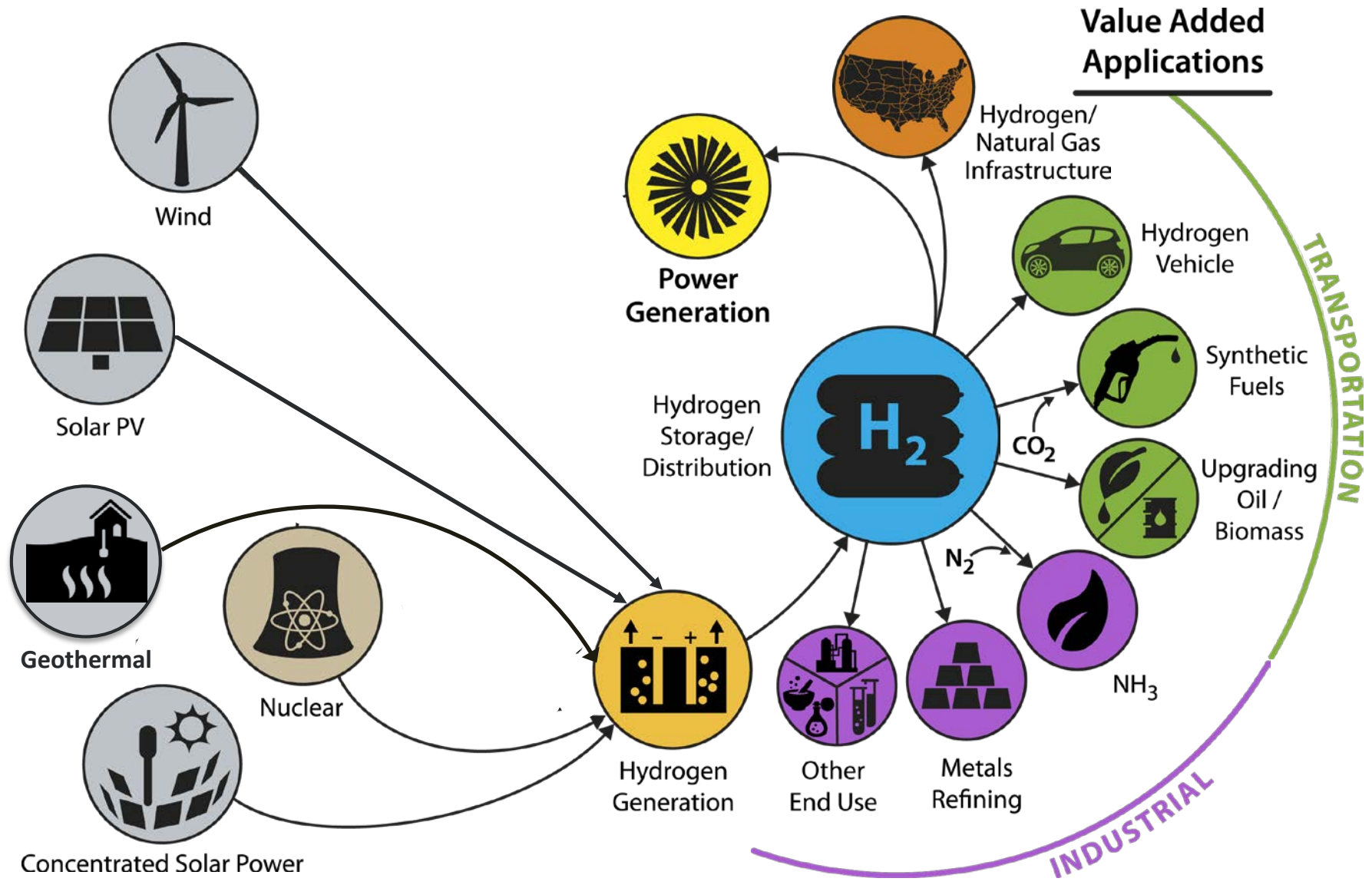
**HydroGEN fosters cross-cutting innovation using theory-guided applied materials R&D to advance all emerging water-splitting pathways for hydrogen production**

# Launched H2@Scale (updates at this HTAC meeting)

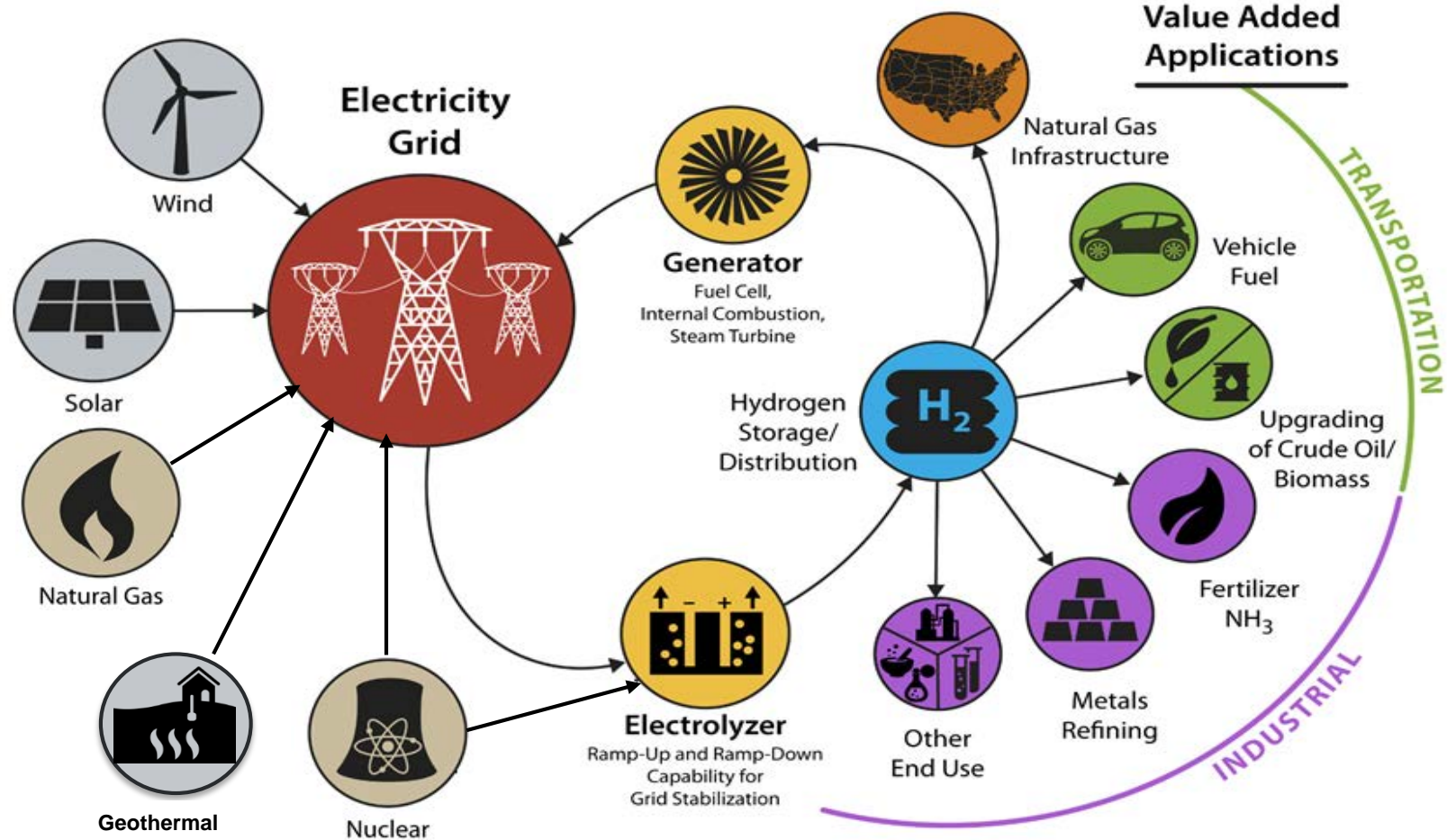


\*Illustrative example, not comprehensive  
Source: NREL

# Launched H2@Scale (updates at this HTAC meeting)



# H2@cale R&D areas (examples)



## Electrolyzer integration

- Grid
- Renewable power generation
- Nuclear power generation

## Electrolyzer and Components

- Low PGM Catalysts
- Manufacturing
- High-temp. electrolysis

## Wide-Scale Infrastructure

- Compression
- Storage
- Delivery

- **Enable early R&D innovation**
  - **Key Focus: Consortia for breakthroughs in hydrogen and PGM-free catalysts, H2@Scale**
- **Leverage activities to maximize impact**
  - **Enable infrastructure and cross-sector impacts**
  - **Partnerships- agencies (e.g. DOD), industry, states, etc.**
  - **Strengthen collaboration on safety and information sharing**

## Save the Dates!

**2017 AMR**  
June 5-9  
Washington, DC

 **National Hydrogen & Fuel Cell Day | 10·08**  
Participate in social media using  
**#HydrogenNow #FuelCellsNow**

**Summer 2018:**  
**AMR and Industry Expo**  
Washington, DC



# Additional Information

**For more information contact:**

**Dr. Sunita Satyapal**

**Director**

**Hydrogen and Fuel Cells Program**

**Fuel Cell Technologies Office**

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

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

- The FY17 Omnibus language has just been released
- There are several specific areas of guidance within the Omnibus (see backup slides)

	<b>House Bill Recommendation</b>	<b>Senate Bill Recommendation</b>	<b>Conference Agreement</b>
<b>Fuel Cell Technologies Office</b>	<b>\$97,000,000</b>	<b>\$92,000,000</b>	<b>\$101,000,000</b>
Difference from FY 2016 Enacted	<i>(\$3,950,000)</i>	<i>(\$8,950,000)</i>	<i>\$50,000</i>
Difference from FY 2017 Budget Request	<i>(\$8,500,000)</i>	<i>(\$13,500,000)</i>	<i>(\$4,500,000)</i>

**FY16 Total DOE Hydrogen and Fuel Cells Funding: ~\$156M**  
 FCTO (\$101M), BES (\$24.7M), FE (\$30M)

	HOUSE	SENATE	CONFERENCE
	<i>Total Recommendation:</i> <b>\$97,000,000</b>	<i>Total Recommendation:</i> <b>\$92,000,000</b>	<i>Total Recommendation:</i> <b>\$101,000,000</b>
<i>Hydrogen Fuel R&amp;D</i>	<i>[No direction.]</i>	<b>\$3,000,000</b> for carbon-free production of hydrogen using new chemical synthesis methods that break apart natural gas to solid carbon and hydrogen.	<i>[No direction.]</i>
<i>Technology Acceleration</i>	Within available funds, <b>\$13,000,000</b> for Technology Validation, of which <b>\$2,000,000</b> is for the EERE share of the integrated energy systems work with the Office of Nuclear Energy and <b>\$7,000,000</b> is to enable integrated energy systems using high and low temperature electrolyzers with the intent of advancing the H2@Scale concept.	<i>[No direction.]</i>	Within available funds, the agreement provides <b>\$18,000,000</b> for Technology Validation, of which <b>\$2,000,000</b> is for the EERE share of the integrated energy systems work with the Office of Nuclear Energy.

	HOUSE	SENATE	CONFERENCE
	<i>Total Recommendation:</i> <b>\$97,000,000</b>	<i>Total Recommendation:</i> <b>\$92,000,000</b>	<i>Total Recommendation:</i> <b>\$101,000,000</b>
<i>Safety, Codes, Standards</i>	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.	<b>\$7,000,000</b> for Safety, Codes, and Standards.	<i>[No direction.]</i>
<i>Other Direction</i>	The Committee recognizes the progress of the program and expresses continued support for stationary, vehicle, motive, and portable power applications of this technology. The Department is encouraged to explore technologies that advance the storage and transportation fuel distribution and retailing systems.	Within available funds, <b>\$7,000,000</b> to demonstrate an integrated hydrogen renewable energy production, storage, and transportation fuel distribution and retailing system.	Within available funds, the agreement also provides <b>\$7,000,000</b> to enable integrated energy systems using high and low temperature electrolyzers with the intent of advancing the H2@Scale concept.

	HOUSE	SENATE	CONFERENCE
	<i>Total Recommendation:</i> <b>\$97,000,000</b>	<i>Total Recommendation:</i> <b>\$92,000,000</b>	<i>Total Recommendation:</i> <b>\$101,000,000</b>
<i>Other Direction</i>	The Department is encouraged to engage the appropriate national laboratories to pursue novel advanced demonstrations that validate how integrated, renewable hydrogen production and storage infrastructure supports transportation and non-transportation applications. The Department is directed to submit not later than 180 days after the enactment of this Act a report on its efforts to deploy hydrogen infrastructure. The report should include a discussion of the Department’s coordination with other relevant agencies.	<i>[No direction.]</i>	<i>[No direction.]</i>

“Focuses funding for the Office of Energy Efficiency and Renewable Energy, the Office of Nuclear Energy, the Office of Electricity Delivery and Energy Reliability, and the Fossil Energy Research and Development program on **limited, early-stage applied energy research and development activities where the Federal role is stronger.** In addition, the Budget eliminates the Weatherization Assistance Program and the State Energy Program to reduce Federal intervention in State-level energy policy and implementation. Collectively, these changes achieve a savings of approximately \$2 billion from the 2017 annualized CR level.”

- From “America First” Budget Blueprint released by OMB on March 16, 2017

HTAC Member and Affiliation	Expertise
<b>Ayers, Katherine</b> Proton OnSite	<b>Hydrogen Production R&amp;D</b>
<b>Azevedo, Ines</b> Co-Director of the Climate and Energy Decision Making Center, Carnegie Mellon University	<b>Academia/ Behavioral Science</b>
<b>Clay, Kathryn</b> American Gas Association	<b>Associations / Non-profits</b>
<b>Dunwoody, Catherine</b> California Air Resources Board	<b>Government</b>
<b>Eggert, Anthony</b> Program Director, Climateworks	<b>Associations/Non -Profits</b>
<b>Freese, Charles F.</b> General Motors Company	<b>Transportation</b>
<b>Gobin, Anne</b> Bureau of Air Management, Connecticut Department of Energy & Environmental Protection	<b>Government</b>
<b>Kaya, Maurice</b> Pacific International Center for High Technology; Chief Technology Officer (retired), Hawaii Dept. of Business, Economic Development, and Tourism	<b>Government</b>
<b>Kodjak, Drew</b> International Council on Clean Transportation (ICCT)	<b>Transportation</b>
<b>Koyama, Hal</b> H2 PowerTech	<b>Stationary Power</b>

HTAC Member Name and Affiliation	Expertise
<b>Leggett, Paul</b> Morgan Stanley, Investment Banking Division	<b>Venture Capital / Investment</b>
<b>Lipman, Timothy</b> Transportation Sustainability Research Center, UC Berkeley; Director, DOE Pacific Region Clean Energy Application Center	<b>Academia</b>
<b>Markowitz, Morry</b> Fuel Cell and Hydrogen Energy Association (FCHEA)	<b>Associations / Non-profits</b>
<b>Novachek, Frank (Chair)</b> Xcel Energy	<b>Utilities (Electricity and Natural Gas)</b>
<b>Ogden, Joan</b> Professor, Dept. of Environmental Science and Policy, UC Davis	<b>Academia</b>
<b>Oge, Margo</b> Office of Transportation and Air Quality, Environmental Protection Agency	<b>Environmental</b>
<b>Powell, Joseph</b> Chief Scientist, Shell Global Solutions	<b>Fuels Production</b>
<b>Ratcliff, Adele</b> Director, Manufacturing Technology Office of the Deputy Assistant Secretary of Defense	<b>Government</b>
<b>Scott, Janea</b> California Energy Commission	<b>Government</b>
<b>Thompson, Levi</b> University of Michigan	<b>Academia</b>