Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)
Washington, D.C.

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 submit the Committee's 2018 Annual Report. HTAC duties under Title VIII of the Energy Policy Act of 2005 (EPACT) Sec 807 are to review and make recommendations to you, the Secretary, on: (1) implementation of programs and activities identified in Title VIII; (2) safety, economic, and environmental consequences of technologies for the production, distribution, delivery, storage and/or use of hydrogen energy and fuel cells; and (3) the Department of Energy (DoE) plan under Section 804.

The United States continues to advance hydrogen-based system development. Significant progress was made in 2018, on commercializing forklift applications and tethered fleets, where local air quality regulations, rapid indoor refueling and up-time advantages, support a favorable fuel cell business model. California largely achieved EPACT goals for light-duty vehicles with 39 operational refueling stations and more than 5,900 hydrogen fuel cell vehicles deployed by end of 2018. A similar roll-out is underway in the Northeast, with 5 operational stations and roughly a dozen more planned.

HTAC recommendations in 2018 led to the creation of the Center for Hydrogen Safety, in partnership with the American Institute of Chemical Engineers and Pacific Northwest National Laboratory. This center will ensure organizational sustainability and will broaden the scope of the Hydrogen Safety Panel, to include consistent standards development and streamlined processes for new hydrogen facility deployments.

The DOE's H_2@Scale program was kicked-off, to capitalize on cross-sector opportunities for hydrogen as an energy vector, not only for mobility, but also for energy storage, industrial uses, and stationary power generation. Today's hydrogen supply is primarily extracted via natural gas reformation, benefiting from expanded U.S. shale gas production. Hydrogen can also be derived from coal, renewable biomass, solar and wind resources, providing a useful energy carrier to integrate diverse energy resources for transport, storage, and deployment, across the grid and the broader energy network. Local solar and wind renewable power generation and light-duty battery electric vehicle deployments have seen substantial uptake, although still at low market penetration within the United States. As deployments increase and approach critical threshold values, there will be increasing need for cost effective seasonal and short-term energy storage, to support the energy grid. Additional requirements to transport renewable power for consumption in distant markets will make molecular energy carriers, such as hydrogen, key for establishing a resilient energy economy. Hydrogen fuel cells will naturally evolve as solutions for certain transportation and stationary power applications, where intermittent renewable energy resources are integrated with fossil and nuclear energy sources.

HTAC views hydrogen and fuel cell technologies as key sources for U.S. job creation. Investments will support U.S.-based fuel cell production jobs and will catalyze infrastructure jobs as hydrogen is leveraged as means to store and export energy, enabling new zero emission solutions for the global marketplace. In 2018 HTAC undertook a competitiveness study, given increased competition from China in technology innovation and deployment. Although the U.S. has pioneered many of the core technologies in this space, global competitors are promoting more favorable conditions to support early adoption and to accelerate investment. These conditions represent a substantial threat to the U.S. and its competitive position with hydrogen fuel cells and energy infrastructure. The implications will also influence future U.S. energy security and defense concerns.

Looking forward, capturing the potential benefits of hydrogen as an energy vector for the U.S. requires public-private partnerships between industry, universities, local, state, and federal governments. The DoE can continue to catalyze the process, by acting upon the following recommendations:

1) Enhanced funding of systems modeling studies for H_2@Scale to identify best opportunities for integration of hydrogen into the U.S. energy infrastructure for energy transmission, storage, and dispatch, considering future commercial and mobility options and trends including increased use of ride share, autonomous vehicles, and medium- or heavy-duty goods transport;
2) System analysis of future storage and vehicle cost to understand what infrastructure investments are warranted;
3) Continuing R&D funding and current or expanded levels of programs to reduce the cost of hydrogen fuels cells (reduced dependence on platinum group metals) and of hydrogen storage and compression (via development of advanced materials), as well as to improve durability for commercial applications;
4) Increased emphasis on development and demonstration of solutions for heavy duty transit, marine, and aviation applications that are not readily served by battery electric systems.
5) Continued support for standardization of codes and best practices for safety system design and approvals.

The Hydrogen and Fuel Cell Technical Advisory Committee members hope you will find these recommendations and the information contained within the 2018 annual report useful. We remain committed to providing ongoing support to the U.S. Department of Energy and are available to address any questions, regarding the annual report.

Sincerely,

Charles E. Freese, V.

Chairman, HTAC

On Behalf of the Hydrogen and Fuel Cell Technical Advisory Committee

2018 ANNUAL REPORT of
The Hydrogen and Fuel Cell Technical Advisory Committee

Hydrogen and Fuel Cell Technical Development and Commercialization Activity

SUMMARY

This 2018 Annual Report of the United States Department of Energy (DOE) Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) summarizes global advances and opportunities for the hydrogen and fuel cell industry in technology research, development, and commercialization, as well as progress and challenges in policy, regulations, standardization, and financial climate for investment.

In 2018, significant progress was made toward meeting program targets for infrastructure and fuel cell vehicle deployment in California. Strong adoption and expansion occurred in the U.S. market for hydrogen fuel cell use in commercial lift truck applications. Global policy interests grew substantially for the role of hydrogen as a common vector for both traditional and emerging sources of energy. Multiple scenarios are now pointing to future hydrogen use at scales that substantially exceed gross domestic product economic growth rates.

Highlights for 2018 include the following achievements and milestones:

- California is on track to meet 2005 Energy Policy Act (EPACT) goals.[1] The state has 200 hydrogen stations planned for 2025, with 39 retail stations currently open and 26 stations in various development stages. There were more than 5,900 fuel cell vehicles deployed in California as of the end of 2018.
- Hydrogen fuel cells have been commercially adopted and deployed in more than 21,000 lift trucks and delivery and ground support vehicles (starting from a DOE base of only 700 units), with plans for additional market expansion (Figure 1).
- DOE's H2@Scale initiative is expanding to address important hydrogen integration opportunities in energy storage, transport, clean mobility, and power, while the Center for Hydrogen Safety was founded to provide global sharing of safety information, tools, and best practices.
- DOE's four new research and development (R&D) consortia (Hydrogen Advanced Water Splitting Materials Consortium [HydroGEN], Hydrogen Materials Advanced Research Consortium [HyMARC], Electrocatalysis Consortium [ElectroCat], and Hydrogen Materials Compatibility Consortium [H-Mat]) are already generating impactful results by mobilizing resources to advance discovery and technology development.
- DOE and the President's Fiscal Year (FY) 2019 budget request created a new line item for Hydrogen Infrastructure R&D, reflecting the importance of this technology area and in alignment with HTAC recommendations to increase resources directed toward infrastructure.
- A ministerial meeting was held in Japan, resulting in agreements between the United States, Japan, and Europe to harmonize codes and standards for safety systems and infrastructure, with information sharing to facilitate development of supply chains for a global hydrogen economy.

Challenges and Opportunities

Hydrogen can play a unique role in integrating across multiple regional energy options and use sectors to enhance U.S. energy security and resilience. A technology leadership position offers the potential for job creation and growth to supply emerging U.S. and global markets. While California is essentially meeting 2005 EPAct goals for hydrogen refueling stations and increased deployment of fuel cell vehicles, the rest of the United States is lagging. Successful widespread deployment across the United States and globally requires further reduction in cost for fuel, vehicles, infrastructure, and storage.

Global competition is ramping up, introducing concerns over whether the United States can maintain its competitive advantage, given the strong emerging challenge from China and other global players. These countries have dramatically increased investment in market development, new technology R&D, and hydrogen infrastructure to accelerate local commercial opportunities and attract domestic developers and producers.

While lift trucks and light-duty vehicles (which complement battery electric options) have provided a proving ground for hydrogen fuel cell deployment, the technology is potentially uniquely advantaged in heavy-duty transit and fleet services, as well as in aviation, rail, and marine applications. Broader uses for hydrogen (H2@Scale) include grid integration and storage, in addition to industrial (e.g., steel manufacturing) and commercial heating and power. HTAC recommends acceleration and expansion of heavy-duty transit and the H2@Scale programs to capitalize on these opportunities. Roadmapping and systems analysis will play an important role in opportunity identification.

Industrial Progress and Activity

Overall, the hydrogen and fuel cell industries continue to make progress with year-over-year growth. The industry can be characterized as being in the early stages of commercialization, which can create funding challenges. China is playing an increasingly dominant role with these investments, including financing existing companies, establishing partnerships, and securing access to markets and technology. Noteworthy events and announcements for 2018 include:

- Hyundai and Toyota announced major investments to scale up manufacturing of commercial fuel cell electric vehicles (FCEVs) for the global market, with Hyundai targeting 40,000 vehicles by 2022[2] and Toyota envisioning FCEV sales increasing significantly after 2020 to at least 30,000 annually.[3] Honda introduced its FCEV, the Clarity, for sale in California in 2018.[4]
- A 2018 Global Executive Survey of leading automotive companies by KPMG indicated that a majority believe FCEVs will become the critical breakthrough for electric vehicle mobility.[5]
- California announced its thirty-ninth retail hydrogen refueling station while Hawaii and Connecticut joined the group of states operating retail hydrogen refueling stations. As a comparison, Germany has more than 50 refueling stations and Japan has more than 100.
- China's influence in the hydrogen and fuel cell industries grew substantially with its financing of joint ventures involving key companies such as Ballard and Ceres Power.
- Japan strengthened its "hydrogen society" vision in the 2018 Strategic Energy Plan by positioning hydrogen as a critical enabler for mid- to long-term energy security and greenhouse gas mitigation. The Japanese government continues to invest heavily in hydrogen refueling infrastructure and supply chain development including liquid hydrogen, liquid organic hydrogen carriers, and ammonia technologies (Figure 2). For 2018, the allocation was 2.4 billion Japanese yen ($22 million).[6]
- Bus, truck, and rail transport sectors continued their progress, with companies announcing commercial offerings, but again at modest scale. Toyota is expected to put 100 fuel cell buses into service ahead of the 2020 Olympics in Tokyo.[7] Nikola, a company based in Arizona, raised $200 million toward a target of full production of Class 8 trucks and 14 refueling stations (electrolysis capacity, to be supplied by Nel) by 2021.[8] The world's first hydrogen fuel cell-powered train entered commercial service in Germany. Contracts were signed for delivery of another 14 by 2021 to replace diesel locomotives.[9]
- Bloom Energy attracted considerable attention within the stationary power sector with its long-awaited initial public offering. However, Bloom's stock price deteriorated to approximately two-thirds of its initial offering price by year end.
- 3M exit: After more than a decade of cutting-edge R&D and commercial production of membrane electrode assemblies, a core component of polymer electrolyte membrane fuel cells, 3M announced in December 2018 that it is exiting the business. As a longtime leader in the fuel cell industry, this sent shock waves to fuel cell integrators and raises questions about where the 3M trove of intellectual property will wind up.
- Air Products reached 8 million total hydrogen fills over a number of global applications.
- Plug Power advanced its leadership in material handling with customers surpassing the 10 millionth hydrogen refueling of their GenDrive fuel cell forklifts. Plug Power also opened a new 38,400 square foot fuel cell manufacturing facility in New York. Investment in its second manufacturing facility was supported by market

Figure 1: Growth in lift trucks, delivery vehicles, and ground support vehicles. *Source: DOE Fuel Cell Technologies Office*

demand plus a performance-based tax credit from New York State.

- In September, Plug Power announced it had begun producing its own membrane electrode assemblies (MEAs) internally, after announcing in June the acquisition of American Fuel Cell, a company focused on MEA technology development. This increased vertical integration could provide more cost and design control for Plug Power, but it reduces industry capacity for more centralized suppliers.
- General Motors (GM) established a new Washington, D.C.-based defense unit called GM Defense, LLC. In addition to developing a fuel cell-powered pickup truck for military evaluation, GM is developing fuel cell-powered auxiliary power units, unmanned undersea vehicles, and a multi-use platform.[10]
- Microsoft established the viability of an innovative data center design that utilizes solid oxide fuel cells to directly power server racks. These systems substantially improve the energy efficiency and reduce emissions associated with energy intense data centers.[11]
- The Center for Hydrogen Safety was created under the American Institute of Chemical Engineers (AIChE) following a 2017 HTAC recommendation. The Center will provide innovative tools and resources to address safety and coordination of standards in global deployment of hydrogen as an energy vector, building upon competencies in AIChE's Center for Chemical Process Safety and worldwide partnering organizations. The new Center will integrate the highly successful hydrogen safety resources developed at the Pacific Northwest National Laboratory and form strategic partnerships with other coordinating groups on the forefront of the hydrogen energy transition such as the California Fuel Cell Partnership and other international organizations.[12]
- Efforts were launched to develop an industry-led roadmap to grow cross-sector U.S. hydrogen market opportunities and integrate hydrogen production pathways. The roadmap is expected to be completed in 2019.

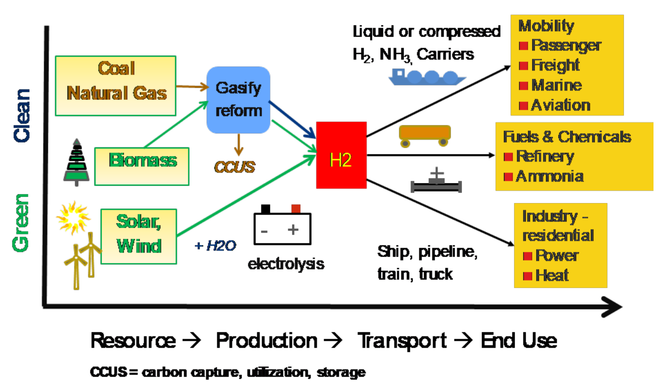

Figure 2: Supply chain options. *Source: Shell*

Global Fuel Cell Shipments

The E4tech industry assessment for 2018[13] reports:

- Global shipments increased 22% in 2018 to more than 800 megawatts (MW), relative to percentage increases of 28% in 2017 and 73% in 2016 (Figure 3).
- The transport sector led with 563 MW and stationary applications came in second at 240 MW.
- North America led in MW adoption with 415 MW, and Asia came in second at 343 MW, with Europe a distant third at 43 MW.
- But when considering units shipped (in thousands), Asia far outpaced North America with 55 vs. 10 and Europe almost matched North America at 9. This result is due to both large deployment of small residential units in Japan and a ramp up of FCEV manufacturing in Japan and Korea.

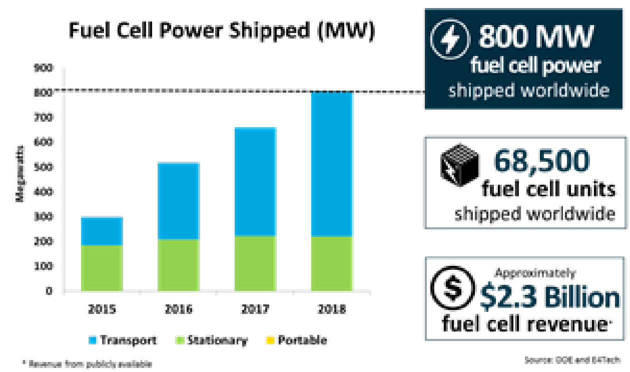

Figure 3: Growth in U.S. fuel cell shipments.
Source: DOE Fuel Cell Technologies Office

Progress toward Policy Goals

2015 and 2020 are milestone years for EPACT, which includes the following goals:

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."[14]

Substantial progress has been made toward critical program goals since 2005, with multiple fuel cell applications around the United States, and the 2015 commitments have been partially met (Figure 4). California has three automakers (Toyota, Hyundai, Honda) offering FCEVs and (as of late 2018) more than 5,900 FCEVs were on the road with 39 retail refueling stations operating, and the market is continuing to grow at an accelerated rate. As an example, the time to market for hydrogen refueling stations in California (from the start of a California Energy Commission-funded project to a retail hydrogen refueling station opening and selling fuel) decreased in 2018 by an average of one year, representing a nearly 50% reduction since 2014.[15]

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

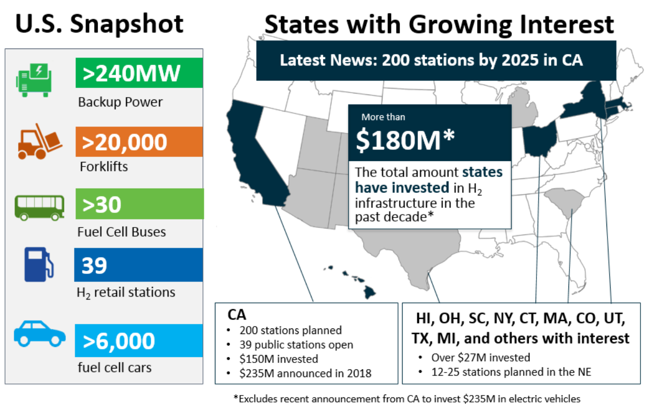

Figure 4: U.S. fuel cell applications (2018). *Source: DOE Fuel Cell Technologies Office*

In addition to building stations faster, California is also steadily increasing hydrogen consumption at refueling stations. Towards the end of 2017, the state dispensed a daily average of 1,500 kilograms per day at vehicle fueling stations. This grew to more than 2,500 kilograms per day in 2018, as shown in Figure 5.

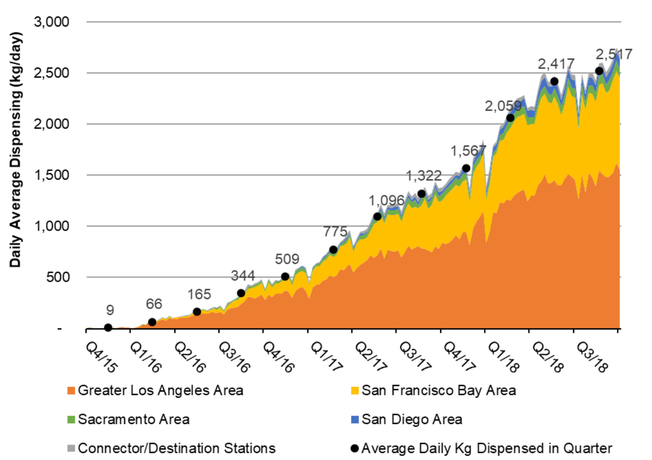

Figure 5: Growth in daily average hydrogen dispensing in California. *Source: California Energy Commission*

California hydrogen refueling station use is also steadily increasing, as shown in Figure 6. The network average utilization rate increased from 28% to 40% from late 2017 to late 2018 with the greater Los Angeles area reaching nearly 50%. The increase in station throughput sets the stage for financially self-sufficient stations.

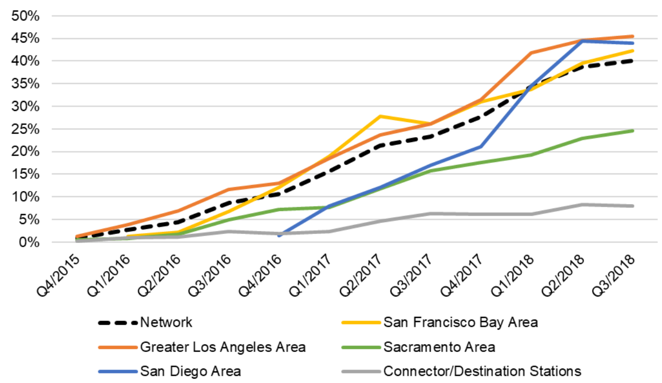

Figure 6: Growth in hydrogen refueling station use in California. *Source: California Energy Commission*

Given various announcements to increase hydrogen production in California, as well as automakers ramping up production of FCEVs, California is expected to approach its 2025 goal. Without a similar broad effort, the balance of the United States will likely continue to lag far behind the 2005 EPACT Title VIII goals.

Five refueling stations (public plus private) are now operational in the Northeastern United States (Massachusetts, Connecticut, New York),[16] with plans for near-term expansion to at least 12 stations. California's success is due to the state's and the industry's strong commitment to hydrogen and fuel cell markets through policies, subsidies, and streamlined project execution for engineering design and implementation.

Industry Risk

After many years of investment, the industry is in the critical stage of transformation from R&D to commercialization. As stated by the Hydrogen Council[17] 2017 report *Hydrogen Scaling Up – A sustainable pathway for the global energy transition*, it is "about scaling existing technologies and considering the beneficial linkages and virtuous cycles of deploying hydrogen technology across the energy system."

At stake for the United States are the jobs and economic benefits of manufacturing the 400 million cars, 15 to 20 million trucks, and 5 million buses by 2050 that are projected by the Hydrogen Council report.

Commercialization Initiatives

Fuel cells continue to make inroads into an array of commercial sectors, further highlighting the broad potential impact of these technologies. Key sectors include transportation (e.g., cars, buses, trucks, trains, ships, and aviation), material handling (forklifts), stationary power (e.g., primary and backup power, off-grid, grid support, and grid resilience/hardening), military applications, undersea vehicles, drones, and small electronics. Hydrogen as an industrial chemical also has broad impact for ammonia production, metal and semiconductor processing, and refining of petrochemicals. The hydrogen delivery infrastructure is critical to the commercial success of the overall industry.

With the founding of the Hydrogen Council in 2017, there is a concerted global effort to expand the hydrogen delivery infrastructure necessary to support the commercialization of fuel cells. Without the hydrogen delivery infrastructure, investments to commercialize fuel cells will suffer greatly. California has called for 200 refueling stations by 2025[18] and it should be noteworthy that both Air Products[19] and Air Liquide[20] are building additional hydrogen production facilities to serve the Western U.S. Shell is building the largest hydrogen electrolysis plant (10 MW) in Germany, and Plug Power opened its third refueling station in Florida.[21]

In October 2018 Japan hosted the first Hydrogen Energy Ministerial in 15 years, attended by representatives from 20 countries, including DOE's Deputy Secretary of Energy. Senior officials from DOE, Japan's Ministry of Economy, Trade, and Industry, and the European Union Commission for Climate Action and Energy signed a joint statement of future cooperation to develop concrete actions toward collaboration on the areas described in the "Tokyo Statement" (released as a Chair's summary of the 2018 Hydrogen Energy Ministerial Meeting).[22]

Fuel Cells for Passenger Cars

2018 was another important year for fuel cell passenger vehicles with Hyundai and Toyota substantially upping their commitments to scaling production of FCEVs during the next few years.

- Hyundai started construction on its second fuel cell system factory in South Korea that will increase fuel cell system output to 40,000 units by 2022. Hyundai also announced that it will invest $6.7 billion through 2030 to raise production of fuel cells by more than 200-fold.[23]
- Toyota broke ground on two new facilities to increase production of fuel cell stacks and high-pressure hydrogen tanks with a target of supplying 30,000 units globally starting around 2020. Toyota currently sells FCEVs in 11 countries and expects to sell 10,000 units annually in Japan by 2020.[24] The Mirai is touted as the first mass-produced FCEV (Figure 7).
- California continues to have supportive policies that have significantly increased the number of FCEVs on the road in 2018 from 2017 as well as increasing the number of refueling stations to 39.

Figure 7: Toyota Mirai. *Source: Toyota*

Fuel Cells for Transport (Bus, Truck, Rail, Marine)

Fuel cells continue to progress toward applications in the medium- and heavy-duty transport sector, with bus and truck applications leading. In an effort to improve the air quality of major European cities, governments are increasingly implementing diesel vehicle restrictions. Industry is finding battery-only propulsion systems add substantial weight, which can restrict payloads for some applications. They also require large capital investments for large fleet vehicle charging systems. Multiple companies are evaluating fuel cell range-extender architectures, which lessen the burden for the batteries and provide customers acceptable vehicle range. California continues to lead the United States with its bus- and truck-related initiatives, though China leads in bus deployment.

- The National Renewable Energy Laboratory released its report on the status of fuel cell electric buses in the United States. The lab assessed fuel cell electric bus designs to be at a technology readiness level of 7 to 8. A technology readiness level of 9 reflects a mature technology such as diesel and compressed natural gas. The report notes fuel cell stacks are reliable and robust with most of the problems associated with balance of plant.[25]
- California is working on vehicle demonstrations and infrastructure support for medium- and heavy-duty vehicles that use fuel cells. For example, in November 2018, the California Energy Commission awarded an $8 million grant to develop a high-capacity hydrogen fueling station to service and promote the expansion of zero-emission fuel cell Class 8 drayage trucks at the Port of Long Beach. The station will source hydrogen from 100% renewable biogas.
- In April 2018, the International Maritime Organization adopted an initial strategy to reduce greenhouse gas emissions from global shipping by 50% in 2050 compared to 2008 levels. This, alongside an existing push from Norway to create an emissions-free zone on water, has cascaded a series of regulations and drives from many port authorities and shipping organizations to push for hydrogen drivetrains on vessels.

- Hyundai launched a hydrogen fuel cell bus for regular service in South Korea with the expectation of putting 30 more buses into regular service next year. Hyundai also announced a partnership with H2Energy of Switzerland to provide 1,000 fuel cell trucks and related supply chain.[26]
- Toyota started sales of its fuel cell bus to the Tokyo Metropolitan Government with the aim to have 100 such buses on the road ahead of the 2020 Olympics in Tokyo.[27]
- Toyota and Kenworth announced a plan for 10 heavy-duty Class 8 fuel cell trucks to haul cargo from San Pedro Bay Ports to cities across Southern California by 2020.[28]
- Nikola, an Arizona-based company, raised $200 million toward its target of beginning full production of Class 8 fuel cell trucks by 2022, as well as 14 hydrogen refueling stations.[29]
- Alstom delivered the first fuel cell-powered train in Germany with the expectation of delivering another 14 by 2021.[30]
- Nine Northeastern U.S. states are now members of the Zero Emission Vehicle Task Force, and planned existing hydrogen refueling stations have increased from 2 to 12 in one year.[31]
- Riversimple (Wales) prototyped a two-seat, 1,200-pound carbon fiber FCEV with a 300-mile range (and fuel costs included in lease/purchase).[32]

Fuel Cells for Material Handling

Fuel cell-powered forklifts in warehouse applications continue to grow.

- Plug Power continued to expand its customer base announcing supply agreements with major global companies such as Carrefour, BMW, and Daimler (Figure 8).
- Material handling equipment was included in the reinstatement of the 30% investment tax credit early in the year.

Figure 8: Plug Power forklifts. *Source: Plug Power*

Fuel Cells for Stationary Power

The stationary market includes both small-scale (back-up and residential applications in the single kilowatt [kW] range) and large-scale (primary power in the MW range) power generation. The stationary market also encompasses off-grid, as well as grid-connected, applications. Microgrids powered by fuel cells are becoming an effective manner to provide critical infrastructure (e.g., hospitals, data centers, and military installations) the necessary resilience to withstand grid outages caused by either adverse weather or equipment failures.

- In February 2018 the U.S. Congress reinstated a 30% investment tax credit that will phase out over five years. This not only helped boost activity in the stationary power market but also spurred the initial public offering of Bloom Energy, which raised approximately $270 million.
- Bloom Energy, FuelCell Energy, and Doosan generally dominated the market with large MW-scale projects for grid support as well as microgrid applications to enhance reliability and resilience for large retail customers and critical infrastructure. Connecticut was the location for a number of these projects as a result of its supportive policies.
- At the smaller scale, both SolidPower and Ceres (both European based) invested in increasing their annual manufacturing capacity to 50 MW and 2 MW respectively.[33]
- In November, Panasonic Corporation of Japan announced it will accelerate its fuel cell commercialization, building on over 140,000 residential combined heating and power (CHP) units shipped as of June 2018. The new fuel cells will have 5 kW of power, compared to ~1 kW current residential systems.[34]
- In early 2018, Viessmann Group, a leading international manufacturer of heating, industrial, and refrigeration systems, launched a residential CHP fuel cell system called the Vitovalor (Figure 9). Viessmann partnered with Panasonic who provided the fuel cell, signaling a new phase to Panasonic's large-scale deployment of fuel cells outside of Japan. According to Viessmann, Great Britain offers a subsidy of approximately 6,000 British pounds ($7,000) per unit through the PACE program.[35]
- SFC Energy, the German-based direct methanol fuel cell maker, has shipped more than 43,000 units to a variety of different markets (3,700 units shipped in 2018), including leisure, defense and security, oil and gas, industrial portable, and small stationary markets. The company specializes in low-power, remote applications (Figure 10).[36]
- CHEM Corporation launched its Generation 5 polymer electrolyte membrane reformed methanol system for weak and off-grid applications such as cellular base stations in Southeast Asia, India and Africa. The "G5"

system is less than half the size of its predecessor, is lower in first cost and higher in efficiency, and uses fuel cells produced in the United States.

Figure 9: Vitovalor PT2 (home heat and power). *Source: Viessmann Werke*

Figure 10: EFOY Pro 2400 Automatic Power Supply. *Source: SFC Energy*

2018 HTAC Activities

Hydrogen Safety

Agreements for creation of the Center for Hydrogen Safety were completed in 2018, in response to a 2017 HTAC recommendation. Launch will occur in early 2019.

Industry Competitiveness and Competition

In 2018, HTAC formed a subcommittee to report on global competitiveness and competition based on the concern that the United States was at risk of losing its competitive advantage and industry leadership due to China's stated goal of acquiring and developing technology in the hydrogen and fuel cell industries. The report with recommendations is expected to be finalized in early 2019.

Significant Technical Challenges Remain to Meet Goals

Despite the significant progress made over the last decades to improve the performance and cost of hydrogen and fuel cells, 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. These objectives are detailed in the DOE Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.[37] These objectives include 2020 targets to develop:

- A 65% 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 fuel cell systems (5 kW) operating on natural gas that achieve 45% 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% electrical efficiency, 90% 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.
- Hydrogen production and on-board storage systems with ultimate costs of <$2/kg and <$8/kWh, respectively.

Figure 11 shows progress against 2020 goals for transportation fuel cells. Power density, system power, and start time goals have been met. Targets for combined durability and cost have yet to be fully achieved, based on DOE's 2017 cost analysis and its 2016 independent durability validation of on-road FCEVs.[38] Current fuel cell vehicle costs are estimated at $180/kW, which is expected to scale to mass production of $45/kW for greater than 500,000 units, with an ultimate goal of $30/kW. However, durability must also be met.

Figure 12 shows the current estimated cost status (low-volume production) versus targets for fuel cells and hydrogen.

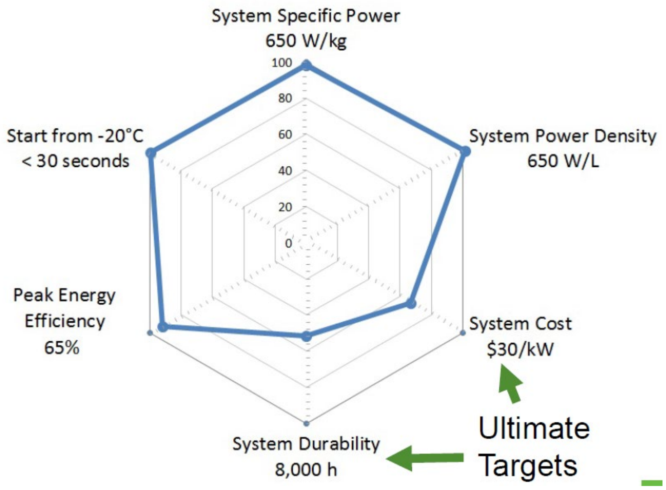

Figure 11: Status toward targets for transportation fuel cells. *Source: DOE Fuel Cell Technologies Office*

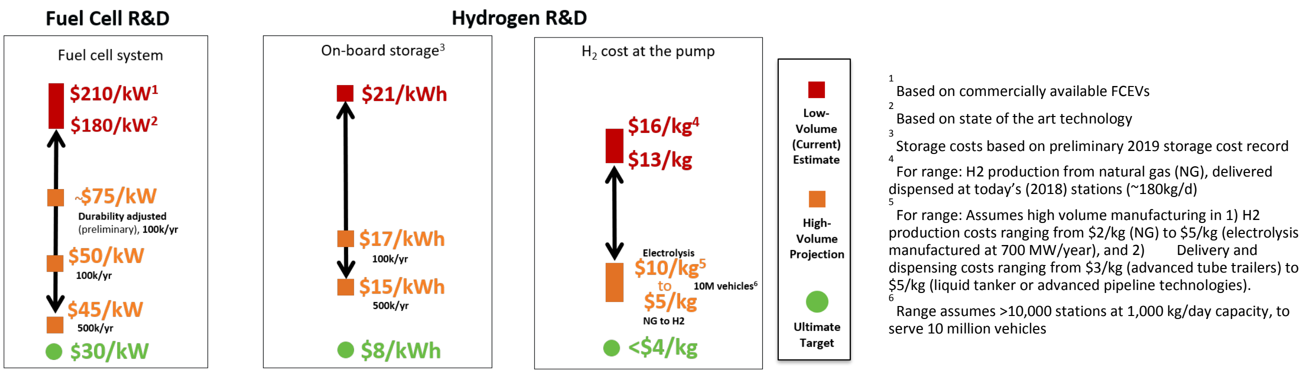

Figure 12: DOE cost targets and estimated status. *Source: DOE Fuel Cell Technologies Office*

Research and Development

Early-stage R&D continues to play a key role in driving down costs for technology development and deployment to enable competitive positioning relative to other energy and mobility options.

Significant accomplishments for 2018 include:

- DOE further progressed its H2@Scale initiative, bringing together a diverse group of stakeholders to advance affordable hydrogen production, transport, storage, and utilization as an energy vector for bridging and integrating renewable, fossil, and nuclear energy sources. The effort is focused upon developing multiple revenue opportunities and thus investment by using hydrogen to unlock value across multiple sectors. It is a framework in which national laboratories and industry work together, through government co-funded projects, to accelerate early-stage research, development, and demonstration of applicable hydrogen technologies to enable the potential for a several-fold increase in production versus today's 10 million tons per year.
- DOE gathered stakeholder feedback on H2@Scale opportunities and R&D needs through workshops and requests for information. Through competitive solicitations in late 2017 and 2018 that elicited wide national participation in teaming opportunities among industry, universities, and national labs, more than 30 awards were made to R&D projects addressing H2@Scale challenges. This included early-stage R&D for hydrogen storage, transport, and delivery options including liquid and compressed hydrogen, metal and organic carriers, and ammonia.
- The ElectroCat consortium demonstrated progress toward fuel cell cost targets of sub-$40/kW (vs. nearly $200/kW today).
- The HydroGEN consortium for hydrogen production via advanced water splitting is leveraging unique capabilities across the national labs to accelerate R&D for innovative materials critical for low-cost hydrogen production. The consortium continues to achieve world records in hydrogen production efficiency via advanced water splitting. Sixteen projects have passed go/no-go milestones to advance to Phase 2. The first annual benchmarking meeting was held October 2018 to develop R&D roadmaps and share best practices and protocols for materials discovery and characterization.[39]
- For safety, codes and standards, a report was published by Sandia National Laboratories on hydrogen FCEV tunnel safety. Aligned with HTAC recommendations, Pacific Northwest National Laboratory established a partnership with the AIChE to create the Center for Hydrogen Safety.
- Systems analysis studies indicated an improved value proposition for fuel cell-powered trucks (Class 8 long- and short-haul and Class 4 parcel) if DOE Fuel Cell Technologies Office program cost and performance targets can be met.
- DOE Fuel Cell Technologies Office funding has now generated more than 730 patents, representing a 350% increase since 2005.[40]

Federal budgets (Figure 13) show moderate increases in funding from 2017 through 2019.

Breakdowns are shown in Figure 14. The DOE and the President's FY 2019 budget request created a new line item for Hydrogen Infrastructure R&D, reflecting the importance of this technology area and in alignment with HTAC recommendations to increase resources directed toward infrastructure.

DOE-wide Hydrogen and Fuel Cells Funding

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

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

EERE – Fuel Cell Technologies Office

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

EERE: Office of Energy Efficiency and Renewable Energy

Figure 13: Federal R&D budget FY 2017–2019.
Source: DOE Fuel Cell Technologies Office

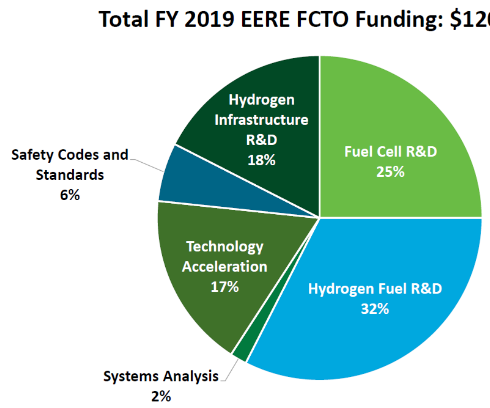

Figure 14: Federal FY 2019 R&D budget breakdown.
Source: DOE Fuel Cell Technologies Office

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