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REPORT IN BRIEF

Review of the Research Program of the U.S. DRIVE Partnership, Fourth Report

Board on Energy and Environmental Systems • Division on Engineering and Physical Sciences • **January 2013**

The government-industry partnership known as U.S. DRIVE (Driving Research and Innovation for Vehicle efficiency and Energy sustainability) was formed in 2011 with the goal of initiating technological progress in the U.S. transportation sector through strategic investment in high-priority research and development (R&D). With a focus on innovative, commercially viable technologies for passenger vehicles, the Partnership's long-term initiative is to provide U.S. consumers with a range of affordable personal transportation choices that reduce both petroleum consumption and harmful emissions. Currently, the work of the Partnership is guided by research needs and targets identified within joint government-industry technical teams. This report assesses progress within the technical areas covered by each team—including internal combustion engines, automotive fuel cell power systems, hydrogen storage, batteries and other forms of electrochemical storage, electric propulsion systems, hydrogen production and delivery, and materials leading to vehicle weight reduction—and suggests potential technological pathways to help the Partnership to reach its goal. The report also recommends that the Partnership's Executive Steering Group continually broaden their understanding of cross-cutting technological issues and adjust the R&D portfolio at a programmatic level so as to effectively prioritize research goals in each technical area.

Background on the U.S. DRIVE Partnership

The transportation sector and the use of light duty vehicles (LDVs)—such as automobiles and light trucks—are almost completely dependent on petroleum. The combustion of petroleum-derived fuels, mostly gasoline and diesel, produces a significant fraction of the nation's greenhouse gases as well as particulate matter and other pollutants that affect local air quality. In addition, the price volatility of gasoline and diesel fuel has had significant economic impacts in recent years on the transportation sector and automotive industry, along with vehicle owners.

These factors have created various national security, economic, and environmental challenges. In recent decades, the federal government has invested in R&D to help enable progress in innovative vehicle and fuel technologies and has enacted legislation that seeks to promote the replacement of petroleum-based fuels with alternative fuels, such as those derived from biomass.

Under President Bush, the Partnership for a New Generation of Vehicles (PNGV), which focused on achieving a significant increase in fuel economy for family sedans, shifted toward addressing the challenges of using hydrogen fuel and fuel cell vehicles. Subsequently, the FreedomCAR and Fuel Partnership was established to address these challenges and to advance the technology within a timeframe that could enable a decision on the commercial viability of hydrogen vehicles by 2015.

Some of the main recommendations for each technical area are summarized in the 2-page insert associated with this Report in Brief; the complete list of recommendations is detailed in the full NRC report.

As President Obama's administration took office in early 2009, a redirection began to take place with reduced R&D on hydrogen and fuel cell vehicles. This shift was in conjunction with increased attention on technologies that use electricity to power LDVs, and with an emphasis on plug-in hybrid electric vehicles (PHEVs) and all-electric vehicles or battery electric vehicles (BEVs). The administration currently views BEVs and PHEVs as a nearer-term technology.

In 2011, the FreedomCAR and Fuel Partnership morphed into U.S. DRIVE, and a U.S. DRIVE partnership plan was formally released in February 2012. Despite these shifts in one or another of the nation's energy goals over the last few decades, the U.S. DRIVE Partnership is very much in line with the partnerships that preceded it—namely, the FreedomCAR and Fuel Partnership and, prior to that, PNGV.

The Partnership is a non-binding, non-legal, voluntary government-industry partnership. It does not itself conduct or fund R&D but each partner makes its own decisions regarding the funding and management of its projects. By bringing together technical experts and providing a framework for frequent and regular interaction, it provides a forum for discussing precompetitive, technology-specific R&D needs. At the same time, it identifies possible solutions and evaluates progress toward jointly developed technical goals. Its frequent communication among partners also helps to avoid duplication of efforts and increases the chances of successful commercialization of publicly funded R&D.

Building on the participants in the previous partnerships, U.S. DRIVE currently includes the following partners:

- Automobile industry: U.S. Council for Automotive Research LLC (USCAR, the cooperative research organization for Chrysler Group, Ford Motor Company, and General Motors Company), and Tesla Motors.
- Electric utility industry: DTE Energy Company, Southern California Edison Company, and the Electric Power Research Institute.
- Federal government: U.S. Department of Energy (DOE).
- Fuel industry: BP America, Chevron Corporation, ConocoPhillips Company, ExxonMobil Corporation, and Shell Oil Products US.

Program oversight is provided by an Executive Steering Group consisting of DOE's Assistant Secretary for Energy Efficiency and Renewable Energy and a vice-presidential-level executive from each of the Partnership companies.

Progress and Barriers

The Partnership addresses the development of advanced technologies for all passenger LDVs: cars, sport utility vehicles, pickups, and minivans. It pursues R&D in a number of technical areas including combustion and emissions control, fuel cells, batteries, electronics and electrical systems, lightweight materials, as well as technologies for hydrogen production, distribution, dispensing, and storage, and the interface and infrastructure issues associated with the electric utility industry for the support of BEVs and PHEVs. The long-term vision of the Partnership is to enable technology development that is successfully introduced into commercially viable passenger LDVs, significantly reducing petroleum consumption and harmful emissions as a result. Specifically, the Partnership examines a portfolio of pathways and precompetitive technologies in four broad categories: vehicles, fuels, joint vehicles/fuels, and joint vehicles/electric utility.

It is likely that, in the coming decades, there will be a diversity of vehicles and fuels that are commercialized. Some options are lower risk and nearer term than others, and they all face different technical, cost, and market risks. Previous NRC studies have concluded that—given the high-risk and uncertain nature of many of these technologies, along with the immense challenge of achieving deep reductions in GHGs and petroleum use—an R&D insurance strategy pursuing a portfolio of possible technological options is the most prudent approach.

Even though the technologies involved are not all under the U.S. DRIVE umbrella, the potential primary pathways to the long-term goals of significantly reduced petroleum consumption and reduced emissions including GHG emissions for LDVs are:

- Improved ICE vehicles coupled with greater use of biofuels and natural gas, with low life-cycle environmental impacts;
- A shifting of significant portions of transportation energy from petroleum to the electric grid through the expanded use of PHEVs and BEVs; and
- The possible transition to hydrogen as a transportation fuel utilized in hydrogen fuel cell vehicles (HFCVs).

None of these pathways is without issues and none is devoid of promise.

Overall, technical progress has been steady and there is evidence of solid progress in all areas, which in some cases has been impressive. The Partnership is effective in advancing toward its goals and the technical teams have been an effective public-private partnering mechanism. However, equally impressive are some of the remaining barriers.

Adequacy and Balance of the Partnership

Distribution of the Partnership funding has shifted significantly since the last NRC review, with the share for hydrogen-related activities decreasing continually from $200 million in FY 2009 to $104 million in FY 2012. Over the same period, battery R&D funding in the vehicle technology program dedicated to U.S. DRIVE rose from $69 to $90 million and from $23 to $31 million for advanced combustion R&D. The committee notes that other vehicle technologies receiving significant funding, such as more efficient electrical components and lighter weight materials, would potentially benefit all future propulsion systems.

Based on the current status and projected incremental improvements of existing technologies, current vehicle technologies do not yet have the performance attributes and cost to dominate the market and meet the goal of large-scale replacement of petroleum-use and reduction of emissions. Therefore, it is appropriate to continue investing resources on the most impactful research to achieve these targets. However it is also important to both focus resources within each technical area on the greatest technological challenges and to not let resources dwindle too far as to be unable to sustain a critical mass required to support a robust decision on any technology.

As detailed in the full NRC report, the committee notes that high-risk, potentially high-payoff R&D is an appropriate expenditure of government resources. Support for precompetitive research on long-term technologies, such as the enablers for hydrogen to become a viable transportation fuel and the fuel cell R&D leading to affordable HFCVs, is important and should be continued. At the same time, due to recent economic issues, government support for technologies that have impact both in nearer and longer terms, especially those that could transfer some of the required transportation energy from petroleum to biofuels or to the electric grid are also appropriate.

The federal government plays an important role in the development of technologies that can help to address national policies and regulations aimed at reducing emissions and fuel consumption from LDVs. The federal government can support fundamental research through the national laboratories and universities, and industry can focus on development. One advantage of having government-industry collaboration is that the private sector can help to transform improvements from research into cost-effective and marketable products. In the full NRC report, the committee has considered which activities are precompetitive and which are most appropriate for U.S. DRIVE and federal government support within each of the technical areas. Implicit in all of the recommendations that relate to the support of additional research, the federal government has a role in the R&D.

Program Management and Decision Making

As in previous NRC reviews of the FreedomCAR and Fuel Partnership, the committee finds the operation and management of the technical teams, and the integration of the systems analysis functions within those teams, to be exemplary for the most part. However, the application of systems analysis to strategic decision making is lagging, especially concerning alternative pathways to achieving objectives such as reduced U.S. petroleum consumption or GHG emissions. It is still unclear to the committee whether and how this work is being adequately applied at the senior-leadership level within DOE or the Partnership to guide overall Partnership direction. The committee recommends that the Executive Steering Group be engaged to set targets for the U.S. DRIVE Partnership that are consistent with the objectives of reduced petroleum consumption and GHG emissions, and for U.S. DRIVE to conduct an overall review of the Partnership portfolio, both for the adequacy to achieve the targets and for focus on the mission of supporting longer term, higher risk pre-competitive activities in vehicle, fuel, and electric utility technologies. U.S. DRIVE should also adopt a portfolio-based strategy based on overall systems analysis performed by a *proactive* vehicle systems and analysis technical team and fuel pathway integration technical team.

Committee on Review of the U.S. Drive Research Program, Phase 4: Vernon P. Roan, *Chair,* University of Florida (professor emeritus); **R. Stephen Berry,** University of Chicago; **David L. Bodde,** Clemson University**; Kathryn Bullock,** Coolohm, Inc.; **Dennis A. Corrigan,** DC Energy Consulting; **Glenn A. Eisman,** Rensselaer Polytechnic Institute; **W. Robert Epperly,** Consultant; **David E. Foster,** University of Wisconsin; **Gerald Gabrielse,** Harvard University; **Linos Jacovides,** Delphi Research Labs (retired); **Harold H. Kung,** Northwestern University; **Gene Nemanich,** Chevron Hydrogen Systems (retired); **Robert Nowak,** Consultant; **Bernard Robertson,** DaimlerChrysler Corporation (retired); **Constantine Samaras,** RAND Corporation; **R. Rhoads Stephenson,** National Aeronautics and Space Administration/ Jet Propulsion Laboratory (retired); **Kathleen C. Taylor,** General Motors Corporation (retired); **Brijesh Vyas,** Bell Labs. LGS Innovations

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This study is based on work supported by a contract between the National Academy of Sciences and the National Science Foundation and between the National Academy of Sciences and the Department of Energy. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project, or the National Research Council.

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Report issued January 2013.

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Recommendations for the U.S. DRIVE Partnership

The Executive Steering Group should be engaged to set targets for the U.S. DRIVE Partnership that are consistent with the objectives of reduced petroleum consumption and greenhouse gas emissions. U.S. DRIVE should also conduct an overall review of the Partnership portfolio, both on the adequacy of the R&D effort to achieve the targets and on the mission of supporting longer-term, higher-risk precompetitive activities in all three potential primary pathways: biofuels, electric vehicles, and fuel cells.

The U.S. DRIVE Partnership should adopt an explicitly portfolio-based R&D strategy to help the DOE to balance the investment among alternative pathways along with the more traditional reviews of the progress of individual pathways. Furthermore, this portfolio-based strategy should be based on overall systems analysis performed by a *proactive* vehicle systems and analysis technical team and fuel pathway integration technical team.

Overall, technical progress has been steady with notable advances in all areas, while the technical teams have been an effective public-private partnering mechanism. However, equally impressive are some of the remaining barriers.

Advanced Internal Combustion Engines and Emission Controls

Internal combustion engines (ICEs) for transportation systems are going to be the dominant automotive technology for decades. Because a better understanding of the combustion process and emissions production can help to overcome a major barrier to more advanced ICEs, work in this area will have widespread relevance. The emergence of natural gas in apparently very large quantities is a factor that must also be considered in future visions of ICEs. *Recommendation: U.S. DRIVE should make an assessment of whether natural gas can be an enabler for achieving the advanced combustion modes currently being pursued in its research portfolio.*

Fuel Cells

Significant progress has been made in fuel cell technologies since the NRC Phase 3 report in 2010. Investigations on fundamental issues related to durability and performance have been expanded in scope and have begun to yield insight into issues important for meeting performance and cost targets for fuel cells. *Recommendation: The DOE should increase efforts in initiatives for reducing costs associated with system-wide technologies for fuel cells. Emerging modeling capabilities should be used for sensitivity analysis and for guiding resource allocation to the areas that will have the greatest impact on performance, endurance, and cost at the system level.*

Onboard Hydrogen Storage

Onboard hydrogen storage is a key enabler for hydrogen fuel cell vehicles (HFCVs). The primary focus of the hydrogen storage program is to foster the development and demonstration of commercially viable hydrogen storage technologies for transportation and stationary applications. *Recommendation: The DOE should initiate a new program that builds on the excellent progress made to date and expands into fundamentally new research areas in hydrogen storage. The first part of the program should focus on a critical assessment of prospects for, and barriers to, advanced storage techniques and concepts.*

Electrochemical Energy Storage

Electrochemical energy storage technology is a key enabler for all electric drive vehicles. Improved technologies in this area are critical to advancing both near- and long-term goals of the Partnership—a significant improvement in performance and a reduction in costs can result in greater electrification of vehicles. Commercial development of hybrid electric vehicles (HEVs) has grown in the past decade due in part to the development of high-power batteries, which was supported by U.S. DRIVE through the United States Advanced Battery Consortium (USABC).

Recommendation: The USABC battery targets for battery electric vehicles (BEVs) are more than 20 years old and should be revised, as also recommended in the NRC's Phase 3 review. U.S. DRIVE should also undertake a diligent effort to develop a consistent set of technical targets across the key electric drive vehicle applications.

Electric Propulsion and Electrical Systems

Many future automobiles will use electric motors in the driveline in addition to power electronics and electrically driven accessories. One notable barrier is the cost and availability of the rare earth materials currently used in permanent-magnet motors. *Recommendation: The U.S. DRIVE Partnership should determine the potential and limitations of designing motors with permanent-magnet materials that would not require using as much rare earth metal.*

Materials

Weight reduction is crucial to achieving aggressive fuel consumption targets, and it will undoubtedly entail enhanced computational methods and widespread material substitution. Competition has raged among the steel, aluminum, and composites automotive supply base for many years in an effort to achieve low-cost weight reduction by means of materials substitution; the aluminum, magnesium, high-strength steel, and composites content of production vehicles has been steadily rising for more than 20 years. *Recommendation: The materials technical team should expand its outreach to the other technical teams to determine the highest-priority collective Partnership needs, and the team should then reassess its research portfolio accordingly. Any necessary reallocation of resources could be enabled by delegating some of the highly competitive metals development work to the private sector.*

Hydrogen

The Partnership in DOE's Energy Efficiency and Renewable Energy office includes the hydrogen production, delivery, and dispensing program and is part of the Fuel Cell Technologies Program (FCTP). The FCTP addresses various methods for producing hydrogen in distributed and centralized plants using technologies aimed at short- and long-term availability. *Recommendation: The DOE should seek the strategic input of the Partnership's Executive Steering Group, who could provide advice on all DOE fuels programs that are potentially critical for achieving reductions in U.S. petroleum dependence and greenhouse gas emissions through advanced vehicle technologies. DOE should subsequently make appropriate program revisions to address user needs.*

Grid Impacts of Electricity as an Energy Source for Vehicles

By including BEVs and plug-in HEVs (PHEVs) in U.S. DRIVE, it is important to consider the impact on the U.S. electric grid. Reasonable forecasts of market penetration indicate that the increased national energy demands appear unlikely to challenge the capacity of the grid. However, clustering of plug-in hybrid electric vehicle and battery electric vehicle owners could result in loads that exceed the capacity of local transformers, especially during fast charging at peak hours. DOE leadership in close collaboration with current and future providers of electricity will be critical to the timely and effective resolution of these issues.

Biofuels and the Partnership

Within DOE, the Biomass Program is responsible for the development of biofuels for bulk needs. Historically, DOE focused on biofuel distribution and end use through the Partnership—a split that puts the responsibility for making biofuels with the Biomass Program, and the responsibility for delivering the biofuel with the Partnership.

Starting in 2010 the Biomass Program reduced its ethanol programs and increased its programs for making biofuels that are indistinguishable from petroleum-based products, sometimes called drop-in fuels, which do not require special ICE technology or distribution systems. These can be produced as gasoline, jet fuel, or diesel-type finished products. If the role of ethanol were diminished, a U.S. DRIVE focus on ICE development capable of handling drop-in fuels and other biofuels is warranted.

Natural Gas and the Partnership

Although natural gas and light-duty vehicles using compressed natural gas (CNG) are not part of the U.S. DRIVE effort, R&D on CNG storage tanks and on refueling systems are being addressed by DOE's Advanced Research Projects Agency-Energy in its Methane Opportunities for Vehicular Energy program. *Recommendation: U.S. DRIVE should include the CNG vehicle and possible improvements to its analysis efforts in order to make consistent comparisons across different pathways. This evaluation would also help to determine whether CNG vehicles should be part of its ongoing vehicle program.*

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This study is based on work supported by a contract between the National Academy of Sciences and the National Science Foundation and between the National Academy of Sciences and the Department of Energy. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project, or the National Research Council.

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