The Hydrogen and Fuel Cell Technical Advisory Committee

Washington, D.C.

May 28, 2015

The Honorable Dr. Ernest Moniz
Secretary of Energy
U.S. Department of Energy
1000 Independence Ave. SW
Washington, D.C. 20585

Dear Mr. Secretary:

Enclosed is the Hydrogen and Fuel Cell Technical Advisory Committee's (HTAC's) Annual Report on Hydrogen and Fuel Cell Commercialization and Technical Development. The Committee is once again pleased to report to you that the working relationships and the complementarity with the Fuel Cell Technologies Office are productive, fully functional and cooperative. The Office is well led and remains essential to addressing the Department's ongoing efforts on fuel cell durability, costs, advanced research and manufacturing, codes and standards and infrastructure. The Office has also monitored and advised the Committee with regard to the progress of fuel cell vehicle and stationary fuel cell advances in technology development and commercialization. Additionally the Office has provided invigorating leadership for H2USA, the public-private partnership focusing on fueling infrastructure for fuel cell electric vehicles.

As much as we celebrate and acknowledge progress, more hard work remains ahead for all of us and the Committee shares its current views with you to both seek your continuing support and assure you that our Members are fully committed to what is needed in the period ahead. Here are the highlights of what we bring to your attention and request your consideration as you consider the many priorities that compel you.

- The consumer incentive to purchase fuel cell vehicles has expired just as commercial vehicles are becoming available. We encourage you to support efforts to reinstate such incentives as complementary to state initiatives so that the vehicle launch is sustained. President Obama's 2016 Budget accommodates renewal of the incentive at a level of $10,000. Your assistance in making this proposal more visible and stimulating a debate would be a valuable first step in seeing its passage.
- The progress being made in California, including the creation of the re-fueling infrastructure, is an opportunity for you to bring these efforts to the attention of other states in the months and years ahead. California is committed to building an initial network of 100 hydrogen refueling stations in critical locations across the state, investing

$90 million to date, anticipating approximately 40 stations constructed by the end of this year. California is further supporting introduction of vehicles by providing rebates of $5000 to each FCEV purchased or leased for a period of at least three years.

- Your leadership of the Quadrennial Review and its focus on infrastructure is an excellent platform upon which to offer support to fuel cells for grid resiliency and storage.
- Considerable attention is being paid to hydrogen and fuel cell progress in Japan and Germany. Japan, in fact, has given hydrogen "the central role" in its low carbon energy future, and has committed more than $500 million this year for research and infrastructure deployment. The Committee remains convinced that the US has an opportunity to regain global competitiveness via increased coordination among the multiple stakeholders in the HFC community. Your active leadership together with the Department's convening authority could help re-invigorate the determination of US decision makers to keep moving forward by finding ways toward mutual support between government and private sector leaders.
- Budgetary support is the perennial item we bring to your attention. The Committee is grateful for the relatively stable level of funding that has been provided in recent years. Of course we would be neglecting our advisory purpose if we did not encourage you to consider a higher level of funding commensurate with global leadership vis a vis both Japan and Germany, considering the opportunity to move more rapidly now to commercialization and the need for infrastructure to support it.

The Committee also wishes to note the sustained support and engagement with key members of your leadership team, including Under Secretary for Science and Energy Franklin Orr, Assistant Secretary for EERE David Danielson, Director of the Office of Energy Policy and Systems Analysis Melanie Kenderdine and Deputy Assistant Secretary EERE Reuben Sarkar. We enjoyed the benefits of their advice and when possible their presence in our meetings during the past year. The Committee continues to assess all the efforts within the Department in order to advise you as best we can. The Committee also continues to utilize a pragmatic subcommittee structure that operates to focus attention on specific issues and opportunities, such as retail infrastructure, on behalf of the full Committee and the Program Office.

To place the 2014 Annual Letter in historic perspective and as prelude to next year's Annual Letter, the Committee notes that under EPAct 2005 the goals of the program were to A) enable a commitment by automakers no later than 2015 to offer safe, affordable and technically viable hydrogen vehicles in the mass consumer market; and B) to enable hydrogen production, delivery and acceptance for consumers of model year 2020 hydrogen fuel cell and hydrogen powered vehicles. Thus it was refreshing to witness the Department's video at a recent Committee meeting documenting your own "drive around town" earlier this year in the new Toyota *Mirai* and the obvious excitement you both displayed and generated among your passengers! This is clear progress against objectives over a sustained period. In addition, the EPAct has a section on grid infrastructure for 2015 that matches a commitment not later than 2015 that would lead to

infrastructure in 2020, which fully complements the Department's Quadrennial Review activities of the past year. Thus the Committee appreciates and commends your personal leadership, clearly evidenced on multiple occasions, on behalf of the hydrogen and fuel cell future for the nation.

We look forward to continuing our service to you, your leadership team and the Program Office. It is a pleasure for us to serve the nation with our contributions to this important and innovative subset of the 21st Century US energy and environmental system. We welcome your feedback.

Via this letter I am also pleased to introduce you to my successor as Chairman of the HTAC, Frank Novachek, who has been unanimously selected by the Committee to serve in this role. He is the Manager of Planning and Technology Assessment at Xcel Energy. He is based in Colorado. Frank has been a member of the Committee for most of its history, served as Vice Chair over the past three years, and has been an active leader and participant in HTAC's subcommittee activities. My term as Chair expires on June 30, 2015. It has been a pleasure to support you and your leadership team at the Department of Energy and to serve my fellow Committee members as well. I also look forward to continuing to serve on the Committee.

Sincerely yours,

John Hofmeister
Chair
On behalf of the Hydrogen and Fuel Cell Technical Advisory Committee

2014 ANNUAL REPORT of The Hydrogen and Fuel Cell Technical Advisory Committee

Hydrogen and Fuel Cell Technical Development and Commercialization Activity

This Annual Report of the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) highlights worldwide advances and challenges with regard to hydrogen and fuel cell commercialization, policy, regulations, standardization, financial climate, and research and development (R&D) during 2014.

Overall, the industry appears to be making headway. Even though it faces entrenched incumbents in power generation, combined heat and power, and forklift markets, the fuel cell industry has found competitive niches, albeit in most cases supported by incentives such as tax credits, renewable energy generation credits, direct payments, or concessionary regulations. The emergence of commercially available fuel cell electric vehicles (FCEVs) has captured the attention of governments and the general public, which bodes well for continued commercial expansion in 2015.

Summary

- A commercial fuel cell and hydrogen energy industry is emerging. Worldwide revenues may reach $2 billion[1] in 2015, dominated by the sale of large power systems. Markets are opening in Africa, South Asia, and South America.
- FCEVs are being sold and leased in Asia, Europe, and the United States (Fig. 1). California dedicated funds to an incentive program worth $5,000 per vehicle; Japan's federal government and the city of Tokyo announced a combined $27,000 per vehicle incentive.
- The number of residential fuel cell systems installed in homes in Japan exceeded 100,000 in 2014, aided by price reductions, continued government support, and consumer concern over energy reliability; new markets are opening in apartment buildings, where fuel cells are offered by builders as an appliance option.
- Total fuel cell power generation capacity in the United States was near 200 megawatts (MWs) by the end of 2014.
- After a difficult 2013, the market for fuel cell forklifts began to recover, led by an order of 1,783 units from Walmart.
- Several U.S. fuel cell companies improved their financial position, in some cases dramatically, through stock sales or private investment.
- Two well-established corporations—Doosan of South Korea and Hyster-Yale—entered the business; General Electric announced a commercialization initiative.

Governments, private companies, and investors made substantial commitments in 2014.

- Japan's new national energy policy gives hydrogen "the central role" in a new distributed energy system and sets ambitious targets for FCEVs and residential fuel cell sales. Japan's budget totals about $500 million for R&D, vehicle infrastructure, and deployment. Japan also set aside $350 million to showcase hydrogen and fuel cells at the 2020 Olympics.

Figure 1. On June 10, 2014, Hyundai leased the world's first mass-produced fuel cell vehicle in Huntington Beach, CA. *Image courtesy of Hyundai Motor America, Inc.*

- In Europe, the European Commission formalized a seven-year commitment for fuel cell and hydrogen research, development, and demonstration (RD&D) and increased its financial commitment to more than $800 million. Industry-led H2Mobility established a new corporation to build stations and sell hydrogen throughout Europe, with a budget of about $445 million, most of it from private funds.
- California, in 2013, pledged up to $20 million annually to finance 100 hydrogen stations; in 2014, Toyota and Honda supported the effort financially with a combined $22 million. Toyota and Air Liquide announced plans for 12 stations in New England.

- California also set aside up to $75 million for zero-emission trucks, buses, and goods movement.
- H2USA, a public-private effort to prepare the United States for FCEVs, contributed to extensive planning in the Northeast. Two national laboratories provide technical support through a partnership project called H2FIRST.[2]

Significant challenges remain for the industry.

- The U.S. federal tax credit for fuel cell power systems is scheduled to expire in 2016. The federal tax credit for FCEVs expired at year-end 2014.
- Two companies focusing on consumer electronics markets for fuel cells exited the business in 2014.
- Investor interest has been slow to return to the sector. After a roller coaster year, enterprise value for the four largest public North American fuel cell companies totaled $1.3 billion at year-end.
- Shipments of larger fuel cell power generation systems may have dipped; a few very large shipments were booked in 2013, and the market is still small.[3]
- FCEV production forecasts from industry for 2014-2016 are in the thousands of units; California projects a fleet of 6,650 vehicles by 2017 and 18,500 by 2020.
- Fuel cell system cost for light-duty vehicles, as estimated by the U.S. Department of Energy (DOE), appears to have hit a plateau.

HTAC Activities in 2014

In 2014, HTAC formed subcommittees to examine two critical issues: retail fueling infrastructure and advanced manufacturing techniques. These subcommittees will finish their work in 2015 and submit their conclusions and recommendations to the Secretary of Energy.

HTAC engaged several fuel cell manufacturers and users, as well as representatives of California and other states planning or implementing hydrogen infrastructure programs. Overall, significant progress is being made in a number of areas. Key issues to be overcome before FCEVs gain significant acceptance include vehicle cost; station cost; profitability; and technical issues such as fuel metering, fuel quality assurance, and station certification.

Commercialization Initiatives

Most segments of the hydrogen and fuel cell industry enjoyed significant commercial activity in 2014, a substantial share of which occurred outside the United States.

Fuel Cells for Stationary Applications: Fuel cells for distributed power continued to dominate the market in 2014, with 70% of total fuel cell units and more than 80% of megawatts shipped.[4]

- Japan's Ene-Farm residential fuel cell program passed several milestones. Installed units surpassed 100,000 in September, buoyed by price reductions and system improvements such as grid-independent capability. Ene-Farm units are now being sold by apartment building developers as an appliance, and more than 1,000 are on order. Government subsidies for the Ene-Farm program are declining and will end in 2016, although it is anticipated that some form of support will continue. The great majority of units are polymer electrolyte membrane (PEM); Japan Oil ended its residential solid oxide fuel cell (SOFC) program.
- In South Korea, POSCO Energy has placed orders for more than 270 MW of FuelCell Energy fuel cells. POSCO Energy, a division of South Korea's largest steel producer, operates the world's largest fuel cell installation and is building the capacity to produce 100 MW of fuel cells per year in South Korea by 2015.

Figure 2. The Dominion Bridgeport fuel cell park, consisting of five FuelCell Energy power plants, provides ultra-clean electricity around the clock. *Image courtesy of FuelCell Energy, Inc.*

- FuelCell Energy completed installation of a 14.9 MW fuel cell power park on only 1.5 acres of land in downtown Bridgeport, CT (Fig. 2). Dominion, the electric and gas utility, owns and operates the fuel cells.
- Bloom Energy reports it had about 130 MW of capacity installed in the United States in 2014, the majority in California, where Bloom has been very successful in gaining support from the state's Self Generation Incentive Program.
- A few demonstration power generation units are operating in Europe, along with more than 1,000 residential systems; another 1,000 are anticipated via a demonstration program called Ene.field.
- General Electric announced an internally funded spin-off, GE Fuel Cell Systems, to develop and commercialize a hybrid fuel cell turbine concept it claims will deliver up to 65% electrical efficiency. GE has been involved in fuel cell research for decades.

Fuel Cells for Transportation – Passenger Cars: Commercial sales and leases of FCEVs began in the U.S. and Japan in 2014.

- Hyundai recorded the first U.S. lease of its Tucson FCEV in June, to a family in Tustin, California.
- In December, Toyota offered its new FCEV, the Mirai, for sale in Japan, following a substantial publicity campaign. It plans to enter U.S. and European markets in fall 2015. Toyota reported greater than expected interest: orders quickly reached 1,500, mostly from corporate and government buyers.
- Honda, which had announced commercialization in 2015, announced a delay until 2016, citing financial pressure from safety recalls unrelated to its FCEVs.
- The Japanese government (¥2 million) and Tokyo government (¥1 million) announced purchase incentives totaling about $27,000 per vehicle.[5]
- Volkswagen (VW) showed three FCEVs at the Los Angeles Auto Show in November. VW also purchased Ballard's automotive fuel cell technology and agreed with SAIC in China to jointly develop fuel cells for automotive applications.
- Toyota made more than 5,000 hydrogen fuel cell patents, royalty free for five years, to spur development and innovation.

Fuel Cells for Transportation – Buses: The year featured planning and pledges for fuel cell buses, with procurements anticipated in 2015 or 2016.

- The U.S. Department of Transportation made funds available for low- or zero-emission buses, and in early 2015 it awarded $18.6 million[6] for 10 fuel cell buses—five each for transit agencies in California and Ohio.
- In Japan, Toyota's Hino Motors put a new fuel cell bus into service and hinted at commercialization in 2016.
- In Europe, five bus manufacturers signed a letter embracing fuel cell technology. Aberdeen took delivery of the first of 10 fuel cell buses and 8 buses are operating in London. North Rhine-Westphalia envisioned a joint procurement of 300 buses in 2016.
- Ballard ended its bus development relationship with Azure Hydrogen of China.

Fuel Cells for Transportation – Other Vehicles: Several demonstrations were announced in 2014.

- Alstom announced plans to build 40 fuel cell passenger rail cars.
- DOE is funding demonstrations in small numbers of terminal tractors, medium-duty delivery vans, a bucket truck, cargo tuggers (Fig. 3), and power units for refrigerated trailers. Budget for these market transformation programs was about $3 million in 2014.

Figure 3. FedEx, Plug Power, and partners are developing 15 fuel cell-powered tow tractors for use at Memphis International Airport. *Image courtesy of FedEx.*

Hydrogen Infrastructure: Although the worldwide hydrogen fueling infrastructure is still in its infancy, several hundred public stations are under construction or planned, with governments and private companies aiming for sufficient stations to support a rollout of vehicles between 2015 and 2017.

- In Japan, 45 stations are open or under construction, with a goal of 100 by the end of 2015. Government support increased in 2014 to about $88 million.
- The total number of hydrogen stations open in Europe by the end of 2015 could approach 80.
- Germany is targeting 50 stations by year-end 2015, with public financing of about $50 million secured.
- The H2 Mobility initiative in Europe focused on the deployment of stations in Germany, with a goal of 100 within four years and up to 400 by 2023, assuming sufficient vehicle sales. The large majority of the estimated $463 million cost will come from private sources.
- UK H2Mobility has a target of 65 stations; the United Kingdom (UK) government set aside about $8.7 million to upgrade 6–8 stations and share the cost of building 4–7 new ones.
- In Scandinavia, 16 stations are operating or under construction; at least 10 more are under review. Planning is also underway in France and Switzerland.
- In California, more than 50 stations were open or in progress at year-end, after the California Energy Commission awarded $46.6 million in May for 28 stations and a mobile refueler. A start-up, FirstElement Fuel, won financing for 19, with support from Toyota (at least $7.2 million) and Honda ($13.8 million).
- In November, Toyota and Air Liquide announced plans to build 12 stations in the Northeast, in states that have adopted California's Zero Emission Vehicle (ZEV) program.

- The ZEV program includes both obligations and incentives for automakers to sell zero-emission vehicles, including FCEVs. FCEV sales in California, or in any state that has adopted the ZEV regulations, earn credit toward obligations in all ZEV states, making FCEV sales highly valuable to automakers.
- As encouraging as they are, these efforts will provide only a skeletal infrastructure. There are more than 14,000 conventional gas stations in Germany, for example, and about 10,000 in California. As vehicle sales increase, infrastructure development will become a job for the private sector.

Fuel Cells for Materials Handling: The U.S. materials handling market recovered in 2014 after a poor 2013, led by an order from Walmart for 1,783 Plug Power units.

- According to DOE, about 7,500 fuel cell forklifts were in use or on order in the United States at the end of 2014.
- In 2014, Plug Power, the dominant supplier of fuel cells for forklifts, began to offer hydrogen fueling infrastructure. It markets this option—along with a service contract under the name GenKey®—as a turnkey product.
- A small number of forklift demonstrations are under way in Europe and Japan.

Fuel Cells for Backup Power Applications: Fuel cells are generally regarded as superior to diesel backup generators in many ways, including their greater reliability, lower emissions, better energy efficiency, and ready installation. Limitations on fuel cell backup power systems include siting restrictions, hydrogen fuel delivery, and cost.

- DOE estimates 4,000 fuel cell telecom backup power systems were in use in the United States in 2014.
- Fuel cells are also in use in smaller numbers at a wide variety of locations where losing power costs money or risks lives, including hospitals, grocery stores, data centers, schools, jails, and other locations.
- The market for fuel cell backup power is even more dynamic in the developing world, where grid power is sporadic or limited to certain hours each day. India, China, and Indonesia, among others, are using fuel cells in varying numbers. Companies pursuing those markets are optimistic that a fuel cell's ability to provide high quality continuous power for many hours per day gives them a competitive edge.

Hydrogen for Grid Support Applications: Electrolyzers are being evaluated to help smooth out generation from wind and solar systems and provide demand for renewable power when grid demand is low or constrained. The hydrogen thus produced can be used for a variety of purposes.

This type of grid support is increasingly necessary as the percentage of intermittent renewable generation increases. The approach is typically called "hydrogen energy storage" in the United States and "power to gas" or "P2G" in Europe.

- More than 30 P2G projects are under way in Europe, primarily in Germany, including at least two that feed hydrogen to the natural gas pipeline grid.
- In July, a $2 million hydrogen energy storage project was initiated for Ontario, Canada.
- Hydrogen energy storage is under study in California and New York, and at the federal level.

Other Applications: Fuel cells are making inroads in other markets, including military (e.g., unmanned vehicles, submarines and subsea weapons, and soldier and forward base power) and aerospace (e.g., auxiliary power for airliners and motive power for aircraft and drones).

Policy, Regulations, and Codes and Standards

Codes and Standards: Efforts to develop or revise safety and product standards made progress in 2014.

- In a major milestone, SAE International published two standards: Standard J2799 – 70 MPa Compressed Hydrogen Surface Vehicle Fueling Connection Device and Optional Vehicle to Station Communications, and Standard J2601 – Fueling Protocols for Light-Duty Gaseous Hydrogen Surface Vehicles.
- DOE released a smartphone app providing access to safety and planning information. DOE reported its safety education program has reached nearly 30,000 people.
- Japan made progress on a list of safety regulations to make them more suitable for hydrogen retail outlets.
- California adopted an expanded set of standards for hydrogen metering to enable retail fuel sales while encouraging development of higher accuracy meters.
- H2FIRST is examining station design as well as developing test devices to verify station fill protocol and hydrogen quality.

Policy: After years in the shadows, hydrogen and fuel cells regained some visibility in 2014 as contributors to sustainable energy systems, whether functioning as an energy carrier; balancing intermittent solar or wind generation; or providing low- or zero-emission power for homes, businesses, factories, or vehicles.

- Japan's 4th Strategic Energy Plan, adopted in April, gives hydrogen "the central role" in Japan's energy future. The "new energy model" emphasizes resilience, open access, and consumer choice.

- A companion hydrogen roadmap was published in June. Targets include 50%–70% of the new car fleet to be "new generation vehicles" by 2030, including FCEVs, as well as 1.4 million residential fuel cell units to be installed by 2020, and 5.3 million by 2030.
- Europe has set new CO_2 targets for new cars, to be phased in from 2015 to 2021, when the new car fleet average standard will be at 95 grams per kilometer, a 40% reduction from 2007 levels. The requirement gives super credits to manufacturers for extremely low-emission cars (50 grams per kilometer), providing incentives for battery electric and fuel cell electric vehicles.
- Germany adopted a new Electric Mobility Law in September that allows non-financial incentives for FCEVs and establishes labeling requirements.
- The UK government committed about $8.7 million (£5.5 million) to a $14.2 million (£9 million) program to bring the number of hydrogen stations to 15 by 2015. It made another $3.2 million (£2 million) available for vehicle purchases.
- California extended its Self-Generation Initiative Program, arguably the most important state-level incentive for fuel cells in the United States. Utilities will contribute $83 million per year through 2019, with 75% available for fuel cells and energy storage in 2015. There is a 20% bonus for California manufacture.
- In May, California joined many of its ZEV partners, including Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont, in a Multi-State ZEV Action Plan to achieve 3.3 million ZEVs on the road by 2025.

Financial Climate

The capital markets were generally more receptive to hydrogen and fuel cell business models in 2014 than they have been in a number of years. Following a surge in public market valuations for several of the leading fuel cell companies in late 2013, a number of companies were able to raise substantial amounts of capital early in 2014.

- Plug Power completed a $22 million private financing and a $116 million underwritten public offering. M&T Bank agreed to finance Plug customers.
- FuelCell Energy (FCE) raised $29.4 million in an underwritten offering and received a $35 million equity infusion and $40 million line of credit from utility industry giant NRG. NRG also agreed to market FCE's fuel cells.
- Two early-stage UK fuel cell companies raised capital in the London markets. Intelligent Energy raised $68 million at an astonishing $1.1 billion valuation. Ceres raised $32.6 million on the AIM market.
- Private financing included $5.4 million to Heliocentris; an undisclosed amount to Sunfire of Germany, from Total; and a $40 million infusion to Altergy as a result of a legal settlement.
- Major utility Exelon announced it would provide equity financing for 21 MW of power projects utilizing Bloom Energy fuel cells.

Mergers and Acquisitions:

- Plug Power acquired Relion for $4 million in stock, materially less than the amount invested in Relion.
- South Korean company Doosan acquired Clear Edge Power for $32.4 million. ClearEdge had declared Chapter 11 bankruptcy only a year after it acquired the fuel cell assets of UTC Power (UTC) and only months after proclaiming a major expansion strategy.
- Hyster-Yale Materials Handling Inc. acquired Nuvera for an undisclosed price. Hyster-Yale expects to spend $40 million–$50 million to bring Nuvera fuel cell and hydrogen generation products to market.
- Ballard Power acquired the transportation fuel-cell-related intellectual property assets of UTC.[7]
- Hydrogen Future Corporation of Houston acquired Hydra Fuel Cell Corporation in a stock transaction.

In 2014, the sector also experienced the following setbacks, in addition to ClearEdge's bankruptcy:

- Danish company Haldor Topsoe closed its fuel cell division after investing almost $270 million. BIC, the French giant developing hydrogen storage technology for consumer products, exited the business.[8] Lilliputian Systems, a developer of SOFCs for portable power devices, liquidated its assets.
- Vision Industries of California filed Chapter 11 bankruptcy and will attempt to reorganize. Acta SpA, an Italian manufacturer of alkaline fuel cells and electrolyzers, also filed for bankruptcy protection.

Research and Development

Research and development can provide important support for commercialization activities. Some advances are being made toward key DOE targets, despite several years of declining budgets. Funding for vehicle-related R&D appears to have stabilized in the $100 million range. Funding for SECA, the solid oxide research program, was proposed at near zero again for fiscal year 2015; Congress approved $30 million (Fig. 4).

- With a $33 million program supporting 13 "medium-temperature" SOFC projects, the Advanced Research Projects Agency-Energy (ARPA-E) became a major contributor to fuel cell R&D.

Funding ($ in thousands)

Office of Energy Efficiency and Renewable Energy	FY 2013	FY 2014	FY 2015	FY 2016
Key Activity	**Approp.**	**Approp.**	**Approp.**	**Request**
Fuel Cell R&D	41,266	32,422	33,000	36,000
Hydrogen Fuel R&D[1]	31,682	34,467	35,200	41,200
Manufacturing R&D	1,899	2,879	3,000	4,000
Systems Analysis	2,838	3,000	3,000	3,000
Technology Validation	8,514	6,000	11,000	7,000
Safety, Codes and Standards	6,808	6,909	7,000	7,000
Market Transformation	2,838	2,841	3,000	3,000
NREL Site-Wide Facilities Support	0	1,000	1,800	1,800
SBIR/STTR	2,139	3,410	TBD	----------
Total	**$97,984**	**$92,928**	**$97,000**	**$103,000**

Funding ($ in thousands)

Other DOE Offices	FY 2013	FY 2014	FY 2015
Basic Science[2]	26,000	~20,000	~20,000
Fossil Energy, SECA	24,000	30,000	30,000
ARPA-E[3]	2,000	~30,000	~33,000
Total	**$52,000**	**~$80 ,000**	**~$83,000**

[1] Hydrogen Fuel R&D includes Hydrogen Production & Delivery R&D and Hydrogen Storage R&D
[2] Estimated from FY14 appropriation
[3] Estimated from FY14 appropriation. FY15 amount will depend on FOA selection.

Total FY15 Budget: ~$180M

Figure 4. Recent DOE funding for hydrogen and fuel cells R&D. *Source: U.S. Department of Energy, Fuel Cell Technologies Office.*

- University of Manchester (UK) researchers discovered that graphene material can filter elements at the atom scale and yet allow protons to pass through. This may serve as a technology for removing impurities from hydrogen fuel.

Significant progress in DOE-funded research in 2014 includes the following:

- Two national laboratories reported development of a new catalyst structure called a nanoframe that offers potential for more than 30x improvement in catalyst activity (Fig. 5). DOE estimates that catalyst costs represent nearly half of stack costs. DOE invested nearly $13 million in fuel-cell-catalyst-related R&D in FY 2014.
- Improvements allowed one membrane electrode assembly (MEA) to achieve DOE's 2014 target for specific power levels, though not the durability target. (Other MEAs had met the durability target but not the specific power target.)

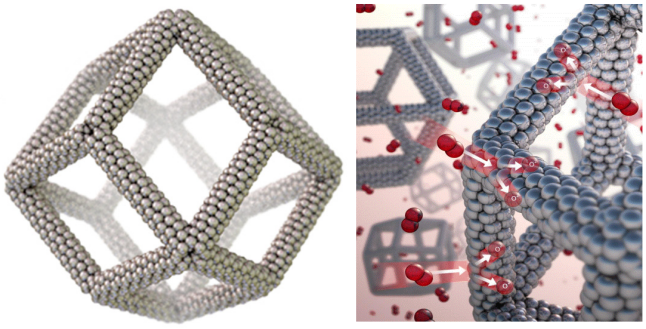

Figure 5. Platinum-nickel alloy nanoframe covered by a thin platinum skin, a new catalyst structure developed by researchers at Argonne National Laboratory and Lawrence Berkeley National Laboratory. *Image courtesy of Vojislav Stamenkovic, ANL, also printed in Science (343: 6177), 2014; pp. 1339–1343.*

- DOE reported a new fueling strategy to improve station capacities during peak hours. The technique reduces on-site compression requirements, yielding a 14% cost reduction for tube trailer hydrogen delivery.
- DOE also reported a continued improvement in carbon fiber tensile strength, which is important for high-pressure storage vessels.
- In hydrogen production, DOE reported improvements in electrolyzer drying techniques, in stability of photoelectrochemical devices, in reactor design for biological production, and in solar thermochemical materials and concepts.
- The number of fuel-cell-related patents remained strong in 2014, with 658 patents granted through three quarters, an increase of 36 year-over-year.[9] Toyota, Honda, and General Motors led the way.
- The cumulative number of patents resulting from DOE research exceeded 500.

Continuing Challenges: While deployment of fuel cells in various applications has been increasing, cost, technical, and marketplace challenges still hinder commercialization.

- Progress toward goals (Fig. 6) set by DOE has slowed over the past few years because of the difficulty in achieving the last increments and because funding has declined by more than half since 2007.
- The projected cost of vehicle fuel cells at 500,000 units per year has remained at about $55 per kW since 2010; catalysts and separator plates are 70% of stack costs. The long-term automotive fuel cell cost goal is $30 per kW, with $40 by 2020 an interim goal.

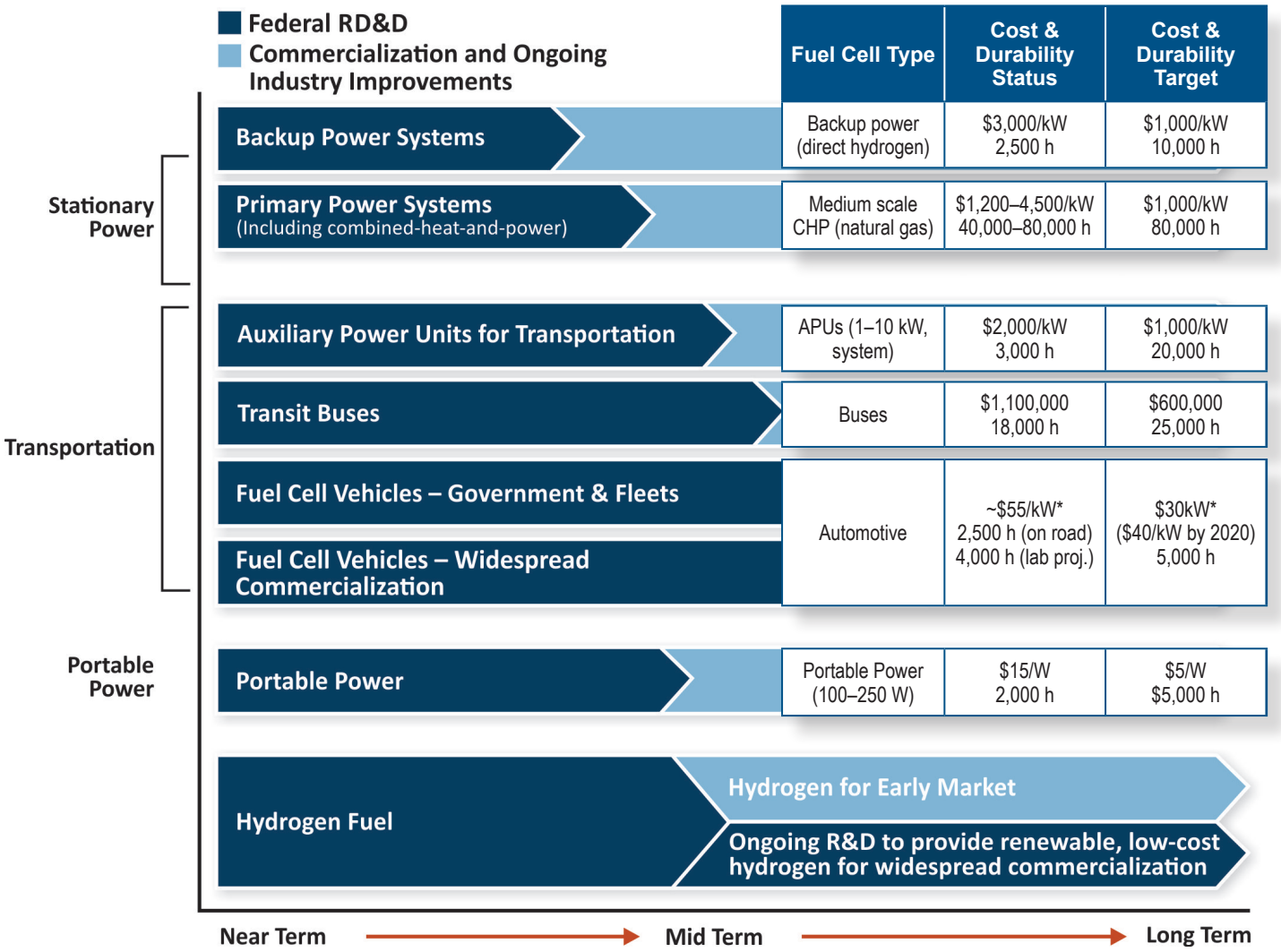

Figure 6. DOE targets and 2014 cost and durability status for fuel cells. *Source: U.S. Department of Energy, Fuel Cell Technologies Office.*

Reports

A number of reports on hydrogen and fuel cells were published in 2014.

- The California Air Resources Board (CARB) published its first *Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*, as required by the California Legislature. CARB concluded 100 hydrogen stations will be needed to support the expected 2020 fleet.
- Japan's 4th Strategic Energy Plan, approved in April, gives hydrogen "the central role" in a new distributed energy system. Japan's METI published a *Strategic Road Map for Hydrogen and Fuel Cells* in June.
- DOE released the *2013 Fuel Cell Technologies Market Report* in the fall. It estimates fuel cell sales reached $1.3 billion and the number of systems shipped increased 26%.
- 4th Energy Wave's *Fuel Cell Annual Review 2013* estimates sales of $1.8 billion and notes a surge of interest in Africa.
- E4tech, a European consultancy, published its *Fuel Cell Industry Review 2014* in October, projecting another year-over-year increase in shipments.
- Breakthrough Technologies Institute published *The Business Case for Fuel Cells 2014*, latest in a series.
- The National Renewable Energy Laboratory updated its report on the performance of fuel cell buses, *Fuel Cell Buses in U.S. Transit Fleets: Current Status 2014*.

Conclusions

Three events have set the tone for fuel cell and hydrogen energy development over the next several years:

- Japan asserted world leadership in 2014 in the transition to hydrogen as a fuel and energy carrier. The Japanese government's choice of hydrogen in "the central role" in a new post-nuclear energy economy is by far the most ambitious country-level endorsement of hydrogen, made even more significant by Japan's status as a top world economy.

- Toyota, and to a lesser extent Honda, of Japan, asserted leadership in FCEVs, with Toyota beginning to market its new Mirai FCEV in December and both companies contributing to fueling infrastructure.
- Governments and private companies in Europe joined Japan and California in financing FCEV infrastructure development sufficient to support market launch in most of the developed world.

The burden now shifts to automakers to sell enough vehicles in a timely way to justify the investment.

The broad marketplace for fuel cell power generation and hydrogen energy is still in its infancy. It relies upon enlightened government activity for regulations, standardization efforts, R&D support, and marketplace incentives in most markets, and likely will for a long time. This is not exceptional. Incentives for solar and wind power systems are still needed despite their multi-gigawatt marketplace success. This need for support puts a burden on the policy community to balance the benefits of fuel cells and other advanced technologies against competing budgetary demands.

The opportunity is enormous. South Korea sees a potential for 2.8 million jobs worldwide over the next two decades. Japan sees its fuel cell market alone growing to $70 billion by 2050. DOE's analysis suggests a peak job potential of 560,000 U.S. jobs over the next two decades. The technology offers additional benefits in emissions, efficiency, fuel flexibility, greenhouse gas reduction, and grid resilience.

In the United States, 2015 will be a critical year.

The federal tax credit for FCEVs has expired, and the credit for power systems is scheduled to expire in 2016.

California's aggressive incentives have proved their value: the vast majority of FCEVs and power systems in the United States are located in the state. But California's market, big as it is, cannot drive commercialization of fuel cells by itself. Other states face decisions on whether and to what extent they wish to support fuel cells; a few have initiated support programs.

Beginning in 2015, states that have adopted California's ZEV program face a particular challenge and opportunity—without fueling infrastructure, there will be no FCEV sales in these states. The challenge will be to find and employ creative financing programs until vehicle sales are sufficient to support commercial fueling stations.

Significant technical challenges remain.

Fuel cells and hydrogen energy technologies have progressed to the point of commercialization in power generation, backup power, and materials handling markets. High system costs; customer unfamiliarity; and cost, production, and delivery challenges with hydrogen fuel remain market-limiting factors. In addition, fluctuating energy prices affect consumer choices and add market uncertainty.

Applying fuel cells and hydrogen technology to passenger vehicles is exceptionally challenging. Systems must be durable, lightweight, compact, cheap, and manufacturable in the millions of units. Hydrogen fueling stations must be customer friendly and reliable, as well as offer competitively priced fuel.

Toyota and Hyundai have demonstrated that fuel cells are developed to the point where functional, desirable vehicles can be manufactured. Figure 7 plots current status (in blue, expressed as a percentage) against 2020 targets set by a DOE/industry panel. It suggests much RD&D remains to achieve parity with incumbent technologies.

The benefits—zero emissions and ultimately zero petroleum consumption, with no sacrifice of vehicle performance or utility—suggest the importance of continuing a robust federal research program.

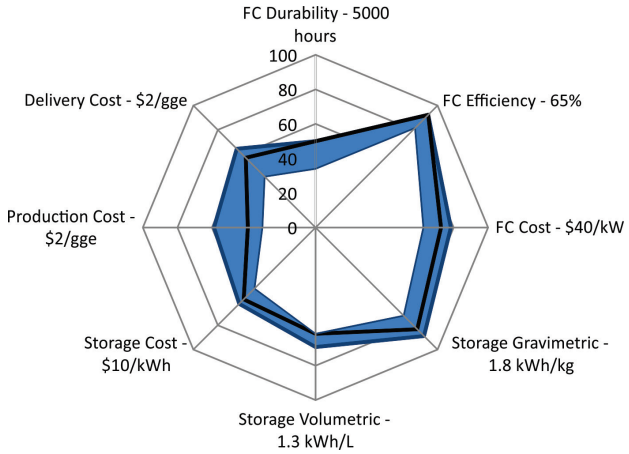

Figure 7. Hydrogen and transportation fuel cell status vs. 2020 DOE/industry targets.[10] *Source: DOE, Fuel Cell Technologies Office.*

(Endnotes)

1 *Fuel Cell Annual Review 2013*, 4th Energy Wave, 2014, p. 22. DOE's Annual Market review estimated revenues of $1.3 billion.

2 The formal name is "Hydrogen Fueling Infrastructure Research and Station Technology."

3 *Fuel Cell Industry Review 2014*, E4tech, 2014, p. 9 ff.

4 Ibid., p. 13.

5 Currency conversions are based on the Internal Revenue Service's 2014 annual average.

6 Early in 2015.

7 The intellectual property was sold to Volkswagen early in 2015.

8 Intelligent Energy bought the technology early in 2015.

9 Clean Energy Patent Growth Index, quarters 1–3, 2014.

10 Black line represents the state-of-the-art lab-scale technology status (projected to high volume) relative to the DOE's 2020 targets. Shaded area represents the range/error bars associated with the status projections at high volume.

The Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) was established under Section 807 of the Energy Policy Act of 2005 to provide technical and programmatic advice to the Energy Secretary on DOE's hydrogen research, development, and demonstration efforts.

For more information see
http://www.hydrogen.energy.gov/advisory_htac.html