U.S. DEPARTMENT OF ENERGY

Hydrogen and Fuel Cell Activities, Progress, and Plans: September 2010 to August 2013

Third Report to Congress
October 2013

United States Department of Energy
Washington, DC 20585

Message from the Assistant Secretary

The enclosed report, *Hydrogen and Fuel Cell Activities, Progress and Plans*, is provided in response to section 811(a) of the Energy Policy Act of 2005 (EPACT), P.L. 109-58, enacted in August 2005.

This report is the third in a series of recurring reports required by Section 811(a). The first report covered the period from the start of the Hydrogen Fuel Initiative in 2004 through July 2008. The second report covered the period from August 2008 to August 2010. This report covers the period from September 2010 to August 2013.

Pursuant to statutory requirements, this report is being provided to the following members of Congress:

The Honorable Joseph R. Biden, Jr.
President of the Senate

The Honorable John Boehner
Speaker of the House of Representatives

The Honorable Rodney P. Frelinghuysen
Chair, House Subcommittee on Energy and Water Development
Committee on Appropriations

The Honorable Marcy Kaptur
Ranking Member, House Subcommittee on Energy and Water Development
Committee on Appropriations

The Honorable Ron Wyden
Chair, Senate Committee on Energy and Natural Resources

The Honorable Lisa Murkowski
Ranking Member, Senate Committee on Energy and Natural Resources

The Honorable Barbara Mikulski
Chair, Senate Committee on Appropriations

The Honorable Richard C. Shelby
Ranking Member, Senate Committee on Appropriations

The Honorable Harold Rogers
Chair, House Committee on Appropriations

The Honorable Nita M. Lowey
Ranking Member, House Committee on Appropriations

The Honorable Dianne Feinstein
Chair, Senate Subcommittee on Energy and Water Development
Committee on Appropriations

The Honorable Lamar Alexander
Ranking Member, Senate Subcommittee on Energy and Water Development
Committee on Appropriations

The Honorable Carl Levin
Chair, Senate Committee on Armed Services

The Honorable James Inhofe
Ranking Member, Senate Committee on Armed Services

The Honorable Howard P. McKeon
Chair, House Committee on Armed Services

The Honorable Adam Smith
Ranking Member, House Committee on Armed Services

The Honorable Fred Upton
Chair, House Committee on Energy and Commerce

The Honorable Henry Waxman
Ranking Member, House Committee on Energy and Commerce

The Honorable Lamar Smith
Chair, House Committee on Science and Technology

The Honorable Eddie Bernice Johnson
Ranking Member, House Committee on Science and Technology

If you have any questions or need additional information, please contact me or Mr. Brad Crowell, Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Dr. David T. Danielson
Energy Efficiency and Renewable Energy

Executive Summary

This report documents the activities of the Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) that fulfill the provisions of Title VIII of the Energy Policy Act of 2005 (EPACT). EERE leads activities related to DOE's Hydrogen and Fuel Cells Program (the Program), which addresses the full range of barriers facing the development and deployment of hydrogen and fuel cell technologies. This Program has been integral to the important progress in these technologies in recent years. Advances achieved through the Program's efforts can be seen in the marketplace today: commercial customers are choosing fuel cells for the benefits they offer, and growing sales and manufacturing volumes for applications, such as forklifts and backup power, are lowering costs, increasing consumer confidence, and growing the domestic supplier base. EERE's efforts have led to more than 400 hydrogen and fuel cell related patents, nearly 40 commercial technologies, and about 65 technologies projected to be commercialized within three-to-five years. In addition, EERE has successfully stimulated early markets for fuel cells through strategically targeted deployments that are cost-shared with industry partners: deployments of more than 1,000 fuel cells in key early markets have led to roughly 9,000 additional orders for fuel cells by industry, *with no additional DOE funding.*

Since the last report period, from August 2007 through August 2010, several major government-industry partnerships have been established around the world to support fuel cell electric vehicle (FCEV) rollout plans (partnerships now exist in the United States, Germany, Japan, the United Kingdom, France, and Scandinavia). To support the technical progress needed to enable widespread commercialization, from FY 2010 to FY 2013, DOE pursued a strong, strategically balanced portfolio of hydrogen and fuel cell activities, dedicating approximately $630 million to these efforts. Over the last three years, the Program has continued to make progress toward the goals laid out in its developmental roadmap (the *Hydrogen and Fuel Cells Program Plan*). The Program's accomplishments are thoroughly documented every year in its *Annual Progress Report*, and a summary of major accomplishments (including citations) is provided in both this report and shown on the "Accomplishments and Progress" page of the Fuel Cell Technologies Office website (www.hydrogenandfuelcells.energy.gov/accomplishments.html).

HYDROGEN AND FUEL CELL ACTIVITIES, PROGRESS AND PLANS: THIRD REPORT TO CONGRESS

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I. Legislative Language

This report addresses subsection 811(a) of Public Law 109-58, also known as the Energy Policy Act of 2005 (EPACT). Subsection 811(a) states:

" . . . not later than 2 years after the date of enactment of this Act, and triennially thereafter, the Secretary shall submit to Congress a report describing--

(1) activities carried out by the Department under this title, for hydrogen and fuel cell technology;
(2) measures the Secretary has taken during the preceding 3 years to support the transition of primary industry (or a related industry) to a fully commercialized hydrogen economy;
(3) any change made to the strategy relating to hydrogen and fuel cell technology to reflect the results of learning demonstrations;
(4) progress, including progress in infrastructure, made toward achieving the goal of producing and deploying not less than--
(A) 100,000 hydrogen-fueled vehicles in the United States by 2010; and
(B) 2,500,000 hydrogen-fueled vehicles in the United States by 2020;
(5) progress made toward achieving the goal of supplying hydrogen at a sufficient number of fueling stations in the United States by 2010 including by integrating--
(A) hydrogen activities; and
(B) associated targets and timetables for the development of hydrogen technologies;
(6) any problem relating to the design, execution, or funding of a program under this title;
(7) progress made toward and goals achieved in carrying out this title and updates to the developmental roadmap, including the results of the reviews conducted by the National Academy of Sciences under subsection (b) for the fiscal years covered by the report; and
(8) any updates to strategic plans that are necessary to meet the goals described in paragraph (4)."

II. Department of Energy Hydrogen and Fuel Cells Program — Activities under EPACT Title VIII

Response to EPACT section 811(a)(1)

The mission of the Department of Energy's (DOE's) Hydrogen and Fuel Cells Program (the Program) is to enable the widespread commercialization of a portfolio of hydrogen and fuel cell technologies across multiple sectors. To enable market success of these technologies, and to achieve the associated benefits of their widespread use, the Program conducts basic and applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges. Success of this mission would play a substantial role in overcoming our Nation's key energy challenges, including significant reductions in greenhouse gas emissions and oil consumption as well as improvements in air quality. Fuel cells also enable more efficient use of energy while increasing the diversity of our energy sources. Fuel cells can provide power from diverse domestic fuels, including hydrogen and other renewable sources, such as bio-methanol or biogas, as well as natural gas. Fuel cells offer numerous potential advantages that make them appealing for end users, including quiet operation, low maintenance needs, and high reliability.

The Program integrates the activities of four DOE offices: Energy Efficiency and Renewable Energy (EERE), Nuclear Energy (NE), Fossil Energy (FE), and Science (SC). The Program's activities are documented at a high level in the *Hydrogen and Fuel Cells Program Plan*, released in September 2011. Detailed discussions of barriers and the current and planned activities are found in the hydrogen and fuel cell plans of the individual DOE offices, as follows:

- Office of Energy Efficiency & Renewable Energy (EERE): *Fuel Cell Technologies Office's Multi-Year Research, Development, and Demonstration Plan (MYRD&D Plan)*[1]
- Office of Fossil Energy (FE): *Hydrogen from Coal RD&D Plan*[2]
- Office of Science (SC): *Basic Research Needs for the Hydrogen Economy*[3]

The most recent results—with information on individual projects—are found in the *DOE Hydrogen and Fuel Cells Program Annual Progress Report*,[4] which summarizes each year's hydrogen and fuel cell activities and accomplishments for projects funded by the Program.

[1] *Fuel Cells Technologies Program Multi-Year RD&D Plan,* U.S. Department of Energy, April 2009, www.eere.energy.gov/hydrogenandfuelcells/mypp.

[2] *Hydrogen from Coal RD&D Plan,* U.S. Department of Energy, September 2009, www.fossil.energy.gov/programs/fuels/publications/programplans/2009_Draft_H2fromCoal_Sept30_web.pdf.

[3] *Basic Research Needs for the Hydrogen Economy,* U.S. Department of Energy, February 2004, www.sc.doe.gov/bes/hydrogen.pdf.

[4] *U.S. Department of Energy Hydrogen Program Annual Progress Report*, www.hydrogen.energy.gov/annual_progress.html.

As shown in figure 2.1, the Program conducts a wide range of activities to address technological and non-technological barriers to commercialization. R&D efforts pursue key technology advances, including reducing the cost and improving the durability and performance of fuel cells; reducing the cost of producing, delivering, and storing hydrogen; and improving the capacity of hydrogen storage systems. Real-world demonstrations are conducted to validate performance and provide feedback to R&D efforts.

The Program also aims to act as a catalyst in the transition from R&D to early deployment. This is accomplished through a strategy integrating real-world demonstrations; public outreach and education; strategic deployments in key early markets; development and dissemination of critical safety information; and efforts to enable nationally and internationally harmonized codes and standards. These activities are integrated into a well-planned timeline that maximizes their benefits and enables a broader transformation of the marketplace.

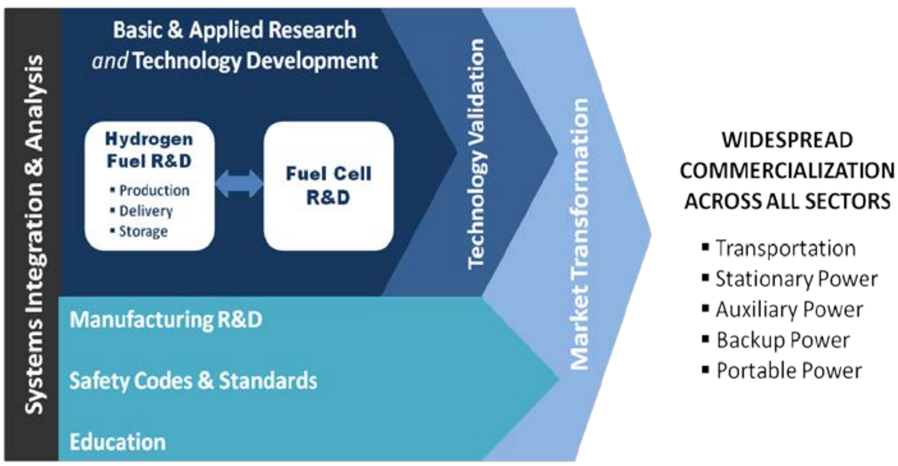


Figure 2.1. *The Program's activities are well integrated and address both technological and non-technological barriers to commercialization.*

The following sections provide a summary of DOE's activities under Title VIII of EPACT (*Progress and accomplishments by these activities are discussed in section 7 of this report*):

Hydrogen Fuel R&D focuses on materials research and technology development to enable the production of low-cost, carbon-free hydrogen fuel from diverse domestic pathways and to address key challenges to hydrogen delivery and storage.

The **hydrogen production** aspect of these efforts includes R&D of technologies for

- Small-scale, distributed hydrogen production at the fueling site (e.g., electrolysis, reforming of renewable liquids), and
- Large-scale centralized production (e.g., biomass and coal gasification, wind and solar-powered electrolysis, solar-driven high-temperature thermochemical

cycles, as well as direct solar conversion, including photobiological and photoelectrochemical pathways).

The Program's **hydrogen delivery** efforts seek to reduce the cost of technologies for transporting hydrogen from centralized production facilities and reduce the cost of compressing, storing, and dispensing hydrogen at the fueling site. The key overarching goal for all production and delivery pathways is to reduce the cost of hydrogen to $2.00–4.00/gallon gasoline equivalent[5] (gge), delivered and dispensed.[6,7] The **hydrogen storage** component of this sub-program focuses on the R&D of low-pressure materials-based storage that will enable widespread commercialization of fuel cell systems for diverse applications. R&D efforts are also conducted to explore advanced conformable and low-cost high-pressure storage technologies. The primary goal of the program's hydrogen storage efforts is to enable a driving range of >300 miles across all vehicle platforms while meeting the packaging, cost, safety, and performance requirements of current and future vehicle markets.

Fuel Cell R&D pursues advances in fuel cell stacks and balance of plant components to address the challenges of improving the durability, reducing the cost, and improving the performance (power, start-up time, transient response, etc.) of fuel cell systems. Key goals are to develop

- A vehicular fuel cell power system with 60 percent peak efficiency and a 5000-hour lifespan (150,000 miles) at a cost of $30/kW (at high manufacturing volumes), and
- Stationary fuel cell systems for distributed power generation for a cost of $1,000–$1,500/kW and a durability of 60,000–80,000 hours, depending on size and application.

The Program is also conducting R&D of fuel cells for auxiliary power units (APUs) and portable power systems.

DOE's Office of Fossil Energy has also been conducting efforts in solid oxide fuel cells (SOFCs), under the Solid State Energy Conversion Alliance (SECA) Program, which aims to reduce the cost and improve the performance of SOFCs. These activities are focused primarily on fuel cells for megawatt-scale, near-zero-emissions stationary power. The Hydrogen and Fuel Cells Program coordinates with SECA and keeps abreast of this program's progress in SOFCs as it relates to distributed energy generation.

[5] The energy content of a gallon of gasoline and a kilogram of hydrogen are approximately equal on a lower heating value basis; a kilogram of hydrogen is approximately equal to a gallon of gasoline equivalent (gge) on an energy content basis.
[6] This cost range results in equivalent fuel cost per mile for a hydrogen fuel cell vehicle compared to gasoline hybrid vehicles in 2020. The full explanation and basis can be found in U.S. Department of Energy (DOE) Record 11007 (see www.hydrogen.energy.gov/program_records.html).
[7] All costs in this plan are in 2007 dollars to be consistent with EERE planning which uses the energy costs from the 2009 Annual Energy Outlook.

Basic Science Research addressing critical challenges related to hydrogen storage, production, and fuel cells is supported by the Office of Basic Energy Sciences within the DOE Office of Science. This basic research complements the applied research and development projects supported by other offices in the Program. Progress in any one area of basic science is likely to spill over to other areas and bring advances on more than one front.

Examples of basic research most relevant to the Program's activities are:

- *Hydrogen Storage:* nanostructured materials; theory, modeling, and simulation to predict behavior and design new materials; and novel analytical and characterization tools.
- *Fuel Cells:* nanostructured catalysts and materials; integrated nanoscale architectures; novel fuel cell membranes; innovative synthetic techniques; theory, modeling, and simulation of catalytic pathways, membranes, and fuel cells; and novel characterization techniques.
- *Hydrogen Production:* long term approaches such as photobiological and direct photochemical production of hydrogen.

By maintaining close coordination between basic science research and applied R&D, the Program ensures that discoveries and related conceptual breakthroughs achieved in basic research programs will provide a foundation for the innovative design of materials and processes. This, in turn, will lead to improvements in the performance, cost, and reliability of fuel cell technologies and technologies for hydrogen production and storage.

Manufacturing R&D develops processes and technologies that reduce the cost of manufacturing fuel cells and systems for the production, delivery, and storage of hydrogen, while ensuring quality and reliability. These low-cost, high-volume manufacturing processes are critical tools that industry needs to produce affordable hydrogen and fuel cell components and systems and to develop a competitive domestic supplier base.

Technology Validation conducts real-world demonstrations, data collection, and analysis of pre-commercial hydrogen and fuel cell technologies. These demonstrations involve multiple types of fuel cells and a variety of systems, such as stationary power installations (including "tri-generation" or combined-heat-hydrogen-and-power systems), hydrogen fueling infrastructure, fuel cell electric vehicles, and systems that integrate renewable power generation with hydrogen production. Technology Validation is an extension of R&D—by providing critical data, this sub-program helps identify issues to be addressed in the Program's R&D efforts, such as system engineering issues that may not be evident in laboratory tests. This aids in measuring progress and making accurate assessments of the status of the technologies.

Safety, Codes & Standards addresses critical needs regarding hydrogen safety and the development of codes and standards, which are essential for commercialization of hydrogen-based products and systems. To address the lack of safety data, inconsistent safety practices, and the general lack of knowledge regarding the safe use of hydrogen, this sub-program develops safety knowledge tools, including hydrogen best practices and lessons-learned, as well as educational resources (on-line and classroom) for first responders, researchers, and permitting officials. These efforts also involve establishing and ensuring safe practices within all Program activities. To support the development and harmonization of national and international codes and standards, this sub-program conducts underlying R&D needed to ensure codes and standards are technically sound; improves access to standards and model codes; supports the harmonization of domestic standards; shares lessons-learned regarding siting and permitting; and plays a leading role in international efforts to harmonize standards. The sub-program also conducts R&D of low-cost, durable hydrogen sensor technologies that can be implemented in various hydrogen applications.

Education and Outreach addresses the knowledge barriers that may impede the acceptance of hydrogen and fuel cell technologies. Overcoming these barriers is important to enabling key early market deployments, as well as longer-term widespread market adoption and acceptance. These efforts focus on developing resources and conducting outreach to increase the understanding of the benefits of the technologies and address safety, codes, and standards concerns. Particular attention is paid to key audiences, such as potential early market end-users, emergency responders, safety and code officials, state and local governments, and educators. These efforts also facilitate the expansion of hydrogen and fuel cell curricula at educational institutions.

Market Transformation identifies strategic opportunities to grow early markets for hydrogen and fuel cells and directly assists in the deployment of commercial and near-commercial hydrogen and fuel cell systems. The primary goal of Market Transformation is to increase sales volumes in key early markets, where a modest amount of new orders will have a significant impact on reducing costs through economies of scale. Early market sales also stimulate further market activity by supporting the growth of domestic industry, overcoming some of the logistical and other non-technical challenges associated with adoption of these new technologies, and establishing key elements of the infrastructure that will be essential for later market growth.

In addition to their direct positive impact on the market, deployments provide valuable data on real-world operation, lessons-learned from early adopters, and information that is used to validate the benefits of the technologies. These activities make up a key final phase in the Program's comprehensive strategic timeline for moving technologies from the laboratory to self-sustaining commercialization, and they are closely coordinated and integrated with the Program's demonstration and education and outreach efforts. In FY 2009, the ***American Recovery and Reinvestment Act (Recovery Act)*** provided increased funding for Market Transformation activities. Much of this funding was implemented by projects during the period covered by this report; *progress made by those projects is summarized in section 7 of this report.*

Systems Analysis and Systems Integration activities ensure that the Program is well-integrated and its efforts are directed in the most effective way. Systems Analysis conducts extensive crosscutting life-cycle analysis, emissions analysis, and environmental analysis to enable a comprehensive understanding of the major issues involved in hydrogen and fuel cell systems. Systems Integration provides tools to integrate Program activities and measure progress toward goals. By providing a structured approach to the research, design, development, and validation of complex systems, Systems Integration ensures that system-level targets are identified, verified, and met. Both of these activities play important roles in Program decision-making, planning, and budgeting.

III. Measures Taken to Support the Transition of Primary Industry (or a Related Industry) to a Fully Commercialized Hydrogen Economy

Response to EPACT section 811(a)(2)

- From FY 2010 to FY 2013, DOE pursued a strategically balanced portfolio of hydrogen and fuel cell activities, as described in section 2 of this report.
    - During this period, the Department dedicated approximately $630 million to these efforts (see fig. 3.1).[8]

	FY 2010 Approp.	FY 2011 Allocation	FY 2012 Approp.	FY 2013 C.R.
Fuel Cell R&D	75,609	41,916	43,634	41,266
Hydrogen Fuel R&D	45,750	32,122	33,824	31,682
Manufacturing R&D	4,867	2,920	1,944	1,899
Systems Analysis	5,408	3,000	3,000	2,838
Technology Validation	13,005	8,988	8,986	8,514
Safety, Codes & Standards	8,653	6,901	6,938	6,808
Market Transformation	15,005	0	3,000	2,838
Education	2,000	0	0	0
SBIR/STTR	3,703	2,153	2,298	2,139
EERE Hydrogen & Fuel Cells Total	**174,000**	**98,000**	**103,624**	**97,984**
Fossil Energy	13,970	11,394	0	0
Nuclear Energy	5,000	2,800	0	0
Basic Energy Sciences	38,053	34,611	27,466	27,466
DOE Hydrogen & Fuel Cells Total	**231,023**	**146,805**	**131,090**	**125,450**

Figure 3.1. *Budget Authority for DOE hydrogen and fuel cell activities. The values shown reflect rescissions and other adjustments included in relevant appropriations. (*Note: In FY 2011, the Fuel Cell Technologies Office was allocated $98 million from the appropriation for EERE.)*

- A key element of DOE's strategy is to enable a steady transition from R&D to commercialization by balancing support for early market applications with efforts in longer-term, higher-impact areas. Therefore, DOE has maintained an inclusive, technology-neutral approach, pursuing advances for a wide range of applications, with varying time frames for commercial success (fig 2.2).

[8] This does not include funding for R&D of megawatt-scale, solid-oxide fuel cells under the Solid State Energy Conversion Alliance, which is not part of the DOE Hydrogen and Fuel Cells Program.

- In May 2013, DOE, along with global automakers and other founding members, launched the H_2USA partnership. H_2USA is a public-private partnership focused on advancing hydrogen infrastructure to support increased transportation energy options for U.S. consumers, including fuel cell electric vehicles. This new partnership aims to coordinate research and identify cost-effective solutions to deploy hydrogen infrastructure—a key challenge to widespread adoption of FCEVs.

Figure 3.2. *A representation of how fuel cell markets are growing (and are expected to continue growing) as costs come down. DOE is pursuing advances in hydrogen and fuel cell technologies for a variety of applications. Growth in early markets helps reduce costs industry-wide, strengthen consumer acceptance, expand the infrastructure, and overcome a variety of logistical challenges.*

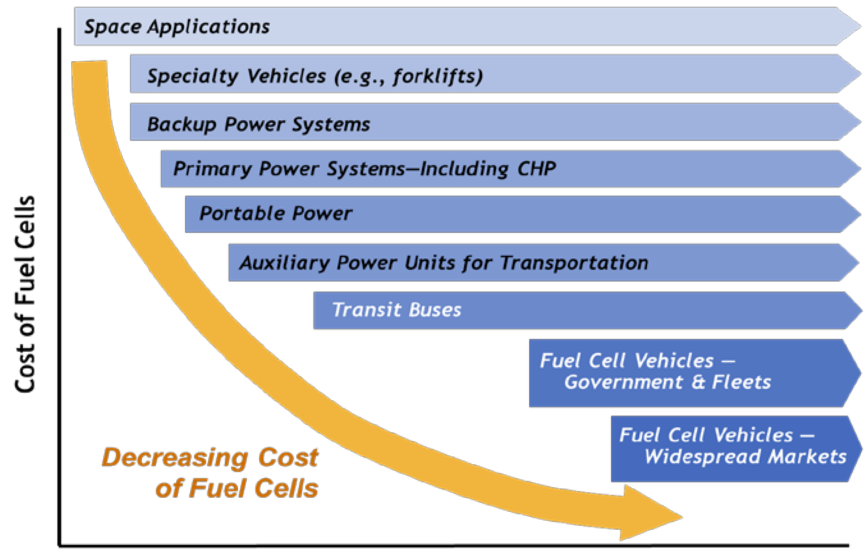
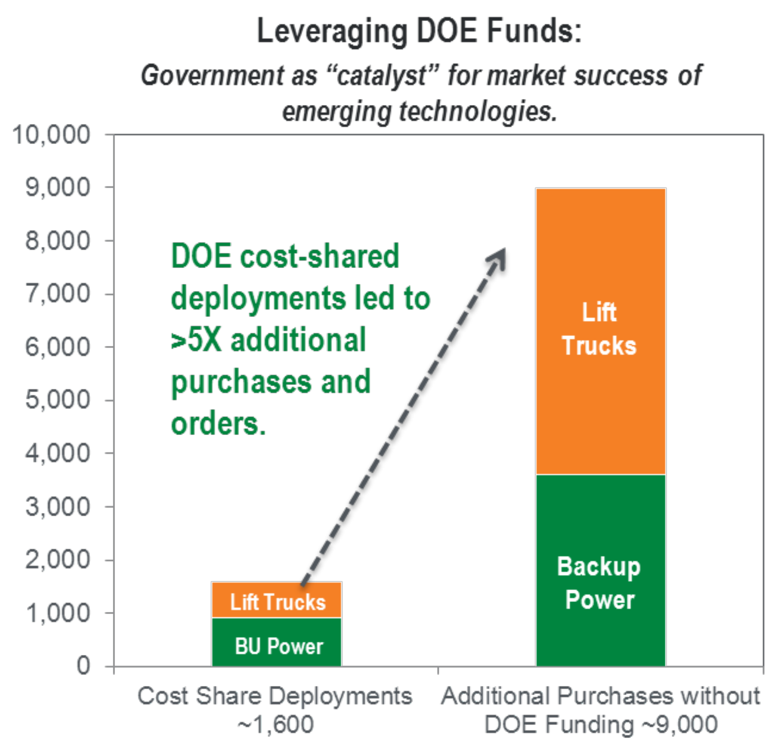


Figure 3.3. *The Program has successfully catalyzed commercialization through targeted deployments of fuel cells in key early markets. Cost-shared deployments of approximately 1,600 fuel cells in material handling equipment and backup power installations have led to an estimated 9,000 additional orders by industry customers, with* *<u>no additional DOE funding</u>*.



- DOE leveraged other established strategic partnerships by (1) collaborating with members of the U.S. DRIVE Partnership[9] to evaluate research results and establish technical requirements; and (2) leading the Hydrogen and Fuel Cell Interagency Task Force (ITF) and Interagency Working Group (IWG) to focus efforts on federal leadership of early adoption of hydrogen and fuel cell technologies. In December 2011, ITF completed the Hydrogen and Fuel Cells Interagency Action Plan, which guides collaborative federal RD&D efforts.
- DOE conducted three annual reviews of the Program (the 2011, 2012, and 2013 *Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meetings)*. These reviews convened technical experts from industry, academia, and national laboratories to evaluate the progress and provide valuable feedback to principal investigators and DOE managers.[10] The most recent review, in May 2013, included nearly 200 projects, almost 300 reviewers, and more than 1700 attendees.
- DOE collaborated with international partners, representing several leading economies, through the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE).[11] IPHE includes members from 17 nations and the European Commission who work to (1) accelerate the market penetration and early adoption of hydrogen and fuel cell technologies and their supporting infrastructure; (2) advance policy and regulatory actions to support widespread deployment; (3) raise the profile of these technologies with policy-makers and the public; and (4) monitor technology developments in hydrogen, fuel cells, and complementary technologies.

[9] Other members of the U.S. Drive partnership include automakers, energy companies, and electric utilities, https://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/usdrive.html.

[10] U.S. Department of Energy Hydrogen Program Annual Merit Reviews, www.hydrogen.energy.gov/annual_review.html.

[11] International Partnership for Hydrogen and Fuel Cells in the Economy, www.iphe.net.

IV. Changes Made to Strategy Reflecting Results of Learning Demonstrations

Response to EPACT section 811(a)(3)

As described in Section 2 of this report, the Program's demonstration efforts (or "learning demonstrations") are conducted by the Technology Validation sub-program. They play an essential role in assessing the status of the technologies, providing feedback to R&D efforts, and ultimately demonstrating commercial readiness to establish business cases for potential industry investors. To date, these efforts have:

- Collected and analyzed more than two million hours worth of operational data involving the use of more than 450,000 kg of hydrogen, and
- Developed and released to the public more than 230 "composite data products" (or CDPs).[12]

The results of these efforts have largely confirmed DOE's strategies for hydrogen and fuel cells, and no major changes in strategy have arisen from these demonstrations. However, the Program's demonstration projects have been a steady and invaluable source of data for the Program and for external stakeholders. Key highlights include:

- Results from demonstrations of early market fuel cells indicated that hydrogen compressors are the leading cause of unscheduled service. This has helped prioritize R&D efforts to address compressor reliability.[13]
- Early market demonstrations have also identified hydrogen dispensers as a significant source of system failure. This has helped inform hose reliability testing and led to funding of an SBIR project on hose material development.[14]
- Data collected from fueling stations and FCEVs helped clarify the correlation between ambient temperature and the temperature of hydrogen tanks during filling.[15] These data fed into the development of SAE J2601 ("hydrogen fast-filling protocol," which is currently transitioning from a technical information report to a full standard).
- Data collected on hydrogen purity helped identify contaminants causing problems at fueling stations and enabled station owners and operators to address the issues.[16]

[12] "Fuel Cell and Hydrogen Technology Validation" web page, NREL, http://www.nrel.gov/hydrogen/cdp_topic.html; http://www.nrel.gov/hydrogen/proj_fc_market_demo.html#cdp; http://www.nrel.gov/hydrogen/proj_infrastructure_analysis.html; http://www.nrel.gov/hydrogen/proj_fc_systems_analysis.html; and http://www.nrel.gov/hydrogen/proj_fc_analysis.html.
[13] http://www.nrel.gov/hydrogen/cfm/images/cdp_mhe_66_infrmaintbycategorydeliveredonly.jpg.
[14] Ibid.
[15] http://www.nrel.gov/hydrogen/docs/cdp/cdp_72.jpg.
[16] http://www.nrel.gov/hydrogen/docs/cdp/cdp_27.jpg.

V. Progress toward Vehicle Deployment and Hydrogen Infrastructure Goals in EPACT Title VIII

Response to EPACT sections 811(a)(4) and 811(a)(5)

Section 7 of this report discusses the significant progress that DOE has made toward its technology development goals. This progress has gone a long way toward enabling widespread commercialization of FCEVs and availability of hydrogen, including major cost reductions and improvements in the performance and durability of fuel cell systems, and reductions in the cost of producing and delivering hydrogen.

Evidence of how far fuel cell technologies have progressed is seen in the increasing emphasis on FCEV rollout plans by major automakers; the partnerships announced among these companies to support FCEV commercialization; and the major government-industry partnerships that have been established around the world to support FCEV rollout plans. In 2013, several major automobile manufactures announced collaborative partnerships to accelerate the introduction of fuel cell vehicles into the marketplace. These partnerships include GM and Honda; Ford, Nissan, and Daimler; and Toyota and BMW. And, most of the world's major automakers (including GM, Toyota, Honda, Daimler, Hyundai-Kia, Volkswagen, and Nissan) have announced plans for commercial rollout of FCEVs in the 2015-2017 timeframe. In September 2009, a number of these companies signed a letter of understanding supporting fuel cell vehicles in anticipation of widespread commercialization, beginning in 2015.[17]

In addition to the H2USA partnership announced in the United States, major government-industry partnerships have been established in Germany, Japan, the United Kingdom, France, and Scandinavia to enable the rollout of FCEVs and to address related hydrogen infrastructure challenges.

While progress has been substantial and DOE's efforts are currently on track to meet key technology-readiness targets, DOE's developmental timeline for hydrogen and fuel cell technologies was not intended to meet the deployment goal specified in EPACT Section 811(a)(4)(A) of 100,000 hydrogen-fueled vehicles by 2010. Furthermore, it is too early to determine whether industry can achieve EPACT's vehicle deployment goal of 2.5 million hydrogen-fueled vehicles by 2020 or the goal of providing sufficient refueling infrastructure for those vehicles. While DOE has already achieved cost reductions necessary to enable hydrogen to be produced from natural gas on a cost-competitive basis and is on track to enable widespread availability of hydrogen from renewable resources, the ultimate decision rests with

[17] Fuel Cell Works, "Major car manufacturers sign Letter of Understanding on fuel cell electric vehicles", September 2009. http://fuelcellsworks.com/news/2009/09/09/major-car-manufacturers-sign-letter-of-understanding-on-fuel-cell-electric-vehicles

industry whether to deploy these technologies and produce sufficient hydrogen for the commercial rollout of FCEVs.

In making plans and budget requests, DOE has not assumed the levels of FCEV deployment that EPACT specifies. For example, past budget requests have identified technology readiness in the 2015–2017 timeframe that would enable industry to begin deployment of FCEVs in this period. Based on these roadmaps, and with industry input, in 2008, Oak Ridge National Laboratory completed a study of transition scenarios for FCEVs, which identified likely scenarios ranging from thousands of FCEVs by 2015 and hundreds of thousands by 2018, to hundreds of thousands by 2019.[18] Also in 2008, using similar assumptions, the National Academies released a study in which they estimated the maximum practicable number of FCEVs on the road by 2020 to be 2 million vehicles, provided major incentives are in place for both vehicles and hydrogen fuel.[19] This was considered to be a maximum estimate, based on available data in 2008—currently plans by automakers do not appear to be of a scale to meet this expectation. In 2010, the California Fuel Cell Partnership published the results of a survey of its automaker members, estimating that more than 50,000 FCEVs would be deployed by the end of 2018, to meet California's Zero-Emissions Vehicle (ZEV) mandate.[20]

In its approach to supporting the development of hydrogen infrastructure, rather than directly funding demonstrations of stations and vehicles, the Program is conducting a rigorous assessment of the challenges and needs involved in developing a hydrogen infrastructure—both from an R&D and business-case perspective. This includes close coordination with DOE's partners in H_2USA. As described in Section 3 of this report, this partnership has brought together automakers, government agencies, gas suppliers, and the hydrogen and fuel cell industries to coordinate research and identify cost-effective solutions to deploy hydrogen infrastructure. The partnership's initial proposed activities are primarily focused on the underlying analysis needed to form a coherent strategy for a coordinated rollout of FCEVs and hydrogen infrastructure.

Efforts by this new partnership will build on past work by DOE and industry, including extensive analysis of the costs and tradeoffs of different options for hydrogen production, delivery, and utilization, as well as analysis of policies for sustaining the early years of hydrogen and fuel cell technology deployment. These analyses have included the development of models to better understand the combined effects of different vehicle market penetration rates, geographic and spatial layouts of fueling stations, hydrogen production and delivery options, and policies and incentives.

A key element of these efforts was a workshop held in 2012 that convened representatives of industry, academia, and the national laboratories to understand the critical elements of infrastructure development needed to support the early market for FCEVs. The workshop conclusions found that common fueling station design was needed to reduce the station cost

[18] http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008_30.pdf

[19] "Transitions to Alternative Transportation Technologies—A Focus on Hydrogen," National Academy of Sciences, 2008; the full report is available from: http://books.nap.edu/catalog.php?record_id=12826 .

[20] *California Fuel Cell Partnership Action Plan: Progress and Next* Steps, April 2010, http://cafcp.org/sites/files/FINALProgressReport.pdf.

and a station calculator was needed to estimate the economies of scale for station construction.[21] Following this workshop, DOE developed a hydrogen station cost calculator (with industry input). DOE used the calculator's results to estimate the cash flow associated with deploying FCEVs and fueling stations in Northeastern states.[22]

[21] The proceedings and findings of the workshop are documented in the following report: Hydrogen Infrastructure Market Readiness: Opportunities and Potential for Near-term Cost Reductions by NREL (http://www.nrel.gov/docs/fy12osti/55961.pdf).
[22] The results were presented to the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) at http://www.hydrogen.energy.gov/pdfs/htac_nov12_3_melaina.pdf.

VI. Problems Relating to Design, Execution, or Funding of Activities under EPACT Title VIII

Response to EPACT section 811(a)(6)

Section 8 of this report covers reviews of the Program from September 2010 to August 2013. These reviews have provided extensive and valuable recommendations and have not identified any significant problems relating to the design or execution of Program's activities in this period.

In addition to their recommendations, the National Academies also recognized the importance of "continued research attention and government funding" for hydrogen and fuel cells. [23] However, the Hydrogen and Fuel Cell Technical Advisory Committee has expressed concern that DOE's efforts in hydrogen and fuel cells are not currently funded at a sufficient level. [24]

From FY 2010 to FY 2013, DOE pursued a strategically balanced portfolio of hydrogen and fuel cell activities, as described in section 2 of this report.

[23] The full report is available from: http://www.nap.edu/catalog.php?record_id=18262.
[24] Letter from John Hofmeister, HTAC Chair, to Secretary of Energy Ernest Moniz, July 15, 2013 (will be posted online at http://hydrogen.energy.gov/advisory_htac.html)

VII. Progress toward Program Goals

Response to EPACT section 811(a)(7)

As the Program continues to make progress toward the goals laid out in its developmental roadmap (the *Hydrogen and Fuel Cells Program Plan*), the overall impact of DOE's efforts in hydrogen and fuel cells is widely felt. The markets for hydrogen and fuel cells continue to grow, and more applications are moving closer to commercialization. DOE's efforts have spurred the development of new hydrogen and fuel cell technologies and helped to move these technologies into the marketplace.

For example, efforts funded by the Fuel Cell Technologies Office have led to more than 400 patents, 39 commercial technologies, and about 65 technologies that are projected to be commercialized within three-to-five years. In addition, DOE has successfully stimulated early markets for fuel cells through strategically targeted deployments, cost-shared with industry partners. Deployments of more than 1,000 fuel cells in key early markets have led to roughly 9,000 additional orders for fuel cells by industry, *with no additional DOE funding*.[25]

The Program's accomplishments are thoroughly documented every year in the *Annual Progress Report*. From September 2010 to August 2013, the Program published three *Annual Progress Reports*, which include more than 700 detailed reports from individual projects, spanning nearly 4,000 pages. A summary of the Program's major accomplishments (including citations) is shown on the "Accomplishments and Progress" page of the Fuel Cell Technologies Office's website (www.hydrogenandfuelcells.energy.gov/accomplishments.html). A few examples of progress are shown in figure 7.1.

The remainder of the response to section 811(a)(7) of EPACT ("updates to the developmental roadmap…") is covered in section 8 of this report. Furthermore, this section of the report (section 7) covers progress toward vehicle deployment and infrastructure goals, as it reports general progress and accomplishments by the Program.

[25] DOE Hydrogen and Fuel Cells Program Records #12013 and #11017, http://hydrogen.energy.gov/program_records.html.

Figure 7.1. Progress and Accomplishments- Key Examples

Hydrogen Fuel R&D

- ✓ Reduced the cost of producing hydrogen from natural gas (projected to high volume production)—to about \$4.00/gge including the projected costs of delivering and dispensing.
- ✓ Reduced the cost of producing hydrogen from several renewable pathways, including reducing the cost of electrolyzer stacks by more than 80% since 2002 (fig. 7.2)
- ✓ Reduced the cost of delivering hydrogen to the end-user via tube-trailer delivery and pipeline delivery of high-pressure gas and truck delivery of liquid hydrogen. (fig. 7.3)
- ✓ Achieved up to 15% reduction the projected cost of high-pressure hydrogen storage systems through improved carbon fiber composites and advanced production processes

Fuel Cell R&D

- ✓ Reduced the projected high-volume cost of automotive fuel cells to \$47/kW in 2012—a more than 80% reduction since 2002 and more than 35% reduction since 2008
- ✓ Achieved a more than five-fold reduction in total platinum content in fuel cells since 2005, through improvements in catalyst specific power (fig. 7.4)
- ✓ Demonstrated more than 2,500-hour durability (~75,000 miles) of fuel cell systems in FCEVs operating under real-world conditions, with < 10% degradation, more than double the durability of 950 hours demonstrated in 2006.

Manufacturing R&D

- ✓ Developed advanced manufacturing methods that enabled a 50% reduction in the cost of gas diffusion layers since 2008
- ✓ Improved processes for manufacturing gas diffusion electrode cloth—resulting in 75% reduction in labor costs and 400% increase in throughput

Technology Validation

- ✓ Demonstrated the world's first "tri-generation" energy station—capable of producing hydrogen, heat, and power. The system uses biogas at a wastewater facility and has demonstrated 54% efficiency for co-production of hydrogen and electricity.
- ✓ Completed the world's largest demonstration of FCEVs and hydrogen infrastructure—including more than 180 FCEVs and 25 hydrogen stations. Notable milestones included: 3.6 million miles traveled, in more than 500,000 trips; fuel cell system efficiency of up to 59% (more than double the efficiency of gasoline internal combustion engines); driving ranges of more than 250 miles between refueling (DOE has also validated one vehicle capable of achieving up to 430 miles on a single fill); and refueling times of approximately 5 minutes for 4 kg of hydrogen (enough fuel for approximately 250 miles of driving).

Safety, Codes & Standards

- ✓ Conducted R&D to enable development of a comprehensive hydrogen code—*NFPA 2: Hydrogen Code Document*
- ✓ Developed resources to disseminate safety information and facilitate the permitting of hydrogen installations, including: the *Hydrogen Safety Best Practices Manual*; the *Technical Reference on Hydrogen Compatibility of Materials*; the *Regulators' Guide to Permitting Hydrogen Technologies*, the *Hydrogen Safety Bibliographic Database*, the *Hydrogen Incidents and Lessons Learned Database*, and the *Permitting Hydrogen Facilities Compendium*
- ✓ Deployed two web-based introductory courses for first responders and code officials and an advanced-level, hands-on first-responder training

Education and Outreach

- ✓ Increased outreach, including publication of more than 70 news articles per year, a monthly Webinar series that reaches over 1,500 attendees per year, and a monthly newsletter that reaches more than 7,500 subscribers
- ✓ Trained more than 10,000 middle school and high school teachers (cumulative total) in 35 states, primarily through "H2 Educate!"

Figure 7.1. Progress and Accomplishments (continued)

Systems Analysis

- ✓ Conducted rigorous well-to-wheels analyses of greenhouse gas emissions and petroleum energy usage (fig. 7.5) and life-cycle costs and for advanced vehicles and fuels.
- ✓ Developed the JOBS FC model to estimate the employment and revenue impacts of manufacturing and deployment of fuel cells and hydrogen infrastructure
- ✓ Updated analysis of fueling infrastructure for FCEVs, including completing a hydrogen station cost calculator (with industry input) to estimate fueling station capital costs

Market Transformation

- ✓ Developed and published guidelines for federal facilities managers to procure energy from stationary fuel cell power systems, including the use of innovative financing mechanisms that require little or no capital investment
- ✓ Demonstrated and validated a fuel cell mobile lighting system that combines high-pressure (5,000-psi) hydrogen storage, efficient lighting, and a 5-kW PEM fuel cell; field tested the system at industry and government installations; and expanded public awareness of the technology by using fuel cell mobile lighting at various entertainment-industry award events.
- ✓ Initiated demonstration and deployment of fuel cell auxiliary power systems for refrigerated trucks.

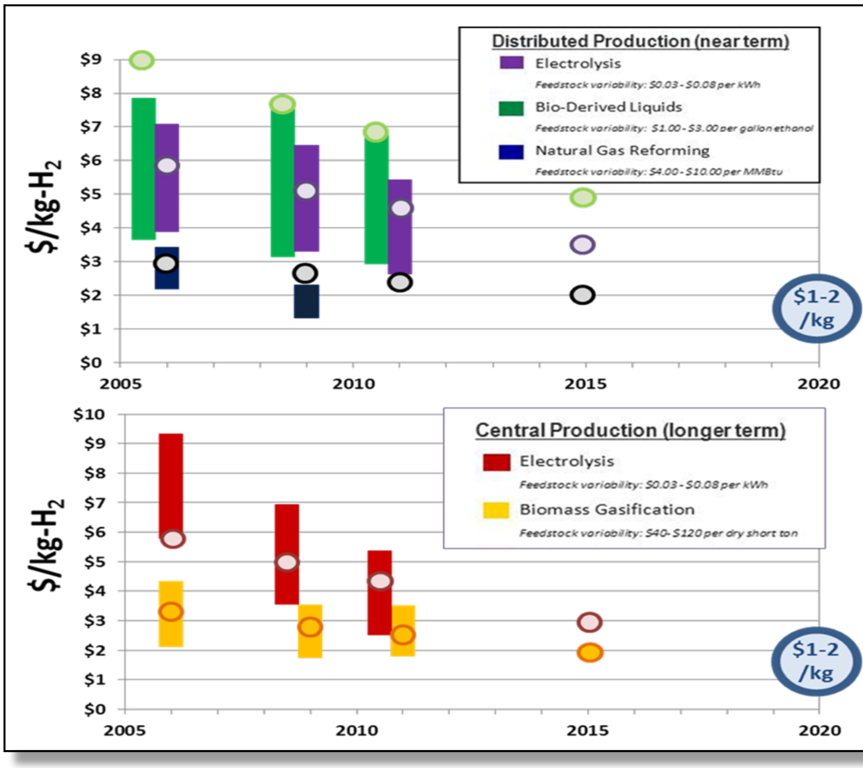


Figure 7.2
Reductions in hydrogen production cost[23]
Status of hydrogen cost is shown in vertical bars, reflecting values based on a range of assumptions (feedstock/capital costs). Targets for hydrogen cost are shown in circles. Targets shown are normalized for consistency in feedstock assumptions and year-cost basis (2007 dollars). Targets prior to 2015 are extrapolated based on 2015 and 2020 targets in the FCT Office's Multi-year RD&D Plan.

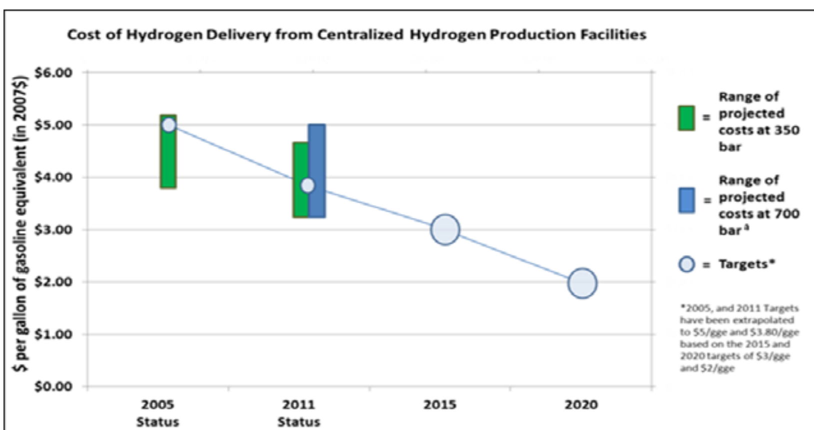


Figure 7.3
Reductions in Cost of Hydrogen Delivery
2015 and 2020 targets are from the Fuel Cell Technologies Office's MYRD&D Plan. Status for 2005 and 2011 are based on analysis conducted by experts from ANL, NREL, and PNNL, using the Hydrogen Delivery Scenario Analysis Model (HDSAM).[24,25]

[26] 2015 and 2020 targets are from the updated 2012 version of the *FCT MYRD&D Plan*; the 2015 target shown for bio-derived liquids is slightly more aggressive (i.e., lower) than the 2015 target in the *MYRD&D* to better reflect likely feedstock options; targets indicated in the plots for prior years are consistent projections back along the trajectories established by the 2015 and 2020 targets (which incorporate updated H2A analysis and cost bases); the status of the projected H_2 production costs (shown as vertical bars to reflect sensitivities to major feedstocks and capital costs) up to 2011 has been documented in the Program record #12002: http://www.hydrogen.energy.gov/pdfs/12002_h2_prod_status_cost_plots.pdf; techno-economic assumptions are consistent with the updated models used in the 2012 *MYRD&D Plan*.

[27] 2005 and 2011 350-bar assumptions included: Indianapolis as the target city (population 1.2 M) – chosen because of its average city size, shape and population distribution; a mature fuel cell vehicle market penetration of 15% that is served by the hydrogen infrastructure under study; all costs were expressed in 2007 dollars; an average refueling station capacity of 1000 kg of H_2/day at 95+% utilization; mature economies of scale with respect to component manufacture for various unit operations; the H_2 production plant is sited 100 km from the edge of the city, or city gate; a hydrogen delivery pressure of 350 bar.

[28] 2011 700-bar assumptions included: Sacramento as the target city (population 1.5 M) – chosen because of its average city size, shape and population distribution and likelihood of being an early adopter; a mature fuel cell vehicle market penetration of 10% that is served by the hydrogen infrastructure under study; all costs were expressed in 2007 dollars; an average refueling station capacity of 750 kg of H_2/day at 95+% utilization; mature economies of scale with respect to component manufacture for various unit operations; the H_2 production plant is sited 100 km from the edge of the city, or city gate; a hydrogen delivery pressure of 700 bar.

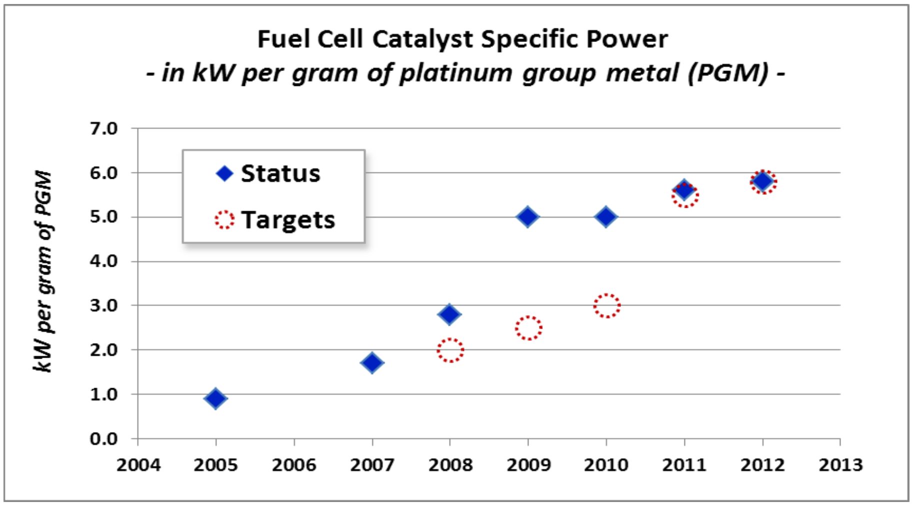


Figure 7.4. ***Reducing Platinum Content of Fuel Cells.*** *The catalyst specific power of fuel cells has improved by about 500% since 2005, resulting in a five-fold reduction in platinum content.*[29]

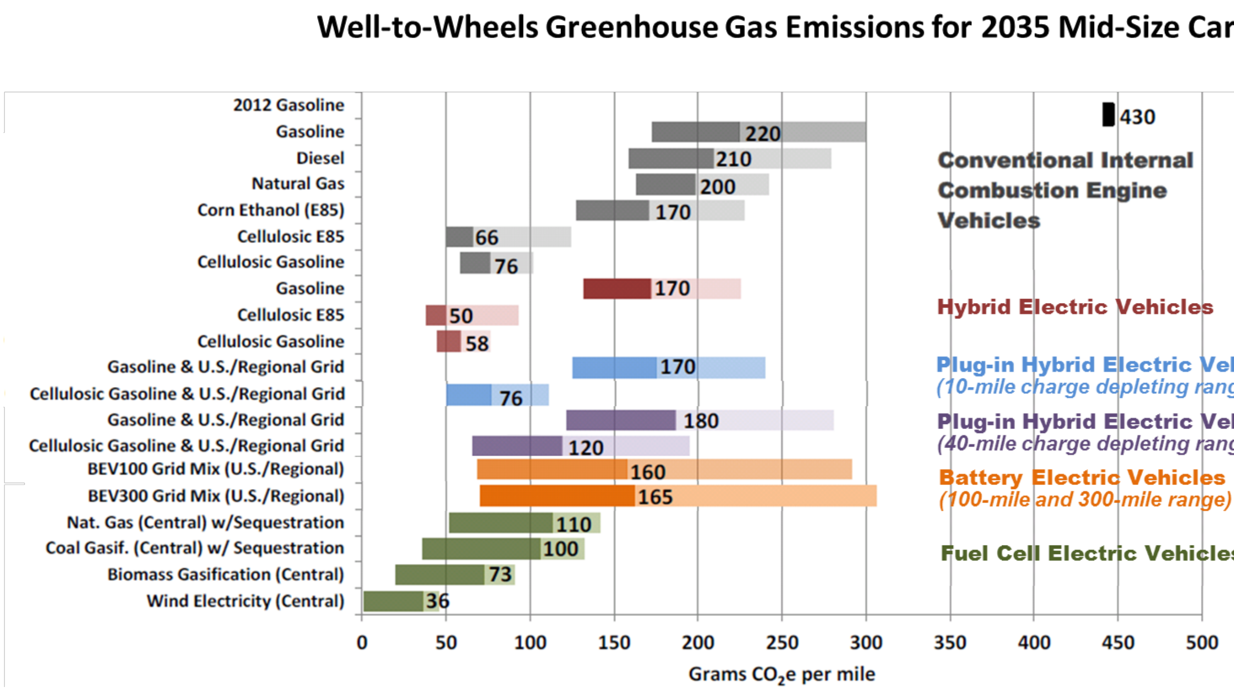


Figure 7.5. *Well-to-wheels analysis*[30] *shows substantial potential reductions in greenhouse gas emissions for several advanced transportation technologies, including fuel cell vehicles using hydrogen from a variety of sources. Ranges shown by the light portions of the bars reflect sensitivity to uncertainties associated with projected fuel economy of vehicles and selected attributes of fuels pathways—e.g., electricity credit for biofuels, electric generation mix, etc. (Note: this is an abridged version of the chart—the full chart is available at* http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf.)

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[29] "Platinum Group Metal Loading," DOE Hydrogen & Fuel Cells Program Record #9018, http://hydrogen.energy.gov/pdfs/9018_platinum_group.pdf

[30] "Well-to-Wheels Greenhouse Gas Emissions and Petroleum Use for Mid-Size Light-Duty Vehicles," DOE Hydrogen & Fuel Cells Program Record #13005, http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf.

VIII. External Reviews and Updates to Developmental Roadmap and Strategic Plan

Response to EPACT section 811(a)(7) and 811(a)(8)

The Program uses a number of mechanisms for obtaining external input, review, and evaluation. For example, the National Academy of Sciences conducts biannual reviews of DOE's R&D progress under the U.S. DRIVE Partnership (formerly the FreedomCAR and Fuel Partnership), and the Hydrogen and Fuel Cell Technical Advisory Committee provides technical and programmatic advice to the Secretary of Energy on hydrogen and fuel cells. In addition, the Program receives feedback through its Annual Merit Review and Peer Evaluation Meeting,[31] which involves almost 200 technical experts reviewing over 200 RD&D projects and includes more than 1,500 participants every year.

The Program periodically revises its planning documents, including the *Hydrogen and Fuel Cells Program Plan* (formerly the *Hydrogen Posture Plan)* and the Fuel Cell Technologies Office's *Multi-Year Research, Development, and Demonstration Plan* (*MYRD&D Plan*) to incorporate both the recommendations of these reviews and updates based on technological progress, programmatic changes, and policy decisions. The *Program Plan* was updated in September 2011, and the *MYRD&D Plan* was updated during 2012 and 2013. The latest version of the *MYRD&D Plan* takes into account the most recent progress toward meeting targets, and it includes a reassessment of the targets themselves, based on requirements to be competitive with both incumbent and advanced technologies.

8.1 National Academies' Review of the U.S. DRIVE Partnership[32]

Reviews by the NRC assess progress in each of the partnership's research and program management areas as well as the responses of DOE program management to recommendations made in prior reports. Since the last Report to Congress, in 2010, the NRC has completed its Phase IV Review of the Partnership. This review was delivered to DOE earlier this year. Key comments in the resulting report[33] included:

- ". . . the committee believes that the Partnership is effective in progressing toward its goals. There is evidence of solid progress in essentially all areas, even though substantial barriers remain."

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[31] For more information on the Annual Merit Review and Peer Evaluation Meeting, see: www.hydrogen.energy.gov/annual_review.html.

[32] U.S. DRIVE stands for "Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability"; the partnership was formerly known as the FreedomCAR and Fuel Partnership.

[33] The full report is available from: http://www.nap.edu/catalog.php?record_id=18262.

- "The fuel cell/hydrogen R&D is viewed by the committee as long-term, high-risk, high-payoff R&D that the committee considers not only to be appropriate, but also to be of the type that much of it probably would not get done without government support."
- "[Fuel cells] . . . along with the hydrogen fuel that they would consume, offer the promise of zero emissions (produced directly by the vehicle), high efficiency, and the smooth, quiet operation that goes with an electric propulsion system. With this focus, progress has been significant, with continuing increases in performance and decreases in projected costs essentially every year."
- ". . . the committee's assessment is that the fuel cell technical team is well coordinated and is aligned with respect to the achievement of the goals and the longer-term, high-risk technology challenges, especially as the automotive OEMs are now road testing prototype fuel cell vehicles."
- "Research aimed at significantly higher hydrogen storage capability needs to be maintained as a primary research focus. Materials-based storage at the level required to meet all program targets is considered theoretically achievable, yet no single material has been identified that simultaneously meets all of the targets (weight, volume, efficiency, cost, packaging, safety, refueling ability, etc.). The discovery and development of materials for effective onboard hydrogen storage is high-technical-risk R&D not likely to be accomplished without continued research attention and government funding."
- "The DOE continues to make important progress toward understanding and preparing for the transition to hydrogen fuel. In the continuing source-to-wheels analyses, seven pathways, including both distributed and centralized hydrogen production, have been assessed, and the key drivers for pathway costs, energy use, and emissions have been identified."
- "Progress has been made in all [hydrogen delivery and production] areas of the program. Delivery models have been developed that predict delivery and dispensing costs for different methods as a function of market penetration."

Specific recommendations from the latest NRC report included:

- "The DOE should establish backup technology paths, in particular for stack operation modes and stack components, with the fuel cell technical team to address the case of current technology selections determined not likely to meet the targets. The DOE should assess which critical technology development efforts are not yielding sufficient progress and ensure that adequate levels of support for alternative pathways are in place."
- "The hydrogen storage program is one of the most critical parts of the hydrogen/fuel cell vehicle part of the . . . Partnership—both for physical (compressed gas) and for materials storage. It should continue to be funded, especially the systems-level work in the Hydrogen Storage Engineering Center of Excellence."

- "The EERE should continue to work closely with the Office of Fossil Energy to vigorously pursue advanced chemical and biological concepts for carbon disposal as a hedge against the inability of geological storage to deliver a publicly acceptable and cost-effective solution in a timely manner."
- "Hydrogen delivery, storage, and dispensing should be based on the program needed to achieve the cost goal for 2017. If it is not feasible to achieve that cost goal, emphasis should be placed on those areas that would most directly impact the 2015 decision regarding commercialization. In the view of the committee, pipeline, liquefaction, and compression programs are likely to have the greatest impact in the 2015 time frame. The cost target should be revised to be consistent with the program that is carried out."

8.2 Review by the Hydrogen and Fuel Cell Technical Advisory Committee

EPACT section 807 requires the establishment of the Hydrogen and Fuel Cell Technical Advisory Committee to advise the Secretary of Energy on programs and activities under Title VIII. EPACT states that the committee is to review and make recommendations to 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 plan called for by section 804 of EPACT, the *Hydrogen and Fuel Cells Program Plan* (formerly known as the *Hydrogen Posture Plan*).

As stated in EPACT section 807(d)(2), the Secretary "shall transmit a biennial report to Congress describing any recommendations made by the Technical Advisory Committee since the previous report. The report shall include a description of how the Secretary has implemented or plans to implement the recommendations, or an explanation of the reasons that a recommendation will not be implemented. The report shall be transmitted along with the President's budget proposal." The Department has submitted three biennial reports outlining the recommendations by the committee and the Department's responses. The most recent report covers recommendations made during fiscal years 2010 and 2011, and it was submitted to Congress in May 2012. Recommendations made in fiscal years 2012 and 2013 will be addressed in the next biennial report, which will be delivered to Congress with the President's fiscal year 2015 budget request.

8.3 Updates to Strategic Plans

The Program periodically updates its planning documents—including the *Hydrogen and Fuel Cells Program Plan* and the *MYRD&D Plan*—to reflect changes in the status of the technologies and the policy and market environment. Formal updates are usually issued every three-to-five years, or as required. These updates include changes to plans for fuel cell research, development, and demonstration activities, and they address recommendations from external reviews and audits.

As described in Section 5 of this report, the Program coordinates closely with industry and other partners to understand the needs and develop strategies for the commercial rollout of FCEVs and hydrogen infrastructure. The Program also stays closely attuned to international activities and strategies for FCEVs and hydrogen. In particular, the Program has initiated information-sharing and analysis activities with Germany and Japan, which have substantial plans for developing hydrogen infrastructure.[34] The Program closely monitors similar hydrogen infrastructure initiatives recently launched in the United Kingdom, France, and Scandinavia. Any changes in strategy emerging from these collaborations will also be reflected in updates to future plans.

[34] International Partnership for Hydrogen and Fuel Cells in the Economy, http://iphe.net/.