THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

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July 10, 2009

The Honorable Steven Chu
Secretary
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

The Honorable Cathy Zoi
Assistant Secretary of Energy Efficiency and Renewable Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Secretary Chu and Assistant Secretary Zoi:

This National Research Council (NRC) letter report was prepared by the Committee on Review of the Research Program of the FreedomCAR and Fuel Partnership, Phase 3 (see Attachment I), in response to a request from the U.S. Department of Energy (DOE) (see Attachment II for the statement of task). It addresses one part of its statement of task, namely, to broadly review the strategy and structure of the FreedomCAR and Fuel Partnership (hereafter referred to as the Partnership). Attachment III lists the presentations to the committee at its April 27, 2009 meeting. The committee welcomes the chance to offer the benefit of its experience and expertise in providing some suggestions and guidance to the Partnership as it addresses future challenges and reviews its goals, strategy, organization, and priorities.

The committee recognizes and agrees with the new Administration's focus on nearer-term technologies. However, it also emphasizes the need for continued investment in longer-term, higher-risk, higher-payoff vehicle technologies that could be highly transformational with regard to reduced use of petroleum and reduced emissions. Such technologies include advanced batteries, technologies for hydrogen storage, and hydrogen/fuel cells. The committee has also concluded that for researchers, contractors, and investors to be willing to make long-term commitments to these and other potentially important developing technologies, a consistent year-to-year level of support must be provided.

The committee has further concluded that, given increasing concerns about greenhouse gas (GHG) emissions and world climate change, the Partnership should incorporate in its planning a broader-scope, "cradle-to-grave" analysis rather than a

"well-to-wheels" approach, to better consider total emissions and the full environmental impact of using various fuels and technologies. In addition, the Partnership should consider broadening the scope of technical approaches being considered within each of what the committee considers to be the three major fuel and vehicle pathways—biofuels/internal combustion engine (ICE) vehicles, plug-in electric vehicles (PHEVs)/battery-electric vehicles (BEVs), and hydrogen-fueled fuel cell vehicles.

Finally, the committee concluded that several measures should be considered by DOE to assist in implementing these suggestions. One is to provide temporary reductions in cost-share requirements to ease the burden on prospective researchers. Otherwise, there could be a significant number of potential worthy contributors who cannot afford the matching funds. Another implementation suggestion, occasioned by the obvious financial problems of the automotive companies (OEMs), is to consider providing direct funding to them to help keep important in-house research programs active. Other suggestions are included in the balance of the report.

INTRODUCTION

The Partnership,[1] as it currently exists, can be described as a focused research and technology development program that emphasizes high-risk, high-payoff technologies believed to be essential for a transition to vastly different light-duty passenger vehicles. "Vastly different" means vehicles that, according to the Partnership's original long-term goals, differ from existing light-duty vehicles (LDVs) in that they include the possibility of a full spectrum of vehicles that can operate without petroleum and free of harmful emissions while sustaining the driving public's freedom of mobility and freedom of vehicle choice. The needed research has been directed and supported by a collaboration among the U.S. government (especially DOE), the United States Council for Automotive Research (USCAR; its members are Chrysler LLC, Ford Motor Company, and General Motors Corporation), five key energy companies (BP America, Chevron Corporation, ConocoPhillips, ExxonMobil Corporation, and Shell Hydrogen [U.S.]), and more recently two major utility companies (Southern California Edison and DTE Energy) (DOE, 2006, 2009a). The Partnership has established, and periodically reviews, a roadmap with research milestones against which to measure progress in moving toward long-term goals. The long-term goals have focused on hydrogen/fuel cell vehicles. (For further information see Attachment IV and previous NRC [2005, 2008a] reports.)

Two reports by the NRC Committee on Review of the Research Program of the FreedomCAR and Fuel Partnership have assessed the structure and management of the Partnership as well as the nature, adequacy, and progress of the research activities (NRC, 2005, 2008a). A third report, based on Partnership activities and progress following publication of the Phase 2 report (NRC, 2008a), is planned to be issued during this third review. However, a number of recent changes in policy as well as technology advancements, described below, will influence the long-term goals of the Partnership as well as the paths to achieving them. In response to a request by DOE that the committee

[1] As described in DOE (2006), the "Partnership" is not a legal entity, and it is not intended that the "partners" have the responsibilities or rights of legal partners. Rather, the terms "Partnership" and "partners" are used in an informal sense to denote participants working together toward the stated goals of the group.

start its Phase 3 work by writing a letter report on the effects of these events and suggesting corresponding changes in the program, work on the Phase 3 report was temporarily delayed. This brief interim letter report is an attempt by the committee to offer constructive suggestions for possible changes to the existing Partnership program, especially its goals and strategy.

GOALS

The long-term goal of the Partnership has been to enable the transition to a transportation system "that uses sustainable energy resources and produces minimal criteria[2] or net carbon emissions on a life cycle or well-to-wheel basis" (DOE, 2006, p. iii).

Achievement of the sustainability goal will also contribute to reducing U.S. dependence on petroleum, another important national objective. A recent NRC report (NRC, 2008b) concluded that hydrogen-fueled fuel cell vehicles offer greater long-term potential for reducing U.S. dependence on imported petroleum and reducing carbon emissions significantly by 2050 than would relying only on fuel economy improvements (e.g., through engine efficiency improvements) and increased use of biofuels.

The Partnership plan envisions a pathway starting with more fuel-efficient ICEs and hybrid-electric vehicles (HEVs), including PHEVs, potential use of all-electric drive vehicles (BEVs), and, ultimately, hydrogen-fueled fuel-cell vehicles concurrent with the addition of an infrastructure for supplying hydrogen fuel. The lightweight materials program will continue to be an integral part of the efforts to improve vehicle fuel economy. It is expected that the Partnership plan will be modified to be more consistent with priorities of the new Administration outlined as major points made in April 2009 presentations to this committee. Among the new Administration's goals and priorities, which will obviously affect the Partnership, are the following as listed by Satyapal and Davis (2009a):

New Energy for America Presented by Obama-Biden Administration

- Help create 5 million new jobs by strategically investing $150 billion over the next 10 years to catalyze private efforts to build a clean energy future.
- Within 10 years save more oil than we currently import from the Middle East and Venezuela combined.
- Put 1 million plug-in hybrid cars—cars that can get up to 150 miles per gallon—on the road by 2015, cars that we will work to make sure are built here in America.
- Ensure that 10 percent of our electricity comes from renewable sources by 2012, and 25 percent by 2025.
- Implement an economy-wide, cap-and-trade program to reduce greenhouse gas emissions by 80 percent by 2050.

[2] Criteria emissions refer to those that are regulated by law.

Energy to Secure America's Future: President's National Objectives for DOE

- Quickly implement the economic recovery package—Create millions of new Green jobs and lay the foundation for the future.
- Restore science leadership—Strengthen America's role as the world leader in science and technology.
- Reduce GHG emissions—Drive emissions 20 percent below 1990 levels by 2020.
- Enhance energy security—Save more oil than the U.S. currently imports from the Middle East and Venezuela combined, within 10 years.
- Enhance nuclear security—Strengthen non-proliferation activities. Reduce global stockpiles of nuclear weapons, and maintain safety and reliability of the U.S. stockpile.

Secretary of Energy Chu's Priorities

- Focus on transformational science:
  - Connect basic and applied sciences
  - Embrace a degree of risk-taking
  - Integrate lab, university and industry activities
- Collaborate universally:
  - Build research networks and global partners
- Demonstrate next-generation energy technologies:
  - Batteries and other storage systems
- Drive step-change energy efficiency:
  - Novel models for collaboration and [use of] intellectual property (IP) for commercialization of energy-efficient technologies
- Reduce vehicle energy demand:
  - Improve internal combustion engines and develop batteries for vehicle electrification
- Build an efficient, smart network:
  - Smart meters/smart grid (and vehicle interface)
- Coordinate and share research globally

Technically, these priorities and goals are expected by the committee to translate into research, development, demonstration, and deployment (RDD&D) of efficient low-carbon transportation technologies and RDD&D of PHEV technology/vehicle electrification. From a programmatic standpoint, they suggest a greater emphasis on manufacturing, production, and commercialization.

For the Partnership, the net effect will be determined partially by the DOE's FY2010 budget request (Chu, 2009) that "cuts less effective programs so we can invest in our economic future." One of the examples mentioned by Secretary Chu is "moving away from funding vehicular hydrogen fuel cells to technologies with more immediate promise." This approach is indeed reflected in the DOE FY2010 budget request to Congress for $0 for hydrogen technologies as compared to $168,960,000 for FY2009 (DOE, 2009b). On the other hand, the vehicle technologies request is up from $273 million to $333 million in addition to requests for biofuel, solar, and wind technologies, which are also up. Further indications of priorities for vehicle electrification are that, of

DOE's Office of Energy Efficiency and Renewable Energy's (EERE's) $4.5 billion American Recovery and Reinvestment Act 2009 (ARRA) funds, $2 billion are proposed for advanced battery manufacturing, $400 million for transportation electrification, and $300 million for the alternative-fueled vehicles pilot grant program (Satyapal and Davis, 2009b).

In apparent support of these priorities, in DOE's Office of Electricity Delivery and Energy Reliability, about $3.4 billion of its $4.5 billion ARRA funds will go to the "Smart Grid Investment Program (Energy Independence and Security Act [EISA] 1306)" and another $700 million to "Smart Grid Regional and Energy Storage Demos" (DOE, 2009b). This distribution is consistent with increased emphasis on PHEVs and BEVs, since the need for Smart Grid technologies increases as the number of such vehicles in the fleet is increased.

Given that the previous administration's priorities were more focused on hydrogen and fuel-cell-powered vehicles for the long term while envisioning that advanced ICEs and HEVs would provide transition technologies, the DOE involvement in the Partnership is virtually certain to change. Recognizing that Partnership changes were likely, the statement of task for the NRC's third review by this committee includes the following: " . . . in examining the Partnership strategy, and given the changes that may take place with the New Administration, the committee at its first full committee meeting will address potential changes in the program strategy and program structure. The committee will write a short interim letter report with suggestions and recommendations on program strategy and structure . . . . " (see Attachment II). That portion of the statement of task is the basis for this letter report. Subsequent meetings by this committee will allow more in-depth review of the progress in the various technology areas and reporting of the Partnership activities since Phase 2.

EVENTS AND DRIVERS FOR POTENTIAL CHANGES IN THE PARTNERSHIP

A number of events since the last NRC review (NRC, 2008a) could have a significant impact on both the technological and the societal goals of the Partnership. Among these, in addition to changes in Administration/DOE priorities, are advances in battery technologies, the continued evolution of biofuels, promising basic ICE research on fuels and combustion processes, increased emphasis on reducing GHG emissions, important advances in learning from vehicle and fuel cell demonstration programs, other basic research programs, and economic issues for both the auto industry and the nation as a whole. Some of these are discussed briefly below.

Because the committee's in-depth review of the Partnership activities since Phase 2 will begin very soon, hydrogen/fuel cell technologies are not discussed to any significant extent in this letter report. However, the committee is concerned about the impact of severely scaling back the DOE hydrogen/fuel cell vehicle programs. It is not yet clear that the hydrogen/fuel cell approach (or for that matter advanced ICEs/biomass, or PHEVs/BEVs) can or cannot meet reasonable emission and driving-range requirements while also being affordable to purchase and operate. Recent fuel cell lifetime and durability improvements are encouraging, as are projected lower costs. Further, even though demonstration hydrogen/fuel cell vehicles are showing safe

operation at ever-increasing driving ranges with compressed hydrogen gas storage, the existing DOE hydrogen storage centers of excellence, in the committee's view, are likely to provide the best opportunity for finding better solutions, if they exist. An in-depth evaluation of the hydrogen/fuel cell option will be part of the current review and the committee's final report.

The Evolution of New Relevant Technologies

Batteries

Cooperative alternative energy automotive programs were greatly influenced by the formation and activities of the United States Advanced Battery Consortium (USABC). The cooperative efforts continued into the Partnership for a New Generation of Vehicles (PNGV) program and later into the FreedomCAR and then the Partnership. An NRC review of this program in 1998 concluded that both nickel- and lithium-based batteries had the potential to meet the automobile industry goals, except for the costs (NRC, 1998).

The evolution of lithium-ion batteries as candidates for HEVs, PHEVs, and BEVs is known and well documented. Several OEMs have already indicated their strong interest in Li-ion, especially for PHEVs and extended-range electric vehicle (EREV[3]) applications, and efforts are underway to construct several new manufacturing facilities in the United States to produce these batteries. Although much more work needs to be done to meet all of the requirements, significant advances have been made in safety, performance increases, and cost reductions for several Li-ion chemistries. While the advances appear to be nearing adequacy for PHEVs and EREVs, this is probably not the case for BEVs, where battery cost and longer range are even more important.

The committee expects that BEVs will represent one of the important vehicle technologies in the mix of technologies for meeting the long-term goals of the Partnership. As such, even if PHEV requirements can soon be met (and certainly if they cannot), efforts to further advance Li-ion technologies are warranted, the committee suggests. It also suggests that lower-cost energy storage technologies, including other battery chemistries, advanced materials for electrochemical capacitors, and combinations of the two, be pursued for both PHEV and BEV applications.

In the PNGV many forms of energy storage and conversion technologies such as flywheels, fuel cells, and ultracapacitors, in addition to a range of batteries, were considered in an effort to meet the miles per gallon (mpg) fuel economy goal of "up to 80 mpg." That work concluded with all three of the PNGV concept cars embracing the HEV configuration using batteries and small diesel engines (NRC, 2000, 2001). In the Partnership, the current plan is to use the continued development of HEV technologies as an interim step toward a final vision of a hydrogen-fueled fuel cell vehicle.

[3] General Motors refers to its "Volt"-type vehicle as an "extended-range electric vehicle (EREV)." The configuration is very similar to that of PHEVs.

HEVs were introduced into the marketplace about 12 years ago and today account for about 3 percent of the new-vehicle automotive market.[4] The acceptance and success of HEVs and the need to accelerate reductions in emissions have resulted in a change in the Partnership plan to include the development of technologies needed for PHEVs. PHEVs are characterized by an increase in the "battery only" range of the hybrid vehicle and a corresponding decrease in onboard fuel consumption. Further improvements in battery technologies and further reductions in cost beyond those needed for PHEVs could allow an even greater increase in the battery driving range in support of producing BEVs, which would use no onboard fuel. For HEVs, PHEVs, and BEVs the primary issues are performance, durability, and the costs of the battery system.

ICE Emerging Technologies[5]

The successful development of biofuel production technologies such as cellulosic ethanol may offer synergistic opportunities with the advanced combustion technologies that are being researched within the Partnership. Successful technologies for the production of biofuels and advanced technologies for the use of biofuels in vehicles could impact the technology pathway and requisite timeline in which PHEVs, BEVs, and hydrogen-fueled fuel cell vehicles are introduced. For example, it may be feasible to marry the interaction between advanced fuel injection systems and in-cylinder fluid mechanics, which is currently being investigated, with the enhanced understanding and predictability of the kinetic pathways to combustion auto-ignition, also a research area within the Partnership, to capitalize on specific fuel characteristics. This enhanced understanding could point the way to the different, and perhaps "tailorable," auto-ignition characteristics of synthesized biofuels. If this were to be done successfully it could enable the development of a clean-burning, biofueled, ICE-powered hybrid vehicle. Such a vehicle could offer very efficient mobility with a minimal carbon footprint. This alternative was not a consideration prior to the initiation of the biofuels program, which was not in effect at the beginning of the Partnership.

Although the Partnership has not focused on biofuels to this point, the synergies noted in this letter report suggest that biofuels are likely to become increasingly important and may well be addressed more specifically in the future. If that were to happen, one important step would be to apply the same cradle-to-grave analysis this letter report advocates for the other technologies being addressed by the Partnership.

Changes in the Automotive Industry

In the past 12 months the world has experienced extreme volatility in the price of crude oil and the corresponding cost of fuel for the consumer. Very high fuel prices caused a rapid ramp-up in consumers' preference for fuel efficient vehicles and in their

[4] Note that with the recent drop in gasoline prices over the last year or so, the market share of new HEVs sold has fallen below this level. Of note is that it has taken more than a decade for this new vehicle technology to achieve a very small share of the new vehicle market sales.

[5] The NRC Committee on Light-Duty Vehicle Fuel Economy Technologies is investigating a variety of options that it plans to report on in the Fall of 2009.

willingness to pay a premium for vehicles with high fuel economy. This preference for fuel efficient vehicles was quickly followed by a decrease in this unique demand as fuel prices came down. The industry infrastructure is not equipped to respond to such a rapid change in product mix.

In addition to the high fuel prices, the dramatic changes in the worldwide economic outlook in the last several months have also had a major impact on the automotive industry. Automobiles are a high-cost purchase, typically the second largest purchase after housing, and robust auto sales require a healthy credit market for both the dealerships and the consumer. The collapse of the credit market meant that dealerships were ordering fewer new vehicles, which caused a cash-flow problem for the OEMs, and consumers deferred new vehicle purchases, which caused further problems for both dealers and OEMs, not only in the United States but essentially globally as well. The dire situation of Chrysler and General Motors in late 2008 and early 2009, including their recent bankruptcies and inability to secure credit for continuing operations, led to the federal government taking a role by investing in the industry.

Simultaneously with the economic problems, the auto industry is also experiencing the effects of new regulations related to fuel economy and the environment. New corporate average fuel economy (CAFE) standards enacted in late 2007 set an aggressive time line for improvement in vehicle fuel economy regardless of oil prices and resulting market demand. At the same time, the regulation of carbon dioxide (CO_2) emissions that was being enacted, along with actions in some states, could have necessitated either using lower-carbon fuels or achieving higher fuel economy levels to meet requirements for CO_2 reductions. Recent rules proposed by the Administration, apparently developed with participation by the OEMs, will result in even more aggressive fuel mileage requirements, which may become uniform nationwide. In addition to the major changes noted above, two already existing trends in the auto industry include a shift to decentralization of operations and internationalization of the industry. Decentralization has meant increasing automotive supplier involvement in contributing to the R&D for product development. Further, many supplier activities that were owned and operated by individual auto companies were spun off into independent companies, again decreasing automakers' internal R&D activities. One result has been a supplier base that moves more toward the center of innovation. Further, common components have become available for the industry at large, thus opening the door to commodity components and systems.

Additionally, foreign auto companies have taken an increasing share of the U.S. auto market, many benefiting from government-sponsored research in their home markets. At the same time the U.S. auto industry is expanding operations outside the United States, which increases the potential for leakage of U.S.-developed technology into emerging markets.

A final consideration is that current fiscal realities raise the unsettling possibility that U.S. industry might, at least in the near term, be unable to continue developing long-term solutions like hydrogen/fuel cell vehicles. The accumulated experience and expertise could be lost as researchers disperse, leaving the Partnership with the more challenging task of developing fuel-cell and other long-term advanced technology options without automobile industry collaboration. Conversely, a robust Partnership with full

participation by the domestic auto industry has the potential to be an important factor in a renaissance of the U.S. auto industry.

SUGGESTED ACTIONS

The Partnership should consider adapting its goals and strategy in response to changing U.S. priorities and new findings (e.g., NRC. 2008b). An increased emphasis is suggested by the committee on the R&D needed to produce usable short-term technologies (e.g., better batteries for PHEVs, improved ICEs), along with continuing R&D on the long-term technologies (e.g., BEVs, cellulosic ethanol and other non-food-crop biofuels, hydrogen fuel, and fuel cells). An increased emphasis is also required for technologies that will produce significantly lower greenhouse gas emissions (e.g., CO_2) and the increased use of domestic energy sources, especially biofuels. As noted previously, some of the goals of the President's *New Energy for America* plan are to save significant amounts of oil within 10 years, put 1 million plug-in hybrid vehicles on the road by 2015, reduce greenhouse gas emissions by 80 percent by 2050, and make significant investments in climate-friendly energy development and deployment over the next 10 years (Satyapal and Davis, 2009a).

Goals and Strategy

Overall the strategy of the Partnership (see Attachment IV) seems to be appropriate and should generally continue, but with some modifications. Specifically, the committee considers that the government-industry partnership is working well and should continue (NRC, 2000, 2001, 2005, 2008a). However, the Partnership should consider whether the timeline for the long-term goals (hydrogen infrastructure/fuel cells) should be extended and more emphasis placed on nearer-term technologies. The latter can possibly help revive the industry and also help with societal issues, such as environmental concerns associated with greenhouse gas emissions, economic concerns associated with massive imports of crude oil, and social issues associated with the loss of many thousands of auto industry jobs.

In addition, the spectrum of needed technologies and the range of applicable time scales suggest the utility of developing new models for stimulating private sector researchers, national laboratory scientists, and academics to engage in new productive collaborations. It is also crucial to attract good students to these research efforts, partly to enhance and restore U.S. scientific leadership, but also to entice the best and brightest of new generations to contribute to long-term energy and environmental solutions.

These factors suggest that support for U.S. industry such as that provided by the Partnership is probably needed now more than ever. With the Administration's goals in mind and given uncertainties about the cost, performance, and consumer acceptance of many of the vehicle technologies under development, it is vital for the Partnership to have a diverse portfolio of options. As is noted in Conclusion 1 of a recent NRC (2008b) report, "A portfolio of technologies including hydrogen fuel cell vehicles, improved efficiency of conventional vehicles, hybrids, and the use of biofuels—in conjunction with required new public drivers—has the potential to nearly eliminate gasoline use in light-duty vehicles by the middle of the century, while reducing fleet greenhouse gases to less

than 20 percent of their current levels" (p. 4). The Partnership should not lose focus on its main goals of providing good management and oversight of all its activities. However, depending on congressional actions and Administration directives, as well as budgets and funding, the Partnership should consider the following:

- Rewording its mission statement and goals to reflect consistency with the new Administration's goals and priorities.
- Not abandoning programs on the long-term high-risk vehicle technologies that could be highly transformational with regard to reduced use of petroleum and reduced emissions, namely, fuel cells, hydrogen storage, and batteries for BEVs, as well the exploration of innovative systems concepts.
- Incorporating the broader scope of a "cradle-to-grave" analysis rather than a "well-to-wheels" approach in program planning from production to recycle to better consider total energy consumption, total emissions, and total environmental impact.[6]
- Emphasizing R&D to support development of nearer-term technologies (such as advanced ICEs, and better batteries for HEVs and PHEVs) and long-term technologies (such as cellulosic-based and other non-food-crop biofuels/ICEs, hydrogen/fuel cell vehicles, and all-electric vehicles) and define a transition pathway from nearer-term to long-term technologies, including targets, milestones, and go/no-go decision points.
- Expanding efforts to support exploratory projects on transformative and revolutionary ideas that are beyond the current scope of the Partnership.[7] This should include, if possible, joint funding and cooperation with different DOE offices, and the enlistment of a broad group of stakeholders including academia, start-ups,[8] and mature companies and providing them with support for at least minimal R&D efforts.
- Maintaining stable funding because of its importance for fuel production and delivery activities. It is the committee's view that it is a critical to understand and address the barriers, costs, and environmental impacts not only of hydrogen but also of other potential energy carriers and fuels as well.

[6] "Well-to-wheels" in the context of motor vehicles commonly refers to an analysis covering fuel production to fuel usage in the vehicle. For example, in Argonne National Laboratory's GREET model, such analyses have been conducted for biofuels, electricity, and gasoline. Life-cycle analyses (LCA) would include the production of vehicles, including energy storage technologies (e.g., batteries), and the distribution of vehicles as well as the disposal of components after the useful life of the vehicle has been reached, which are not included in the "well-to-wheels" analysis. However, a comprehensive "cradle-to-grave" analysis would include all these aspects. Unlike gasoline, some fuels do not come from wells, and hence some prefer the term "source-to-wheels." Similarly, those interested in complete recycle (which is probably not practically possible) use "cradle to cradle" instead of "cradle to grave."

[7] There may be opportunities to leverage the newly formed Advanced Research Projects Agency–Energy (ARPA-E), a new DOE organization created specifically to foster R&D of transformational energy-related technologies. See http://www.energy.gov/news2009/documents2009/ARPA-E_FOA.pdf

[8] Note that start-up companies typically need technology maturation funds (i.e., proof-of-concept and product-development support) more than funds for R&D.

- Finally, the Partnership should consider broadening the scope of the technical approaches being considered within each of the three major fuel and vehicle technology pathways (biofuels/ICEs, PHEVs/BEVs, and hydrogen/fuel cell vehicles). In the electric vehicle area, other storage approaches such as nano-enhanced capacitors and batteries beyond those with lithium chemistries should be the subject of basic and potential future applied research. In addition, many fuel cell approaches and hydrogen storage options should continue to be investigated, and options should not be prematurely shut down.

The committee recognizes that many of the actions it might see as desirable for pursuing revised goals involve primarily the DOE but cannot be implemented unilaterally by the DOE. It also recognizes that successful R&D alone does not necessarily translate into the commercialization of advanced vehicles and fuels and entry into the marketplace. Further, even with commercialization, substantial penetration into the general U.S. economy is required if significant reductions are to be achieved in petroleum consumption and greenhouse gas emissions. Achieving such goals will require an enthusiastic "buy-in" by the private sector.

Many components of the private sector, in addition to OEMs and major suppliers, can make meaningful contributions to technology advancements. In the committee's view, the innovation capacity of the private sector is best motivated through consistent and predictable policy and market incentives. For example, innovators, entrepreneurs, and investors rely on stable policies and incentives to evaluate the risks and benefits of pursuing alternative technologies and thereby allocate private resources efficiently.

An environment of stable and predictable incentives for vehicle technologies could be created in several ways, including the establishment of predictable carbon prices, a carbon trading plan, performance standards, and policies or incentives to reduce energy imports, as well as commitments with long enough timescales to encourage active participation.[9] The committee recognizes that the Partnership does not have complete control of the broader market and policy environment. It simply notes that such policy signals can provide important "market pull" to aid in the deployment of technologies arising from the "technology push" of R&D programs. Stable incentives are also pointed out because of their importance, in the committee's view, in enabling the nation to realize the rapid transformation in vehicle technologies that appears to be an Administration priority.

National policy clearly seeks that the manufacturing of advanced new vehicles occur in the United States to the greatest extent possible. But for this goal to be realized, U.S. manufacturing will need a durable, structural advantage to compete effectively in world markets.

This competitive advantage could derive from two sources: (1) design of vehicle systems and components to improve manufacturability; and (2) general research in manufacturing technologies and processes to develop competitive manufacturing advantages. High-priority areas for vehicle systems and components in which proprietary competitive advantage could be gained, which the committee suggests be actively

[9] For a recent discussion of the policy issues related to the market adoption of high-risk technologies like fuel cell vehicles and the associated hydrogen fuel infrastructure, see NRC (2008b).

pursued, include both component technology advancements and advanced manufacturing processes for:

- Lithium-ion and other promising batteries,
- Power electronics, including packaging, and
- Advanced ICEs.

In addition the committee also suggests continuing similar efforts on long-term technologies including:

- Fuel cell and stack components, and
- Vehicle onboard hydrogen storage.

The committee also suggests that the lightweight materials program continue to be an integral part of the efforts for improving fuel efficiency for vehicles that would utilize both nearer-term and longer-term technologies.

Implementation

The following are some committee suggestions for the Partnership for implementing efforts to deal with the changes in the automotive sector and the goals the Administration is pursuing:

- Consider temporary reductions in cost-share requirements for a number of joint program efforts. Many universities and small industrial organizations could have considerable difficulty, under current economic conditions, in providing matching funds as currently required.
- Consider directly funding the OEMs to keep their in-house, non-petroleum research, development and demonstration (RD&D) programs active (e.g., RD&D on hydrogen/fuel cells, BEVs, PHEVs, and biofueled ICEs).
- As the Partnership moves toward possible commercialization decisions for a technology, consider allocating more funding to private sector companies to seed development of a robust, strong supply base in these developing advanced technologies.
- Consider whether the Partnership might benefit from exploring systematic linkages with entrepreneurs and innovators whose contributions could accelerate the pace of innovation in the industry. Equally important, such new ventures might benefit from systematic contact with the markets provided by current Partnership members.
- Assess Partnership member makeup and collaborations. New members added to the Partnership can bring expertise in important areas and contribute to reaching goals. There is also the danger that too many non-contributing members can lead to a more cumbersome and inefficient operation that is more difficult to manage. If new members and/or other active participants are added, the Partnership should consider including:

1. Electric Power Research Institute (EPRI) representative(s) and DOE representatives that are involved with Smart Grid activities, for the utilities technical team;
2. Biofuels representative(s), for the production and delivery technical teams;
3. More involvement and coordination with appropriate representatives from the U.S. Department of Transportation, especially in areas that will interact with Partnership long-term goals; and
4. Expertise in and activities relevant to manufacturing processes, including relevant supplier industries, among the technical programs.

- Expand support for next-generation research being performed at current and future automotive suppliers as well as OEMs.

Once again, the committee appreciates the opportunity to have provided some suggestions to the Partnership as it moves forward in these challenging times.

Sincerely,

Vernon P. Roan, *Chair*
Committee on Review of the Research Program of the
FreedomCAR and Fuel Partnership, Phase 3

Cc: Patrick Davis, DOE Office of Vehicle Technologies
Keith Hardy, DOE Office of Vehicle Technologies
Carl Maronde, DOE National Energy Technology Laboratory
Ken Howden, DOE Office of Vehicle Technologies

Attachments

I. Committee on Review of the Research Program of the FreedomCAR and Fuel Partnership, Phase 3
II. Statement of Task
III. Presentations and Discussions with Representatives of the Partnership at the Committee Meeting, April 27, 2009
IV. FreedomCAR and Fuel Partnership

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ACKNOWLEDGMENT OF REVIEWERS

This letter report was reviewed in draft form by the following individuals, chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee: Allen J. Bard (NAS), University of Texas, Austin; John Heywood (NAE), Massachusetts Institute of Technology; Thomas M. Jahns, University of Wisconsin, Madison; Trevor Jones (NAE), ElectroSonics Medical, Inc.; William F. Powers (NAE), consultant, Ford Motor Company (retired); Robert W. Shaw, Jr., Aretê Corporation; Dan Sperling, University of California, Davis; and Jay Whitacre, Carnegie Mellon University. The review was overseen by Granger Morgan (NAS), Carnegie Mellon University. Although the individuals listed above provided many constructive comments and suggestions, they were not asked to endorse the report's conclusions or recommendations, nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Attachment I

Committee on Review of the Research Program of the FreedomCAR and Fuel Partnership, Phase 3

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[1]NAE=member, National Academy of Engineering.
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Attachment II

Statement of Task

The National Academies' National Research Council (NRC) Committee on Review of the Research Program of the FreedomCAR and Fuel Partnership, Phase 3, will address the following tasks **(Note: the interim letter report will address Task 6)**

(1) Review the challenging high-level technical goals and timetables for government and industry R&D efforts, which address such areas as (a) integrated systems analysis; (b) fuel cell power systems; (c) hydrogen storage systems; (d) hydrogen production and distribution technologies necessary for the viability of hydrogen-fueled vehicles; (e) the technical basis for codes and standards; (f) electric propulsion systems; (g) electric energy storage technologies; (h) lightweight materials; and (i) advanced combustion and emission control systems for internal combustion engines (ICEs).

(2) Review and evaluate progress and program directions since the Phase 1 and 2 reviews toward meeting the Partnership's technical goals, and examine ongoing research activities and their relevance to meeting the goals of the Partnership.

(3) Examine and comment on the overall balance and adequacy of the research and development effort, and the rate of progress, in light of the technical objectives and schedules for each of the major technology areas.

(4) Examine and comment, as necessary, on the appropriate role for federal involvement in the various technical areas under development, especially in light of activities ongoing in the private sector or in the states.

(5) Examine and comment on the Partnership's strategy for accomplishing its goals, especially in the context of ongoing developments in biofuels, plug-in hybrid electric vehicles, electric vehicles, the recent enactment of legislation on corporate average fuel economy standards for light-duty vehicles, and possible legislation on carbon emissions. Other issues that the committee might address include (a) program management and organization; (b) the process for setting milestones, research directions, and making Go/No Go decisions; (c) collaborative activities needed to meet the program's goals (e.g., among the various offices and programs in DOE, the U.S. Department of Transportation, USCAR, the fuels industry, electric power sector, universities, other parts of the private sector [such as venture capitalists], and others); and (d) other topics that the committee finds important to comment on related to the success of the program in meeting its technical goals.

(6) As a first step in examining the Partnership's strategy, and given the changes that may take place with the new Administration, the committee at its first full committee meeting will address potential changes in the program strategy and program structure. The committee will write a short interim letter report with suggestions and recommendations on program strategy and structure and aim to deliver it to the sponsor within 1 month after the meeting. The date of delivery of the letter report will be contingent on when the meeting is scheduled and timely input of information from the representatives of the Partnership.

(7) Review and assess the actions that have been taken in response to recommendations from the NRC Phase 2 review of the Partnership.

(8) Write a final report documenting its conclusions and recommendations.

Attachment III

Presentations and Discussions with Representatives of the Partnership at the Committee Meeting, April 27, 2009

Changes in Objectives in the Partnership
Sunita Satyapal and Patrick Davis, Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy (DOE)

- General priorities being set by the Secretary
- Major initiatives that might influence Partnership

Budget Outlook (FY09-10)
Sunita Satyapal and Patrick Davis, EERE, DOE

- Overall Level of Resources
- How are Resource Allocations Changing?
- How Does Stimulus Plan/Loan Program Affect Partnership?

Overview and Progress & Outlook on Existing Program Efforts
Sunita Satyapal and Patrick Davis, EERE, DOE

- Progress and outlook for meeting future targets, especially with regard to critical technologies, and optimistic and pessimistic views and the need for (or lack of) changes in projected timescales
- Where has the program made significant progress?
- Where has progress not been adequate?
- Do targets and milestones need to be changed?

Automotive Industry Partners' Views on Progress, Strategy, Future Outlook, and Structure of Program
William Peirce, General Motors Corporation; Reginald Modlin, Chrylser LLC; and John Sakioka, Ford Motor Company

Fuel Industry Partners' Views on Progress, Strategy, Future Outlook, and Structure of Program
George Parks, ConocoPhillips; Puneet Verma, Chevron Technology Ventures; and James Kegerreis, ExxonMobil

Utility Industry Partners' Views on Progress, Strategy, Future Outlook, and Structure of Program
Robert Graham, Southern California Edison

DOE's Views on Progress, Strategy, Future Outlook, and Structure of Program
Sunita Satyapal and Patrick Davis, EERE, DOE

Attachment IV

FreedomCAR and Fuel Partnership

HISTORY AND BACKGROUND

The FreedomCAR and Fuel Partnership is a research and development (R&D) program designed to enable long-range, significant changes in automobiles and their energy supply systems for the purpose of obtaining major societal benefits, such as reduced petroleum consumption and reduced levels of harmful gaseous emissions to the atmosphere. Research projects sponsored at government laboratories, universities, and private companies are chosen and monitored by joint industry/government technical teams. This structure helps focus expenditures on research to support projects that are relevant to the long-range, pre-competitive research needs envisioned by automotive, energy, and, now, utility companies, and help to meet the nation's societal needs as articulated by the government. The basic structure has evolved and has improved over almost 15 years and has proven to be an excellent mechanism for achieving progress (NRC, 2000, 2001, 2005, 2008a).

The DOE has been involved for about 30 years in R&D programs related to advanced vehicular technologies and alternative transportation fuels. During the 1990s, much of this R&D was conducted as part of the Partnership for a New Generation of Vehicles (PNGV) program, which was formed between the federal government and the auto industry's USCAR.[1] Building on the PNGV program, in January 2002 the Secretary of Energy and executives of DaimlerChrysler, Ford, and General Motors announced a new government-industry partnership between DOE and USCAR called FreedomCAR, with CAR standing for Cooperative Automotive Research. In September 2003, FreedomCAR was expanded to include the five large energy companies mentioned previously to address issues related to the supporting fuel infrastructure. The expanded partnership is called the FreedomCAR and Fuel Partnership (DOE, 2006).[2] During the

[1]USCAR, which predated the formation of PNGV, was established by Chrysler Corporation, Ford Motor Company, and General Motors Corporation. Its purpose was to support intercompany, precompetitive cooperation that would reduce the cost of redundant R&D, especially in areas mandated by government regulation, and make the U.S. industry more competitive with international companies. Chrysler Corporation merged with Daimler Benz in 1998 to form DaimlerChrysler. In 2007, DaimlerChrysler divested from a major interest in the Chrysler Group and Chrysler LLC was formed; DaimlerChrysler was renamed Daimler AG. The PNGV sought to significantly improve the nation's competitiveness in the manufacture of future generations of vehicles, to implement commercially viable innovations emanating from ongoing research on conventional vehicles, and to develop vehicles that achieve up to three times the fuel efficiency of comparable 1994 family sedans (NRC, 2001; PNGV, 1995; The White House, 1993).

[2]In February 2003, before the announcement of the FreedomCAR and Fuel Partnership, the President announced the FreedomCAR and Hydrogen Fuel Initiative to develop technologies for (1) fuel efficient motor vehicles and light trucks, (2) cleaner fuels, (3) improved energy efficiency, and (4) the hydrogen production and nationwide distribution infrastructure needed for vehicle and stationary power plants, to fuel both hydrogen ICEs and fuel cells (DOE, 2004a). The expansion of the FreedomCAR and Fuel Partnership to include the energy sector after the announcement of the initiative also supports the goal of the Hydrogen Fuel Initiative.

time period since the last NRC phase 2 review (NRC, 2008a), the Partnership has expanded to include the utility industry (as noted previously, DTE Energy and Southern California Edison) (DOE, 2009a). These new partners were added to address issues associated with use of the electric transmission and distribution systems that would accompany commercial deployment of PHEVs and BEVs.

The Partnership addresses the development of advanced technologies for all light-duty passenger vehicles. It also addresses technologies for hydrogen production, distribution, dispensing, and storage. Funding for research, development, and demonstration activities goes to the national laboratories, private companies, and universities. Especially in the case of development activities, projects costs are often shared between the private sector and the federal government.

The Partnership plays an important role in the planning, pursuit, and assessment of high-risk R&D for many of the needed vehicle and fuel technologies, and federal funds allow much of this work to move forward. It also serves as a communication mechanism for the interested players, including government, the national laboratories, private industry, universities, the public, and others. This structure recognizes both the long-range, high-risk research needs envisioned by automotive and energy companies, and the nation's societal needs related to automotive vehicles and fuels, as articulated by government, in defining the appropriate goals and selecting the best way of achieving them. This capability is seen by the committee as a major strength of the Partnership that should be retained even if other changes are made.

CURRENT STRUCTURE OF THE PARTNERSHIP

The administrative structure of the Partnership includes the Executive Steering Group, which oversees the Joint Operations Group, Fuels Operations Group, FreedomCAR Operations Group, and the newly added Utility Operations Group. The DOE managers and respective energy company, automotive companies (OEMs), and utility directors of these groups oversee technical teams that are responsible for developing R&D plans and roadmaps, reviewing research results, and evaluating technical progress toward meeting research goals. Realizing that there will be a portfolio of energy carriers (fuels) and mobility technologies necessary to move forward, and to address the technical challenges associated with the different fuel/vehicle technology pathways, the Partnership has established a technical roadmap with specific, quantitative 2010 and 2015 technology and cost goals in eight areas:

- Internal combustion engines (both petroleum and hydrogen fueled),
- Fuel cell power systems,
- Fuel cells,
- Hydrogen storage systems,
- Energy storage systems for hybrid vehicles,
- Hydrogen production and delivery systems,
- Electric propulsion systems, and
- Materials for lightweight vehicles.

It is within this structure that the Partnership sets priorities, determines technical targets and milestones, and performs the research attempting to achieve those targets. Regular reviews, both internal and external, are conducted to receive feedback and critiques of individual and group projects.