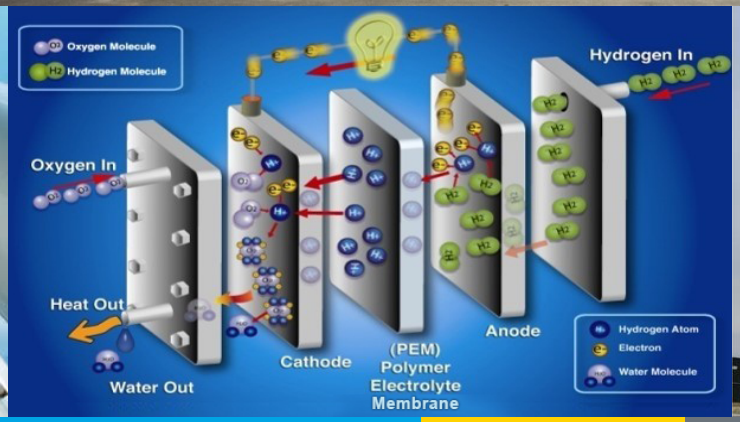
# U.S. Department of Energy
# Fuel Cell Technologies Office

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

# The Beginning of the DOE Fuel Cell Program…



## 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….

*Hyundai Tucson Fuel Cell SUV*

*Toyota Mirai*

*Honda Clarity*

Commercial fuel cell electric cars are here!

**Power, performance, petroleum-free, pollution-free**

**Refuels in minutes**

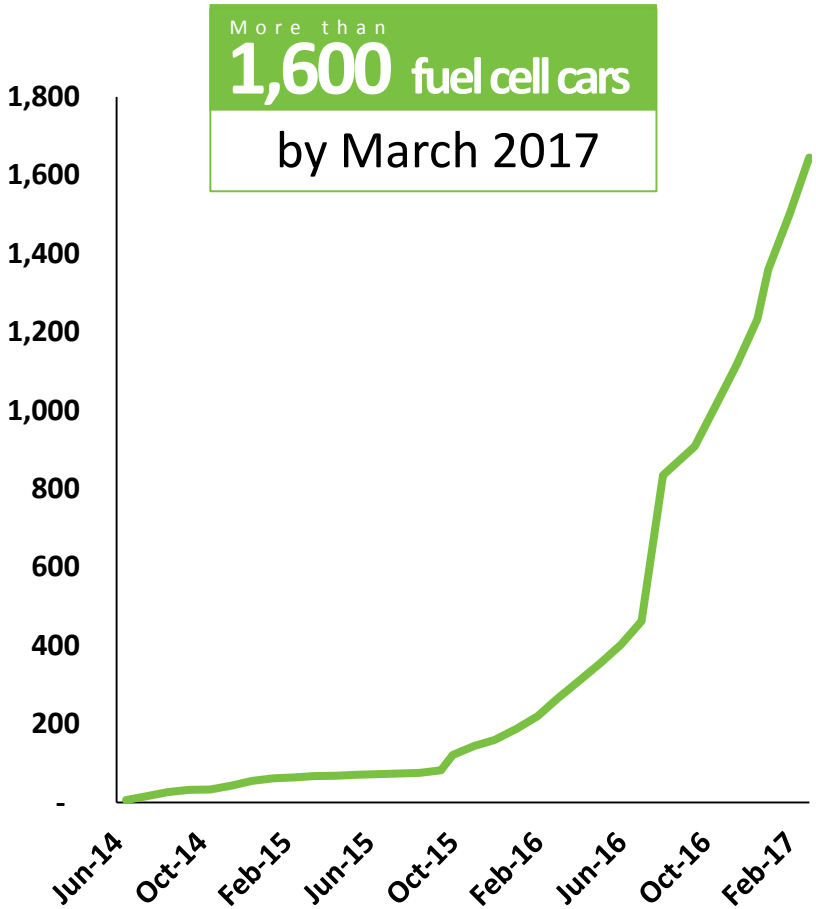
**>360 mi driving range**

**>60 mpgge**

# Fuel Cell Car Sales and $H_2$ Stations on the Rise

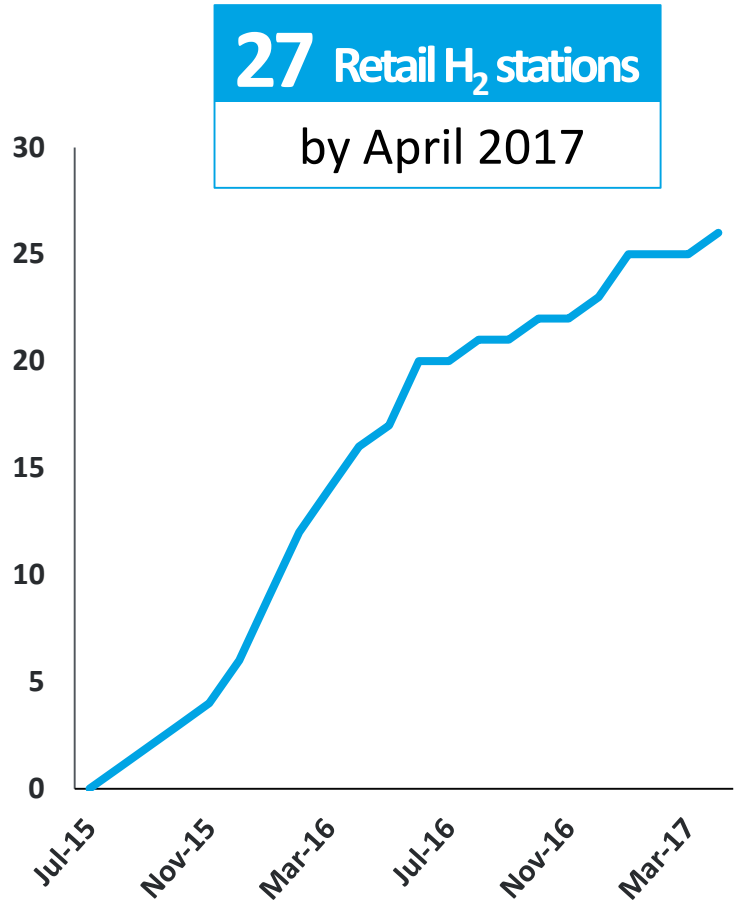


## U.S. Fuel Cell Car Sales Growing Exponentially




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

## Number of Retail $H_2$ Stations in CA Increasing



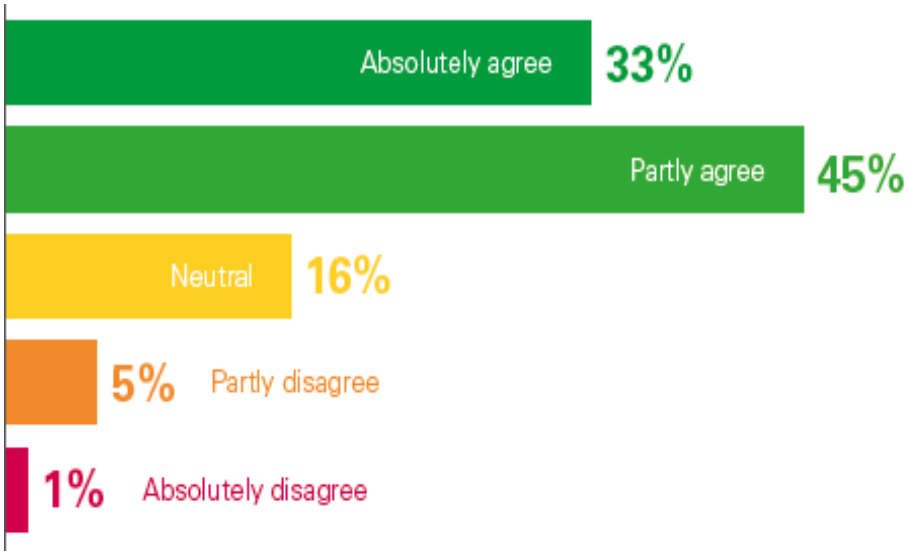

Sources: CaFCP

# 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 $H_2$ refuelings**

**Fuel cell buses surpass 15M passengers**

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

# 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

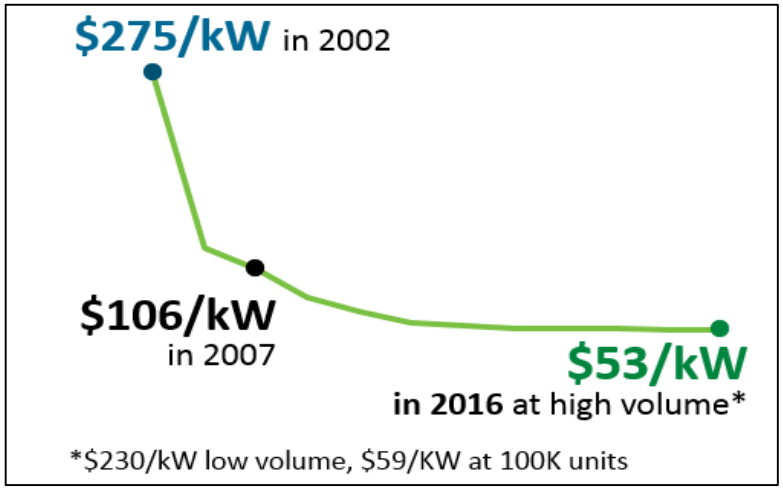
## World's first fuel cell for maritime ports

# The Role of the Government Enabling Progress



## Technology Innovation

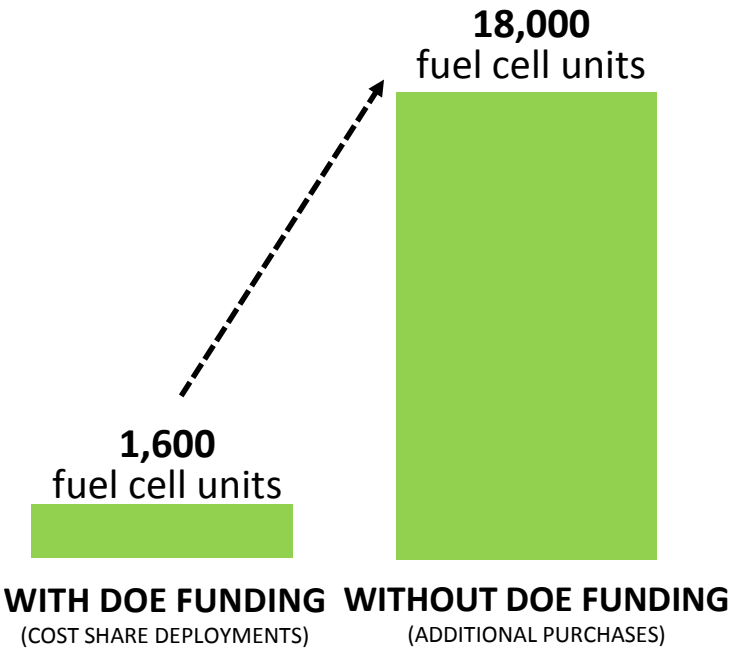
- **Cut fuel cell cost by 80%**




- **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***

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

# 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

Air Liquide (co-chair), ALSTOM, AngloAmerican, BMW GROUP, DAIMLER, ENGIE, HONDA, HYUNDAI, Kawasaki, Shell, THE LINDE GROUP, TOTAL, TOYOTA (co-chair)

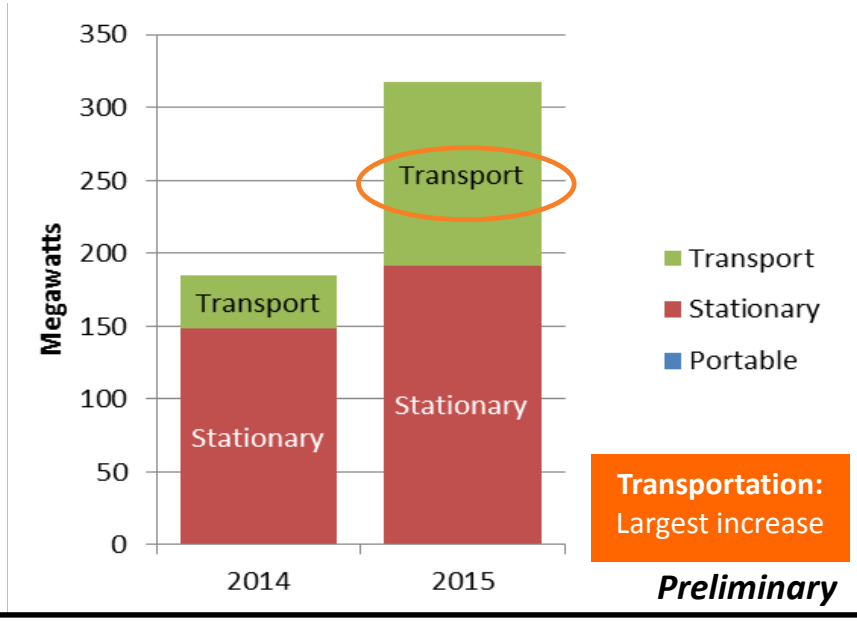
**Revenues of >$1 Trillion and 1.7 Million Jobs***

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

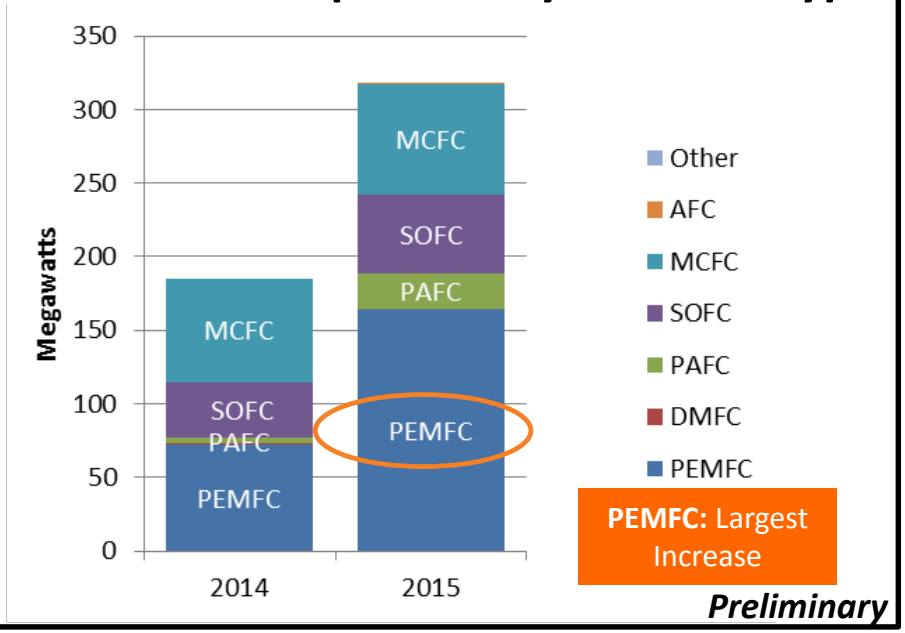
* Indicates total number of employees working at member companies.

# Global Landscape: Recent Trends

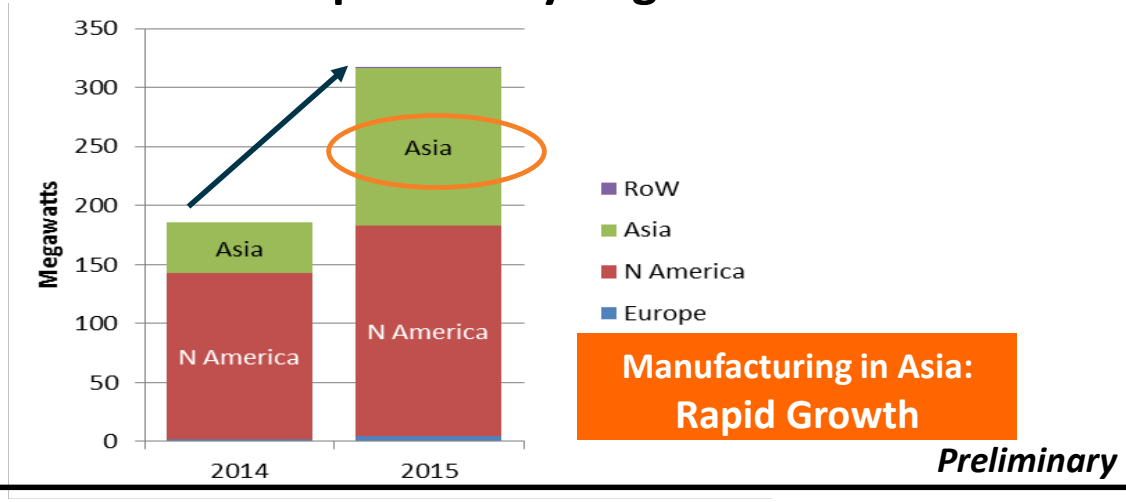
## Worldwide Shipments by Application




## Worldwide Shipments by Fuel Cell Type




## Worldwide Shipments by Region of Manufacture




## International RD&D Commitments in $H_2$ and Fuel Cells- Examples

- **Japan**: $500M & $350M to showcase H2 and FCs at the 2020 Olympics
- **EU:** $800M and industry-led H2Mobility partnership with a ~$445M budget

Source: 2014 HTAC Annual Report

# Background



**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 $H_2$ 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**

# 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
- $H_2$ energy storage/H2@Scale feedback
- Communications/outreach

## Technical

- $H_2$ cost target revision review
- $H_2$ Production Expert Panel R&D review
  - Technology deep dive by experts
- Feedback on H-Prize
  - Topics, criteria, etc.

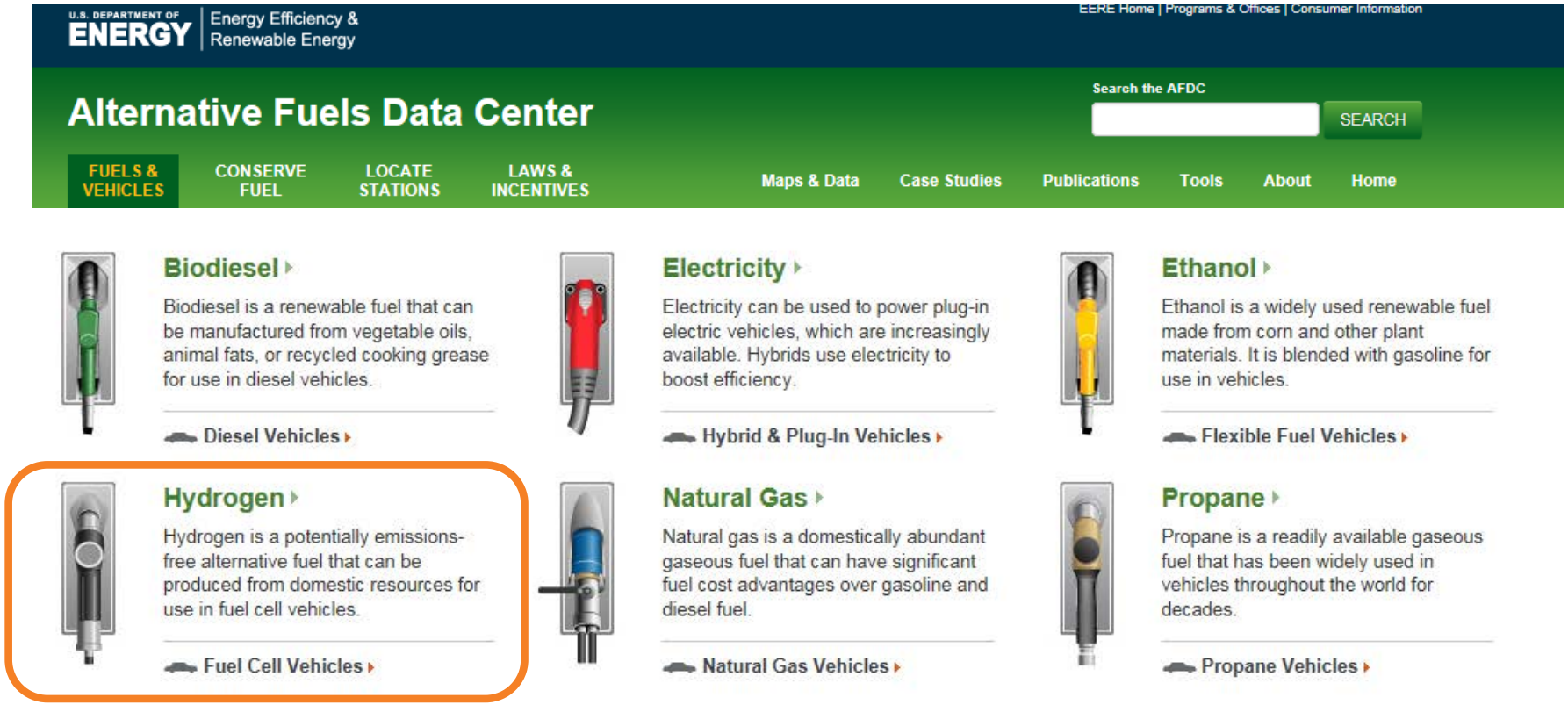
## Additional and Ongoing Needs:

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

# Example responses to HTAC recommendation



- **Recommendation:** Clean Cities program emphasis must actively promote and educate consumers on FCEV technology.
- **Response:** The AFDC has been updated with $H_2$ station language and counts.




More at: **afdc.energy.gov**

# Examples of Recommendations and Responses: Draft 2016 Hydrogen Safety and Event Response Subcommittee Report



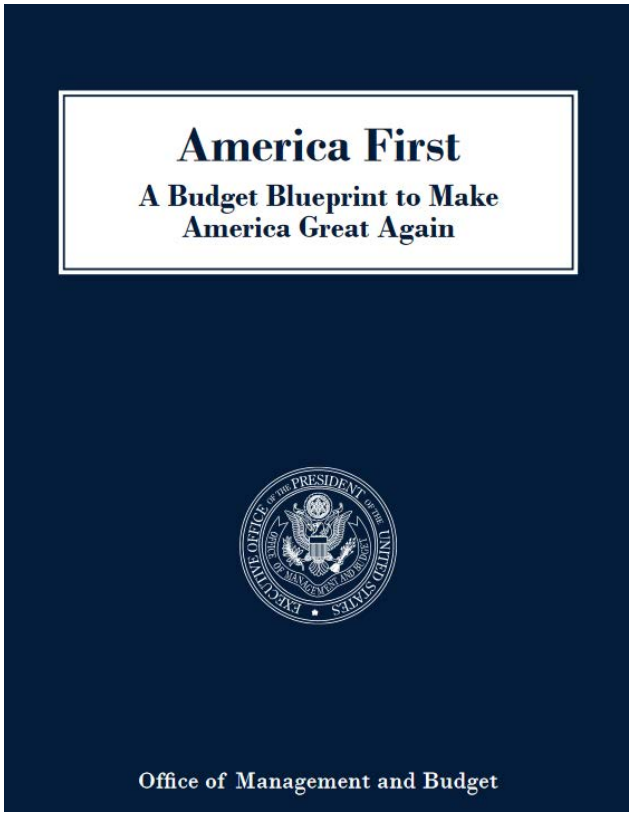
| Recommendation | Response |
|---|---|
| **Maximize the Role of the Hydrogen Safety Panel (HSP)** | Developed draft **HSP Strategic Plan focusing on broadening the impact of the Panel** and setting it up as resource to state and regional entities. |
| **Leverage the Capabilities of Public–Private Partnerships**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

# Updates since last HTAC meeting



- 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.**"



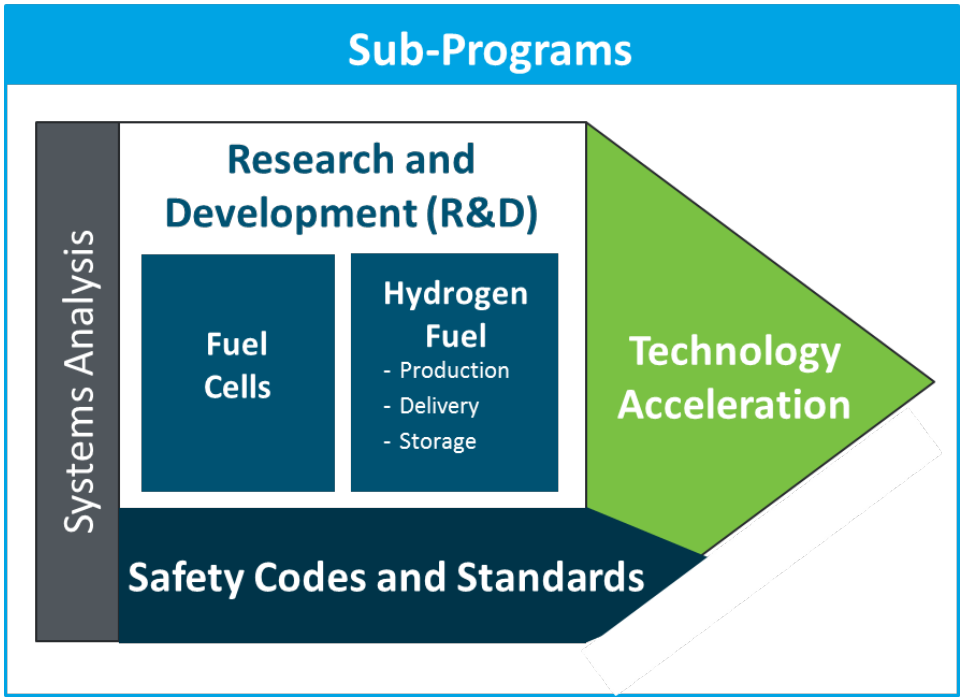

**WH Budget Blueprint released on March 16**

# 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

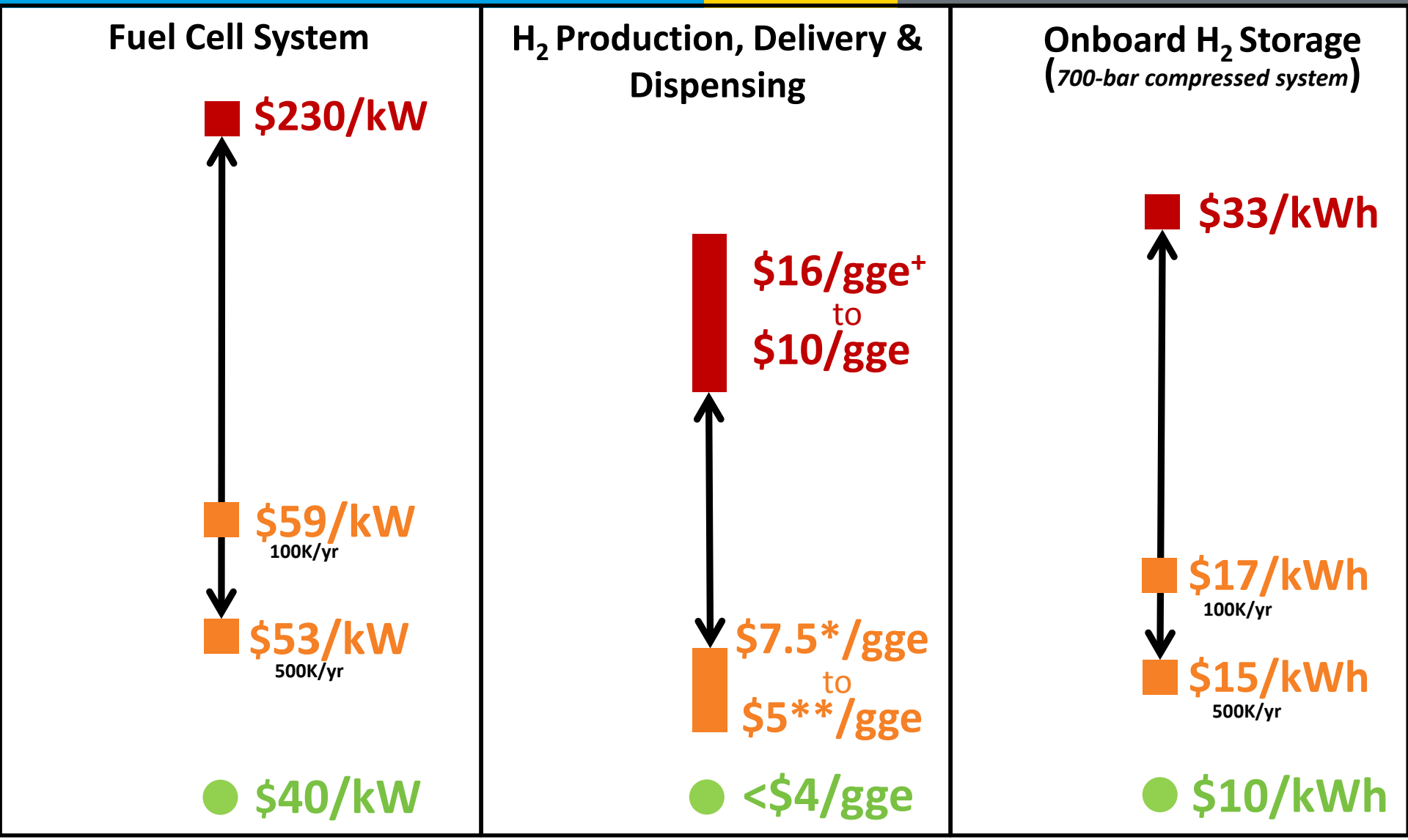
| | | |
|---|---|---|
| Fuel Cell Cost | $40/kW | $1,000/kW*<br>$1,500/kW** |
| Durability | 5,000 hrs | 80,000 hrs |
| $H_2$ Storage Cost (On-Board) | $10/kWh<br>1.8 kWh/L, 1.3 kWh/kg | |
| $H_2$ Cost at Pump | <$4/gge<br><$7/gge (early market) | |

*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






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

*For illustration purposes only, not drawn to scale*

# Techno-Economic Analysis Guides R&D Portfolio



Focusing on…

## Fuel Cells

Bipolar Plates
Membranes
BOP
MEA
Frames/Gaskets
GDLs

**Low and Non PGM Catalysts,**

**Alkaline Membranes**

## $H_2$ Station

Storage
Cooling
Dispensing
Other

**Advanced Compression**

**Alternate Approaches**

## $H_2$ Storage

BOP/Assembly
Other processing
Resin

**Low Cost Carbon Fiber (CF)**

**Long term Materials Approaches**

# Leveraging National Labs



## Consortia Launched

**Improved PEM fuel cells**

FCPAD
FUEL CELL PERFORMANCE AND DURABILITY

**PGM-free catalysts**

ElectroCat
Electrocatalysis Consortium

**Advanced $H_2$ materials storage**

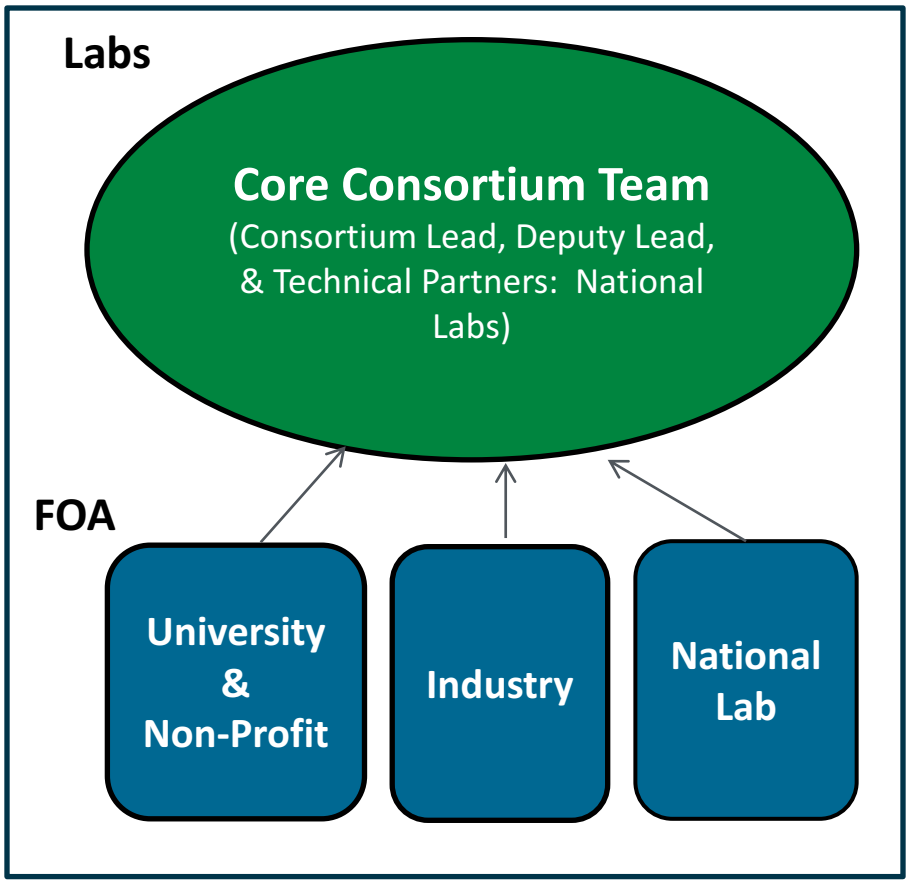
HyMARC
Hydrogen Materials Advanced Research Consortium

**Materials for renewable $H_2$ production**

HydroGEN
Advanced Water Splitting Materials

## Consortium Approach

**Multi-lab core capabilities with steady influx of new partners**



# Example: HydroGEN - Advanced Water-Splitting Materials Consortium



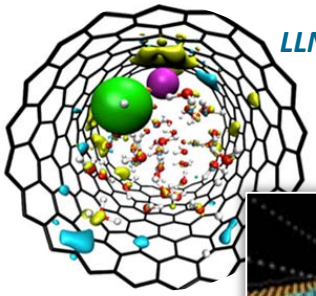
HydroGEN
Advanced Water Splitting Materials

*Core Labs*

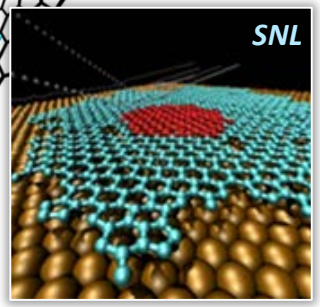
NREL, Berkeley Lab, Sandia National Laboratories, INL, Lawrence Livermore National Laboratory, SRNL

- **Accelerating the discovery & development of innovative materials critical to advanced technologies for sustainable $H_2$ production, including:**
  - ***Advanced high- and low-temperature electrochemical conversion***
  - ***Direct photoelectrochemical solar water splitting***
  - ***Direct solar thermochemical water splitting***
- **Comprising more that 80 unique, world-class capabilities/expertise in materials theory/computation, synthesis, characterization & analysis:**

## *Materials Theory/Computation*

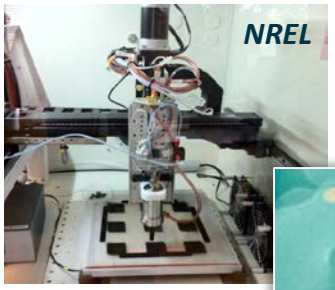



*Bulk & interfacial models of aqueous electrolytes*

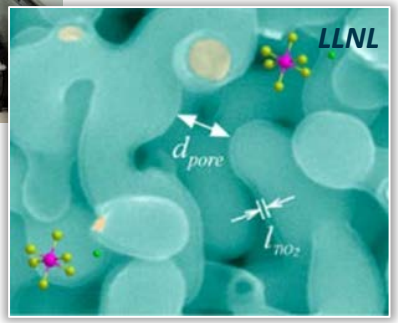



*LAMMPS classic molecular dynamics modeling relevant to $H_2O$ splitting*

## *Advanced Materials Synthesis*




*High-throughput spray pyrolysis system for electrode fabrication*




*Conformal ultrathin $TiO_2$ ALD coating on bulk nanoporous gold*

## *Characterization & Analytics*

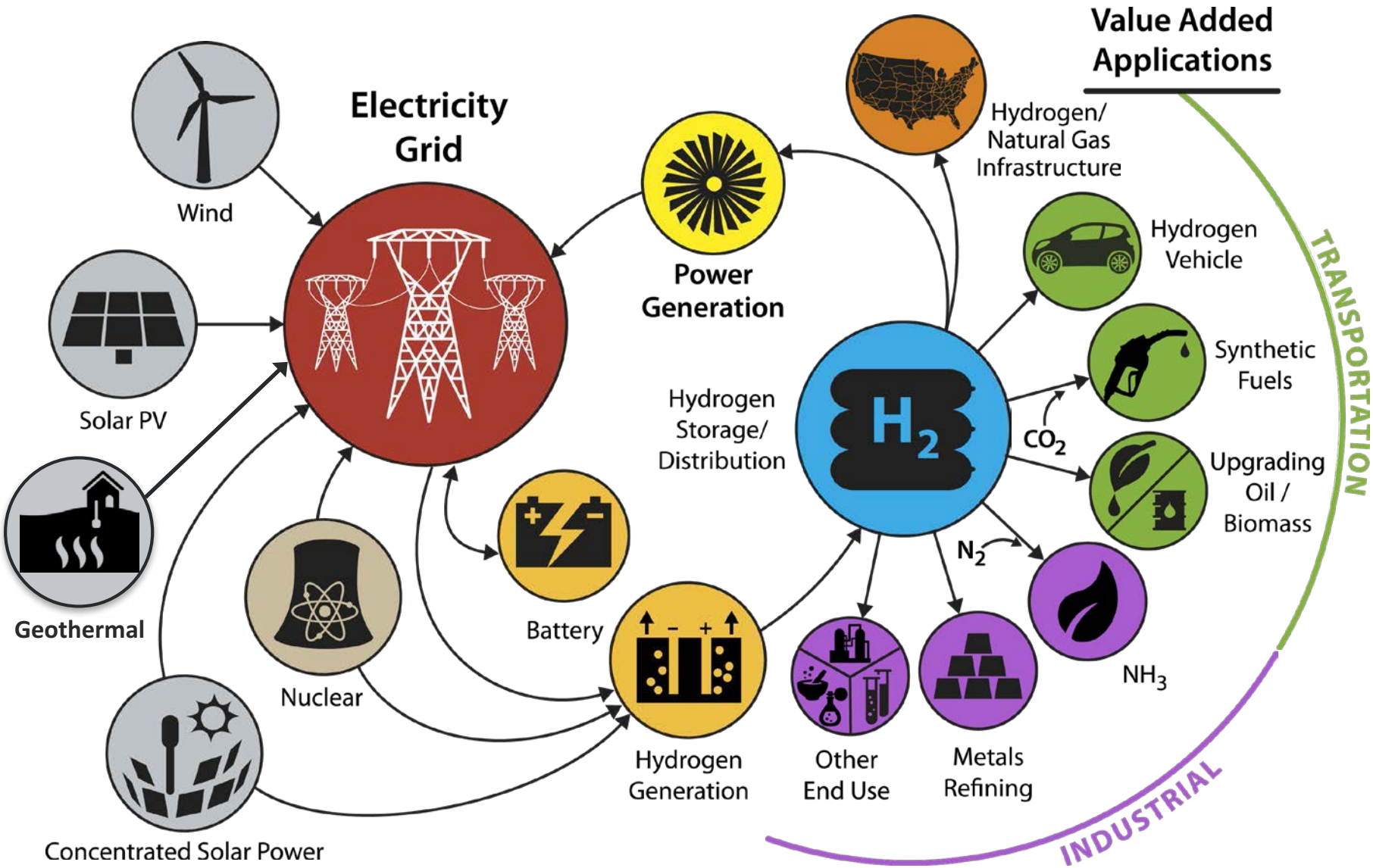
*Stagnation flow reactor to evaluate kinetics of redox material at high-T*

*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)

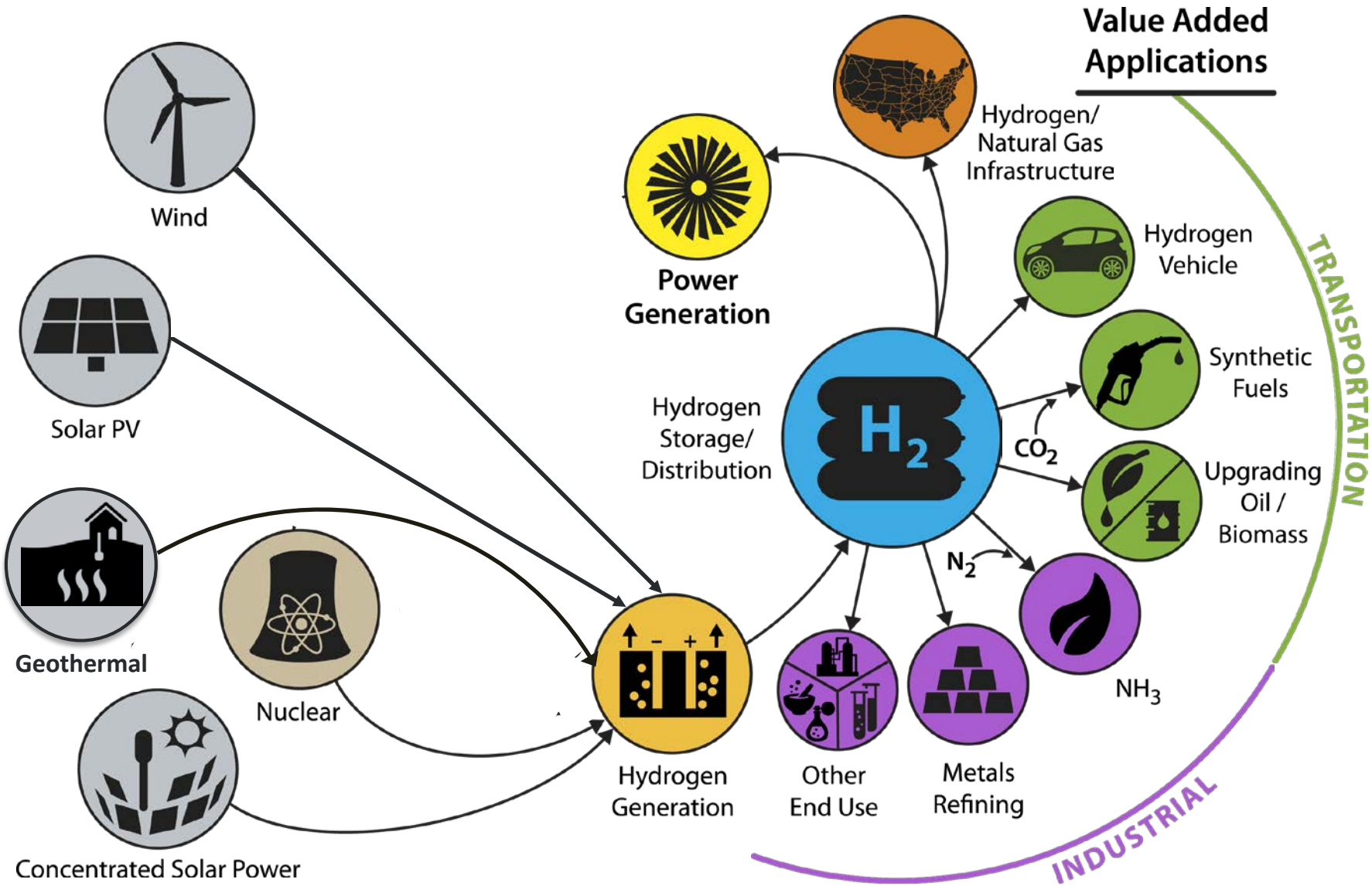





*Illustrative example, not comprehensive
Source: NREL

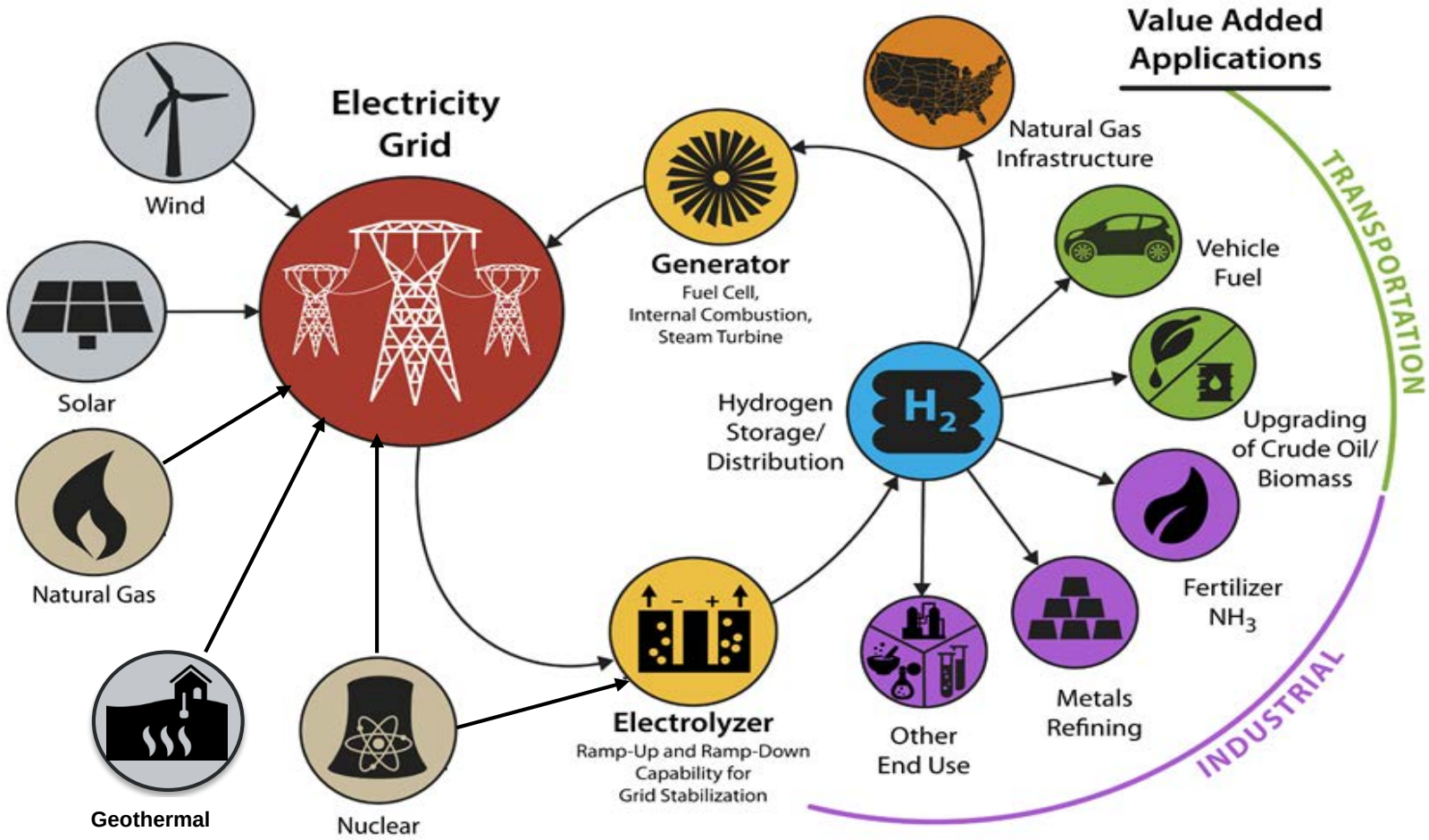
# Launched H2@Scale (updates at this HTAC meeting)





# H2@cale R&D areas (examples)






| Electrolyzer integration | Electrolyzer and Components | Wide-Scale Infrastructure |
|---|---|---|
| - Grid<br>- Renewable power generation<br>- Nuclear power generation | - Low PGM Catalysts<br>- Manufacturing<br>- High-temp. electrolysis | - Compression<br>- Storage<br>- Delivery |

# Strategic Direction

- **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**

**hydrogenandfuelcells.energy.gov**

# Fuel Cell Technologies Office FY17 Omnibus Budget



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

| | House Bill Recommendation | Senate Bill Recommendation | Conference Agreement |
|---|---|---|---|
| **Fuel Cell Technologies Office** | **$97,000,000** | **$92,000,000** | **$101,000,000** |
| Difference from FY 2016 Enacted | *($3,950,000)* | *($8,950,000)* | *$50,000* |
| Difference from FY 2017 Budget Request | *($8,500,000)* | *($13,500,000)* | *($4,500,000)* |

**FY16 Total DOE Hydrogen and Fuel Cells Funding: ~$156M**

FCTO ($101M), BES ($24.7M), FE ($30M)

# FY17 Omnibus Budget



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

# FY17 Omnibus Budget



| | HOUSE | SENATE | CONFERENCE |
|---|---|---|---|
| | *Total Recommendation:* **$97,000,000** | *Total Recommendation:* **$92,000,000** | *Total Recommendation:* **$101,000,000** |
| *Safety, Codes, Standards* | 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. | **$7,000,000** for Safety, Codes, and Standards. | *[No direction.]* |
| *Other Direction* | 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, **$7,000,000** to demonstrate an integrated hydrogen renewable energy production, storage, and transportation fuel distribution and retailing system. | Within available funds, the agreement also provides **$7,000,000** to enable integrated energy systems using high and low temperature electrolyzers with the intent of advancing the H2@Scale concept. |

# FY17 Omnibus Budget



| | HOUSE | SENATE | CONFERENCE |
|---|---|---|---|
| | *Total Recommendation:* **$97,000,000** | *Total Recommendation:* **$92,000,000** | *Total Recommendation:* **$101,000,000** |
| *Other Direction* | 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. | *[No direction.]* | *[No direction.]* |

# White House Blueprint Language



"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*

# 2017 HTAC Members



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

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