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Report to Congressional Requesters

March 2000

COOPERATIVE RESEARCH

Results of U.S.–Industry Partnership to Develop a New Generation of Vehicles

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Contents

Abbreviations

CIDI	compression ignition direct injection
CRADA	cooperative research and development agreement
CRS	Congressional Research Service
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DME	dimethyl ether
EGR	exhaust gas recirculation
NASA	National Aeronautics and Space Administration
NRC	National Research Council
OMB	Office of Management and Budget
OTA	Office of Technology Assessment
PNGV	Partnership for a New Generation of Vehicles
USCAR	United States Council for Automotive Research

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United States General Accounting Office
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Resources, Community, and
Economic Development Division

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March 30, 2000

The Honorable John R. Kasich
Chairman, Committee on the Budget
House of Representatives

The Honorable F. James Sensenbrenner, Jr.
Chairman, Committee on Science
House of Representatives

In light of increased competition from international car companies, the importance of automobile-related jobs to the U.S. economy, and other policy concerns, in 1993 President Clinton announced a partnership between the federal government and three domestic automobile manufacturers—Ford, General Motors, and Chrysler.[1] The goals of the partnership were to (1) significantly improve U.S. competitiveness in manufacturing, (2) implement commercially viable innovations from ongoing research in conventional vehicles, and (3) develop vehicles that can achieve up to three times the fuel efficiency of comparable 1994 family sedans, or approximately 80 miles per gallon, by 2004. This partnership, called the Partnership for a New Generation of Vehicles (PNGV), was to coordinate and focus ongoing federal automobile research at several federal agencies with similar efforts undertaken independently by the automobile industry and to jointly pursue research into some technologies.

The administration believed that staff, knowledge, and equipment at the federal government's national laboratories could provide innovative technologies and research tools that industry could further develop and integrate into new fuel-efficient vehicles. The federal government was expected to fund research into areas deemed promising by the federal and industry partners. Industry believed that the open dialogue with federal researchers and regulators could provide opportunities to identify new technologies and would lead to improvements in industry-federal relations. Industry, with its expertise and technical knowledge of automobile issues,

[1] In 1998, the German company Daimler-Benz combined with the Chrysler Corporation to form DaimlerChrysler. Since that time, DaimlerChrysler has continued to participate in PNGV in the same capacity as Chrysler. Throughout the remainder of this report, we will jointly refer to all activities of the Chrysler Corporation and its successors as DaimlerChrysler.

was expected to help identify technologies and areas for future federal research and to share the cost of pursuing some research projects through cooperative agreements and other arrangements.

You requested that we examine several aspects of PNGV. Specifically, we agreed to (1) discuss the progress made to date toward achieving the partnership goals; (2) describe the historical federal funding levels; (3) identify the technologies being developed under PNGV; and (4) compare the overall research and development activities of the automobile manufacturer participants with research sponsored by the partnership. In addition to addressing your specific questions, we are providing our observations about particular aspects of the partnership and research supporting this effort.

Results in Brief

Overall, the partnership is making progress toward its goals, but obstacles remain. Regarding the partnership's goal to improve U.S. competitiveness in manufacturing, it is not currently possible to assess the extent to which this goal is being met because it will take time before the effects of this research can be observed. The partnership has made progress, however, toward its second goal of implementing commercially viable innovations in conventional vehicles. Examples of this include the increased use of lightweight materials, including the development of a lightweight polymer composite truck bed; improved manufacturing processes; and decreased emissions. The partnership has focused much of its effort on the third goal of developing technologies for vehicles that can achieve up to 80 miles per gallon, and as of March 2000, all three of the industry partners had released concept cars that demonstrate the ability to achieve this goal. Nonetheless, according to the National Research Council's 1999 peer review report, while the partnership is making good progress toward the third goal, it still needs to overcome significant technological and affordability obstacles.

We estimate that federal research in support of the partnership totaled about $1.25 billion from fiscal year 1995, the first year in which the program was funded, through fiscal year 1999, averaging about $250 million per year. The partnership was established by a presidential initiative, and it receives no direct appropriations. Rather, it reflects the sum of research budgets for previously existing programs that are related to PNGV at five federal agencies. Department of Energy research efforts account for about half of the total partnership funding, the National Science Foundation and the Department of Commerce account for another 40 percent, and the Environmental Protection Agency and the Department of Transportation

account for the remainder. In addition to this federal funding, industry supported the partnership through cost-shared research, although we have not obtained comprehensive information from industry partners or federal agencies on the level of support.

The federal agencies and industry partners supporting the partnership are jointly developing technologies to improve fuel efficiency and manufacturing processes in the automobile industry. To improve fuel efficiency, about 84 percent of the total federal research funds supporting the partnership included technologies such as advanced diesel engines, fuel cells that directly convert hydrogen and oxygen to electricity, hybrid drivetrains that use both an electric motor and engine, improved use of energy for operating accessories such as air-conditioning as well as vehicle electronics, advanced batteries, lightweight materials, aerodynamic bodies, and tires with less friction. As part of the research to improve fuel efficiency, funding supporting the partnership has also included research on reducing emissions, including examining fuels with less sulfur and improved filters and processes for removing particulates as well as other pollutants from exhaust gases. The partnership also dedicated 16 percent of the federal research funds to improving automobile manufacturing by concentrating on working with advanced materials, such as composites and ceramics; improving machining and processing; and manufacturing new components for use in fuel cells.

Automobile manufacturers participating in PNGV reported that their overall research and development is largely focused on fulfilling consumer preferences and complying with government regulations, while their research conducted under the partnership is more narrowly focused on developing fuel-efficient vehicles and improving manufacturing processes. These automobile manufacturers also conduct proprietary research to pursue goals similar to PNGV's, but this research is not coordinated with the partnership. However, the time frame and nature of this proprietary research differs from the research they conduct jointly under the partnership. Because of the competitive nature of the automobile industry, automobile manufacturers prefer to conduct research leading to technologies that can be incorporated profitably into existing vehicles in the near term. The federal government-industry partnership, on the other hand, emphasizes more basic scientific research that may be less likely to produce near-term profits for an individual company, although it may benefit the industry as a whole. Automobile manufacturers said that this longer-term orientation complements their own research.

In conducting our work to address the specific questions you asked, we also made two observations. First, while the partnership is making progress towards developing an 80-mile-per-gallon production prototype vehicle by 2004 (the focus of the program), according to senior industry representatives, such a vehicle is unlikely to be manufactured for the general public at a cost that is competitive with conventional vehicles in the near future. Second, the federal funding attributed to the partnership may overstate federal support of its goals because 45 percent of the reported funding for the activities of the partnership is either only indirectly relevant to its goals or is not coordinated through the partnership so that the technical merits of the research can be considered by the partners.

Background

In 1993, concerns over increased competition in the automobile industry, growing U.S. dependence on foreign oil, and significant environmental impacts of motor vehicles led the Clinton administration to approach the domestic automobile industry about forming a research and development partnership. Administration officials viewed improvements in fuel efficiency, reductions in automobile emissions, and better manufacturing processes as ways to address some of these concerns. In addition, the administration believed the partnership could make use of the federal government's national laboratories' substantial technical resources and expertise. This partnership also provided an opportunity for automobile manufacturers to participate in developing technologies with the government to achieve energy efficiency and environmental objectives. On September 29, 1993, the President, the Vice President, and the chief executive officers of Ford, General Motors, and DaimlerChrysler announced the formation of PNGV. The partnership's primary purpose was to develop technologies so that these companies could produce a new generation of more fuel-efficient automobiles and demonstrate these technologies in prototype vehicles within 10 years. The initiation of the partnership was not accompanied by specific authorizing legislation, since the activities were already independently authorized.

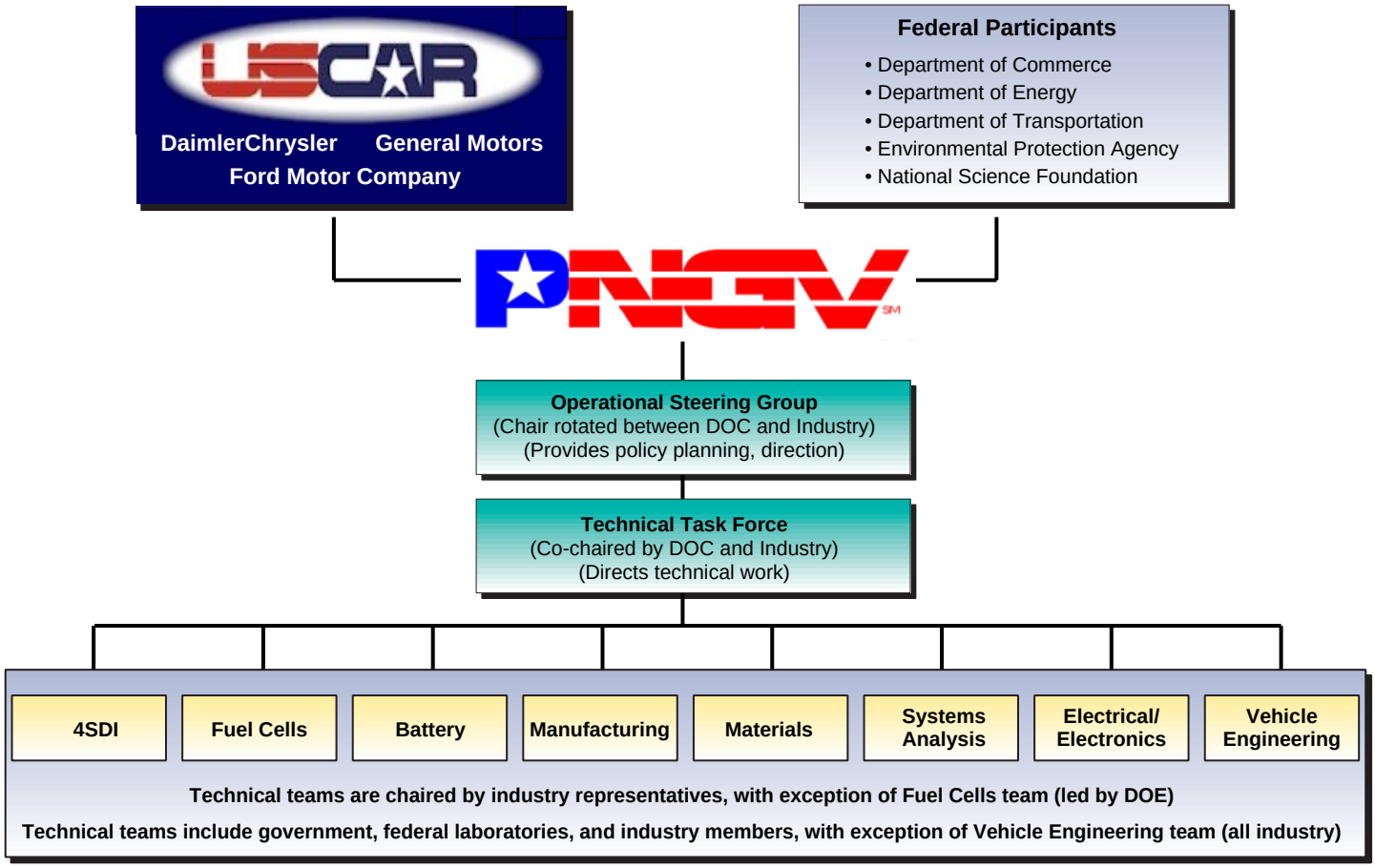
The partnership sought to highlight research on energy efficiency, emissions, and occupant safety. Historically, the federal government has conducted research on improving the fuel efficiency of vehicles through several agencies, including the departments of Energy and Defense, as well as the Environmental Protection Agency (EPA). The U.S. automobile manufacturers have also been involved in research into several areas related to the goals of PNGV for many years. Some of this work has focused

on meeting consumer demands and regulatory requirements, including emissions control and occupant safety. However, the industry has also pursued some more exotic research on technologies such as turbines, electric and fuel cell vehicles, and a variety of advanced materials.

Ultimately, PNGV brought together five federal agencies[2] and three industry participants. In 1992, prior to the beginning of PNGV, Ford, General Motors, and DaimlerChrysler formed the United States Council for Automotive Research (USCAR) to jointly develop pre-competitive technology in selected research areas. PNGV was organized with the Department of Commerce acting as the lead for federal efforts and USCAR serving to coordinate industry efforts. Figure 1 shows the organizational structure of the partnership.

[2] Initially, eight other agencies or entities were identified as potential PNGV participants but did not provide direct financial support to the program. These agencies included the Department of Defense (DOD), Department of the Interior, National Aeronautics and Space Administration (NASA), the Office of Management and Budget, Office of Science and Technology Policy, Council on Environmental Quality, National Economic Council, and the Office of the Vice President. While DOD and NASA provide no direct funding, PNGV officials said that they participate on the Technical Teams and the Operational Steering Group.

Figure 1: PNGV Organizational Structure



Source: Developed by GAO on the basis of comments by representatives from agencies and industry.

As shown in figure 1, PNGV members created committees to make decisions about the activities of the partnership. Within PNGV, the Operational Steering Group, comprised of members from government and industry, formulates policy and makes final policy decisions. The chair of this committee rotates between the Department of Commerce and industry. The Technical Task Force recommends to the Operational Steering Group the areas of technical research PNGV should pursue, based on recommendations made by the eight technical teams—one for each of the major areas of research. The Technical Task Force is co-chaired by the Department of Commerce and industry. As figure 1 indicates, the technical teams are primarily led by industry representatives, but most include staff

from the government and/or national laboratories. Through these committees, the partnership makes recommendations about areas of federal research, although the individual agencies make final decisions on funding. Industry partners and their suppliers, individually or jointly, may also participate in proprietary cost-shared research with the federal government's national laboratories through arrangements such as cooperative research and development agreements (CRADA). Federal funding is provided through the agencies to the automobile manufacturers, parts suppliers, national laboratories, universities, and others.

Since the partnership began, it has been reviewed by several organizations: the former Office of Technology Assessment (OTA); the National Research Council (NRC); the RAND Corporation, a nonprofit research institute; the Congressional Research Service (CRS); and the Inspector General of the Department of Energy (DOE). Shortly after the announcement of PNGV, OTA identified and assessed the performance and cost of potentially relevant advanced vehicle technologies, publishing its results in 1995. OTA concluded that technology assessment would be difficult without adequate government funding. At the request of the Department of Commerce, NRC conducted five peer reviews from 1994 to 1999, with a sixth anticipated in 2000. Overall, NRC reported that PNGV has been making good progress towards meeting its goals, considering cost and regulatory constraints, but that these goals are ambitious. Unlike the OTA and NRC , which examined PNGV technologies in detail, the RAND Corporation and CRS concentrated on PNGV's organization, politics, and funding. In its 1998 book entitled *The Machine That Could*, RAND examined the government and industry collaboration within PNGV to identify elements that could be applied to future government-industry partnerships. RAND also concluded that PNGV peer reviews and the technology selection process appeared to have been successful. In 1996, CRS raised questions on the management structure, federal role, and funding of PNGV, but provided no conclusions. DOE's Inspector General reported in 1998 that the Department's research projects contributed to the goals of PNGV but that some technologies were unlikely to be developed in time for use in the 2004 prototype vehicles.

PNGV Making Progress Toward Goals, but Obstacles Remain

While progress has been made toward the goals of the PNGV partnership,[3] technological and affordability obstacles still need to be overcome. It is not yet possible to assess if the partnership is improving U.S. competitiveness in manufacturing, its first goal. The partnership is making progress towards its second goal of implementing commercially viable innovations in conventional vehicles. In addition, the partnership has made progress

toward its third goal, releasing concept cars by March 2000 that manufacturers stated demonstrate the ability to achieve nearly 80 miles per gallon. However, the manufacturers and NRC stated that significant technological and affordability obstacles remain.

To achieve its first goal of improving competitiveness in manufacturing, PNGV partners identified the need to improve the design and development of motor vehicles through computer simulation and better manufacturing systems so that time and costs could be reduced. They also identified the need to develop new manufacturing and assembly machinery; improve the casting, forming, machining, and joining of metals and other materials used in automobile bodies; and decrease the time and cost to produce vehicles. The partners believed that some of the innovations produced to achieve the fuel-efficiency goal would improve the competitiveness of U.S. automakers. Currently, it is not possible to assess if the partnership has improved U.S. competitiveness in manufacturing because it will take time before the effects of this research can be observed and because it would be difficult to isolate the effects resulting solely from the partnership.

The second goal of PNGV, incorporating new technologies into existing vehicles, highlighted the importance of using commercially viable technologies in vehicles as soon as practical. According to the PNGV participants, this goal reflected a realization that incorporating many new technologies all at once would require a redesign of the entire automobile, which could take several years, while many of the new technologies could provide more immediate benefits for industry and consumers. The partnership has made progress in implementing this goal, with the manufacturers incorporating PNGV-related technologies into their conventional vehicles. Specifically, DaimlerChrysler reported the increased use of aluminum, magnesium, and composites to reduce weight. Ford reported that it has increased the use of aluminum and other lightweight components in its Lincoln LS luxury car, used advanced examination techniques to improve the manufacturing and durability of brake rotors, and reduced the emission of pollutants. General Motors reported progress toward the second goal, including the increased use of aluminum and other lightweight materials in engines and structural components, improved

[3] The three goals of the partnership have not changed since it began in 1993. However, according to industry representatives, the technical challenge of achieving the emissions component, a key technical element of PNGV, has increased as a result of the recently announced EPA Tier 2 emissions standards, which are much more stringent than anticipated at the beginning of PNGV.

electronic controls that increase engine performance and lower emissions, and the introduction of a composite truck bed on its 2001 Silverado pickup. We did not attempt to determine whether these new technologies were a direct result of federally funded research, solely developed through company-funded research, or a combination of the two.

The main focus of PNGV research and development has been its third goal of developing a vehicle capable of up to three times the fuel efficiency of 1994 family sedans[4] without sacrificing emissions, safety standards, performance, utility, or affordability. The federal and industry partners agreed the program would focus on developing technologies each manufacturer could use to develop a production prototype, rather than a mass-produced vehicle. Specifically, as part of the 1995 program plan, the partners agreed to three milestones, including the final one of developing the production prototypes by 2004. In the industry, production prototypes are vehicles that integrate and demonstrate technologies, in this case those capable of meeting the fuel-efficiency goal and the other design objectives, and are capable of being economically manufactured within 3 to 5 years. In addition to this milestone, the partnership established two interim milestones: (1) in 1997, PNGV was to select technologies for future research that it considered most promising to meet the goal; and (2) in 2000, Ford, General Motors, and DaimlerChrysler are to independently introduce concept cars. Concept cars are vehicles that may not be easily manufactured or affordable but that demonstrate and integrate technologies capable of achieving and demonstrating the PNGV energy-efficiency goal.

The partnership has demonstrated progress toward the third goal. In 1997, it selected several technologies for continued research while deciding not to pursue others as part of PNGV. By March 2000, all three industry partners had released their concept cars, and all three reported that they planned to meet the 2004 deadline for release of production prototypes. In their 1999 report, NRC officials stated that the partners are making good progress towards developing vehicles that will achieve up to 80 miles to the gallon, but they still need to overcome several significant technological and affordability hurdles. A description of individual concept cars introduced prior to release of this report and cars similar to PNGV is included in appendix I.

[4] PNGV identified mid-sized sedans such as the Ford Taurus, Chevrolet Lumina, or Chrysler Concorde.

PNGV Not Directly Funded, but Several Federal Agencies Support the Partnership

Federal funding in support of PNGV totaled about $1.25 billion from fiscal year 1995, the first year that the program was funded, through fiscal year 1999, averaging about $250 million per year. The federal budget supporting PNGV consists of the sum of the research budgets appropriated for various previously existing PNGV-related activities at five federal agencies: DOE, the National Science Foundation, the Department of Commerce, the Environmental Protection Agency (EPA), and the Department of Transportation. In addition to this federal funding, industry supported the partnership through cost-shared research, although we have not obtained comprehensive information from industry partners or federal agencies on the level of this support. According to DOE data for fiscal years 1997 through 1999, the Department spent about 46 percent of its total PNGV budget on research projects that had cost-sharing by industry participants. Industry cost-sharing in support of this DOE research totaled about $130 million, according to DOE data. In addition, DOE reported that it competitively awarded about 94 percent of its research funds in fiscal year 1999. Finally, we found that 40 of DOE's 114 private contractors participating in PNGV research received a total of $1 million or more for fiscal years 1997 through 1999.

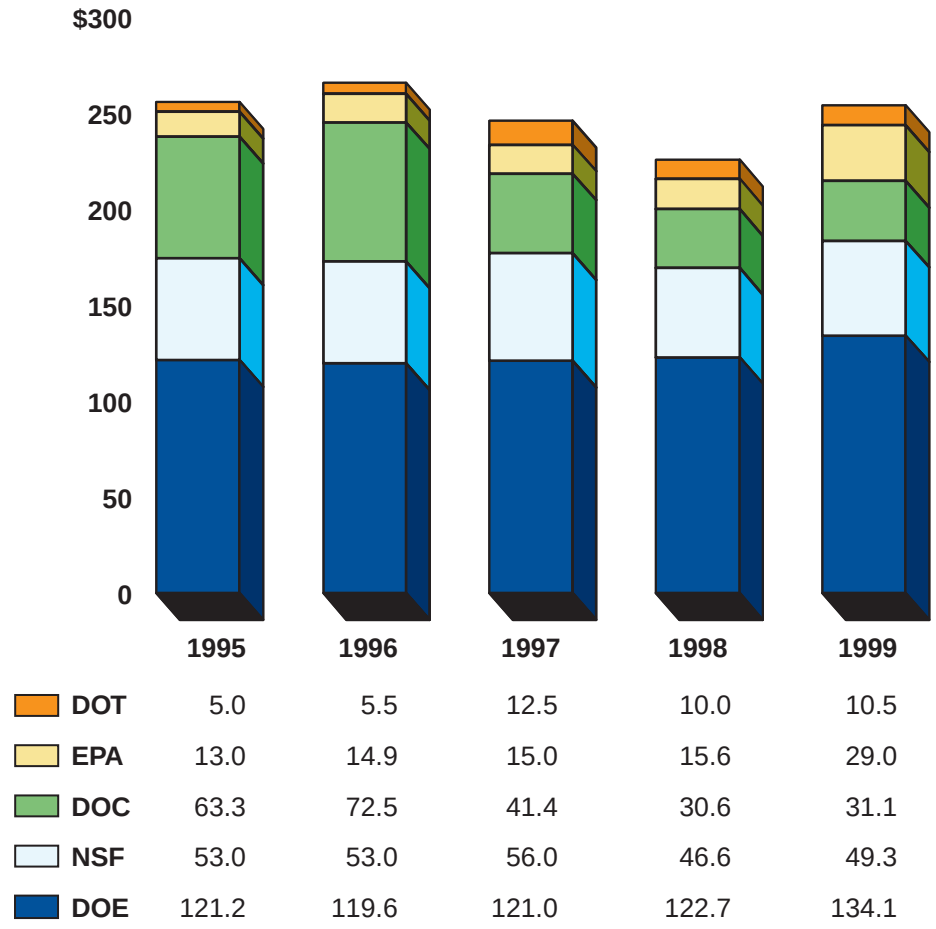
Five Agencies Provided Funds Supporting the Partnership Research

The partnership was established by presidential initiative and receives no direct federal appropriations. Rather, it simply reflects the sum of research budgets for previously existing programs that are related to PNGV at the five federal agencies. Total federal funding in support of PNGV was not readily available from the Office of Management and Budget (OMB) or the agencies in sufficient detail for us to address our objectives. All funding data presented in this report therefore reflect estimates we developed on the basis of our analysis of agency and OMB data. In developing our estimates, we examined the funding tracked by OMB and the budget submissions provided by each of the five agencies identified as supporting the partnership. In developing the budget data, we reconciled various aspects of the agencies' individual budget submissions by combining research categories into common areas.

As illustrated in figure 2, DOE accounted for about 50 percent of the $1.25 billion in federal research and development supporting PNGV, while the National Science Foundation, the Department of Commerce, the Environmental Protection Agency, and the Department of Transportation accounted for about 21 percent, 19 percent, 7 percent, and 3 percent, respectively, of total federal funding for fiscal years 1995 through 1999.

Figure 2: GAO Estimate of PNGV Funding Allocations by Federal Agency, Fiscal Years 1995-99

Dollars in millions



	1995	1996	1997	1998	1999
DOT	5.0	5.5	12.5	10.0	10.5
EPA	13.0	14.9	15.0	15.6	29.0
DOC	63.3	72.5	41.4	30.6	31.1
NSF	53.0	53.0	56.0	46.6	49.3
DOE	121.2	119.6	121.0	122.7	134.1

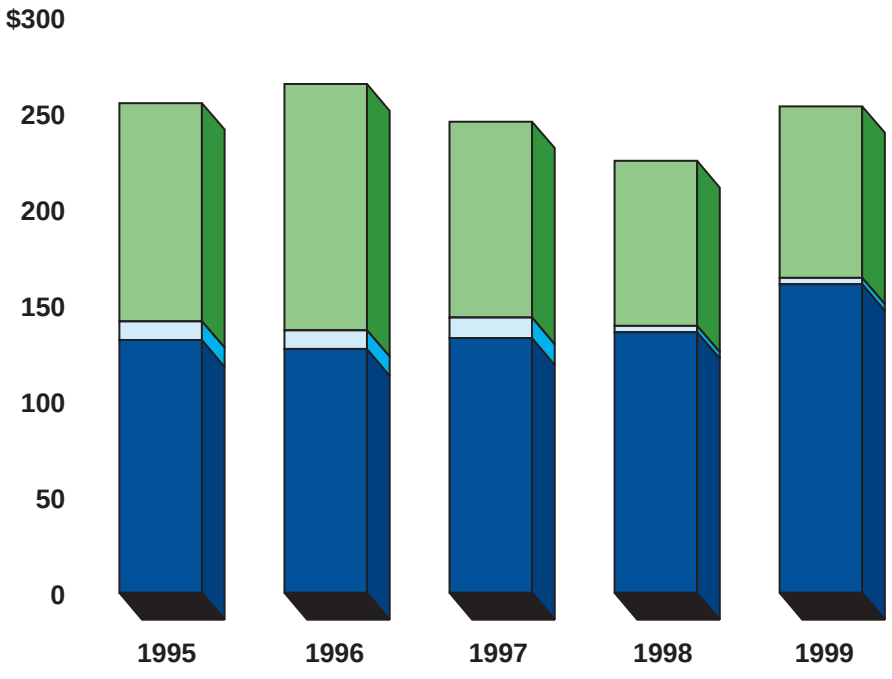
Source: GAO's analysis of agencies' data

As shown in figure 3, federal funding of research to support the partnership is divided into three categories, which are tracked by OMB and are based on the degree of relationship to the goals and on coordination with PNGV's leadership. The first and largest category, referred to as Tier 1 funding, accounted for about 55 percent of PNGV's total funding for fiscal years 1995 through 1999. DOE and EPA research and development activities account for almost all of these funds. Tier 1 research is directly relevant to PNGV and is coordinated with the PNGV technical teams. The second

largest category of federal funding, referred to as Tier 3, includes general automobile research that may be valuable to the industry. Tier 3 research is only indirectly relevant to PNGV or supportive of long-term research and is not coordinated with PNGV teams. In total, Tier 3 research accounted for about 42 percent of PNGV's total funding for fiscal years 1995 through 1999. Funding by the Department of Commerce (primarily through the Advanced Technology Program) and the National Science Foundation accounted for 88 percent of Tier 3 research. The third, and smallest, category of federal funding, referred to as Tier 2, constitutes only 3 percent of PNGV funding. Tier 2 research is directly relevant to PNGV, but is not coordinated with the PNGV technical teams.

Figure 3: Categories of Research Supported by PNGV

Dollars in millions



	1995	1996	1997	1998	1999
Tier 3	113.8	128.2	102.2	85.8	89.3
Tier 2	9.8	9.8	10.7	3.3	3.5
Tier 1	131.6	127.0	132.5	135.8	160.6

Source: GAO's analysis of agencies' data.

DOE Used Cost-Sharing and Competitive Awards in Funding Some Research Projects

DOE used various financial arrangements to fund research in support of PNGV, some of which required the automobile industry to share research costs. According to DOE data, the Office of Advanced Automotive Technologies spent about 46 percent of its total PNGV budget on cost-shared projects. In total, the automobile industry shared costs on about 23 percent of research projects over fiscal years 1997 through 1999. Industry cost-sharing in support of this DOE research totaled about $130 million, according to DOE data. DOE officials note that a large amount of the funding provided by this office goes to the national laboratories and that the laboratories cannot share costs with DOE. DOE reported those financial arrangements that require cost-sharing included CRADAs, cooperative agreements, and some contracts. CRADAs are agreements signed by DOE laboratories and private parties when both are expected to benefit from the arrangement. According to DOE, it uses cooperative agreements when it transfers money or property to a recipient to support or stimulate research in which the Department plays an active role.

In addition, DOE reported that it has historically funded PNGV projects both competitively and noncompetitively. According to DOE, in fiscal year 1999 it competitively awarded 94 percent of its research funds. The 94 percent reported for competitively awarded projects includes funds distributed to its laboratories, which the agency considers to be competitively awarded.

To determine how many contractors received PNGV funding of $1 million or more from DOE, we used its Office of Advanced Automotive Technologies' database. Our analysis identified 40 of DOE's 114 private PNGV contractors as having received $1 million or more for fiscal years 1997 through 1999.[5] In total, these 40 contractors received about 90 percent of the funding in the database for nonfederal, nonlaboratory research. Twenty-eight, or 70 percent, of these 40 contractors received from $1 million to $5 million. Nine contractors received between $5 million and $10 million, and the remaining three received over $10 million. A complete list of the 40 contractors receiving $1 million or more appears in appendix II.

[5] For the purposes of this analysis, we excluded projects for which the contractor was a federal agency or a national laboratory.

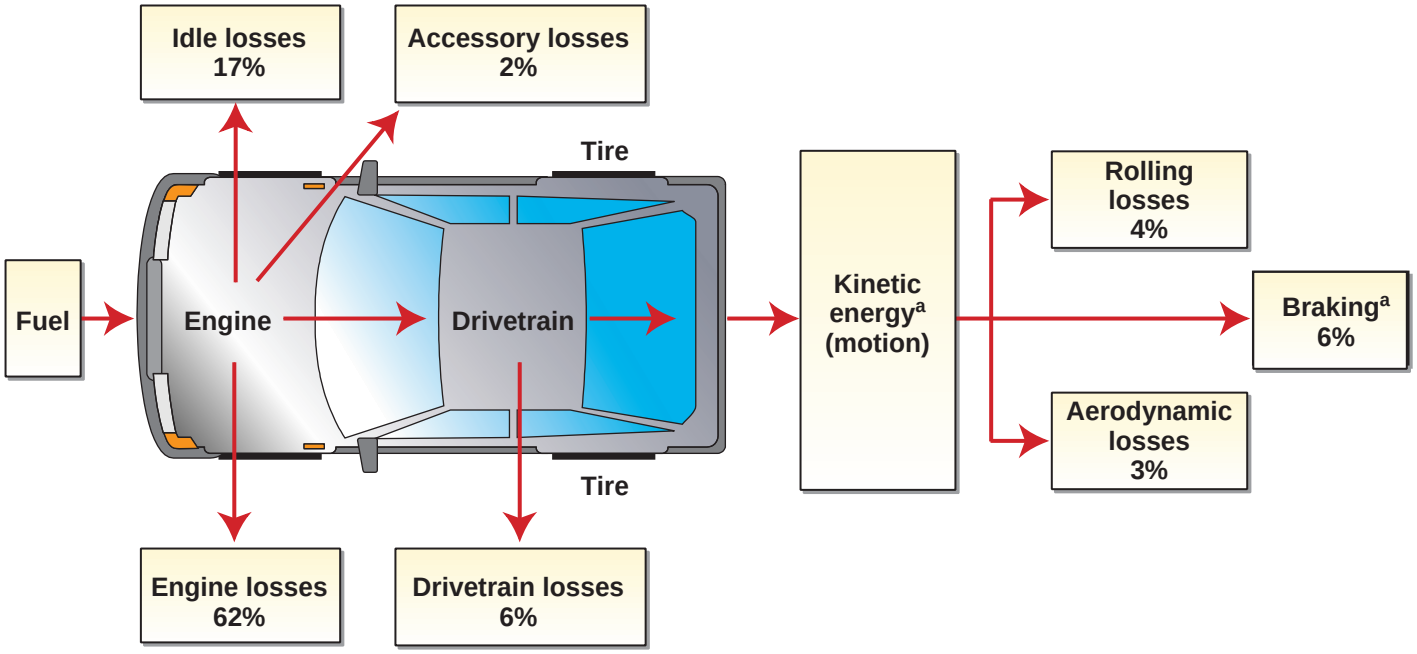
PNGV Research Focused on Energy Efficiency and Advanced Manufacturing

Under PNGV, the federal government and the automobile industry are jointly developing technologies that are expected to improve fuel efficiency and manufacturing processes in the automobile industry. In total, about 84 percent of the total federal funding for PNGV for fiscal years 1995 through 1999 was directed at energy efficiency objectives, while about 16 percent was focused on advanced manufacturing. Research on energy efficiency technologies includes energy converters, such as engines and fuel cells; drivetrains; techniques to improve energy use; batteries; and lightweight materials, such as aluminum. Research on advanced manufacturing over this same period sought to improve the manufacturing and processing of lightweight materials; the machining and processing of conventional materials, such as steel; and the manufacturing of new components, such as those used in fuel cells.

Energy Efficiency Research Targeted Automobile Systems With the Greatest Energy Losses

PNGV researchers realized that automobiles needed to be lighter and that engines and other major systems needed to be more efficient to improve fuel efficiency. To assess priorities for research, PNGV members examined the average energy losses associated with various automobile systems in a mid-sized car during typical urban and highway driving cycles. As shown in figure 4, about 62 percent of the energy during a typical urban driving cycle is lost to friction within the engine and incomplete combustion; about 17 percent to engine idling, such as when waiting at stoplights; and about 2 percent to accessories, such as air-conditioning and power steering. Another 6 percent is lost as energy is transferred from the engine to the wheels. Hence, only about 13 percent of the initial energy in the tank of gas reaches the wheels in a typical urban driving cycle. About another 3 percent is lost to the aerodynamic resistance of the vehicle, and about 4 percent is lost due to resistance of the tires. The remaining 6 percent of the initial energy in the tank of gas is used to move the vehicle, and it is eventually lost when the driver applies the brakes.

Figure 4: Typical Energy Distribution in Mid-Sized Sedan During Urban Driving

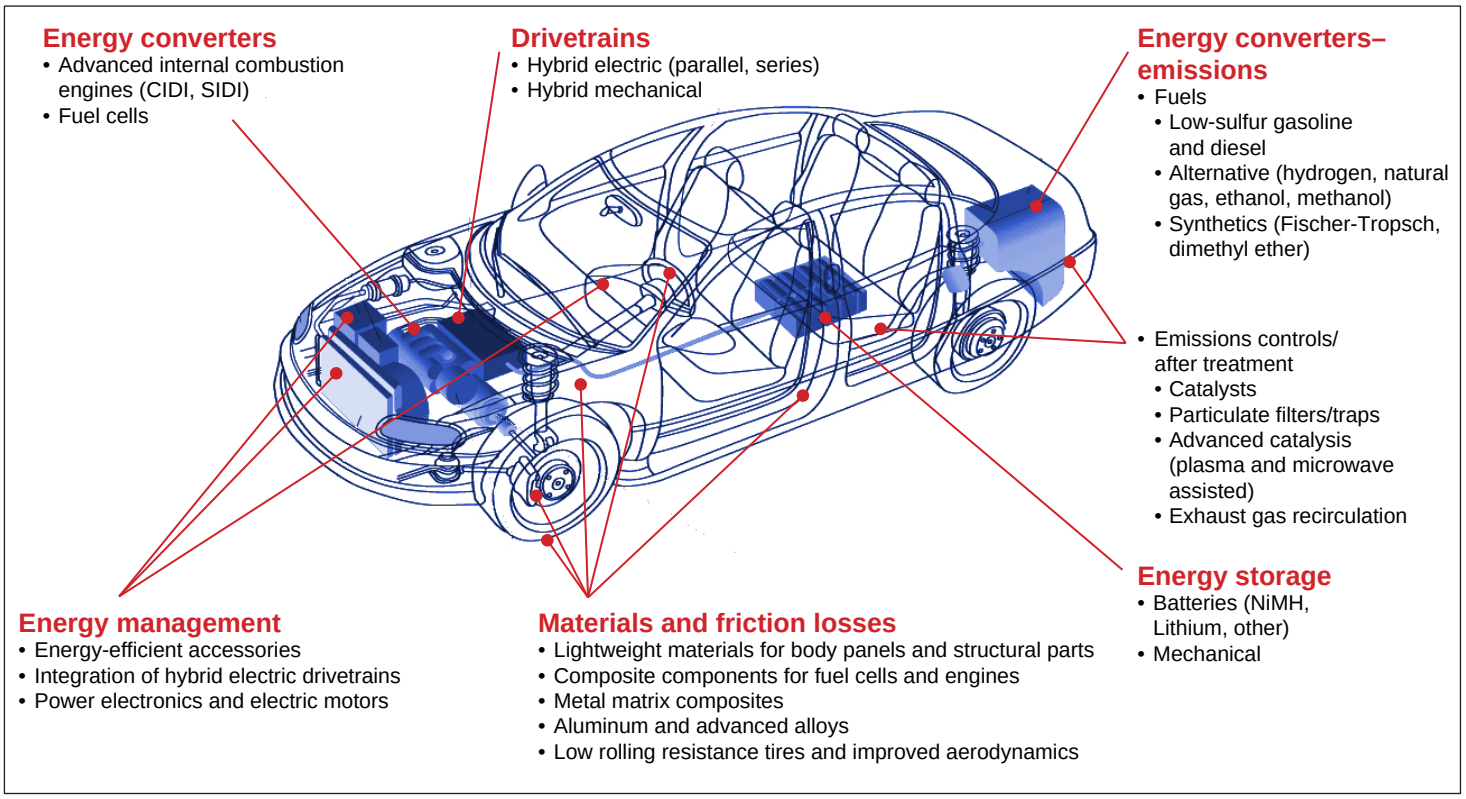


[a]Kinetic energy used to propel the vehicle is eventually consumed when the vehicle is brought to a stop.

Source: Department of Commerce.

This analysis of vehicle energy losses suggested that research needed to focus on developing technologies principally in five key research areas: materials and friction losses, energy conversion (and related emissions), drivetrains, improved energy management, and energy storage such as batteries. These broad areas for research are illustrated in figure 5.

Figure 5: Major Technologies Being Investigated in Support of PNGV



Source: Illustration provided by the National Renewable Energy Laboratory; data developed by GAO from agency and industry information.

In 1997, PNGV selected technologies most likely to meet the objectives of the program, after initially researching a wide range of technologies identified as potentially applicable to the PNGV goals. This selection process compared technologies within each of the broad categories to identify those most likely to achieve the efficiency, performance, and cost levels required to meet the third goal of the program, to produce an 80-mile-per-gallon vehicle at a cost comparable to that of conventional vehicles.

In order to boost the overall efficiency to the high levels pursued by PNGV in light of the extensive energy losses identified, federal and industry officials determined that a lightweight hybrid vehicle would be the most likely to achieve the target efficiencies in the near term. Lightweight vehicles improve energy efficiency by decreasing the amount of energy necessary to move the vehicle as well as by reducing the size and weight of

other vehicle systems. A hybrid vehicle can improve efficiency by using a smaller engine and an electrical motor to propel the vehicle. Several potential hybrid configurations have been identified and examined. However, one of those investigated by PNGV and identified as most promising, the parallel electric hybrid vehicle, allows the electric motor and/or the engine to drive the wheels. In general, a parallel hybrid electric vehicle consists of a small high-efficiency engine, an electric motor, a computerized control system to switch between the two, a braking system that recaptures the energy usually lost when the car is slowed,[6] and an energy storage system (often batteries) that provides energy to operate the electric motor. One advantage of these hybrids is that they allow the engine to operate at its most efficient level, such as it does during highway driving. Another advantage of some hybrid vehicles is the ability to automatically turn off the engine to conserve fuel when the vehicle is stopped in traffic, operating on battery power and the electric motor. The National Research Council reported in its fourth report that it agreed with PNGV's technology selections.

Each of the technologies still considered by the partnership after the 1997 selection poses unique challenges, and some are unlikely to be adequately developed in time to be incorporated into the 2004 prototypes. We refer to the technologies that automobile manufacturers are most likely to incorporate into the 2004 prototype vehicles as short-term technologies. We define long-term technologies as those technologies that automobile manufacturers are unlikely to incorporate into the PNGV prototypes, either because of the technologies' costs or complexity, but they still show substantial promise for development outside of PNGV's 2004 time frame. A more complete description of selected technologies appears in appendix III.

Energy Efficiency Technologies Research Accounts for Most of the Funding

Most of the federal research supporting PNGV has targeted improving energy efficiencies, which received about $1 billion, or 84 percent of all PNGV funding for fiscal years 1995 through 1999. Of this $1 billion, PNGV officials have allocated about 29 percent to advanced materials and friction loss technologies, about 26 percent of total PNGV funding to energy

[6] Hybrid drivetrains can capture the energy that is lost in braking through a process known as regenerative braking. During braking, the electric motor acts as a generator and recharges the battery. The energy in the battery can later be used to power the electric motor that turns the wheels.

converters,[7] about 23 percent to drivetrains, about 8 percent to energy management, about 5 percent to energy storage, and the remaining 9 percent to miscellaneous areas such as crashworthiness and program administration (about $2.6 million was used for program administration at the Department of Commerce). Each of these areas is discussed below.

Advanced Materials

Increased use of lightweight materials throughout a car can improve fuel efficiency by decreasing the amount of energy needed to move the vehicle. One design objective of PNGV is to reduce the weight of a mid-size passenger sedan by 40 percent while retaining roughly the same cost for materials. Overall, PNGV supported research into advanced materials and the reduction of friction losses with about $307 million of federal funds for fiscal years 1995 through 1999. Of that total, approximately $266 million (or 87 percent) funded research and development (R&D) for lightweight materials, $31 million (or 10 percent) funded R&D on propulsion system materials, and $10 million (or 3 percent) funded improvements in aerodynamic and rolling resistance and other areas of energy loss.

Initially, researchers working on PNGV investigated several lightweight materials, including aluminum, titanium, magnesium, and composites such as carbon fiber and metallic composites. Aluminum is considered a short-term technology and is likely to appear in the 2004 production prototypes in greater amounts than current vehicles because automobile manufacturers already have design and manufacturing experience with this metal and because its price is favorable compared with the prices of other applicable materials. PNGV officials regard composites as a very promising long-term technology due to properties such as the high strength and formability of the material. The high cost of magnesium and titanium will probably prevent substantial amounts of these materials from appearing in the 2004 prototypes.

Likewise, the reduction of friction can conserve energy, thereby increasing fuel efficiency. Major sources of friction in automobiles include propulsion systems, such as engines, and aerodynamic and rolling resistance. The application of advanced materials, such as ceramics and advanced alloys, in the engine can decrease friction and increase the efficiency of internal combustion engines. Changes in the shape of the PNGV vehicles and the use of smooth underbody covers can reduce the aerodynamic losses that PNGV participants identified. Improved tires, relying on a new design

[7] This figure also includes funding for emissions control.

researched through PNGV, can reduce rolling resistance—the internal friction of the rubber in the tire as it makes contact with the road.

Energy Converters

Technologies explored by PNGV that convert the chemical energy in fuel into the mechanical energy that turns a vehicle's wheels are called energy converters and include engines and fuel cells. In total, about $276 million of federal funds went to support R&D on energy converters, including work focused on emissions. In total, about half of this energy converter funding was focused on fuel cells, and over 40 percent was focused on internal combustion engines, fuels, and emissions.

After the 1997 technology selection, PNGV focused energy conversion research on small high-efficiency internal combustion engines[8] and fuel cells. PNGV officials consider the diesel versions of these engines to be a promising short-term technology that automobile manufacturers may incorporate into the 2004 prototype cars. Alternatively, fuel cells—devices that directly convert fuel energy into electricity through a chemical reaction without combustion[9]—are viewed by PNGV officials as having significant long-term potential. However, during the 1997 selection, PNGV participants did not believe that they would reach the PNGV design objectives in time to appear in the 2004 prototypes.

Even with improvements in the combustion process, the internal combustion engines that were selected faced considerable challenges to reach the low emissions levels agreed to at the inception of the partnership. As a result, further research focused on reducing tailpipe emissions of EPA-regulated pollutants such as nitrogen oxides and particulates. Current efforts supported by PNGV include the treatment of the exhaust after combustion, referred to as aftertreatment, and improvements in fuels. Aftertreatment processes funded by PNGV include using filters for

[8] Since 1997, PNGV has continued research into small (0.6-1.9 liter) four-stroke, direct injection engines similar to those in small passenger cars. There are two types of these engines, spark-ignited direct injection (SIDI) and compression ignition direct injection (CIDI), both of which use high-pressure fuel injection systems to directly inject fuel into the combustion chamber. SIDI engines rely on a spark to ignite the air and fuel in the combustion chamber similar to conventional vehicles. In CIDI engines, the air and fuel in the combustion chamber self-ignites as a result of high temperature and pressure in the cylinder head similar to conventional diesel engines.

[9] Fuel cells commonly use hydrogen as a fuel and can be highly energy efficient. When using hydrogen as a fuel, they can produce emissions of only water. Many fuel cells integrate a device, called a reformer, that allows them to use many other fuels such as gasoline.

removing particulates, improving catalysts and catalytic processes that reduce nitrogen oxides, and experimenting with improving recirculation of exhaust gases back through the engine. Reducing nitrogen oxides and particulates is particularly challenging for the diesel engine since common techniques for decreasing nitrogen oxides in these engines, such as exhaust gas recirculation, can result in increases in particulates, and vice versa. According to industry and some government representatives as well as the National Research Council, recent developments since the inception of PNGV, such as the adoption of more stringent nitrogen oxide and particulate standards by EPA and the state of California, make this goal even more challenging.

Another partnership effort to reduce emissions levels focuses on improving fuels. The different types of fuel used to power any of these energy converters also produce different types and amounts of tailpipe emissions. PNGV has supported research examining a range of fuels with the potential to improve vehicle emissions. In the short term, PNGV participants have emphasized fuels that are already available through fueling stations. As a result, fuels research has focused on low-sulfur traditional fuels[10] (such as gasoline and diesel fuel) but also included alternative fuels (such as compressed natural gas, ethanol, methanol, and hydrogen); synthetic fuels (such as Fischer-Tropsch and dimethyl ether); and various fuel blends. A description of these other fuels appears in appendix III.

Drivetrains

The drivetrain consists of the parts between the engine and the wheels—the clutch, transmission, differential, drive shafts, and universal joints. Drivetrains transfer power from the engine to turn the wheels. As discussed, PNGV officials selected the parallel hybrid drivetrain as the most promising short-term technology. Industry representatives reported that it is the most likely drivetrain that automobile manufacturers will incorporate into the 2004 prototypes. Federal research has also continued on a mechanical hybrid drivetrain. In total, federal PNGV funding for research and development of advanced drivetrains accounted for about $244 million, or about 20 percent of the total federal funding for PNGV.

Energy Management

Hybrid electric vehicles have greater electrical demands than conventional vehicles, and hence more efficient energy management is needed. Energy

[10] Fuels such as gasoline and diesel fuel with less sulfur were judged to be necessary to lower pollutant emissions. Sulfur can reduce the effectiveness of aftertreatment by deactivating catalytic converters.

management and control technologies have concentrated on reducing the weight, size, and cost while increasing the reliability and ruggedness of power electronics and electrical machines such as motors and generators. PNGV researchers have also studied ways to improve energy management by decreasing the power requirements of electrical accessories and by more effectively integrating the hybrid electric drivetrain, energy converters, and batteries.[11] In total, federal PNGV funding for fiscal years 1995 through 1999 for energy management and control equaled about $88 million, or about 7 percent of the total federal PNGV funding.

Energy Storage

Hybrid electric vehicles need a device that can store the energy produced by the engine or the braking system to supply the electrical equipment, including the motor that turns the wheels. PNGV officials selected advanced batteries as the most promising technology for energy storage. These batteries, such as nickel-metal hydride and lithium-ion batteries, use materials other than the lead and acid or the nickel and cadmium in conventional batteries. Nickel-metal hydride batteries are currently used in electric vehicles and hence appear more likely to be incorporated into the prototypes. PNGV officials consider the lithium-ion batteries to be a long-term technology. Research has also continued on a non-flywheel mechanical energy storage system. In total, the federal government has funded about $48 million to support R&D into energy storage, or about 4 percent of the total federal PNGV funding for fiscal years 1995 through 1999.

Funding of Manufacturing Processes Accounted for a Smaller Percentage of Total Funding

Advanced manufacturing research accounted for about $196 million, or almost 16 percent of total federal research funds spent by PNGV for fiscal years 1995 through 1999. In 1999, the National Research Council reported that PNGV made significant progress in manufacturing processes for vehicles and their components, including improvements in light metal castings, the production of composites, high-speed drilling, and the manufacturing of components used in fuel cells. PNGV also reported that it made advancements in the arc welding of drivetrain and emissions components, laser welding, die casts and injection molds, case-hardening of steel components, and more wear-resistant coatings on metals.

[11] Electrical accessories include heaters, vents, air conditioners, power locks and windows, and stereo systems.

Most Industry Research and Development Focuses on Consumer Preferences and Government Regulations, but Some Also Supports PNGV Goals

Automobile industry research focuses largely on satisfying consumer preferences, complying with federal regulations, and decreasing manufacturing costs. Together, Ford, General Motors, and DaimlerChrysler estimated that they spent about 5 percent of their 1998 research budgets of $18 billion on research directly related to PNGV's goals. These automobile manufacturers also conduct proprietary research to pursue goals similar to PNGV, but this research is not coordinated with the partnership. Automobile industry representatives contrasted the short-term, product-based industry research in these broad areas with the long-term, broadly applicable research done under PNGV. These companies stated that PNGV had accelerated and focused their own efforts in these areas and that these different orientations complemented each other.

Most Industry Research Is Short-Term and Focuses on Consumers and Regulations

The automobile manufacturers, Ford, General Motors, and DaimlerChrysler, reported that in 1998 they collectively spent $18 billion on motor vehicle research and development largely oriented towards fulfilling consumer preferences and complying with government regulations. Consumer preferences on which the automobile industry conducts research include comfort, convenience, performance, durability, reliability, quality, and safety. Automobile industry representatives reported that they also conduct research on complying with government regulations for fuel efficiency, emissions, and safety. In addition, automobile industry representatives said that they spend research funds on reducing the design and production costs of vehicles.

In contrast to the automobile industry's own research, federally supported PNGV research is more narrowly focused on PNGV's goals of improving fuel efficiency and automobile manufacturing and incorporating innovations from this research into conventional vehicles. PNGV research is not oriented toward consumer preferences, such as comfort and convenience. Furthermore, unlike automobile industry research aimed at meeting fuel-efficiency regulations, such as the combined average fleet efficiency standards, PNGV research focuses on substantially exceeding these regulations.

Some Industry Research Is Related to PNGV's Goals but With Different Time Frame and Nature

Ford, General Motors, and DaimlerChrysler reported that in 1999 they collectively spent about 5 percent of their total reported 1998 research funds, or about $980 million, on research that is related to PNGV's goals. However, company representatives reported that much of this research is proprietary and conducted independently and, as such, not coordinated through PNGV. They said that this research involves studying similar technologies, some of which they jointly pursue with the federal government under PNGV.

The similar technologies funded by the federal government that are also independently pursued by the automobile manufacturers include advanced diesel engines, fuel cells, hybrid electric drivetrains, advanced batteries, lightweight materials, advanced catalysts, and low-sulfur fuels. For example, all three companies cited the importance of fuel cell research and pointed to partnerships they have formed with other companies outside of PNGV. Specifically, Ford and DaimlerChrysler have collectively invested over $1 billion to acquire a partial ownership in Ballard Power Systems, a major manufacturer of fuel cells, and have reportedly collaborated to develop fuel cells for use in vehicles. General Motors reported that it is actively working with Toyota to examine the use of fuel cells in automobiles. Similarly, General Motors and other companies have pursued research focused on advanced drivetrains that are similar to the hybrids examined by PNGV. According to representatives from General Motors, these drivetrains can be used in combination with a variety of different propulsion systems, including internal combustion engines, electric batteries, and fuel cells. Vehicles using these technologies—including General Motors' EV-1 and Ford's Ranger EV, both commercially available electric vehicles—represent automobile industry research that focused on technologies similar to those pursued under PNGV.

Automobile industry representatives participating in PNGV reported that the time frame of their independent research differs from the time frame of the research conducted under PNGV. They said that the automobile industry concentrates on near-term research that can produce immediate results, often through incremental improvements to existing products. Industry analysts and the car manufacturers explained that international competition and excess production capacity have created pressure to cut costs, and as a result, research budgets have been trimmed, some research has been shifted to automobile part manufacturers, and companies have pooled research funds to reduce risk. Automobile industry representatives added that long-term industry research has been cut the most because it

contributes less to the companies' profitability in the short term and because it is riskier.

Unlike the automobile industry's own research, federal research supporting PNGV was characterized as more likely to produce a technological breakthrough in the more distant future, according to automobile industry representatives. The industry representatives also described PNGV research as including more basic science and broadly applicable projects compared with their own research, which they described as being applied research. For example, DOE research on the fundamental combustion process of fuel in the engine cylinder is more basic in nature than an automobile company's research on combustion inefficiencies in a particular engine model. Automobile industry representatives said that this difference in orientation was complementary. They added that DOE is particularly effective at conducting more basic scientific research because DOE researchers know about a broad range of scientific and engineering disciplines and are particularly adept at integrating these different disciplines in solving automobile problems. Automobile industry representatives also stated that DOE facilities provided them access to specialized and expensive equipment, such as scanning electron microscopes, electron microprobes, and a neutron source from Oak Ridge's nuclear reactor.[12] Although automobile industry representatives said that they possessed advanced equipment like scanning electron microscopes, they were reluctant to purchase the most recent models, such as those at DOE laboratories. They explained that such equipment would be underutilized, and they could not justify dedicating funding to support sufficient staff and the upkeep and calibration of the equipment. Automobile industry representatives explained that this difference in time frames is beneficial to them because the automobile industry now conducts less long-term research.

Observations on Impact and Federal Support of PNGV

During the course of our work to address the specific questions you asked, we identified two relevant issues.

[12] Research conducted under PNGV has used the neutron source at Oak Ridge to examine the atomic structures of various materials. Research in this area has identified ways to improve the manufacture of several vehicle parts.

Efforts Are Unlikely to Result in a Near-Term PNGV Production Vehicle

Although PNGV has made progress toward building production prototypes that meet many of the PNGV objectives, at this point it does not appear likely that such a car will be manufactured and sold to consumers. Automobile industry representatives participating in PNGV reported that PNGV research is unlikely to result in the introduction of a PNGV production vehicle to the general public at a cost competitive with conventional vehicles in the near future. According to these representatives, an adequate market for a lighter weight, fuel-efficient vehicle does not currently exist nor is it expected to develop in the near future in the United States. U.S. consumers, they explained, have shown an increasing preference for larger vehicles, such as vans, sport utility vehicles, and light-duty trucks, which tend to be heavier and less fuel-efficient. Automobile industry representatives also explained that relatively low gasoline prices do not encourage U.S. consumers to actively seek more fuel-efficient vehicles. However, automobile industry representatives stated that some of the fuel-saving technologies developed through PNGV would gradually be incorporated into existing product lines. They said that some of these technologies are more likely to first appear in the European and Japanese markets, where gasoline is more expensive and consumers are already more interested in smaller vehicles and diesel engines.

Budget May Overstate Support of PNGV Goals

Since some of the research funding that the agencies reported is either not directly relevant to the goals of the partnership or is not coordinated through the partnership so that the technical merits of the research can be considered by the partners, the $1.25 billion in federal research and development funding attributed to PNGV may overstate federal support of the program. As we previously explained, only research identified as Tier 1, which accounts for about 55 percent of total federal PNGV research funding, is both directly relevant to PNGV's goals and is coordinated by the PNGV steering committee. DOE funds about 86 percent of this Tier 1 research. The other two categories, Tier 2 and Tier 3, make up the remaining 45 percent of research and are carried out mostly at the National Science Foundation and the Department of Commerce. Tier 2 research is directly relevant to PNGV's goals but is not coordinated by its committees. Tier 3 funding is only indirectly related to achieving PNGV's goals or supports long-term research, and it is also not coordinated by its committees. In addition, automobile industry representatives told us that they had difficulty in obtaining sufficient information on research projects at the National Science Foundation and the Advanced Technology Program within the Department of Commerce to assess their relevance to PNGV. Because of this lack of direct relevance to and coordination with the

partnership along with industry's inability to assess or identify the value of the research undertaken at the Department of Commerce and the National Science Foundation, counting Tier 2 and 3 funding as support for PNGV may overstate federal support of PNGV's goals.

Agency Comments

We provided a draft of this report to the departments of Commerce, Energy, Defense, and Transportation; the Environmental Protection Agency; and the National Science Foundation for their review and comment. The Department of Commerce (the Department) coordinated and consolidated the comments of these departments and agencies. In general, the Department characterized the report as being a well-written, factual overview of the partnership. However, the Department also expressed two concerns that they characterized as substantive and upon which they elaborated in detail.

First, the Department believes that our observation—that PNGV efforts are unlikely to result in the manufacturing and selling of PNGV production vehicles to the general public at a cost that is competitive with the cost of conventional vehicles in the near future—should be placed more clearly in the context of the program's goals. Specifically, it noted that one of the goals of PNGV was to develop a production prototype and that the decision to produce these vehicles for sale would be made by the automotive partners when a market develops. We understand that under this goal, PNGV is to develop a production prototype capable of up to three times the fuel efficiency of comparable 1994 sedans, not to mass-produce and market such vehicles by 2004. However, industry partners told us that since they do not currently see a market in the United States for PNGV vehicles, they think it is unlikely that they will introduce such vehicles in the near-term under current economic conditions.

Second, the Department provided an explanation of why it believes all funding tiers are correctly characterized as supporting PNGV. We acknowledge that including all federal research provides a broader perspective on research with varying degrees of applicability to PNGV. However, we continue to believe that by including funding that is either not directly relevant to the goals of the partnership or that is not coordinated through PNGV's committees, the federal funding attributed to PNGV may be overstated. Furthermore, such research is unlikely to influence the path of PNGV, as suggested by the Department, since PNGV's committees do not coordinate the research. Thus, industry, as part of these committees, is not aware of the content of ongoing research in these areas, and is therefore

unlikely to help direct the path of future research in a way to help meet the goals of PNGV.

In addition to these two concerns, the Department provided clarifying comments on the genesis of PNGV, DOD's and NASA's participation, PNGV's third goal, the 1997 technology selection process, and differences between the PNGV concept cars and Toyota's Prius and Honda's Insight. The Department also provided technical and editorial comments, which we incorporated as appropriate. The consolidated comments from the Department of Commerce and our full response appear in appendixV.

We also provided portions of a draft of this report relating to the automobile industry's involvement in PNGV to USCAR, which coordinated and consolidated the comments of Ford, General Motors, and DaimlerChrysler. We discussed this report with senior officials of USCAR's Office of the Executive Director and each of the manufacturers, who said that, overall, the report provides a good overview of the program. They also provided technical clarifications, which we incorporated into this report as appropriate. In addition to these clarifications, industry partners commented on two of the issues that were also raised by the Department of Commerce. First, in keeping with the Department's perspectives on recently introduced vehicles similar to the concept cars, industry partners added that the Toyota Prius and the Honda Insight fall short of PNGV goals such as the utility, comfort, ride, handling, and performance of a conventional family sedan. Second, in contrast to the Department's comment on the importance of the different tiers of funding, industry partners suggested that some government research may even be less supportive of PNGV's goals than GAO has observed. We included industry's views on these observations under GAO's response to the Department's second and seventh comments, respectively, in appendix V.

Scope and Methodology

In reviewing the partnership, we considered available literature, examined agency budget data, conducted interviews, and visited research facilities involved in PNGV. Specifically, we reviewed: publications by the Department of Commerce and USCAR; the peer reviews published by the National Research Council and others (including Rand, OTA, and CRS); research summaries published by DOE and others; and a range of publications related to the automobile industry and its finances. Budget data examined included submissions by each of the five agencies and OMB. We interviewed staff at federal agencies and five national laboratories, as well as staff at each of the three industry partners and USCAR. In addition,

we interviewed senior representatives from the financial community and the peer review committees. We also toured the research facilities of the five national laboratories and the three industry partners. In addition, we toured vehicle manufacturing facilities located in Detroit, Michigan. We performed our review from September 1999 through March 2000 in accordance with generally accepted government auditing standards. For a more detailed discussion of our scope and methodology, see appendix IV.

As agreed with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 14 days from the date of this letter. At that time, we will send copies of this report to Senate and House Committees with jurisdiction and oversight of energy, commerce, and transportation issues; the Honorable William M. Daley, the Secretary of Commerce; the Honorable Bill Richardson, the Secretary of Energy; the Honorable William S. Cohen, the Secretary of Defense; the Honorable Rodney E. Slater, the Secretary of Transportation; the Honorable Carol M. Browner, Administrator, Environmental Protection Agency; and the Honorable Eamon M. Kelly, Director, the National Science Foundation. We will also make copies available to others on request.

If you or your staff have any questions about this report, please call me or Derek Stewart at (202) 512-3841. Key contributors to this report are listed in appendix VI.

Jim Wells,
Director, Energy, Resources,
and Science Issues

Description of PNGV Concept Cars and Cars Similar to PNGV Cars

During the course of our review, all three Partnership for a New Generation of Vehicles (PNGV) partners and two Japanese manufacturers released vehicles incorporating many of the technologies pursued under PNGV. The PNGV partners began to release their year 2000 concept cars as part of the milestones agreed to under PNGV. In addition, both Toyota and Honda announced the introduction of hybrid electric vehicles to the marketplace in Japan and the United States. All three PNGV cars are larger and achieve higher overall energy efficiencies than those produced by Toyota and Honda.

PNGV 2000 Concept Cars

PNGV concept vehicles are cars that are not necessarily manufacturable or affordable, but they integrate multiple systems and technologies to achieve PNGV's goals. In 1997, PNGV selected those technologies most likely to achieve the goal of a vehicle capable of up to three times the fuel efficiency of 1994 family sedans while maintaining the same emissions and safety standards without sacrificing performance, utility, or affordability, as illustrated in table 1. As of March 2000, Ford, General Motors, and DaimlerChrysler had introduced their concept vehicles. Furthermore, each company expected that they will be successful in introducing a production prototype to meet the 2004 time frame.

Table 1: Attributes of PNGV Vehicle

Characteristic	PNGV target
Acceleration	0-60 miles per hour in 12 seconds
Number of passengers	up to 6
Operating life	100,000 miles (minimum)
Range	380 miles on 1994 combined drive cycle
Emissions	Meet or exceed EPA Tier 2
Luggage capacity	16.8 cubic feet, 200 pounds
Recyclability	80%
Safety	Meet federal motor safety standards
Utility, comfort, ride, handling	Equivalent to current vehicles
Purchase and operating cost:	Equivalent to current vehicles, adjusted for economics

Source: Department of Commerce.

DaimlerChrysler revealed its PNGV concept car, the Dodge ESX3, in February 2000. It is a four-door family sedan that can achieve up to 72 miles per gallon (gasoline equivalent). The car incorporates a parallel electric hybrid drivetrain with low energy storage and a high-efficiency six-speed transmission. The hybrid drivetrain features a lightweight aluminum and magnesium1.5-liter compression ignition direct injection (CIDI) diesel engine, electric motor, and lithium-ion battery. The lightweight body uses injection–molded thermoplastic body panels reinforced with tubular aluminum and meets all federal safety standards, according to the company. The company announced that this lightweight body design costs less to manufacture than a conventional steel body. In addition, it is simpler to manufacture—the car's main structure has only 12 pieces, compared with up to 100 metal pieces in a conventional car. The vehicle also uses lightweight seats, incorporating aluminum frames, to significantly reduce weight as well as provide heating and cooling functions at the occupant's point of contact.

Figure 6: DaimlerChrysler ESX3 Concept Vehicle

Source: DaimlerChrysler AG.

Ford revealed its PNGV concept car, the Prodigy, in December 1999. It is a mid-sized family sedan that is built on a lightweight platform and integrates

a low-energy storage requirement and a parallel hybrid electric powertrain. Its fuel economy is estimated at 70 miles per gallon (gasoline equivalent). The vehicle is powered by a 1.2-liter CIDI diesel engine and an electric motor linked to a battery pack stored in the trunk. Weight reduction is achieved through computer optimization and lightweight materials, such as aluminum, magnesium, composites and titanium. To reduce aerodynamic resistance, Ford uses cameras instead of outside mirrors, variable ride height, a smooth underbody, and flush wheelcovers. The concept car also employs low rolling resistance tires. When the vehicle is coasting or stopped, the engine shuts off and can instantly restart when needed. Regenerative braking captures the energy normally lost through braking and returns the energy to the battery. In addition, Ford has announced that it plans to produce and market a car similar to its Prodigy and a fuel-cell vehicle during 2003 through 2005. However, details on the characteristics, price, and availability of the planned vehicles were not released at the time of our review.

Figure 7: Ford Prodigy Concept Vehicle

Source: Ford Motor Company.

General Motors unveiled its first PNGV concept car, the Precept, in January 2000. It is a four-door family sedan designed to achieve 80 miles per gallon. A battery–powered electric motor supplies power to the front wheels. A lightweight, 1.3-liter, turbocharged three-cylinder diesel engine is mounted in the rear of the vehicle. The CIDI diesel engine supplies energy to the battery, which in the Precept can be one of two types—nickel metal hydride or advanced lithium polymer. The Precept uses a regenerative

braking system. General Motors has used lightweight materials that would make the car too expensive for current production. In a related matter, the company unveiled an advanced fuel-cell system with battery storage packaged in a second version of the Precept, the Precept FCEV.

Figure 8: General Motors Precept Concept Vehicle

Source: General Motors.

Cars Similar to PNGV

According to Toyota, its Prius is the world's first mass-produced gasoline-electric hybrid car. It is not currently available in the United States, but Toyota expects to deliver a U.S. model in the summer of 2000. Toyota estimates that the Prius can achieve 66 miles per gallon—an estimate based on the driving patterns common in Japan. The Prius combines a gasoline engine and an electric motor powered by nickel-metal hydride batteries. An onboard computer system controls how the two power sources are combined. The batteries power the car from zero to about 25 miles per hour. As the car accelerates, the computer turns on the 1.5-liter gasoline engine, blending its power with that of the electric motor. As the car reaches cruising speed, some of the power from the gasoline engine is diverted to generate electricity to recharge the battery packs. The major differences between the Prius and the PNGV concept cars are that the Prius is smaller and more costly than conventional mid-sized sedans.

Figure 9: Toyota Prius

Source: Toyota Motor Corporation.

According to Honda, its Insight is the first gasoline-electric hybrid vehicle to be sold in the United States. The Insight is a two-passenger vehicle that delivers up to 70 miles per gallon with a three-cylinder, 1.0-liter gasoline-powered engine with an integrated electric motor/generator system. The vehicle integrates lightweight materials, such as aluminum, magnesium, and plastic in the engine, and extensively uses aluminum in the body and chassis. The Insight hybrid system, called integrated motor assist, utilizes the small gasoline engine as the primary power propulsion source during driving, with the electric motor used as a supplement during acceleration or times of heavy loads, such as when driving uphill. The primary difference between the Insight and the PNGV vehicles is that the Insight is smaller than mid-sized sedans.

Figure 10: Honda Insight

Source: Honda Motor Company.

DOE Contractors in the Office of Advanced Automotive Technologies Receiving $1 Million or More, Fiscal Years 1997 Through 1999

Contractor	Total funding
DaimlerChrysler Corporation	$19,697,079
AlliedSignal Automotive	12,277,300
Ford Motor Company	11,068,701
General Motors Corporation	8,690,000
EPYX	7,016,035
Delphi Automotive Systems	6,475,000
Plug Power	6,426,000
Detroit Diesel Corporation	6,390,053
International Fuel Cells	6,250,001
Energy Partners, Inc.	6,055,000
ALCOA Technology Center	6,014,000
US Advanced Materials Partnership	5,055,000
Stirling Thermal Motors	4,587,000
FEV Engine Technology	4,443,141
SAFT America, Inc.	4,365,000
VARTA Autobatterie	3,959,000
Silican Power Company	3,600,000
Allison Engine Company	3,504,340
Optima Advanced Technologies Inc.	3,405,000
Institute of GasTechnology	3,154,000
Computer Systems Management Inc.	3,059,000
Delco Propulsion System	2,959,868
Aero Vironment Laboratories	2,805,000
Teledyne	2,698,600
US Advanced Battery Consortium	2,597,000
Southwest Research Institute	2,049,000
SatCon Technology Corporation	1,864,989
Hydrogen Burner	1,690,000
Northwest Alliance for Transportation Technologies	1,615,000
3M	1,606,000
McDermott Technologies, Inc.	1,524,000
DuPont Lanxide Corporation	1,396,000
Vairex Corporation	1,249,000
Cummins Engine Company	1,200,000

Continued

Contractor	Total funding
The Analytic Sciences Corp.	1,109,000
PolyStor, Inc.	1,023,000
Ballard Power Systems, Inc.	1,000,000
Consortium for Fossil Fuel Liquification	1,000,000
Energetics, Inc.	1,000,000
Ravenswood Aluminum Company	1,000,000

Continued from Previous Page

Notes:

This list excludes the Department of Energy and its national laboratories and other federal agencies.

Data for total DOE funding do not include funding that may have been subcontracted through national laboratories to private companies. These data were not available. Including the total laboratory spending of about $179 million, some of which may be subcontracted from the laboratories, may result in larger totals for the above listed companies. It may also result in a greater number of companies receiving more than $1 million in federal spending from the PNGV program at the Office of Advanced Automotive Technologies if the subcontracts were with companies already included in the database.

The Northwest Alliance for Transportation Technologies is a consortium between Pacific Northwest National Laboratory and industry, coordinated by the Laboratory.

Source: GAO's analysis of DOE data.

Selected Technologies Examined Under PNGV

Energy Converters

Gas turbines are internal combustion engines, similar to those used in small aircraft, that use a compressor in place of pistons to ignite the air-fuel mixture. The resulting hot gases drive a turbine, thereby converting the energy from combustion into mechanical energy. Gas turbines' high power output, lack of vibration, and low emissions make them attractive, but their high cost and poor performance in comparison with internal combustion engines make them unlikely candidates for the 2004 concept cars.

Stirling engines, often described as heat engines or external combustion engines, convert an external heat source to mechanical energy through a working fluid such as hydrogen. The hydrogen is heated and compressed instead of combusted inside the engine. Cost and reliability problems prevent Stirling engines from being used in the 2004 concept cars.

Fuels

Fischer-Tropsch fuel is a synthetic gasoline derived from the Fischer-Tropsch process discovered in 1923 by the German coal researchers Franz Fischer and Hans Tropsch. By following the Fischer-Tropsch process, synthetic gasoline, waxes, alcohols, and methane can be made by reacting hydrogen and carbon monoxide in the presence of an iron or cobalt catalyst, with water or carbon dioxide produced as by-products. Fischer Tropsch fuel is free of sulfur, but the absence of an adequate distribution system precludes its use in PNGV concept cars.

Dimethyl ether (DME) is another sulfur-free synthetic fuel that can be manufactured from natural gas. DOE is investigating it as a substitute for diesel fuel because of its low emissions. Like Fischer-Tropsch fuel, its lack of an adequate distribution system precludes its use in the 2004 concept cars.

Emissions Reduction

Catalytic processes used by PNGV researchers for reducing nitrogen oxide emissions include exposing exhaust gases to microwaves or electricity. Under plasma-assisted catalysis, exhaust gases are exposed to electric currents to form nitrogen ions that then combine with nitrogen oxide to form molecular nitrogen and atomic oxygen. Under microwave-assisted catalysis, microwaves are used to selectively increase the temperature, and hence the activity of catalysts, during engine start-up.

The exhaust gas recirculation (EGR) systems mix small amounts of oxygen-poor exhaust gas with intake air and reinject this mixture into the

combustion chamber. The lower oxygen level and the subsequent lower combustion temperature result in the formation of fewer nitrogen oxides.

Particulate traps are filters that are used to remove particulates, or soot, from the exhaust stream before they exit the tailpipe of the vehicle. One difficulty of these technologies is disposing of the accumulated soot, which is periodically burned off by heating the trap.

Drivetrains

Hybrid drivetrains are drivetrains that use two sources of power: generally mechanical energy produced by an engine or electrical energy stored within a battery, and often delivered by an electric motor. In vehicles with parallel hybrid drivetrains, power to turn the wheels comes from either the engine or motor, either individually or simultaneously. In vehicles with series hybrid drivetrains, the engine supplies power to the electric motor to turn the wheels. PNGV officials expressed preference for the parallel hybrid drivetrain because of its greater versatility. Alternatively, hybrid mechanical drivetrains transmit stored energy through a mechanically actuated propulsion system to turn the wheels. The Environmental Protection Agency and others are experimenting with mechanical drivetrains under PNGV, as well as mechanical devices to store excess energy recovered by regenerative braking.

Energy Storage Devices

Capacitors are devices that store power in an insulating layer, such as air or certain liquids, that is sandwiched between two plates or foils having different electrical charges. Ultracapacitors can store more energy for their size than normal capacitors, and they can be discharged more quickly. Although PNGV discontinued research on ultracapacitors as primary energy storage devices, the program is continuing to investigate capacitors for use in power electronics.

Flywheels are energy storage devices that are different from batteries. They do not store their energy in chemicals but instead in a rapidly spinning rotor or disk (in some cases 65,000 revolutions per minute). Flywheels sometimes use a composite instead of steel because of the composite's ability to withstand the rotating forces exerted on the flywheel. To store energy, a flywheel is placed in a vacuum to reduce air resistance, and it is accelerated using a method similar to the way an electric motor is accelerated. Energy is released in the opposite way, with the kinetic energy of the spinning wheel captured by an electric generator. Magnets embedded in the flywheel pass near pickup coils. The magnet

induces a current in the coil, changing the rotational energy into electrical energy. PNGV research on flywheels was discontinued because of their high cost and the difficulty in containing fragments of blades, which can result from their failure at high speeds.

Scope and Methodology

To determine progress made toward the goals of PNGV, we reviewed various PNGV-related documents produced by the Executive Office of the President, PNGV's Declaration of Intent, PNGV's 1995 Program Plan, and RAND's 1998 book entitled *The Machine That Could*. We also examined reviews of PNGV written by the National Research Council (NRC) in each year from 1994 through 1999, the Department of Energy's Inspector General in 1998, and the Congresssional Research Service in 1996. We also interviewed federal agency officials with the Department of Commerce (DOC), Department of Defense (DOD), Department of Energy (DOE), Department of Transportation (DOT), Environmental Protection Agency (EPA), the National Science Foundation (NSF), current representatives from the executive branch, including the Office of Management and Budget (OMB), the Office of Science and Technology Policy, and the Council on Environmental Quality. In addition, we interviewed representatives from the industry partners, including DaimlerChrysler, Ford Motor Company (Ford), General Motors (GM), and United States Council for Automotive Research (USCAR), for their perspectives on PNGV's goals.

To determine the historical funding levels of PNGV, we collected budget documents from OMB, DOC, DOE, DOT, EPA, and NSF for fiscal years 1995 through 1999. We interviewed officials at these agencies to clarify budgetary figures, including relative funding on the different technologies and relevance to PNGV's goals. We did not independently verify budgetary figures for the agencies. Budgets for DOC and NSF are estimated each year and awarded as a result of an on-going grant review process. At our request, DOC conducted an inventory of funded projects that it considered related to PNGV and provided detailed project information for these projects. NSF informed us that unlike DOE, EPA, DOT, and DOC, it did not inventory individual grants. NSF officials explained that they took a sample of grants from a single year and determined each grant's relevance to PNGV and then projected the results of this single year's sample to the agency's entire population of grants for all years to determine overall funding. We also reviewed references to funding in *The Machine That Could*, the NRC reports, and the Congressional Research Service report. After reviewing all OMB and agency data, we created broad funding categories to merge the budget data provided by each agency because none of the data were tracked in a consistent set of categories for all years across agencies. All the agencies, excluding DOC, reviewed and accepted our categorization of PNGV supportive funding. DOC staff neither agree or disagree with our categorization, but said that the use of any categories other than those used by OMB may remove some relevant details. We obtained information on DOE's cost-sharing, competitively awarded funds, and contracts of $1

million or more, from DOE's program plan and a related electronic database for fiscal years 1997 through 1999, as well as interviews with program staff. Because of the time constraints, we present industry cost-share funding only for DOE for fiscal years 1997 through 1999. We did not collect or develop data on industry's cost-share funding in support of other federal agencies' research.

To describe the short- and long-term technologies pursued jointly by PNGV and industry and to compare these with technologies pursued independently by industry, we met with research and development (R&D) program managers and researchers at DOE, EPA, and industry R&D facilities; interviewed staff at federal agencies; members of the NRC peer review committee; and representatives from the financial community who analyze the automobile industry and its parts suppliers. The DOE laboratories we visited were Oak Ridge National Laboratory, Lawrence-Livermore National Laboratory, the National Renewable Energy Laboratory, and the Sandia-Livermore National Laboratory. Funding at these four laboratories accounted for about 70 percent of total DOE funding on PNGV at its laboratories for fiscal years 1995 through 1999. We visited EPA's National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan. We also met with managers and researchers at Ford, General Motors, and DaimlerChrysler and toured related R&D facilities in the Detroit, Michigan, area. In addition to the work at the R&D facilities, we reviewed discussions of automobile technologies in PNGV's 1995 Program Plan, PNGV's 1996 report on Technical Accomplishments, DOE's Advanced Automotive Technologies R&D Plan for 1998, the Office of Technology Assessment's 1995 report on Advanced Automotive Technology, NRC's five annual reviews of PNGV, various publications covering the condition of the automobile industry and its finances, as well as general automotive literature. We interviewed staff at each of the five federal agencies funding projects counted as supportive of PNGV, as well as staff at the DOD. We interviewed members of the National Research Council's committee that reviewed PNGV to clarify the relevance of individual technologies. We also met with financial analysts in New York to gain their perspective on trends in the automobile industry and the value of vehicle R&D to the financial community.

Comments From PNGV Through the Department of Commerce

Note: GAO's comments supplementing those in the report text appear at the end of this appendix.

UNITED STATES DEPARTMENT OF COMMERCE
Technology Administration
Washington, D.C. 20230

March 17, 2000

Mr. Derek Stewart
Associate Director, Energy, Resources, and Science Issues
Resources, Community, and Economic Development Division
U.S. General Accounting Office
441 G Street, N.W.
Washington, DC 20548

Dear Mr. Stewart:

The Partnership for a New Generation of Vehicles Secretariat and its participating Federal agencies appreciate the opportunity to review the General Accounting Office draft report, GAO/RCED-00-81, "COOPERATIVE RESEARCH: Results of Partnership between Federal Government and Industry to Develop a New Generation of Vehicles." While generally we believe that the report presents a well-written, factual overview of the Partnership, we have several substantive concerns that we believe should be addressed.

Our most serious concerns relate to what you have characterized as your two observations related to the program.

See comment 1.

GAO's first observation was: "First, while the partnership is making progress towards developing an 80 mile per gallon production prototype vehicle by 2004 (the focus of the program), according to industry representatives such a vehicle is unlikely to be manufactured for the general public at a cost competitive with conventional vehicles in the near future."

This observation needs to be placed more clearly in the context of the program's goals. PNGV is a research partnership with a long-term goal of developing the technologies to enable the production of mid-size passenger sedans capable of achieving up to 80 miles per gallon. The final milestone of the PNGV program is a production prototype, developed by each of PNGV's automotive partners in 2004, capable of achieving up to 80 miles per gallon. The government recognized from the program's outset that the decision to produce high volumes of such vehicles would necessarily fall to PNGV's automotive partners—DaimlerChrysler, Ford and General Motors—and that the production decision would depend on the existence of a consumer market for these vehicles. In order to address the issue of marketability, we set multiple goals for the PNGV production prototype in addition to fuel economy. We believe that if all PNGV goals are met—including a three-fold fuel economy improvement, affordability, safety, low emissions, comfort, utility and performance—there will be a market for these vehicles. PNGV has identified affordability as one of the key remaining challenges, and is undertaking research efforts to drive down the cost of these technologies. In addition, external factors, such as the cost of automotive fuels, could have a substantial impact on the formation of a market for these vehicles, and thus their commercial viability.

We also believe that this GAO observation seems to be predicated on the mistaken inference that PNGV had established a goal of achieving production vehicles in the 2004 timeframe. Production vehicles generally follow production prototypes by three to five years. Thus, it follows that the PNGV automotive partners would not have been expected to bring such vehicles to market until the 2007-2009 timeframe at the earliest, even assuming both that the program is successful in achieving its technical targets in production prototypes in 2004 and that a market exists at that time in the United States for highly fuel efficient vehicles.

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While recognized elsewhere in the report, your first observation fails to mention that the technologies developed under PNGV are already migrating—and will continued to migrate—into production vehicles as they become commercially viable (Goal 2 of PNGV, toward which GAO reports that PNGV has achieved substantial success). Migration is a primary path for PNGV technologies to enter the marketplace.

See comment 2.

GAO's second observation was: "Second, the federal funding attributed to the partnership may overstate federal support of its goals because 45 percent of the reported funding for the activities of the partnership is either not directly relevant to its goals or is not coordinated through the partnership so that the technical merits of the research can be considered by the partners."

The Partnership has always been very clear about the nature and characterization of PNGV funding. For purposes of budget characterization, OMB established three tiers of PNGV funding defined by the level of their applicability to the program's goals and their coordination with the program. Tier 1 funding is directly applicable to PNGV goals and directly coordinated through the Partnership. Tier 2 funding is directly applicable to PNGV goals and but not coordinated through the Partnership. Tier 3 funding is indirectly applicable to PNGV goals and is not coordinated through the Partnership.

Tier 2 (3 percent of PNGV funding) and Tier 3 funding (42 percent) are included as part of the PNGV Federal research portfolio for several reasons. First, this provides a broad perspective of the Federal role in advancing automotive technologies. Second, many of the activities supported by Tier 2 and Tier 3 funds have, to varying degrees, applicability to PNGV goals. Third, by aggregating these investments under the banner of PNGV, we can influence the path of these investments by allowing them to tie into PNGV research. Underlying the value of Tier 3 funding—which is, in large measure, peer reviewed research funded by the National Science Foundation and competitively-awarded projects of the Department of Commerce's Advanced Technology Program—is the notion that good ideas are not limited to the PNGV partners. Tier 3 funding sources provide an alternative channel for such ideas to blossom. Finally, NSF-funded projects generally focus on areas of basic research. Basic research, by its nature is not directed to the development of particular products, but to the explanation of fundamental scientific principles. These scientific principles are the building blocks for applied research projects which do relate directly to product goals. The inclusion of the Tier 3 projects in the PNGV program helps to steer fundamental research in a direction to provide answers needed to further the applied research projects.

We believe several additional clarifications need to be made as well:

See comment 3.

- The genesis of PNGV is broader than stated in the first sentence of the report. Concerns about oil dependence and the adverse impacts of the automobile on the environment also contributed to the formation of PNGV.

See comment 4.

- While the Department of Defense and NASA are not PNGV funding agencies, they have been and remain full partners in PNGV. Both agencies have participated on the PNGV technology teams and participate in the policy oversight of the partnership as members of the PNGV Operational Steering Group.

See comment 5.

- The report incorrectly states that PNGV was formed "with the primary purpose of creating a more fuel efficient automobile within 10 years." The partnership set out to develop precompetitive technologies to enable the production of a new generation of highly fuel-efficient automobiles, and to demonstrate these technologies in production prototypes within 10 years.

See comment 6.

See comment 7.

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- The program's first major milestone, completion of the technology selection process in 1997, narrowed the portfolio of technologies under consideration to those considered 'most promising' to meet the third goal of the partnership. Some technologies, such as gas turbines and Stirling engines, that received PNGV funding in the early years of the partnership were eliminated from the PNGV research portfolio. Those deemed 'most promising'—including four-stroke direct injection engines, fuel cells, lightweight materials, and hybrid systems— were selected for focused, accelerated research.
- In Appendix I, GAO discusses the Toyota Prius and the Honda Insight. While GAO makes a brief attempt to distinguish these cars from a Goal 3 PNGV vehicle, we believe that a more detailed differentiation is necessary.

  First, the fuel economy improvements of these vehicles, while substantial, fall significantly short of PNGV's Goal 3 three-fold fuel economy improvement over comparable conventional vehicles. The increase in fuel economy achieved by the Prius over the comparable Toyota vehicle, the Corolla, is considerably less (49 miles per gallon, or 1.4 times the Corolla's fuel economy) than PNGV's three-fold improvement goal. The Insight achieves less than a two-fold improvement in fuel economy.

  Another significant difference is size. The PNGV target vehicle is a mid-size, five-to-six passenger vehicle; the Prius is a compact-size, four-passenger vehicle and the Insight is a subcompact two-passenger vehicle.

  In addition, the Prius is based on a conventional steel body, rather than the aluminum and injection-molded thermoplastic used in the PNGV concept vehicles to reduce their weight. Also, a considerable body of evidence indicates that Toyota's announced sales price for the Prius in the United States is substantially below its production cost. In Japan, there are substantial government tax incentives to encourage the purchase of the Prius.

  The Insight is currently available only with a manual transmission. The Insight's hybridization strategy depends on the driver putting the car in neutral and releasing the clutch; integration of an automatic transmission—typically favored in the United States—with nearly instant engine start presents an additional significant technical challenge.

Additional substantive comments and minor editorial changes have been provided to the General Accounting Office under separate cover. The PNGV Secretariat hopes that the comments in both letters will be helpful in the preparation of the final report. If there are any questions regarding this response, please contact me at (202) 482-6268.

Sincerely,

John F. Sargent
Acting Director
PNGV Secretariat

GAO's Comments

The following are GAO's comments on the Department of Commerce's letter dated March 17, 2000, which consolidated comments by all federal departments and agencies.

1. GAO understands that under goal 3, PNGV is to develop a production prototype capable of up to three times the fuel efficiency of comparable 1994 sedans, not to mass-produce and market such vehicles by 2004. We emphasized that it is unlikely that the automobile manufacturers will manufacture and sell their prototypes in the near-term because we wanted to dispel the belief that these prototypes will be mass-produced and available to consumers by 2004. Industry made us aware of how long manufacturers need to take a product from concept to market. However, industry partners told us that since they do not currently see a market in the United States for PNGV vehicles, they think it is unlikely that they will introduce such vehicles in the near term under current economic conditions. While we acknowledge that economic conditions may change, we defer to industry partners for their judgment on the automobile markets. We made no changes to our report for this comment.

2. We acknowledge that including research in Tiers 2 and 3 may provide a broader perspective on federal research with varying degrees of applicability to PNGV. However, we continue to believe that by including funding that is either not directly relevant to the goals of the partnership or that is not coordinated through PNGV's committees, federal funding attributed to PNGV may be overstated. Furthermore, such research is unlikely to influence the path of PNGV, as suggested by the Department, since PNGV's committees do not coordinate the research. Thus, industry, as part of these committees, is not aware of the content of ongoing research in these areas, nor is it able to help direct the path of future research in a way to help meet the goals of PNGV. In addition, while Tier 3 research, consisting mostly of basic scientific research, may have relevance to PNGV's goals, we found no evidence that PNGV is substantially influencing the path of this research. Industry partners were unanimous in stating that they had difficulty assessing the relevance to PNGV's goals of most of the research conducted by the Department of Commerce and the National Science Foundation, which collectively account for 88 percent of Tier 3 funding. In addition, in commenting on this report, industry partners suggested that some of the Environmental Protection Agency's Tier 1 and Tier 2 funding may not be coordinated well enough to achieve PNGV's goals. Specifically, they stated:

"It should be noted that although EPA's funding of PNGV research is classified as Tier 1 and Tier 2, industry does not have total access to all of this EPA research, including much that is labeled Tier 1. Furthermore, when guidance is provided to EPA regarding the direction and focus of its PNGV research, that guidance is frequently disregarded."

We believe our report accurately characterizes PNGV funding and accordingly made no change in response to this comment.

3. Concerns over dependence on foreign oil and the adverse impacts of the automobile on the environment are discussed in the background section of this report. However, we added in the first paragraph of this report that other policy concerns also played a role in the genesis of PNGV.

4. The roles of DOD and NASA have been clarified, as suggested.

5. This distinction was incorporated into the report, as suggested.

6. This clarification was made in the report, as suggested.

7. Industry partners made a similar suggestion. Our intent was not to provide an exhaustive distinction between the recently introduced concept cars and the Toyota Prius and the Honda Insight but rather to acknowledge that there are fuel-efficient vehicles currently on the market, albeit there are major differences between these and the PNGV concept cars. We made no change to the report in response to these comments.

GAO Contacts and Staff Acknowledgments

GAO Contacts

Jim Wells (202) 512-3841

Daniel Haas (202) 512-3841

Staff Acknowledgments

In addition to those named above, Jon Ludwigson, Ron Belak, Melissa Francis, and Kathy Hale made key contributions to this report.

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