The Hydrogen and Fuel Cell Technical Advisory Committee
Washington, D.C.

June 29, 2017

The Honorable Rick Perry
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave. SW
Washington, D.C. 20585

Dear Mr. Secretary:

On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), I hereby submit the Committee's 2016 Annual Report. The HTAC duties, under Title VIII of the Energy Policy Act of 2005, SEC. 807, are to review and make recommendations to you, the Secretary, on: (1) the implementation of programs and activities under Title VIII; (2) the safety, economical, and environmental consequences of technologies for the production, distribution, delivery, storage, or use of hydrogen energy and fuel cells; and (3) the Department of Energy (DOE) plan under section 804. The enclosed report summarizes the Committee's observations and recommendations in this regard.

The success of our Committee has been enabled by our very cooperative working relationship with your Department's Fuel Cell Technologies Office (FCTO). The progress made this year in the areas of fuel cell and hydrogen technologies clearly demonstrates their commitment, and that progress is even more evident when comparing the state of these technologies to that during the early days of President Bush's Hydrogen Fuel Initiative. The Office effectively orchestrates the Department's ongoing efforts on fuel cell durability, costs, advanced research and manufacturing, codes and standards and infrastructure. It also provides important leadership for other programs, including H2USA, the public-private partnership focusing on fueling infrastructure for fuel cell electric vehicles (FCEVs). The HTAC has received sustained support and strong engagement from key members of your leadership team over the past several years, particularly the Office of Energy Efficiency and Renewable Energy (EERE) Deputy Assistant Secretary for Sustainable Transportation, Reuben Sarkar, and FCTO Director, Sunita Satyapal. We also valued the opportunity to meet and speak with your then newly appointed Acting Assistant Secretary for EERE, Daniel Simmons during our May 5 meeting in Washington, DC. The Committee very much appreciates the advice they provide on how our Committee can best advise both you and the Department to help it complete its mission to support commercial hydrogen and fuel cell deployment within the United States.

Observations/Recommendations from 2016 HTAC Annual Report and Supporting Efforts

Be assured that as we share our observations and recommendations with you, the Committee stands ready to support you and the Department in addressing the challenges during this critical period. We respectfully request that you consider the following points, as you balance the many priorities facing you.

- ***The hydrogen and fuel cell industries made steady progress in 2016, in advancing hydrogen and fuel cell system utilization.*** *Noteworthy were ongoing R&D developments and growing sales in the stationary, transportation, backup, off-grid, military and material handling sectors.*
- ***The U.S. has led the world in developing fuel cell and hydrogen technologies, but our leadership position is now potentially at risk.*** *Most commercial advances in the areas of FCEVs, stationary power, and hydrogen technologies are now from outside the U.S., creating a growing gap in leadership and competitiveness. The importance of federal support in these areas cannot be understated.*
- ***Securing industry commitments to high volume manufacturing requires clear and stable policy.*** *FCEVs and associated refueling infrastructure investments are capital intensive and require a predictable environment, with a pathway to positive long-term economic returns. Commitments in line with those for Battery Electric Vehicles would send a clear signal of that promise and encourage the sharing of R&D between these complementary technologies.*
- ***The Committee reasserts that the U.S. is still not on track to meet the 2020 EPACT Title VIII goals for FCEVs.*** *Evidence shows that even the 2015 Title VIII goals have still only partially been met, and only in California where state zero emission vehicle (ZEV) mandates (with favorable "travel provisions" that are well aligned with the Title VIII goals) exist.*
    - *DOE support is critical to continue efforts in material and process integration and technology acceleration in order to meet the 2020 goals. Rapid learning cycles and manufacturing scale economies are essential prerequisites to overcome challenges in reducing costs to competitive levels.*
    - *DOE support is also critical to ensuring positive retail hydrogen fueling experiences, especially during early stage vehicle and fueling infrastructure deployments.*
    - *Extending federal FCEV tax credits and power generation investment tax credits is an essential enabler to promoting fuel cell commercialization and achieving Title VIII goals.*
    - *The Department should provide an explicit plan in 2017-2018, including measureable milestones, stating how the 2015 and 2020 Title VIII goals will be achieved and how the plan will be funded.*
    - *The Clean Cities Program should continue its emphasis on actively promoting and educating consumers on FCEV and hydrogen technologies along with promoting compressed natural gas, biofuel, renewable diesel, and electricity solutions.*
- ***The Committee finds the Department's updated draft Hydrogen and Fuel Cells Program Plan to be comprehensive and should be effective in meeting its objectives with appropriate resource commitments.***

In addition to the 2016 HTAC Annual Report, I have enclosed a report of the HTAC's Safety and Event Response Subcommittee, which provides an assessment of the current status of resources and practices that support a comprehensive, consistent, and coordinated response to hydrogen safety-related events. This assessment was deemed necessary by the Committee because of the potential for even a single safety related fueling event to negatively influence public perception about hydrogen fuel cell vehicles. Ms. Catherine Dunwoody (Assistant Chief, Monitoring and Laboratory Division, for the California Air Resources Board) led this Subcommittee. She and her cross-cutting team of experts worked with the goal of enabling the community of hydrogen stakeholders to understand event causes, address issues, share learnings, communicate status effectively with multiple stakeholders, including media, and maintain focus on advancing commercialization of hydrogen fuel. The recommendations from the report are summarized below.

- ***Recommendation #1: Maximize the Role of the Hydrogen Safety Panel (HSP)***

  DOE should develop a strategic plan that ensures continuation of safety and event response R&D activities that are fundamental to overall Program success. This includes a key element to position the HSP as a trusted resource on hydrogen safety and invest in marketing to make the HSP more visible. The plan should also provide resources to enable the HSP to develop relationships with safety officials at the local, state, and national levels. At the same time, state and privately funded projects should also budget for HSP involvement,

- ***Recommendation #2: Leverage the Capabilities of Public–Private Partnerships, Including Clean Cities Coalitions and Other Regional Partnerships***

  The broader stakeholder community can play an important role in supporting those who are new to the industry and communicating information to the media regarding hydrogen properties and safety.

- ***Recommendation #3: Take Steps to Support Reopening Hydrogen Stations in a Timely Fashion After a Safety-Related Incident***

  Hydrogen stations should be able to recover and reopen from safety-related incidents on a timeline similar to incidents at gasoline stations. Helping to establish clear event response decision tree procedures and response timelines is important in this regard.

- ***Recommendation #4: Identify and Support Other Federal and State Agencies that Need to Incorporate Hydrogen into Their Programs***

  Hydrogen fuel is on a trajectory to be as familiar as gasoline fuel as we move toward low-carbon, zero-emission fuels. Federal and State agency coordination is critical to achieving that end, and enhanced efforts should be made to connect Federal and State level programs for shared learning and knowledge transfer.

Hydrogen and fuel cells have an integral role in your portfolio approach to ensuring our nation's energy security. As such, The HTAC respectfully asks that that appropriate resources continue to be dedicated to this program to meet its congressional intent and to help the country achieve its energy security goals. We look forward to continuing our service to you, your Department of Energy team, the Fuel Cell Technologies Office, and the nation in advancing this important subset of the 21st Century U.S. energy system. We welcome your feedback and any ideas about how we can best support you.

Sincerely yours,

Frank J. Novachek

Chairman, HTAC
On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee

2016 HTAC ANNUAL REPORT SUMMARY

This Annual Report of the United States (U.S.) Department of Energy (DOE) Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) highlights worldwide advances and challenges in 2016 regarding hydrogen and fuel cell commercialization, policy, regulations, standardization, financial climate, and research and development (R&D).

Progress in 2016 has moved hydrogen and fuel cells toward greater realization of their potential to provide reliable and efficient power, serve as an energy storage medium, and create U.S. manufacturing jobs. There were growing shipments in commercial markets, including motive, stationary and portable applications, and new technical milestones and cost reductions were reached through ongoing research, development & demonstrations (RD&D) conducted by national laboratories, industry and academia. Continued investment in R&D and vehicle fueling infrastructure will enable these technologies to fully contribute to the nation's energy security and domestic economic resilience. Highlights from 2016 include:

- **Progress on the DOE "Hydrogen at Scale" (H2@Scale) concept** introduced in 2015. H2@Scale addresses the potential of hydrogen production to enable resiliency of the power generation and transmission sectors, while simultaneously serving multiple domestic industries and reducing U.S. emissions. Preliminary analysis performed by the national laboratories on the H2@Scale concept indicated that wide-scale use of electrolytic hydrogen can reduce U.S. petroleum consumption by about 1.2 billion barrels per year. An in-depth analysis is now underway to project future price points of electrolytic hydrogen, and thereby more accurately estimate future demand and value proposition.
- **Introduction of a third commercial fuel cell electric vehicle (FCEV), the Honda Clarity Fuel Cell**, to California customers in December 2016. Toyota and Hyundai have sold or leased more than 1,000 FCEVs in the U.S. and nearly 3,000 worldwide through late 2016.[1]
- **The addition of 18 retail hydrogen stations in California**, with a total of 25 hydrogen stations operating in the state at the end of the year.[2]
- **An announcement by Toyota and Air Liquide of the locations of the first four northeast public hydrogen stations, to be sited in Connecticut, New York, and Massachusetts.** These are the first in an initial 12-station refueling network that will span 300 miles across five states to support the introduction of FCEVs.[3]
- **Development of the Hydrogen Station Equipment Performance (HyStEP) testing device to validate operation of new hydrogen stations**. The open-source designs, developed by Sandia National Laboratories and the National Renewable Energy Laboratory, can be used to accelerate hydrogen fueling station deployment.[4]
- **The sale of approximately 50,000 Ene-farm residential fuel cell systems in Japan**, with a total of 190,000 Ene-farm fuel cells installed since 2009.[5]
- **Ten percent growth in natural gas fuel cell power generation installations, dominated by U.S. companies and technology.**[6]

Despite ongoing progress, challenges remain for the hydrogen and fuel cell industry. These challenges include:

- Reducing hydrogen cost from renewable resources below $2/kilogram, a key to the success of H2@Scale.
- Additional reductions in catalyst material costs for membrane electrode assemblies (MEAs) for low temperature fuel cell and electrolyzer systems.
- Better system integration and reduced component costs for lower balance-of-plant costs.
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell system manufacturing.
- Reduction in components costs, improved compressors and metering/metrology for hydrogen refueling stations.
- Lower cost and simpler systems for continuous monitoring of impurities and contaminants in hydrogen gas streams.

In addition, two federal tax credits expired at the end of 2016: the 30 percent Investment Tax Credit (ITC) for stationary fuel cell systems and forklifts; and the Fuel Cell Motor Vehicle Tax Credit of up to $8,000. Expiration of these incentives is expected to significantly slow adoption.

Evidence suggests the U.S. is still not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. In response to the Committee's recommendation on this issue in 2015, DOE committed to provide the Committee a strategy paper outlining a pathway toward those goals. The Committee stands ready to provide feedback on that paper once it is developed.

The hydrogen and fuel cell industries made steady progress in 2016, with ongoing R&D developments and growing sales in the stationary, transportation, backup, off-grid, military and material handling sectors. Significant developments include:

- Three automakers now sell commercial FCEVs in the U.S. (California), Asia, and Europe. In California, 1,074 FCEVs were sold or leased in 2016, up from 112 FCEVs sold or leased in 2015.[7] Worldwide sales approached 3,000 units.
- Twenty-five retail hydrogen stations were open in California at the end of 2016, up from six in 2015, and more stations are in development.[8] Ninety-two new stations were opened worldwide.[9]
- Twenty-four fuel cell buses carry transit riders in the U.S. (California, Delaware, Massachusetts, Michigan, Ohio) and more deployments are planned. Fuel cell bus durability reached 23,000 hours, surpassing the DOE and FTA 2016 target of 18,000 hours, and range has reached up to 340 miles, more than 13 percent above the 2016 target.[10] Average fuel economy is 1.4 to 1.9 times higher than conventional diesel buses.[11]
- The number of fuel cell residential combined heat and power (CHP) units in Japan is approaching 200,000 with about 50,000 Ene-farm systems deployed in 2016.
- The H2@Scale concept moved beyond the National Lab team and DOE offices to include industrial/other stakeholders. The concept describes the potential for multi-sector energy benefits of wide-scale renewable hydrogen production.
- The California Fuel Cell Partnership (CaFCP) released a Medium & Heavy-Duty Fuel Cell Electric Truck Action Plan. Categories selected as the most feasible near-term vehicle platforms are the Class 4-6 urban "last mile delivery" trucks and Class 7-8 short haul/drayage trucks.

Unfortunately, 2016 also saw the expiration of the federal Investment Tax Credit (ITC) for most non-solar renewable energy technologies, including fuel cells and hydrogen. A federal FCEV tax credit of up to $8,000 also expired at the end of 2016. The expiration of these incentives is expected to significantly slow adoption rates.

Industry Metrics

Key industry metrics, reported in an annual assessment by E4Tech, *The Fuel Cell Industry Review 2016*, show worldwide fuel cell shipments increased by two-thirds on a megawatt basis, growing from 298 megawatts (MW) to 478 MW. On a unit basis, global fuel cell shipments grew from almost 61,000 units in 2015 to more than 65,000 in 2016. The increase in unit shipments, combined with a large increase in megawatts shipped, indicates many shipments were larger units.[12]

North American unit shipments grew slightly, from 6,900 fuel cells in 2015 to 7,300 in 2016, but on a megawatt basis, North America almost doubled the previous year's shipments, growing from 108 MW in 2015, to 209 MW in 2016.[13]

Asia supplied almost 54,000 of the total global shipments of more than 65,000 fuel cell units. Asia also shipped almost 246 MW, more than half of the 2016 global total of 478 MW.[14]

In 2016, FCTO reported other milestones, including:[15]

- More than 4 million passengers on fuel cell buses;
- More than 11,000 fuel cell forklifts in operation;
- More than 1,100 FCEVs sold or leased in the U.S.;
- More than 1.5 million hydrogen refuelings;
- The finding that 10-kW solid oxide fuel cell (SOFC) systems in volume production (50,000 units annually) would meet the DOE 2020 equipment cost target.[16]

Fuel cell technology was originally developed in the U.S. Despite aggressive, well-funded competition from Europe and Asia, U.S. products and technology still hold a strong position. Fully commercializing fuel cell technologies will mean significant high-wage job growth and economic gains for American companies. Figure 1 highlights the impact of DOE's fuel cell and hydrogen RD&D activities and U.S. job potential.

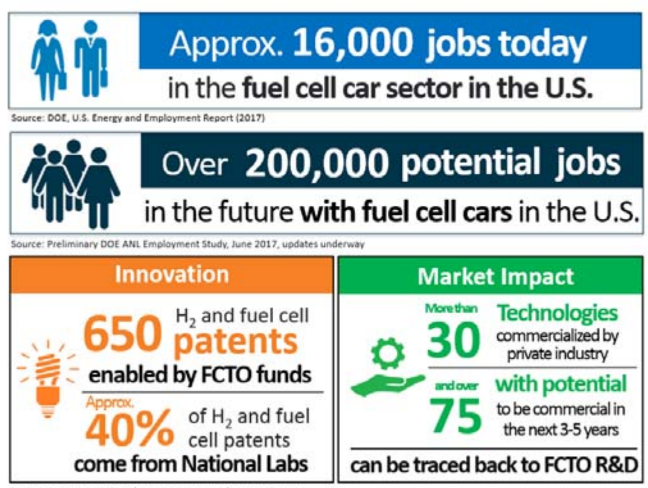


Figure 1: Fuel Cell Technologies Office (FCTO) Program Impact: H2 and Fuel Cells. *Source: DOE FCTO*

EPACT 2020 Goals

2016 accomplishments are important as the year 2020 approaches – a milestone year highlighted in Title VIII of the U.S. Energy Policy Act of 2005 (EPACT), which set forth the following goals for FCEV commercialization:

1) "To enable a commitment by automakers no later than year 2015 to offer safe, affordable, and

technically viable hydrogen fuel cell vehicles in the mass consumer market and to enable production, delivery, and acceptance by consumers of model year 2020 hydrogen fuel cell and other hydrogen-powered vehicles that will have, when compared to light duty vehicles in model year 2005: 1) fuel economy that is substantially higher; 2) substantially lower emissions of air pollutants; and 3) equivalent or improved vehicle fuel system crash integrity and occupant protection;" and

2) "To enable a commitment not later than 2015 that will lead to infrastructure by 2020 that will provide: 1) safe and convenient refueling; 2) improved overall efficiency; 3) widespread availability of hydrogen from domestic energy sources; and 4) hydrogen for fuel cells, internal combustion engines, and other energy conversion devices for portable, stationary, micro, critical needs facilities, and transportation applications."

Considerable progress has been made toward these goals since 2005, and the 2015 commitments have been partially met. Efforts such as H_2USA have brought industry and government together working in important ways toward these goals. FCEVs by three manufacturers have now been fully safety certified and offered for sale or lease; more are expected in the 2018–2020 timeframe. In the U.S. this progress has been mostly driven by state-level zero emission vehicle (ZEV) programs. Support does not appear to be adequate to spur the momentum needed to achieve the 2020 EPACT goals.

In response to the Committee's recommendation on this issue in 2015, Acting Assistant Secretary David Friedman committed to developing a strategy paper outlining steps toward the 2020 goals. The Committee stands ready to provide feedback on that strategy once it is developed.

Significant Challenges Remain

The efficiency and environmental advantages of hydrogen and fuel cells are well demonstrated and the economic and manufacturing potential is well understood. Significant strides have been made over the last decade to improve electrolyzer and fuel cell performance and durability, and to lower costs. Fuel cells are now making inroads in early commercial markets (material handling, backup power, military, specialty products) and as an alternative option to conventional power generation.

Despite these successes, challenges remain. DOE has set technical goals and objectives to advance hydrogen production and fuel cell technologies for transportation, power generation and other market applications. The 2020 objectives include:[17]

- A 65 percent peak-efficient, direct hydrogen fuel cell power system for transportation that can achieve 5,000-hour durability (ultimately 8,000 hours) and be mass produced at a cost of $40/kW (ultimately $30/kW).
- Distributed generation and micro-CHP (combined heat and power) fuel cell systems (5 kW) operating on natural gas that achieve 45 percent electrical efficiency and 60,000-hour durability at an equipment cost of $1,500/kW.
- Medium-scale CHP systems (100 kW–3 MW) that achieve 50 percent electrical efficiency, 90 percent CHP efficiency and 80,000-hour durability at a cost of $1,500/kW for operation on natural gas and $2,100/kW when configured for operation on biogas.

The current status of technology development has been reported by DOE in the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan (updated September 2016).[18]

For light-duty vehicles, current cost modeling (2015) places the cost of an 80-kW net automotive fuel cell system based on next-generation technology and operating on direct hydrogen at $53/kW when manufactured at a volume of 500,000 units/year and $60/kW at a volume of 100,000 units/year.

For CHP systems, the plan finds that common challenges across all fuel cell types include decreasing cost and increasing durability and cell component stability. For PEM systems, challenges also include decreasing fuel processor costs and raising operating temperatures.

- While durability of residential micro CHP systems has been improved to 70,000 hours for PEM systems, the price of deployed systems (Germany, Japan) is approximately $22,000/kW for a 0.7-kW system, substantially higher than DOE cost targets.
- For medium-scale CHP/distributed generation (100 kW–3 MW), phosphoric acid fuel cells (PAFCs) and molten carbonate fuel cells (MCFCs) have demonstrated durability of >80,000 hours and >40,000 hours respectively. Increasing MCFC durability requires, among other things, a more robust cathode. Reducing PAFC costs requires increasing performance, durability and stability for catalysts and supports.
- Common technical challenges for MCFCs and PAFCs include reducing system conditioning time, developing low-cost manufacturing methods, and decreasing the cost of the fuel processor and cleanup system.
- SOFCs have demonstrated durability of >25,000 hours. High operating temperature can lead to compatibility and reactivity issues among cell and stack components, especially over extended operating times. The ability of the stack to survive repeated thermal cycling and the relatively long start-up times are additional challenges.
- DOE cost estimates for a 100-kW low temperature - PEM CHP system show that balance of plant, catalyst and fuel processor costs are the main contributors to system costs. Increasing the temperature of operation could help simplify the fuel processor, reduce costs, and provide higher quality waste heat.

Hydrogen R&D

DOE's hydrogen program has made significant R&D progress in hydrogen production, storage and delivery over the past several years. DOE continued to advance the Hydrogen at Scale Big Idea concept initiated in 2015. This project shows great potential for hydrogen and fuel cell technologies to enable resiliency of the power generation and transmission sectors, while simultaneously serving multiple domestic industries and reducing U.S. emissions.

- A workshop on the cross-cutting value proposition of H2@Scale was held November 16-17, 2016, at the National Renewable Energy Laboratory, with representation from 10 DOE offices and a total of about 170 attendees. The workshop was meant to guide the development of an H2@Scale roadmap, which is currently being drafted. The workshop report is now online: http://www.nrel.gov/docs/fy17osti/68244.pdf.
- Analysis has been completed on the technical potential of hydrogen demand and hydrogen supply from domestic resources (including renewable, nuclear, and fossil fuel feedstock). The technical potential of demand for refining, direct reduction of iron, ammonia production, use of hydrogen as a combustion fuel (via blending into the natural gas infrastructure), biofuels production, and transportation (i.e. FCEVs) has been determined to be 60 million metric tonnes per year.

The cost and durability of electrolyzers and other hydrogen production technologies need improvement to enable greater customer acceptance which will drive manufacturing volume and, in turn, enable further cost reductions. Growing markets can also stimulate infrastructure development and resolve other key challenges.

Reducing electrolytic hydrogen production costs below $2/kilogram would enable success of the H2@Scale concept and improve U.S. competitiveness within this market.

Natural gas can provide a cost effective hydrogen source for initial fueling infrastructure, but continued R&D is needed to bring renewable hydrogen to equal or lower generation costs (Figure 2). Factors such as the cost of feedstock electricity and technology utilization, or capacity factor, have a significant impact on electrolytic hydrogen production costs.

The initial costs for capital equipment, manufacturing processes, installation, and warranty associated with fuel cell and electrolyzer systems need to be reduced.

In spite of these challenges, fuel cell and hydrogen R&D conducted over the past decade has spurred significant and ongoing cost, performance and durability improvements. Today, hydrogen and fuel cell technologies are making inroads into several early market areas where reliability and efficient power generation are valued.

HTAC Activities In 2016

HTAC activities in 2016 included formation of three new HTAC subcommittees.

EXTERNAL COMMUNICATIONS: This subcommittee will develop a standard communications package that consolidates a vision, objective and supporting messages for implementing hydrogen & fuel cell technology.

Key Deliverables: The primary focus is to provide communications resources online, accessible by industry, government stakeholders and the public. The subcommittee has identified messaging gaps and subcommittee members have gathered content, organizing it into packages in the areas

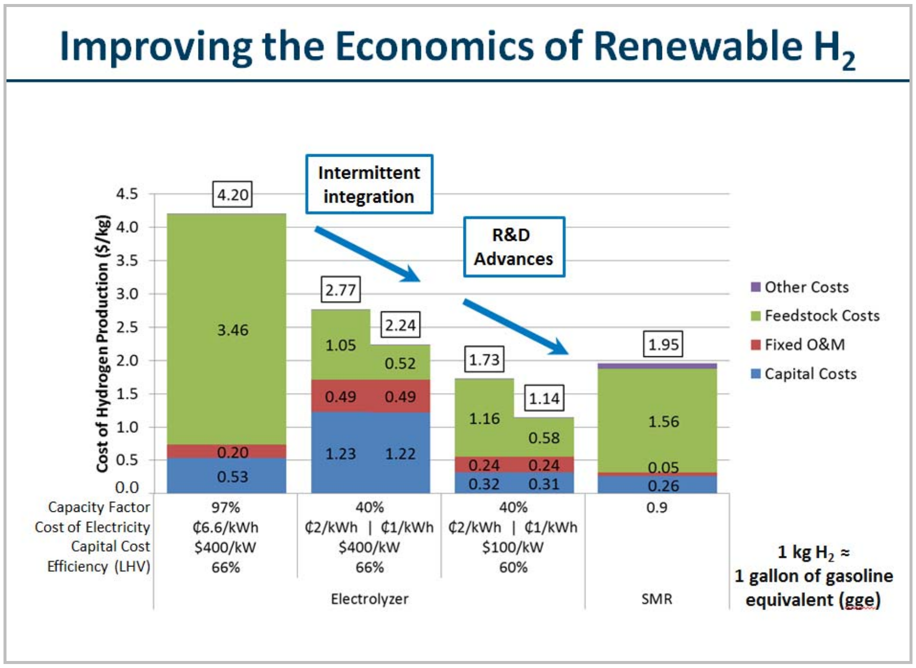


Figure 2. Improving the Economics of Renewable Hydrogen. *Source: U.S. Department of Energy*

of hydrogen, fuel cells, and electrolysis. A question-answer section will provide a streamlined location for users to review expert responses to frequently asked questions. The subcommittee plans to launch the site in 2017.

SAFETY/EVENT RESPONSE: The subcommittee has prepared a report identifying existing resources and resource gaps for responding to safety related events at retail hydrogen stations and recommended actions to address current and projected needs. The subcommittee's goal is to enable a comprehensive, consistent (to the extent practical) and coordinated response to hydrogen safety-related events to understand causes, address issues, share learnings, communicate status and maintain focus on advancing commercialization of hydrogen fuel.

Key Deliverables: The subcommittee has completed a final report that addresses technical, procedural and communications topics, identifies gaps, and offers the subcommittee's recommendations.

HYDROGEN AT SCALE CONCEPT REVIEW: The Committee actively monitored development of the H2@Scale concept. Project leads updated HTAC at both 2016 meetings. Individual members also participated in H2@Scale workshops held to solicit and incorporate feedback.

Hydrogen presents a unique potential to positively impact a number of areas. The H2@Scale value summary includes:

- Reducing greenhouse gas emissions and criteria pollutants across industrial, electrical, and transportation sectors. Analyses show that a 50 percent reduction in greenhouse gas emissions is possible by 2050.
- Supporting the needs of dynamic, variable power systems, including dispatchable, scalable storage. Additional benefits include energy security via energy diversity, resiliency and domestic energy production, manufacturing competitiveness and job creation, and decreased water requirements.

Figures 3 and 4 (next page) show the potential for sustainable hydrogen to support future energy needs across multiple sectors.

Commercialization Initiatives

Fuel cells are making significant inroads into an array of commercial sectors, including stationary power markets (primary and backup power), transportation markets (passenger vehicles, buses, trucks, rail, and forklifts), electricity grid-support applications, specialty (unmanned vehicles, aviation) and portable/off-grid applications (military, small electronics). Hydrogen, as an industrial chemical, also has broad impact for ammonia production, metal and semiconductor processing and refining of petrochemicals.

To help U.S. suppliers connect to original equipment manufacturers (OEMs) to improve the fuel cell industry supply chain, DOE supported the launch of Hydrogen Fuel Cell Nexus website in July**.** Managed by Virginia Clean Cities, the website serves as a business-to-business portal.[19]

Fuel Cells for Stationary Applications

Demand for stationary fuel cells continues to grow in both commercial and municipal applications. Systems finding markets range from micro-CHP systems to multi-MW power plants. More than 200 MW of stationary fuel cells were shipped globally in 2016, compared to 183 MW in 2015.[20]

- Bloom Energy has new or planned natural gas-powered fuel cell projects at more than 200 locations, including 40 MW at 170 customer sites for Exelon, 60 Home Depot stores integrated into Southern Company/ PowerSecure smart storage solutions, and 1.5 MW at five IKEA retail stores (Figure 5).
- Doosan Fuel Cell America partnered with Samsung C&T Corp. and Korea Hydro & Nuclear Power on a project that will supply power to 71,500 Korean homes. Seventy fuel cells will produce 30.8 MW of energy and heat.[21] Doosan also will deliver an 8-MW CHP system to Implats' South African platinum refinery.[22]
- FuelCell Energy installed a 5.6-MW CHP fuel cell power plant at Pfizer's Connecticut R&D facility.[23] FuelCell Energy has new or planned MW-scale fuel cell projects at wastewater treatment plants in Tulare and Riverside, California, and at two locations in Germany.[24]
- The European Commission's Fuel Cell and Hydrogen Joint Undertaking (FCH JU) announced it will provide almost 34 million € (US $36 million) to fund the PACE initiative, which will deploy 2,650 micro-CHP fuel cells in European to foster commercialization.[25]
- About 50,000 Ene-farm micro-CHP fuel cells were installed in Japanese homes in 2016, bringing the total installed since 2009 to more than 190,000 (Figure 5).[26]

Source: BloomEnergy.com *Source: OsakaGas.jp.co*

Figure 5: Bloom Energy fuel cells at IKEA store, Ene-farm system.

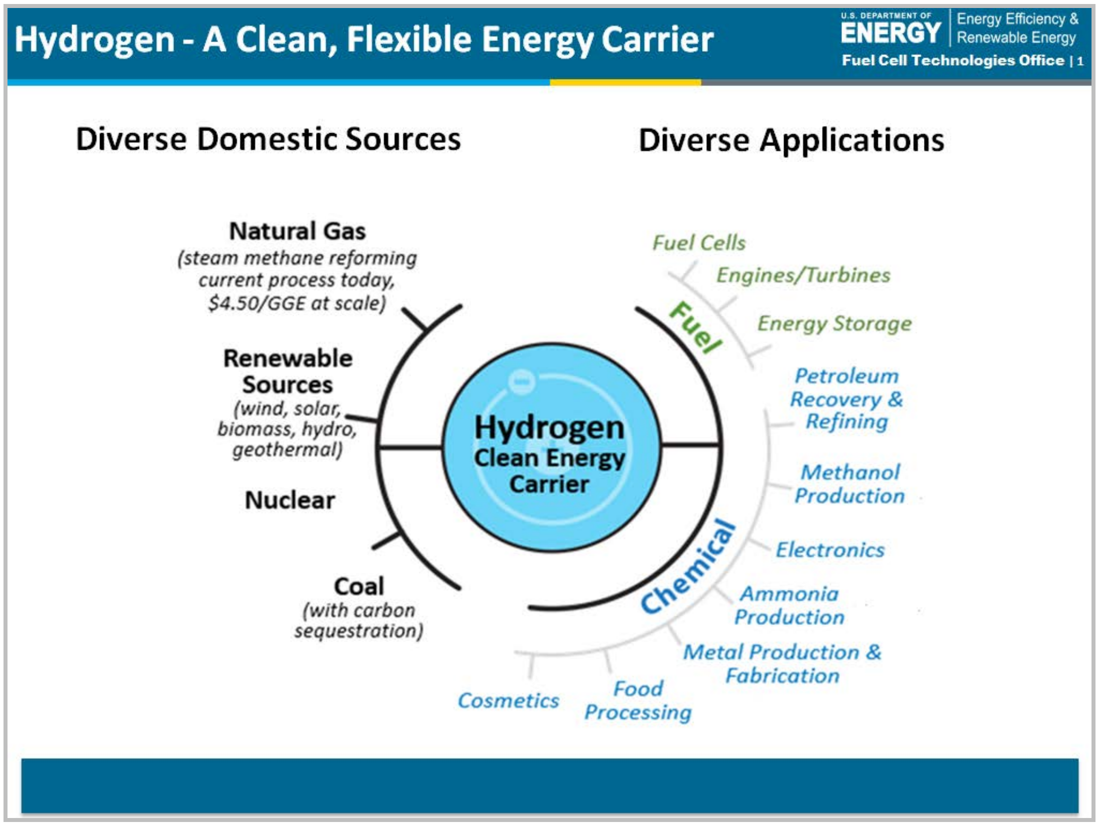
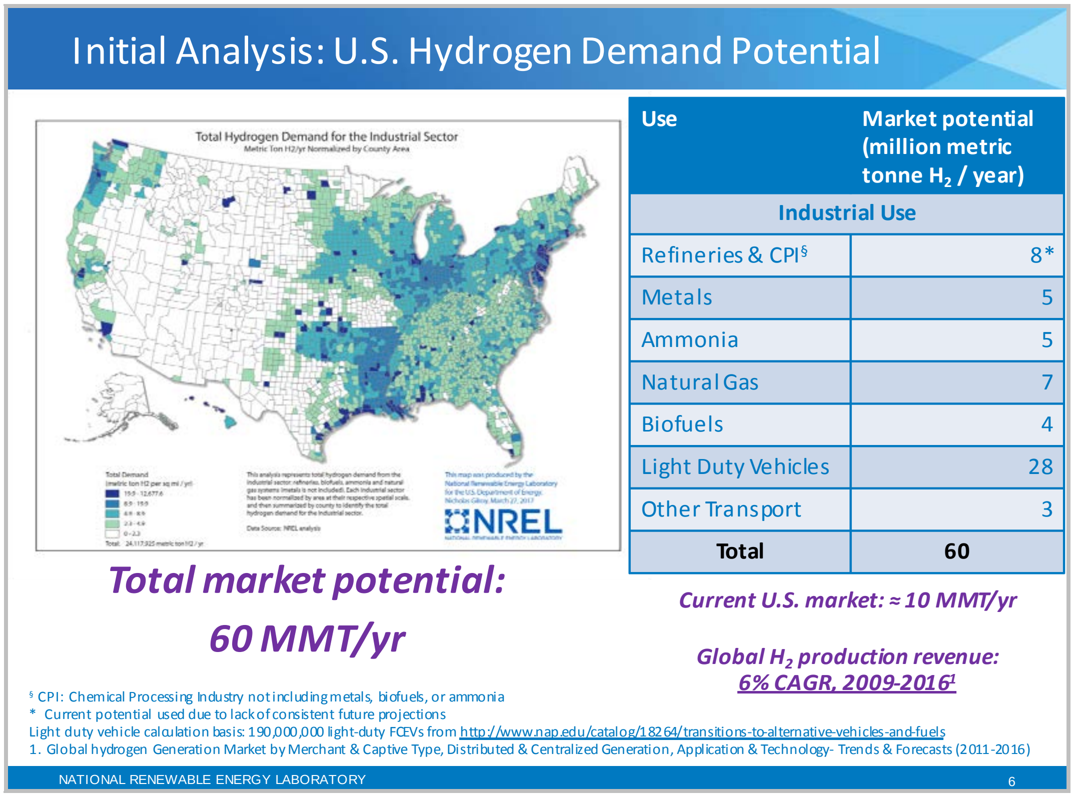


Figure 3. H2@Scale – hydrogen enables diverse feedstocks and applications. *Source: U.S. Department of Energy*



Use	Market potential (million metric tonne H_2 / year)
Industrial Use	
Refineries & CPI§	8*
Metals	5
Ammonia	5
Natural Gas	7
Biofuels	4
Light Duty Vehicles	28
Other Transport	3
Total	**60**

Figure 4. U.S. Hydrogen Demand Potential. *Source: U.S. Department of Energy*

Fuel Cells for Back-up Power Applications

More than 900 back-up power fuel cell systems have been deployed with DOE support, stimulating more than 6,900 back-up power fuel cell shipments and orders with no DOE funding. These total more than 39 MW.[27]

In addition:

- Ballard Power Systems signed an agreement for a Chinese company to exclusively manufacture and sell Ballard's fuel cell backup power systems in China.[28]
- Proton Power signed a seven-year agreement with a German company for fuel cell emergency power units to be deployed in the Bavaria region of Germany.[29]

Fuel Cells for Passenger Cars

Automakers are selling and leasing increasing numbers of FCEVs around the globe.

- Three automakers now lease or sell FCEVs in California (Figure 6). Honda began deliveries of its 2017 Clarity in December. Toyota reduced the down payment and monthly lease payment on its 2017 Mirai FCEV, which was introduced in late 2015. Hyundai began leasing its Tucson FCEV in 2014 and has announced an update for 2018.[30]
- Several car companies committed to initial or next-generation commercial fuel cell vehicle rollouts, including Mercedes-Benz and Lexus.[31]
- Honda and GM announced a Fuel Cell System Manufacturing Joint Venture, based in Brownstown, Michigan. Production will begin sometime after 2020. This partnership's primary goal is system cost reduction.
- Nissan is researching and developing a SOFC-powered vehicle system that runs on bio-ethanol.[32]

Fuel Cells for Buses

Fuel cell buses are operating in revenue service in the U.S., Asia and Europe. Fuel cell buses are a particular interest in China, which has quickly become a world leader. Hyundai, New Flyer, Toyota, and Wrightbus announced plans to produce fuel cell buses. Other key developments include:

- The AC Transit fleet of 13 fuel cell buses is approaching 2 million miles and has carried more than 15 million passengers. The initial bus, built in 2003 and never expected to survive beyond 5,000 hours, has now exceeded 23,450 hours and remains in daily service. Four others are near or beyond the 20,000-hour mark.[33]
- The Federal Transit Administration (FTA) awarded Ohio's Stark Area Regional Transit Authority (SARTA) funds to buy three more buses, bringing its fuel cell bus fleet to 10 – the largest in the U.S. outside California.[34]
- The Fuel Cell Electric Bus Commercialization Consortium (FCEBCC) will deploy 20 fuel cell buses at two California transit agencies by December 2018. Ballard Power Systems will supply fuel cells for FCEBCC's 20 buses, for SARTA's 10 buses, and for California's Orange County Transportation Authority's (OCTA) American Fuel Cell Bus (Figure 7).[35] Ballard also is supplying modules for Solaris in Europe[36] and for 22 fuel cell buses operating in China.[37]
- The U.K. government awarded £2.8 million (US$3.6 million) to Birmingham City Council and Transport for London for 42 fuel cell buses.[38]
- Toyota and Wrightbus each announced they will make fuel cell-powered buses available in 2017. Toyota's bus features a high-capacity external power supply that can be used as a power source in an emergency.
- New Flyer of America's 60-foot electric heavy-duty transit bus, which incorporates a small Ballard Power Systems fuel cell operating as an on-board battery charger, will be tested at the FTA's proving grounds.[39]

Fuel cells are being utilized in a number of vehicles, including material handling vehicles, aircraft, ships, trucks, and unmanned vehicles. Among the 2016 announcements were:

- Plug Power announced new orders and deployments, including 96 additional fuel cells for forklifts in New Jersey's Newark Farmers Market, which already operates 240 units, and several orders from French companies.[40]
- A new class of ships, in 2022, from Royal Caribbean Cruises, will use fuel cell power generation. They will test fuel cells on an Oasis-class ship in 2017.[41]
- General Motors and the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) developed the off-road capable Chevrolet

Source: Toyota.com

Source: HyundaiUSA.com

Source: Honda.com

Figure 6: Toyota Mirai, Hyundai Tucson, and Honda Clarity FCEVs.

Colorado ZH_2 FCEV; it features an Exportable Power Take-Off unit to power activity away from the vehicle (Figure 7).[42] GM and the U.S. Navy have also partnered on fuel cells for unmanned undersea vehicles.[43]

- Kenworth is building a fuel cell truck for drayage operations at a Southern California port.[44]
- EasyJet disclosed plans to use fuel cells on aircraft for taxiing, saving up to 50,000 metric tons of fuel a year.[45]
- Alstom presented its Coradia iLint fuel cell-powered train, with a range of up to 500 miles per fueling (Figure 7). The train will be tested in 2017.[46] The German state of Schleswig-Holstein plans to electrify its entire railway network using fuel cell equipment by 2025.[47]
- H3 Dynamics unveiled a fuel cell-powered unmanned aerial vehicle (UAV) capable of 10 hour/300 mile flight.[48]

Hydrogen Production and Distribution

Milestones in hydrogen production and distribution include the opening of 13 retail hydrogen stations in California, for a total of 25 public stations at the end of 2016. True Zero announced its California stations had powered 2 million miles of FCEV driving, attaining this milestone just 60 days after reaching the first million. It took nine months to reach the first million.[49]

- Hydrogenics and StratosFuel will build a 2.5 MW renewable hydrogen plant, North America's largest, in Palm Springs, California, using wind and solar power.[50]
- Proton OnSite announced a 13 MW electrolyzer order for bus fueling in China and supplied an electrolyzer to produce renewable hydrogen for Switzerland's first public hydrogen station.[51]
- A demonstration hydrogen station was opened in Washington, D.C., through a partnership of Proton OnSite, SunHydro, Air Products, DOE and the National Park Service.[52]
- Toyota and Air Liquide will open four retail hydrogen refueling stations in 2017 in Connecticut, New York, and Massachusetts. The stations are part of a network of 12 retail hydrogen stations spanning 300 miles across five northeastern states that will support FCEVs.[53]
- Japan's Ministry of Economy, Trade and Industry outlined a plan for 160 hydrogen stations in 2021, growing to 320 in 2026. Toshiba, Tohoku Electric Power and Iwatani plan to produce enough hydrogen for 10,000 FCEVs annually using solar and wind power.
- Royal Dutch Shell, Kawasaki Heavy Industries, Iwatani and J-Power are partnering to produce hydrogen from low-quality brown coal in Australia and ship it to Japan markets.[54]
- H_2 MOBILITY, a joint venture of Air Liquide, Daimler, Linde, OMV, Shell, and Total, plan to develop up to 400 hydrogen stations in Germany by 2023.[55]

Hydrogen for Grid Support Applications

- FuelCell Energy announced a solid oxide electrolysis cells (SOEC) system that converts water into hydrogen during periods of excess electricity and low demand.[56]
- University of California, Irvine, engineers implemented the first U.S. power-to-gas (P2G) hydrogen pipeline injection, demonstrating how electricity from solar or wind can be used to make hydrogen and integrated into existing natural gas pipelines.[57]
- Japan's Obayashi and Kawasaki Heavy Industries, working with Kansai Electric Power, plan to use hydrogen to generate power in Kobe in 2018 via turbines using 80 percent natural gas and 20 percent hydrogen, with 100 percent hydrogen operation considered in the future.[58]

Policy, Regulations, Codes, and Standards

Policy and Regulations

Two federal tax credits expired at the end of 2016: 1) the 30 percent Investment Tax Credit (ITC) for stationary fuel cell systems and forklifts, and 2) the Fuel Cell Motor Vehicle Tax Credit of up to $8,000 on light-duty FCEVs. Expiration of the incentives is expected to slow adoption rates.

State policy developments include:

- Ongoing and new state-level FCEV purchase incentives, including in California ($5,000, and a new $7,000 incentive for low income drivers), Connecticut

Source: GM.com

Source: Alstom.com

Source: Ballard.com

Figure 7: GM/TARDEC's ZH2 vehicle, Alstom's fuel cell train, and Orange County's American Fuel Cell Bus.

(increased to $5,000 from $3,000), Massachusetts ($2,500), Pennsylvania ($1,000), and New York (up to $2,000, starting in 2017).

- Continuation of capital cost support for stationary fuel cell systems under California's Self-Generation Incentive Program, New York's Fuel Cell Program, and Pennsylvania's Alternative and Clean Energy Program.
- New policies that support stationary fuel cells, such as tax incentives, feed-in tariffs and sustainable energy goals, were implemented in five states (Connecticut, Delaware, Massachusetts, New York, and Rhode Island).

Noteworthy policy events in 2016 in the United States included a June 23 Congressional Fuel Cell and Hydrogen Policy Briefing on Capitol Hill, celebration of the second National Hydrogen and Fuel Cell Day on October 8, and a November 17 Hydrogen and Fuel Cell Forum in Hartford, Connecticut.

Codes and Standards

Codes and standards activities during the year include:

- Publication of the International Organization for Standardization (ISO) TS 19880-1 for hydrogen fueling stations, a first step towards standardizing hydrogen filling stations, superseding guidance developed as the earlier ISO TS 20100, published in 2008. The scope covers the processes from hydrogen production and delivery to compression, storage and fueling.[59]
- Publication of CSA Group's standard HGV 4.9, *Hydrogen fueling stations,* the first standard published for an entire hydrogen fueling station.[60]
- Passage of legislation in Connecticut allowing hydrogen-fueled vehicles to be parked under grade level.[61]

Financial Climate

Key finance and partnership agreements in 2016 include:

- FuelCell Energy and Exxon Mobil agreed to pursue a new application of carbonate fuel cells that captures carbon dioxide more efficiently than conventional technology, with the potential to substantially reduce capture costs for natural gas-fired power generation.[62]
- Cenovus Energy contracted with FuelCell Energy for front-end design and engineering for a fuel cell system to capture CO_2 from flue gas of boilers used to make steam in oil sands production at a 14-MW natural gas-fired co-generation facility in Alberta, Canada.[63]
- A strategic alliance was formed between Bloom Energy, Southern Company and its subsidiary PowerSecure, for project investment and joint-technology development.
- Hydrogenics and SinoHytec established a strategic partnership for the delivery of fuel cells designed for the Chinese market. The power systems will be integrated into buses and trucks in China.[64]
- Plug Power and two Chinese companies signed a Memorandum of Understanding to develop fuel cell and hydrogen fueling solutions for China's industrial electric vehicle market. The project's long-term goal is to deliver 13,500 industrial fuel cell vehicles over three years with a widespread hydrogen fueling network.[65]
- FuelCell Energy entered into a long-term loan facility with Hercules Capital for up to $25 million.[66]

Research and Development

Research and development activities focusing on hydrogen and fuel cell technologies continues at a steady pace in industrial, government lab, and university settings.

The U.S. DOE continued to advance the H2@Scale Big Idea concept initiated in 2015. This project shows great potential for hydrogen and fuel cell technologies to support multiple demands in transportation and industry (Figure 8), enabling dramatic emission reductions across many sectors/industries.

DOE's Advanced Research Projects Agency-Energy (ARPA-E) announced two new projects:

- The Integration and Optimization of Novel Ion-Conducting Solids (IONICS) projects will work to create high performance solid ion conductors that allow ions to be mobile and store energy, serving as a lower cost, high-performance alternative to parts used today.[67]
- The Renewable Energy to Fuels through Utilization of Energy-dense Liquids (REFUEL) program supports research on technologies that use renewable energy to convert air and water into cost-competitive liquid fuels.[68]

In addition:

- Researchers at UCLA and Caltech demonstrated how altering nanoscale wires from a smooth surface to a jagged one could dramatically reduce the amount of precious metal used as fuel cell catalysts.[69]
- Researchers at Sandia National Laboratories patented a polyphenyline membrane for PEM fuel cells that operates over a wide temperature range and lasts three times longer than comparable commercial products.
- Researchers at Stanford University developed solar cells that, after electrolysis, capture and store 30 percent of the energy from sunlight into stored hydrogen.[70]

Important areas for additional R&D include:

- Additional reductions in catalyst material costs for MEAs for low temperature fuel cell and electrolyzer systems, while maintaining durability over time.
- Optimized porous transport layers for electrolyzers to enable high current density and high catalyst utilization.
- Improved membranes for high efficiency and durability over a range of operating conditions.

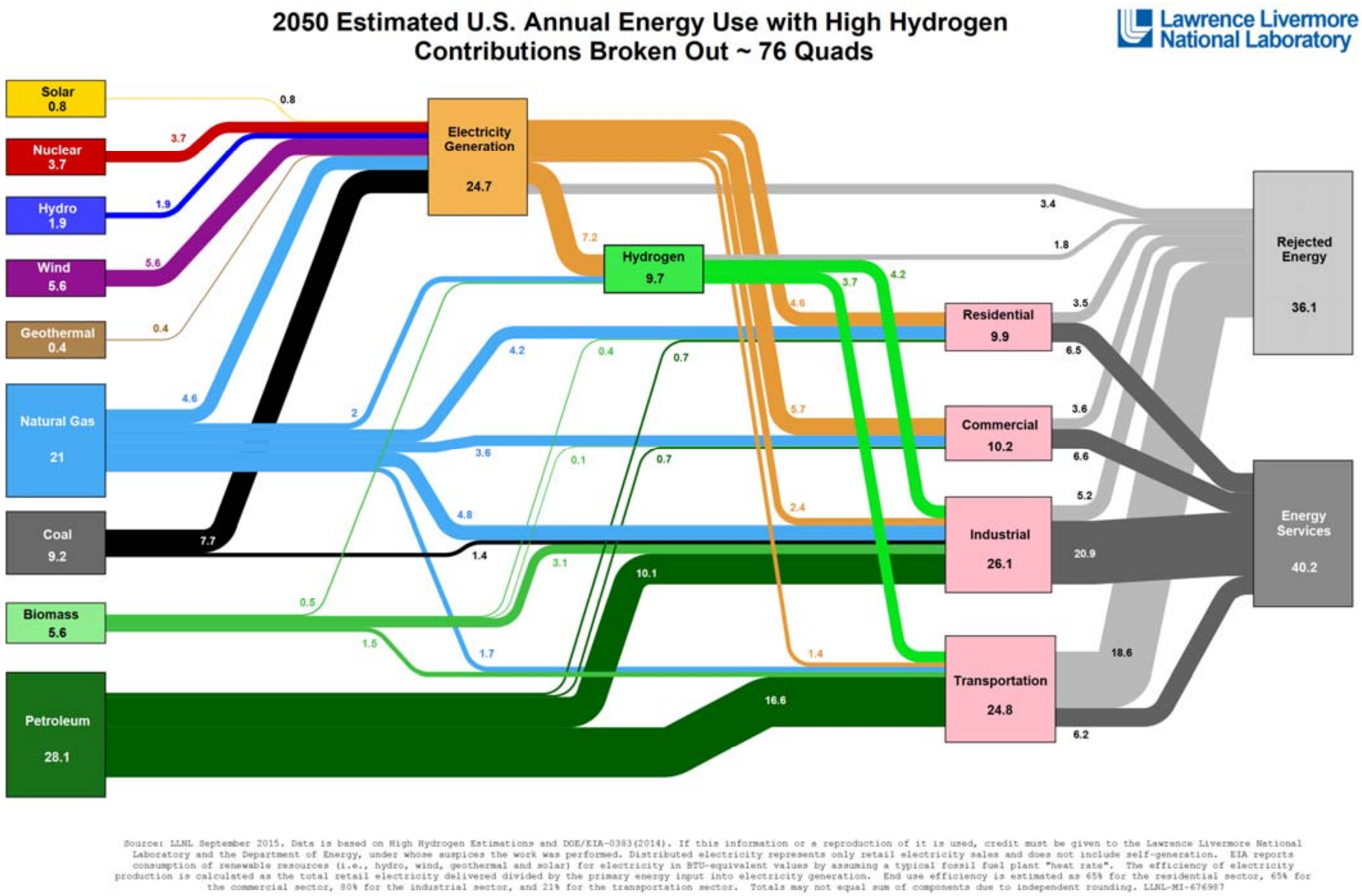


Figure 8: H2@Scale – Hydrogen Enables Diverse Feedstocks and Applications. *Source: U.S. Department of Energy*

- Better system integration and reduced component costs for lowered balance-of-plant costs.
- Improvements in manufacturing processes and yield rates for electrolyzer and fuel cell stacks and systems.
- Reduced component costs, improved compressors, and improved metering/metrology for hydrogen refueling.
- Improved and simpler systems for continuous monitoring of impurities and contaminants in hydrogen and reformate gas streams, with lowered costs.

Figure 9 presents the current cost and durability status and targets for various fuel cell market sectors.

Studies and Reports

Key reports were released in 2016 include:

- The DOE's *2015 Fuel Cell Technologies Market Report*[71]
- The DOE's *State of the States: Fuel Cells in America 2016*[72]
- The National Renewable Energy Laboratory (NREL)'s *Fuel Cell Buses In U.S. Transit Fleets: Current Status 2016*[73]
- California's *2016 ZEV Action Plan*[74]
- The California Air Resource Board's *2016 Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*[75]
- The California Fuel Cell Partnership's *Medium & Heavy-Duty Fuel Cell Electric Truck Action Plan for California*[76]
- The Northeast Electrochemical Energy Storage Cluster (NEESC) analysis *Economic Impact of the Northeast Hydrogen and Fuel Cell Industry*[77]
- The Fuel Cell and Hydrogen Energy Association's *2015 State Policy Activity Wrap Up: Fuel Cells & Hydrogen*[78]

Federal R&D Budget

U.S. government support for hydrogen and fuel cell technology development efforts has remained relatively constant in recent years, with $101 million in funding allocated for FY 2017 for the Fuel Cell Technologies Office, about the same as in FY 2016. However, this is approximately $100 million lower than the historical peak funding level of over $200 million.

Budget details are shown in Figure 10.

Fuel Cell Type	Cost & Durability Status[a]	Cost and Durability Target[a]
Backup Power (direct hydrogen, 1-10 kW)	$6,100/kilowatt (kW) 8,000 hours (h)	$1,000/kW 10,000 h
Medium Scale CHP (natural gas, 100 kW – 3 MW)	$1,200 - 4,500/kW 40,000-80,000 h	$1,000/kW 80,000 h
APUs (diesel, 1-10 kW, system)	$2,100/kW 3,000 h	$1,000/kW 20,000 h
Buses	$800,000 +20,000 h	$600,000 25,000 h
Automotive (direct hydrogen, 80 kW, system)	~$53/kW 4,100 h (on road)[b]	$30/kW ($40/kW by 2020) 8,000 h
Portable Power (100 – 200 watts)	$15/watt 2,000 h	$5/kW 5,000 h

[a] Unless otherwise noted, all data is from the U.S. DOE, Fuel Cell technologies Office, Multi-Year Research, Development and Demonstration Plan, 2016 Fuel Cells section, https://energy.gov/sites/prod/files/2016/10/f33/fcto_myrdd_fuel_cells.pdf.

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Figure 9: Cost and Durability Status and Targets for Various Fuel Cell Market Sectors.

Hydrogen & Fuel Cells Budget

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
Fuel Cell Technologies Office | 1

Key Activity	FY 15 Approp. ($ in thousands)	FY 16 Approp. ($ in thousands)	FY17 Enacted ($ in thousands)
Fuel Cell R&D	33,000	35,000	32,000
Hydrogen Fuel R&D[1]	35,200	41,050	41,000[1]
Manufacturing R&D	3,000	3,000	-
Systems Analysis	3,000	3,000	3,000
Technology Validation	11,000	7,000	-
Safety, Codes and Standards	7,000	7,000	7,000
Market Transformation	3,000	3,000	-
Technology Acceleration[2]	0	0	18,000[2]
NREL Site-wide Facilities Support	1,800	1,900	N/A
Total	97,000	100,950	101,000

Office	FY 2016
EERE	$101.0M
Basic Science	$24.7M
Fossil Energy, SOFC	$30.0M

FY 2016 DOE Total: ~$156M

New in FY17

[1] Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D
[2] Combines Manufacturing R&D, Technology Validation, and Market Transformation

Figure 10: Recent DOE Funding for Hydrogen and Fuel Cells R&D. *Source: U.S. Department of Energy, Fuel Cell Technologies Office*

Conclusion

Fuel cell and hydrogen technologies continue to show progress and the overall outlook is promising. Fuel cells are making inroads in a variety of applications, including stationary, backup, off-grid and portable power, and in motive applications such as light- and heavy-duty vehicles, material handling, rail and unmanned systems. Hydrogen and fuel cell technologies are recognized as important solutions in providing grid support, in storing energy, and in delivering reliable and efficient, low emission power generation.

The expiration of the 30 percent ITC and FCEV tax credits, however, represent a significant risk to continued market development.

There is a worldwide race to foster fuel cell commercialization. Governments in Asia and Europe are supporting RD&D and early commercial deployment. China is fast becoming the leader in fuel cell buses. Japan's national energy strategy assigns hydrogen the central role, in partnership with renewable and advanced combustion systems.

Fuel cells are commercial today in some applications but like every game changing technology, early units are expensive. Where fuel cells may not yet be economical, for many individual applications, the technology offers more value streams than competitors. These include:

- Transportation applications: FCEVs offer the sustainable operation and rapid acceleration of other electric vehicles, but with faster refueling times and longer driving range.
- Electric grid support: Fuel cell systems offer clean, reliable distributed power, important in areas where local air quality is an issue, and can also provide various grades of waste heat and enhanced power reliability for host sites.
- Energy storage: Hydrogen can provide long-duration energy storage, which will be important in maximizing the benefits of high-penetration renewable energy systems.
- Natural gas system utilization and support: Fuel cell power generation overwhelmingly uses natural gas today but has the greatest fuel flexibility of any generating technology. Power-to-hydrogen and power-to-methane can utilize stranded intermittent renewable energy to supplement local natural gas-based fuel supplies.
- Industrial applications: Hydrogen is widely used today in industrial settings, but there are opportunities to expand the use of hydrogen for chemical manufacture, ammonia production, metals production and processing, enhancement of liquid fuels, and to take advantage of hydrogen produced as a co-product of industrial processes such as chlor-alkali production.

Commercializing fuel cells carries a big payoff in job growth, economic activity, competitiveness, and energy security. Fuel cell and hydrogen intellectual property originated in the United States and the U.S. has been the global leader in technology development. If the U.S. is to maintain its leadership, investment and innovation will be needed until the technologies and manufacturing capability have become more mature and established.

Evidence suggests that the U.S. is still not on track to meet the 2020 goals for hydrogen FCEVs and refueling infrastructure set by the U.S. Energy Policy Act of 2005 (EPACT) Title VIII. In response to the Committee's 2016 recommendation, DOE committed to developing a paper outlining efforts underway to work toward those goals.

The Committee re-asserts the need for an explicit plan to be provided in 2017 showing the pathway for achieving the 2020 EPACT Title VIII goals "endgame" for hydrogen and fuel cell technologies, with benchmarks and milestones required to reach this point. Achieving these goals will carry substantial benefits to American workers and industries and contribute to the Administration's jobs, infrastructure, and American manufacturing vision.

The Administration's 2018 budget blueprint stresses basic science and limited, early applied energy R&D activities. While the Committee supports early stage R&D, there is a critical need to continue efforts in material and process integration and technology acceleration in order to meet EPACT 2020 goals and to maintain U.S. competitiveness, and to meet competition from offshore companies and governments.

In conclusion, much progress is being made, but greater momentum is needed for these technologies to provide the benefits they are capable of in 2020 and beyond.

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