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United States Government Accountability Office

GAO

Report to Congressional Requesters

January 2008

HYDROGEN FUEL INITIATIVE

DOE Has Made Important Progress and Involved Stakeholders but Needs to Update What It Expects to Achieve by Its 2015 Target

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Accountability * Integrity * Reliability

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The Honorable Bart Gordon
Chairman
Committee on Science and Technology
House of Representatives

The Honorable Nick Lampson
Chairman
The Honorable Bob Inglis
Ranking Member
Subcommittee on Energy and Environment
Committee on Science and Technology
House of Representatives

The Honorable Michael M. Honda
House of Representatives

The United States uses more than 20 million barrels of oil each day, roughly two-thirds of which is imported. Disruptions in supply from natural disasters such as hurricanes in the Gulf of Mexico and political instability in some oil-producing regions have caused prolonged price spikes, at times quadrupling the price of oil. In recent years, reduced domestic production and increased world consumption have contributed to recent records for the price of oil. In 2004, when oil cost refiners about $41 a barrel, the nation spent about $6 billion a week for its oil when adjusted for inflation; by October 2007, oil cost refiners about $80 per barrel and the nation spent more than $11 billion a week. Oil prices are likely to climb even higher as global oil production peaks, which many studies estimate could occur within the next 35 years. Moreover, the nation's transportation sector is 97 percent dependent on oil-derived products that, when burned in conventional internal combustion engines, produce harmful emissions that raise health problems and global warming concerns.

To reduce the nation's dependence on foreign oil and to decrease greenhouse gas emissions, President Bush in January 2003 announced the initial phase of a 5-year, $1.2 billion Hydrogen Fuel Initiative to conduct research, development, and demonstration (R&D) for developing hydrogen-powered fuel cells as an alternative to the internal combustion engine in vehicles. Hydrogen fuel cells emit only water and heat as among other things, the necessary supporting infrastructure, including pipelines and fueling stations. The act also directed DOE to work with industry and established the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)—which includes representatives of industry, academia, professional societies, government agencies, financial organizations, and environmental groups—to review and make recommendations to the Secretary of Energy on DOE's implementation of its hydrogen R&D programs and activities; the safety, economical, and environmental consequences of technologies; and DOE's long-term R&D plans. In addition, the act directed the President to establish the Interagency Task Force, chaired by the Secretary of Energy, to coordinate federal agencies' hydrogen and fuel cell R&D efforts and promote hydrogen technologies. The task force is to include representatives from, at a minimum, DOT, the Department of Defense (DOD), the Department of Commerce, the Department of State, the National Aeronautics and Space Administration (NASA), the Environmental Protection Agency, and the White House's Office of Science and Technology Policy. Subsequently, in November 2006, HTAC recommended that the Interagency Task Force include assistant secretary-level officials with policy-setting authority from each participating agency.

DOE—with input from industry, university, and federal agency stakeholders—identified the following four major technical challenges that must be overcome before hydrogen technologies can be deployed on a large scale:

- *Production.* Current production R&D efforts focus on economically extracting hydrogen from other compounds using fossil, renewable, and nuclear energy. For example, DOE established 2015 as the target date for extracting hydrogen from natural gas at a cost equivalent of $2 to $3 per gallon of gasoline.

- *Storage.* Storing hydrogen requires it to be either compressed under very high pressure as a gas or super-cooled to obtain a liquid; however, these technologies consume significant amounts of energy and are currently too costly. Current hydrogen storage R&D efforts focus on developing less energy-intensive and less expensive methods of storing hydrogen. For example, DOE established 2015 as the target date for developing a hydrogen fuel cell vehicle that can travel at least 300 miles using only the hydrogen stored onboard.

- *Delivery.* Current truck delivery technologies cannot compete with gasoline technologies because of the cost of compressing or liquefying

You asked that we assess DOE's Hydrogen Fuel Initiative as DOE enters the last year of its initial 5-year, $1.2 billion program. Specifically, you asked that we examine the extent to which DOE's hydrogen R&D program has (1) made progress in meeting the initiative's R&D targets, (2) worked with industry to set and meet R&D targets, and (3) worked with other federal agencies to develop and demonstrate hydrogen technologies.

To ensure that we obtained a thorough understanding of DOE's hydrogen R&D program, we reviewed documents and interviewed DOE program managers and national laboratory scientists, company and industry association executives, independent experts, and state government officials. More specifically, to assess DOE's progress in meeting its R&D targets, we (1) reviewed DOE's *Hydrogen Posture Plans* and R&D project reports; (2) attended DOE's annual review of its projects in May 2007; (3) interviewed DOE hydrogen program managers and scientists at DOE's National Renewable Energy Laboratory and Los Alamos National Laboratory; (4) spoke with HTAC members and attended HTAC meetings; (5) interviewed industry representatives and reviewed industry assessments of DOE's progress in developing and demonstrating vehicle, stationary, and portable technologies; and (6) reviewed reports of the National Academies of Science and Engineering on the hydrogen program and spoke with cognizant officials. To determine the extent to which DOE has worked with industry to set and meet R&D targets, we reviewed pertinent documents and assessed DOE's processes for soliciting industry input, including attending a meeting of the fuel cell technical team at Los Alamos National Laboratory. We also interviewed cognizant DOE managers and scientists and executives of car manufacturers, energy companies, utilities, hydrogen producers, fuel cell manufacturers, and suppliers of hydrogen-related components. To determine the extent to which DOE has worked with other federal agencies to develop and demonstrate hydrogen technologies, we reviewed pertinent documents and spoke with officials at DOE, DOT, DOD, the Department of Commerce, NASA, and the U.S. Postal Service. We also attended the Interagency Task Force's first meeting in August 2007. We conducted our work from March through December 2007 in accordance with generally accepted government auditing standards. Appendix I provides additional information about our scope and methodology.

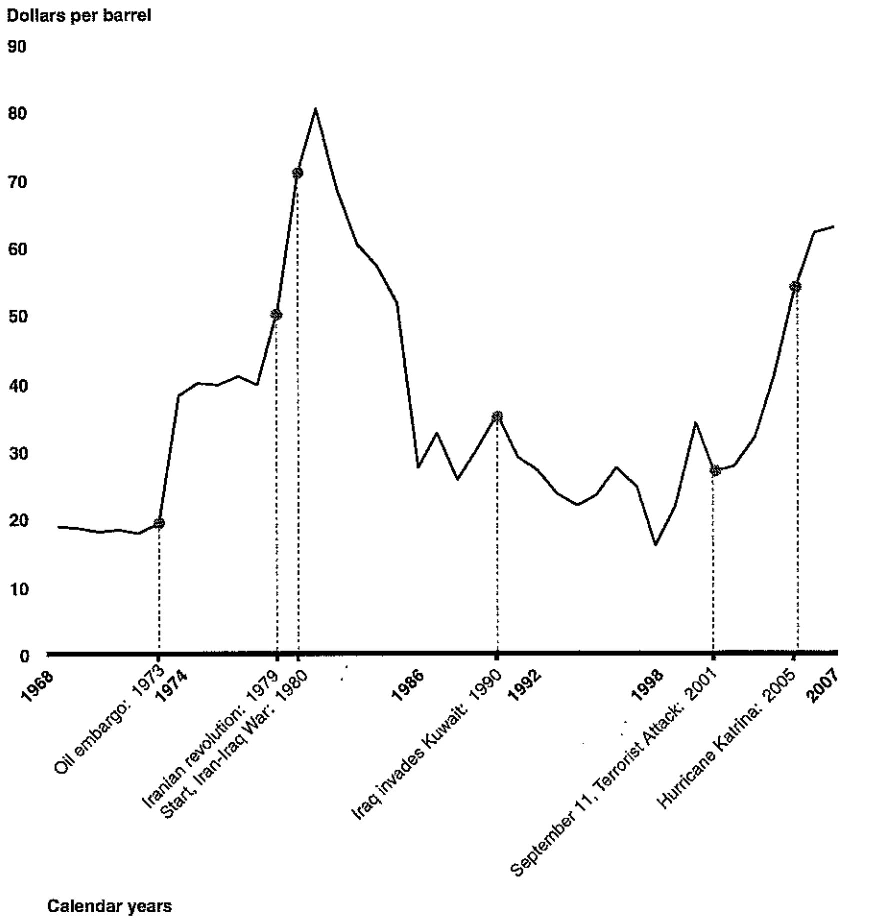
Results in Brief

DOE's hydrogen R&D program has made important progress, but some of the most difficult technical challenges—those that require significant scientific advances—lie ahead, and many years of hydrogen R&D and infrastructure development beyond the 2015 target date will be needed technical and other issues to management attention. In addition, both the National Academies of Science and Engineering and HTAC provide input. One area of criticism that industry representatives identified is that DOE has focused its limited resources on developing vehicle technologies and given low priority to stationary and portable technologies. These industry representatives note that stationary and portable technologies may have more near-term market potential than vehicle technologies and, therefore, may be integral to resolving technical or infrastructure challenges and developing the public acceptance necessary to deploy hydrogen nationally. DOE recently has begun to emphasize near-term stationary and portable market applications by soliciting industry, non-profit, and federal organizations for ideas on early adoption of technologies and providing R&D grants.

DOE's interagency coordination efforts among working level managers and scientists have been productive and useful, but it is too early to evaluate collaboration among senior officials at the policy level because a body created to do so, the Interagency Task Force, just held its first meeting in August 2007. At the working level, DOE has established several interagency coordination bodies to facilitate cooperation and share knowledge. For example, one working group has created Web-based tools and joint workshops to coordinate R&D activities and facilitate interagency technology partnerships by bringing the Defense Logistics Agency together with DOE in an initiative for deploying hydrogen-fuel-cell-powered forklifts. Working level managers at federal agencies involved in hydrogen-related activities generally were satisfied with the level of coordination. However, the Interagency Task Force—composed of deputy assistant secretaries, program directors, and other senior officials—has just begun to plan actions to demonstrate and promote hydrogen technologies. In its inaugural meeting in August 2007, the task force did not clearly define its role or strategy, but member agencies plan to develop a path forward and an action plan by May 2008. HTAC criticized DOE for taking too long to initiate the effort and for not securing participation of departmental assistant secretaries to ensure appropriate authority inside each agency for making hydrogen-related budget and policy decisions. In addition, some Interagency Task Force members observed that lack of a common vision may hinder decision making.

To accurately reflect the progress made by the Hydrogen Fuel Initiative and the challenges it faces, we recommend that the Secretary of Energy update the *Hydrogen Posture Plan's* overall assessment of what DOE reasonably expects to achieve by its technology readiness date in 2015, including how this updated assessment may differ from prior posture

Figure 1: U.S. Refineries' Oil Prices, 1968 to 2007

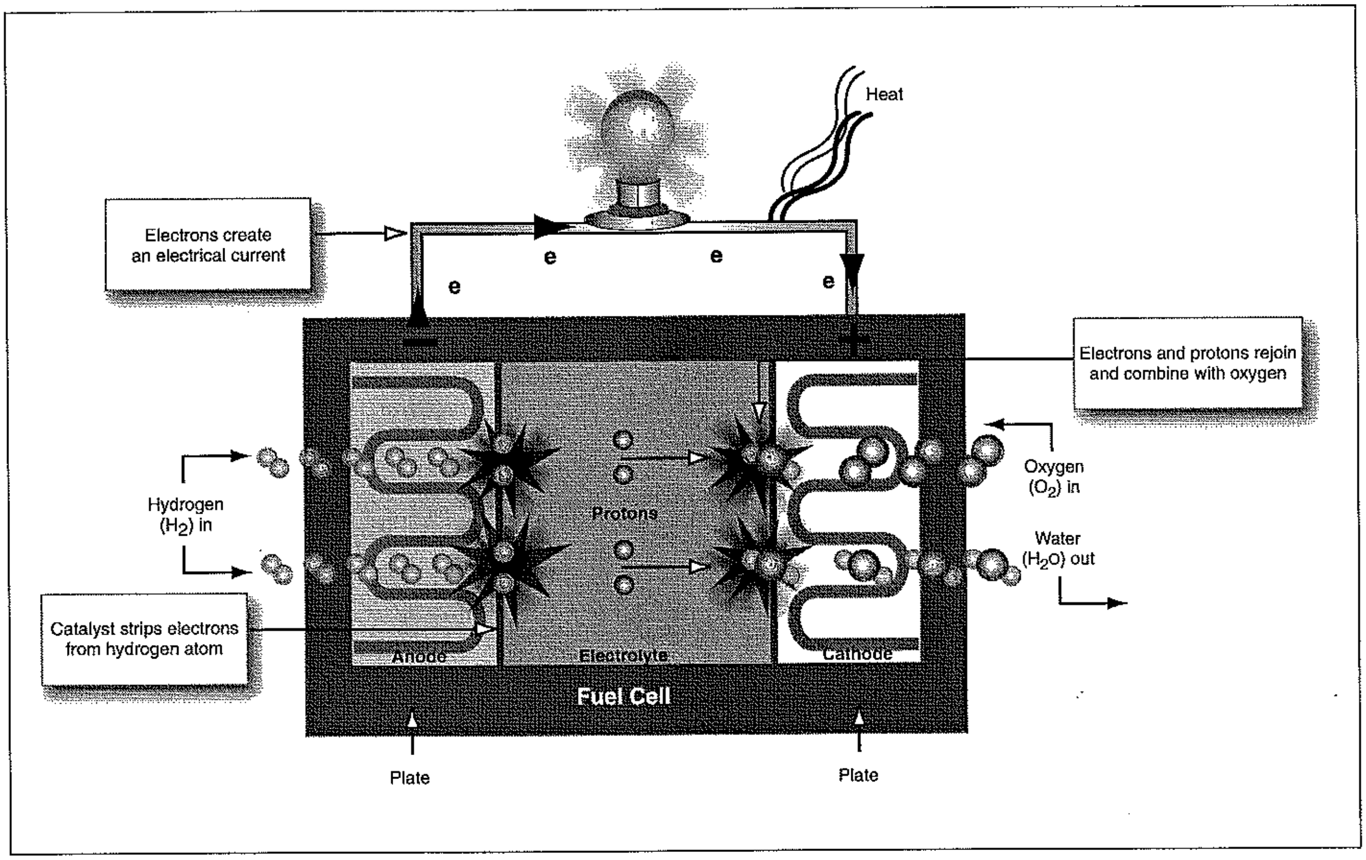


Source: GAO analysis of DOE data.

Note: Oil prices are in real terms, adjusted to fiscal year 2007 dollars to account for inflation. For 2007, oil prices for January through September were averaged. Refiners' oil prices better reflect the cost of oil than spot market prices because refiners typically purchase oil through long-term contracts that generally are not affected by short-term price changes.

In 2005, the world consumed about 84 million barrels of oil per day, and world oil production has been running at near capacity to meet the growing demand. DOE's Energy Information Administration projects that world oil consumption will continue to grow, reaching about 118 million barrels per day in 2030. In February 2007, we reported that most studies,

Figure 2: Schematic of a Typical Fuel Cell



Source: DOE.

Fuel cells typically are classified according to their type of electrolyte and fuel. Table 1 identifies the various types of fuel cells and their uses.

demonstrate and deploy other types of fuel cells for stationary and portable applications.

DOE further focused its hydrogen R&D in response to the National Energy Policy issued in 2001, which highlighted hydrogen as one of several R&D priorities. DOE hosted several meetings and workshops, including two major workshops in 2001 and 2002 that were designed to develop an R&D agenda and involved stakeholders from industry, universities, environmental organizations, federal and state agencies, and national laboratories.[3] These meetings and workshops laid the groundwork for identifying a common R&D vision and challenges, and each DOE program has used meetings and workshops to develop separate detailed R&D plans that set near-term and long-term targets to enable commercialization decisions by 2015.

In February 2004, DOE integrated these plans into its first *Hydrogen Posture Plan,* a single high-level agenda. The *Hydrogen Posture Plan's* approach is to conduct R&D in multiple pathways within key technology areas with the intent of providing several promising options for industry to consider commercializing. For example, DOE is using a mix of fossil, renewable, and nuclear energy to develop and demonstrate technologies that can extract hydrogen from a variety of sources, including natural gas, coal, biomass, water, algae, and microbes. DOE officials state that they prioritize the most promising technologies and terminate specific efforts that show little potential. Based on its review of the posture plan, the National Academy of Engineering made 48 recommendations, most of which were incorporated by DOE, including focusing on both applied and fundamental science R&D.[4]

In addition to the R&D funded through the Hydrogen Fuel Initiative, DOE conducts R&D on various other hydrogen-related technologies. For example, the Office of Fossil Energy is working on a hydrogen-based solid oxide fuel cell, with funding provided through the Solid State Energy Conversion Alliance, for stationary applications of electricity generation. Fossil Energy's R&D plan for extracting hydrogen from coal complements

[3]DOE, *A National Vision of America's Transition to a Hydrogen Economy—to 2030 and Beyond,* (Washington, D.C.: February 2002) and DOE, *National Hydrogen Energy Roadmap,* (Washington, D.C.: November 2002).

[4]National Research Council of the National Academies, *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs,* (Washington, D.C.: 2004).

40,000 hours for stationary applications. As shown in table 2, DOE has made progress on meeting some of its near-term targets, in both applied and fundamental science, important stepping stones for meeting DOE's 2015 targets.

Table 2: Status of Key Hydrogen Fuel Initiative Technologies and Target Dates

Technology	Target area	Status	Target (2010)	Target (2015)
Fuel cell	Cost[a]	$107/kW	$45/kW	$30/kW
	Durability	2,000 hours	5,000 hours (80°C)	5,000 hours (80°C)
Storage	System gravimetric capacity (net)[b]	2.3 wt%	6 wt%	9 wt%
	System volumetric capacity (net)[c]	0.8 kWh/L	1.5 kWh/L	2.7 kWh/L
	Cost[d]	$15-$18/kW	$4/kW	$2/kW
Production	Cost, distributed natural gas[e]	$3.00/gge	$2.00-$3.00/gge	$2.00-$3.00/gge
	Cost, distributed bio-derived renewable liquids	$4.40/gge	$3.80/gge (2012 target)	<$3.00/gge (2017 target)
	Cost, distributed water electrolysis	$4.80/gge	$3.80/gge (2012 target)	<$3.00/gge (2017 target)
	Cost, central wind-water electrolysis	$5.90/gge	$3.10/gge (2012 target)	<$2.00/gge (2017 target)
Technology validation (demonstrated in vehicles)	Driving range	200 miles	250 miles (2008 target)	300 miles
	Efficiency	53-58 percent	(see 2015)	60 percent
	Durability	1,600 hours	2,000 hours (2009 target)	5,000 hours

Source: DOE.

[a]Cost projections are for 500,000 units per year.

[b]Measures usable hydrogen energy based on weight. Storage system projections are based on complex metal hydride and include material, tank, and balance of plant. Note that compressed tanks have capacities of 3.5 to 4.7 weight percent and can enable partial market penetration.

[c]Measures usable hydrogen energy based on volume.

[d]Projection for 5,000 to 10,000 pounds-per-square-inch tanks; assumes high volume manufacturing for 500,000 units.

[e]Modeled cost, delivered at the pump for dispensing at 5,000 pounds per square inch; assumes large equipment volumes (e.g., 500 units).

Hydrogen Production

For hydrogen to compete with gasoline, DOE must be able to produce hydrogen at prices that approximate the cost of gasoline. Specifically, in the near term, DOE must extract hydrogen from natural gas at a cost of $2 to $3 per gallon of gasoline equivalent and, in the longer term, develop biomass and biomass-derived liquids at similar costs or, for large centralized production facilities, at costs less than $2 per gallon of gasoline equivalent. DOE has established targets of less than $2 per gallon of

Because steam reformation of natural gas reflects the most mature technology, natural gas is expected to be the primary source of hydrogen through the next 20 years. However, extracting hydrogen from natural gas will simply substitute one fossil fuel for another with similar vulnerabilities to supply disruptions and adverse environmental effects. In the long term, DOE is developing technologies that rely on renewable or nuclear energy from non-carbon-producing sources. DOE officials noted that although the R&D efforts do not require fundamental advances in science, they generally acknowledge that developing the technologies will take years of applied scientific effort before costs can be reduced enough to be competitive with gasoline. One challenge, for example, is minimizing carbon or sulfur impurities when extracting hydrogen from coal. Impurities can shorten the life-span of the separation membranes used in the gasification process and can also impact the life span and performance of fuel cells. Although higher-temperature stationary fuel cells—such as solid oxide fuel cells operating at temperatures exceeding 1,200 degrees Fahrenheit—are more tolerant of impurities, lower temperature proton exchange membrane vehicle fuel cells begin to fail when impurities are present.

Hydrogen Storage

For hydrogen fuel cell vehicles to compete with conventional gasoline vehicles, DOE must develop technologies to store enough hydrogen on board the vehicle to achieve a driving range of at least 300 miles without compromising passenger or cargo space and while meeting all consumer expectations for performance, safety, refueling ease, and cost. In addition, DOE must develop technologies to store and dispense enough hydrogen at fueling stations to meet consumer needs. None of the current technologies have attained these requirements, and none is likely to do so without fundamental scientific breakthroughs, according to DOE officials and industry representatives. Although on a weight basis, hydrogen has almost three times the energy content of gasoline, it has almost four times less energy than gasoline on a volume basis. This means DOE must store a much larger amount of hydrogen within specified space constraints than gasoline to obtain equivalent amounts of energy, raising the technical challenges and the cost.

Currently, hydrogen is most commonly stored as a gas, compressed under high pressure, or is super-cooled to a liquid, but neither technology is likely to meet DOE's 2015 performance and cost targets. For example, focus on developing new materials that can store hydrogen on the surface of a material—called "adsorption;" absorb the hydrogen into a material; or bind the hydrogen within a chemical compound. Adsorption and absorption R&D typically involve nanotechnology to develop new materials structured to increase surface area. Chemical storage of hydrogen has additional challenges, including processing centers that would be needed to bind and release hydrogen from the chemical carrier before the hydrogen can be used by consumers, raising the overall costs. In the last few years, a number of materials have been developed, but not within the energy, temperature, or cost required for commercial scale deployment.

Hydrogen Delivery

Successful commercialization of hydrogen fuel cell technologies—particularly hydrogen fuel cell vehicles—will depend upon a hydrogen delivery infrastructure that provides the same level of safety, convenience, and functionality as the existing gasoline delivery infrastructure. The delivery infrastructure will initially need to support hydrogen production at small facilities distributed throughout the country and, eventually, larger centralized facilities. The delivery infrastructure includes operations at the refueling site itself, such as compression, storage, and dispensing, as well as the actual delivery of hydrogen. DOE developed its 2015 targets with significant input from industry. Specifically, DOE used a sophisticated model for estimating hydrogen delivery costs for a city the size of Indianapolis with 50 percent of the vehicles being hydrogen fuel cell vehicles and with central production of hydrogen located 60 miles from the city's edge. DOE determined that the cost of delivering hydrogen to fueling stations must be less than $1 per gallon of gasoline equivalent. This cost includes operations at the delivery site, such as transferring the hydrogen to storage or dispensing equipment. To put DOE's R&D requirements in perspective, the cost of delivering gasoline from a Gulf Coast refinery to a fuel pump in Dallas, Texas, has been estimated at about $0.18 per gallon.

Currently, hydrogen is delivered by truck as a liquid or gas or by a modest pipeline infrastructure, but at delivery costs mostly ranging from $4 to $9 per gallon of gasoline equivalent, significant advances must be made to reduce costs to meet DOE's targets. Hydrogen is difficult to deliver economically using conventional methods because the hydrogen atom is small and diffuses rapidly, making it difficult to design equipment to prevent leakage. Hydrogen can also corrode the steel used in pipes and trucks, which make up the bulk of current conventional delivery systems. Trucks can carry about 10 times more liquid hydrogen than gaseous hydrogen, but since liquefying hydrogen requires so much energy, degrees Fahrenheit and must be able to start up quickly at low temperatures with minimal energy consumption. In addition, the cost of commercial scale production of vehicle fuel cells must drop from the current $107 per kilowatt to $30 per kilowatt—nearly a quarter of the current cost—to meet DOE's 2015 target.[7] Stationary fuel cells must have a longer life span than those for vehicles, up to 40,000 hours, equivalent to about 4.5 years of continuous operation.

In the early 1990s, DOE estimated the cost of manufacturing fuel cells at high volume to be about $3,000 per kilowatt. Since then, DOE's focus has been on materials that can reduce costs at high volume. DOE succeeded in reducing manufacturing costs at high volume to $175 per kilowatt in 2004 and about $107 per kilowatt in 2006. The cost reductions have been achieved primarily by reducing the amount of platinum required as a catalyst and developing less expensive membranes. DOE is just beginning to focus R&D efforts on improving processes for commercial scale manufacture of fuel cell components. In particular, DOE has announced its intention to fund R&D for commercial scale manufacture of fuel cells for stationary applications.

DOE has achieved a life span of about 1,600 hours for vehicle fuel cells, but has not yet demonstrated start-up from sub-freezing temperatures. In addition, although DOE has reduced the cost of fuel cells, significant gains in cost remain to be achieved, in part, because fuel cells rely on platinum catalysts. Platinum, which is in high demand primarily for use in catalytic converters for automobiles and as jewelry, is the only catalyst that can sufficiently generate enough power at low operating temperatures to operate a vehicle. To reduce the cost of fuel cells, DOE's target focuses on decreasing the amount of platinum used in 2005 by more than 80 percent in 2015. DOE officials noted that Los Alamos National Laboratory has succeeded in reducing platinum requirements and improving performance of fuel cells, but they also noted that reliance on the current amount of platinum—considering its rising costs—poses significant challenges to reducing the costs enough to meet the 2015 targets. In addition, DOE has not yet met the size and weight packaging requirements of the automobile manufacturers for fuel cells. Complex equipment, such as heat exchangers and humidifiers, must be added to the fuel cell to keep it operating at its current 140 to 176 degrees Fahrenheit in a controlled environment of 80 to 100 percent relative humidity. Furthermore, impurities in the hydrogen

[7] These are projected costs, based on high volume manufacturing of 500,000 units per year.

representatives believe that $1.2 billion over 5 years is insufficient to meet DOE's ambitious technical and cost targets. Furthermore, congressionally directed projects—primarily for activities outside the initiative's R&D scope—accounted for almost 25 percent of the Hydrogen Fuel Initiative's budget for fiscal years 2004 through 2006.

Table 3: Funding for the Hydrogen Fuel Initiative, Fiscal Years 2004 through 2008

Dollars in millions

	Fiscal year					
Office	**2004**	**2005**	**2006**	**2007**	**2008 request[a]**	**Total**
Basic Science	$0	$29.2	$32.5	$36.4	$59.5	**$157.6**
Fossil Energy	4.9	16.5	21.0	23.6	12.5	**78.5**
Nuclear Energy	6.2	8.7	24.1	19.3	22.6	**80.8**
Energy Efficiency and Renewable Energy	144.9	166.8	153.5	193.6	213.0	**871.7**
Total DOE	**$156.0**	**$221.2**	**$231.0**	**$272.8**	**$307.6**	**$1,188.5**
Total DOT	**$0.6**	**$0.5**	**$1.4**	**$1.4**	**$1.4**	**5.36**
Total Hydrogen Fuel Initiative	**$156.5**	**$221.7**	**$232.5**	**$274.2**	**$309.0**	**$1,193.9**
Percent of funds congressionally directed[b]	28	21	20	0	[a]	

Source: DOE.

Note: We present funding data solely for background purposes. The reliability of the database from which these data were drawn was thoroughly assessed in our December 2006 report entitled *Department of Energy: Key Challenges Remain for Developing and Deploying Advanced Energy Technologies to Meet Future Needs* (GAO-07-106). For the current report, we updated the prior assessment of data reliability and discussed the accuracy of the hydrogen funding data with cognizant DOE officials. We found these data to be sufficiently reliable for the purposes of this report. The dollar amounts were not adjusted for inflation.

[a]Reflects the President's budget proposal for fiscal year 2008.

[b]Includes funds designated for particular purposes through legislative language or directives in congressional reports.

In response to both budget constraints and technical challenges, DOE has pushed back target dates for certain key technologies—the target date for using wind energy to produce hydrogen was pushed back from 2015 to 2017—and reduced funding for stationary and portable applications that might, through early penetration in small markets, resolve technical issues and stimulate public acceptance of hydrogen vehicles. However, DOE's hydrogen program manager expressed confidence that DOE remains on schedule for the higher priority targets. Nevertheless, because some target dates have been pushed back 2 or more years, what DOE currently projects for technology readiness in 2015 differs from its original set of expectations laid out in the 2004 *Hydrogen Posture Plan*. DOE has not foods, most of which are produced near end-use along the Gulf Coast and in California to avoid the high cost of delivery. Current production reflects about one-eighth of the projected need and most of it is localized in specific areas. Facilities capable of extracting hydrogen economically will have to be constructed throughout the country. Some of these facilities could be co-located with existing gasoline fueling stations, but some stations have spatial limitations that raise challenges of using them. Also, the current cost of delivering hydrogen does not meet cost targets and cannot compete with the gasoline infrastructure. Although pipelines represent more attractive economics for delivering hydrogen than delivery by truck at high market penetration, they reflect high initial capital investments, estimated at about $1 million per mile. One industry official estimated that building new pipelines along interstate highways capable of serving about 75 percent of the U.S. population would cost approximately $14 billion, assuming there would be no barriers prohibiting the effort. The development and use of carriers may allow use of the existing pipeline infrastructure and may also resolve some embrittlement concerns, but such carriers also raise other technical and cost challenges, such as storage and recycling of the chemical carriers. For example, existing gasoline stations—already stretched for space—could face additional challenges if equipment were needed on site to separate the hydrogen from a chemical carrier, purify the hydrogen, and store the chemical carrier so it can be returned to a central facility for recycling. Although new fueling stations could be constructed, industry has estimated the construction of new fueling stations at about $1 to $2 million each.

In addition, other issues, such as safety codes and standards, may impact investment decisions. For example, one industry representative noted that safety concerns among local approving officials, among other things, may prevent some conventional hydrogen storage systems from being buried underground, as is common with gasoline tanks. The National Hydrogen Association also reports that industry must put a lot of energy and resources into educating local officials on codes and standards involving hydrogen-related technologies. Even if hydrogen-related technologies are approved, they often carry a cost premium. For example, typical gasoline dispensing nozzles cost about $40 to $110, but hydrogen dispensing nozzles currently cost about $4,000 each. Some high costs could be expected to drop with high-volume manufacturing and competition.

DOE officials and industry representatives also acknowledged the high degree of risk for investors, noting that there are other near-term and mid-term options for stationary and vehicle energy technologies. They speculated that transitioning to hydrogen fuel cell technologies will most be sufficient to meet initial demand. In addition, this distributed approach requires less capital investment. DOE officials and industry representatives noted that substantial changes to the infrastructure eventually will be needed to not only support large-scale production and delivery of hydrogen, but also to support multiple sources from which to extract hydrogen to minimize reliance on natural gas. As the demand for hydrogen grows, large centralized facilities for extracting hydrogen will be needed to take advantage of economies of scale. The centralized extraction of hydrogen will require deliveries over greater distances and, correspondingly, greater investments in the delivery infrastructure. Similarly, as the demand for hydrogen grows, there must be more stations where consumers can conveniently purchase hydrogen for vehicles or for stationary or portable applications.

DOE Has Partnered Well with Industry on Vehicle Technologies, but Efforts to Develop Stationary and Portable Technologies Are Too New to Evaluate

DOE has effectively solicited industry input and has worked to align R&D priorities, particularly for developing vehicle technologies. However, DOE has just begun to prioritize resources to develop stationary and portable technologies, which are much closer to being ready for commercial application and could play a role in laying the groundwork for vehicle technologies. Industry representatives acknowledge DOE's efforts, but note that they are too new to evaluate. Nevertheless, industry representatives stated that DOE generally has managed and coordinated its hydrogen R&D resources well.

DOE Has Effectively Involved Industry and Other Stakeholders

Industry executives told us that DOE's efforts to involve industry early in the planning stages and its ongoing efforts to solicit industry feedback on priorities have been effective in keeping the R&D agenda focused and headed in the right direction. Although industry representatives have sometimes disagreed about DOE's priorities, they generally agreed that DOE has institutionalized processes to effectively solicit feedback from industry. Just as importantly, DOE officials noted that being a presidential initiative with congressional backing has helped Hydrogen Fuel Initiative managers to garner support from industry and within the federal government.

DOE's workshops in 2001 and 2002 involved industry and independent experts at the earliest stages of planning an R&D agenda and laid the groundwork for identifying market challenges and technical targets that could lead to the development and deployment of hydrogen and fuel cell at least once a year. For example, through one of the technical teams on fuel cells, industry provided information on optimal relative humidity when DOE began work on high temperature fuel cells. The technical teams also provide an informal forum outside regular meetings for frequent exchanges among scientists. The National Academies noted the creation of technical teams as an important achievement, and industry representatives stated that tech teams help transfer automakers' requirements to the R&D portfolio.

HTAC, made up of industry executives and outside experts, also provides advice to the Secretary of Energy on technical and programmatic issues related to DOE's hydrogen R&D program. HTAC hosts periodic meetings, which DOE officials attend, to review budget status, discuss R&D plans, and propose changes. In its September 2007 report to the Secretary of Energy, HTAC recommended, among other things, that DOE elevate the role of hydrogen in the national energy portfolio. HTAC also expressed its pleasure with the DOE hydrogen R&D program's use of best management practices, including peer review in its solicitation processes, assessment of technical progress, individual project selection and monitoring, and overall program management.

DOE also obtains feedback from industry and academia through its Centers of Excellence. To facilitate storage R&D, DOE coordinated the creation of three Centers of Excellence to work on R&D in both applied and fundamental science. Each center is led by a DOE national laboratory and has about 15 industry and academic partners.

In addition, a DOE program dedicated to commercialization efforts exchanges information with industry on DOE activities, including hydrogen R&D, and explores potential for commercial development opportunities. Another program focused on market transformation works to build partnerships with industry and federal, state, and local governments to foster the early adoption of hydrogen and fuel cell technologies.

Furthermore, DOE is active at the state and local level and participates in numerous organizations that bring together a range of groups to foster the development and deployment of hydrogen technology. For example, DOE is involved in the California Fuel Cell Partnership, a group of auto, fuel, and fuel cell technology companies and government agencies working to deploy fuel cell vehicles on state roads.

would reduce the technical and market risks associated with longer-term vehicle applications.

Industry has expressed concerns that DOE has focused on developing vehicle technologies and has given less priority to stationary and portable technologies. At its May 2007 meeting, HTAC suggested that DOE has not focused enough on stationary and portable fuel cell R&D. Senior executives of companies told us they had urged DOE to focus more on demonstrating near-term stationary and portable technologies. The U.S. Fuel Cell Council and the National Hydrogen Association also stated that stationary fuel cell research had been overlooked and underfunded. DOE noted that it had focused on vehicle R&D because of the significant energy savings in the transportation sector.

Industry representatives stated that DOE has responded to industry's input. Senior executives from industry told us that DOE's support for stationary and portable R&D has grown substantially in the past year and that DOE has done a good job of incorporating this R&D into its program. In June 2007, to facilitate early adoption of hydrogen and fuel cell technologies, DOE sought input from industry, non-profit organizations, and local, state, and federal agencies to identify hydrogen and fuel cell applications in stationary and portable power. Such applications could include, for example, backup power installations for telecommunications providers and public schools designated as emergency shelters, warehouse lift-trucks currently employing battery or internal combustion systems, and portable fuel cells for battery operated devices. DOE has also begun to emphasize near-term stationary and portable market applications by providing a grant opportunity for hydrogen and fuel cell systems manufacturing R&D focusing on technologies that are near commercialization.

Industry representatives acknowledged DOE's efforts but noted that these efforts are too new to evaluate because DOE had not devoted as many resources to them as it had to vehicle technologies. A representative from the National Hydrogen Association, however, stated that DOE's recent emphasis on high-volume manufacturing is a good sign and could facilitate early market penetration of fuel cells.

separately funded a $49 million bus demonstration program to facilitate the development of commercially viable fuel cell technologies in real-world environments.[9]

- DOD receives no funding under the Hydrogen Fuel Initiative; however, it has several entities involved in hydrogen-related activities. For example, the Defense Logistics Agency has spent $11.7 million on a fuel-cell powered fork lift program and a solid hydrogen storage program,[10] the Army supports a small amount of fuel cell R&D, and the Navy has deployed fuel cells at several installations and is conducting R&D in several areas, including for unmanned underwater vehicles.

- NASA is the largest user of hydrogen in the United States, employing it as fuel for rocket launches. NASA conducts limited hydrogen-related R&D but is interested in coordinating with DOE on a proposed project to demonstrate stationary fuel cells to generate electricity at NASA's White Sands Test Facility.

- The U.S. Postal Service conducted a 3-year hydrogen fuel cell demonstration program with mail delivery vehicles at test sites in Virginia and California. Plans are underway to continue the effort using the next generation of hydrogen vehicles in partnership with General Motors and DOE. In addition, the Postal Service is considering hydrogen technology as an option for its planned replacement of its fleet of about 215,000 vehicles in 2018.

- The Department of Commerce's National Institute of Standards and Technology (NIST) is working with federal agencies and standards organizations on a variety of activities including certification of hydrogen fuel dispensers, hydrogen quality standards, building safety standards, and pipeline safety standards. In partnership with DOE, NIST also is conducting manufacturing R&D and imaging research to investigate how water moves through fuel cells to better understand their operation.

As the main interagency coordination vehicle, the IWG has contributed to implementing hydrogen technology partnerships among agencies and

[9]Buses have potential for early market penetration because they generally refuel at central locations and have room to store an amount of hydrogen that enables a practical driving range.

[10]The Defense Logistics Agency's fiscal year 2007 funding included $11.7 million for a congressionally directed project to demonstrate fuel-cell powered fork lift technology.

DOE established the International Partnership for the Hydrogen Economy (IPHE) in 2003 to provide a working-level coordinating mechanism for more than a dozen partner countries to organize, coordinate, and implement international research, development, demonstration, and commercial utilization activities. IPHE also provides a forum for advancing common policies, technical codes, and standards, and it educates stakeholders on the benefits of, and challenges to, transitioning to hydrogen technologies. Although participation is voluntary, IPHE has contributed to international information exchange, facilitated engagement from senior level officials, and influenced the creation of hydrogen technology road maps in China and other countries. In addition, DOE, DOD, and DOT are collaborating through the IPHE to standardize data collection for all hydrogen fuel vehicles and hydrogen-fueling demonstrations. While IPHE highlights its accomplishments, it also acknowledges room for improvement by, for example, better defining its role and developing performance metrics in the future.

DOT officials told us that while overall DOE has ably managed its hydrogen program, some areas of interagency coordination have been more effective than others. For example, DOT and the Defense Logistics Agency conduct joint R&D planning and information sharing, a successful relationship that grew out of the IWG. However, DOT's Pipeline R&D Program was not included in early discussions at DOE, hampering collaboration and communication on technology development. DOT officials acknowledged that they now are involved in these discussions but cited the importance of ensuring DOT representation at the onset of coordination efforts.

Efforts with Other Federal Agencies at the Policy Level Have Just Begun

To ensure appropriate authority inside each agency for making hydrogen-related budget and policy decisions, HTAC recommended in October 2006 that the IWG be elevated to require participation of an assistant secretary or higher. In response, DOE created the Interagency Task Force—a new entity composed of deputy assistant secretaries, program directors, and other senior officials—which held its inaugural meeting August 2007. Because the organization was created recently, its membership is still in flux as the most appropriate participants are being identified. The goals of the task force are to

- increase understanding of available hydrogen and fuel cell technologies and how they can contribute to the agencies' energy and environmental goals, from the earliest stages; (2) use of annual merit reviews, technical teams, centers of excellence, and other coordination mechanisms to continually involve industry and university experts to review the progress and direction of the program; (3) emphasis on both fundamental and applied science, as recommended by independent experts; and (4) continued focus on such high priority areas as hydrogen storage and fuel cell cost and durability. Although DOE has made important R&D progress, its 2015 technology readiness target is very ambitious, requiring scientific breakthroughs in hydrogen storage, for example. Budget constraints and technical challenges have led DOE to push back its targets for providing certain technologies to automakers from 2015 to 2017 or later, which according to DOE, generally still lies within the window for the automobile companies to provide hydrogen fuel cell vehicles by 2020. However, DOE has not updated its 2006 *Hydrogen Posture Plan's* overall assessment of what the department reasonably expects to achieve by its technology readiness date in 2015 and how this updated assessment may differ from prior posture plans. DOE also has not identified R&D funding needed to achieve the 2015 target. This information is important to the Congress and industry as they set priorities and make funding decisions. Furthermore, developing a nationwide commercial market for hydrogen fuel cell vehicles is expected to cost tens of billions of dollars for production facilities, fueling stations, pipelines, and other support infrastructure and take decades to achieve, requiring a sustained investment by government and industry in R&D and the infrastructure.

Recommendation

To accurately reflect progress made by the Hydrogen Fuel Initiative and the challenges it faces, we recommend that the Secretary of Energy update the *Hydrogen Posture Plan's* overall assessment of what DOE reasonably expects to achieve by its technology readiness date in 2015, including how this updated assessment may differ from prior posture plans and a projection of anticipated R&D funding needs.

Agency Comments and Our Evaluation

We provided DOE with a draft of this report for its review and comment. In written comments, DOE agreed with our recommendation, stating that it plans to update the *Hydrogen Posture Plan* during 2008 to reflect the progress made and any changes to the activities milestones, deliverables, and timeline. (See app. II.) However, DOE found the title of the draft report to be confusing, stating that R&D on hydrogen technologies would inevitably continue beyond 2015. In response, we revised the title to highlight the need for DOE to update what it expects to achieve by its 2015 target. DOE also disagreed with our statement that it has not determined

Appendix I: Scope and Methodology

To assess the extent to which the Department of Energy's (DOE) Hydrogen Fuel Initiative has made progress in meeting its R&D targets, we reviewed documents and interviewed DOE program managers, national laboratory scientists, company and industry association executives, independent experts, and state government officials. More specifically, we reviewed DOE's 2004 and 2006 *Hydrogen Posture Plans* and R&D project reports, attended DOE's annual review of its projects in May 2007, and interviewed DOE hydrogen program managers and scientists at DOE's National Renewable Energy Laboratory and Los Alamos National Laboratory. We also reviewed the R&D plans, technology roadmaps, assessments and reviews from each of DOE's programs, including Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy, and Science, and from several of the technical teams that DOE established to review R&D progress in specific technologies. In addition, we spoke with members and attended meetings of the Hydrogen and Fuel Cell Technical Advisory Committee, interviewed industry representatives, and reviewed industry assessments of DOE's progress in developing and demonstrating vehicle, stationary, and portable technologies. Furthermore, we reviewed reports of the National Academies of Sciences and Engineering on the hydrogen R&D program and spoke with cognizant officials.

To determine the extent to which DOE has worked with industry to set and meet R&D targets, we reviewed pertinent documents, assessed DOE's processes for soliciting industry input, and attended a meeting of the fuel cell technical team at Los Alamos National Laboratory. We also interviewed cognizant DOE managers and scientists and executives of car manufacturers, energy companies, utilities, hydrogen producers, fuel cell manufacturers, and suppliers of hydrogen-related components about DOE's processes for soliciting industry input and we toured several industry facilities.

To determine the extent to which DOE has worked with other federal agencies to develop and demonstrate hydrogen technologies, we reviewed pertinent documents and spoke with officials at DOE, the Department of Transportation, the Department of Defense, the Department of Commerce, the National Aeronautics and Space Administration, and the U.S. Postal Service. We also attended the Interagency Task Force's first meeting in August 2007.

We conducted this performance audit from March through December 2007 in accordance with generally accepted government auditing standards. These standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our

Appendix II: Comments from the Department of Energy

Department of Energy
Washington, D.C. 20585

January 3, 2008

Mr. Mark E. Gaffigan
Acting Director, Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Gaffigan:

Thank you for the opportunity to comment on the draft Government Accountability Office (GAO) report entitled *"Hydrogen Fuel Initiative: DOE Has Made Important Progress and Involved Industry and Other Agencies, but R&D Will Continue Past Its 2015 Target Date (GAO-08-305)."* The Department of Energy (DOE) has partnered with industry, academia, Federal laboratories and other Federal agencies in taking a leadership role in the research and development (R&D) of hydrogen and fuel cell technologies that have the potential to reduce U.S. oil use and greenhouse gas emissions. We commend the GAO for taking the time to interview experts within the Department, our national laboratories and industry in preparation for this report. We have reviewed the report in detail and provide our general response below, as well as detailed comments and clarifications as an enclosure to this letter.

The Department agrees with the GAO findings that the Hydrogen Program has made significant progress in the research and development of hydrogen and fuel cells over the past four years, and that the program has worked effectively with industry and other Federal agencies. However, we disagree with the underlying premise that forms the basis for the report's title, which implies that DOE did not envision the need for R&D of hydrogen and fuel cell technologies beyond 2015. The Department never stated that R&D of hydrogen technologies would end in 2015. As indicated in the Hydrogen Posture Plan[1], the program established a milestone of 2015 to complete the critical path technology development that would enable industry to make commercialization decisions for market introduction in the 2020 timeframe, and clearly stated that R&D would continue beyond this point to support renewable and nuclear-based hydrogen production, infrastructure development, and basic science. Just as we continue to support research on the internal combustion engine today, over 100 years after its introduction, the Department will continue to improve hydrogen and fuel cell technologies beyond 2015.

We also disagree with the report's statement that "DOE has not determined what reasonably can be achieved by 2015 for use in a 2020 vehicle." As the GAO report points out, the program has

[1] Hydrogen Posture Plan, December 2006, http://www.hydrogen.energy.gov/pdfs/hydrogen_posture_plan_dec06.pdf

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Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

Mark Gaffigan, (202) 512-3841 or gaffiganm@gao.gov

Staff Acknowledgments

In addition to the individual named above, Richard Cheston, Assistant Director; Robert Sanchez; Thomas Kingham; Marc Castellano; and Alison O'Neill made key contributions to this report. Also contributing to this report were Kevin Bray, Virginia Chanley, Patrick Gould, Anne Stevens, and Hai Tran.