Chapter 5

Advanced Automotive R&D Programs: An International Comparison

This chapter attempts to describe and evaluate the federal role in the research and development (R&D) of advanced automotive technologies. It begins with a historical perspective on federal involvement in automotive R&D, from the early 1970s to the present. It then describes ongoing government/industry programs in the United States, Japan, and Western Europe, and draws some conclusions about the competitive position of the U.S. automotive industry in these technologies. The analysis compares the R&D needs resulting from the Office of Technology Assessment 's (OTA's) technical assessment with federal R&D budget priorities proposed for fiscal year (FY) 1996. The chapter concludes with a discussion of the federal role and the way it might evolve in the future.

At this writing, Congress is considering significant cuts in finding for federal agency programs that have supported advanced automotive R&D. If these cuts are implemented, recent initiatives such as the Clinton Administration's Partnership for a New Generation of Vehicles (PNGV, see below) will be seriously jeopardized, and will be competing with more traditional R&D programs (e.g., alternative fuels, heavy-duty engines) for a smaller pool of government resources. In any case, while this chapter provides a snapshot of current federal R&D efforts as of the summer of 1995, the reader should be aware that the landscape of federal R&D programs could change radically in the coming months and years.

AUTOMOTIVE R&D

It is important to understand that the largest source of finding for automotive R&D around the world is the industry itself. There is intense pressure on the manufacturers and their suppliers to innovate and to reduce production costs through the adoption of new technologies. The costs of innovation are very high. For example, the total cost of developing a new vehicle from concept to prototype may be hundreds of millions of dollars; moving it from prototype to production typically costs billions more. In 1992, R&D expenditures in the U.S. auto industry (vehicles and parts) totaled $12.3 billion, the second highest of all U.S. industrial sectors, and about 4 percent of total sales. [1] In 1992, General Motors (GM) and Ford had the first and third highest R&D expenditures among all U.S. companies. [2]

Some of the research conducted by the manufacturers is quite long term. For example, GM has investigated fuel cells for decades, and Ford has developed expertise in advanced composites for body structures. Yet, according to OTA's analysis, neither fuel cells nor advanced composites will likely be commercialized in light-duty vehicles for at least 10 years.

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[1] International Trade Commission, *Industry, Trade, and Technology Review,* August 1994, p.22.

[2] Ibid.

The bulk of private R&D funding, however, goes toward incremental technological improvements that could be commercialized in the next 5 to 10 years. The funding levels and directions of these private R&D programs are closely held, particularly for near-term products. For longer term technologies of the type discussed here, however, results are often published in the literature. Where information on these private R&D programs is available, it is included here.

Collaborative R&D

Compared with the billions of dollars spent by the industry on product R&D, government-supported R&D programs amounting to a few hundred million dollars per year may seem insignificant. However, there is a growing acceptance by manufacturers that commercialization of many of the advanced technologies discussed above will require a precompetitive, collaborative effort involving the major manufacturers, suppliers, universities, and government laboratories.

This has come about for several reasons. First, the manufacturers realize that it makes little sense for each separately to fund the development of technologies whose benefits are uncertain and difficult for an individual company to capture. Moreover, some of the benefits are social goods, such as increased energy security and reduced emissions, which are legitimate reasons for government interest, but not a high priority for the typical car buyer. Finally, much of the expertise in these technologies lies outside the knowledge base of the manufacturers or their traditional suppliers, residing instead with defense-oriented companies or government laboratories. It is too expensive for the major manufacturers to develop and maintain all the necessary engineering expertise for the advanced technologies in-house.

SCOPE

In this chapter, OTA focuses primarily on those collaborative programs that receive federal funding, including consortia of the major manufacturers and regional consortia involving suppliers, small entrepreneurial companies, and public utilities. OTA believes that an examination of these collaborative programs is most relevant to congressional committees making decisions about advanced automotive technology program funding and direction. It also provides a basis for evaluating the relative emphases of comparable efforts in Europe and Japan, particularly for "leapfrog" technologies that are still at the precompetitive stage. Nevertheless, the sketchy information available on the in-house R&D activities of individual manufacturers is an important caveat to recall in evaluating the conclusions reached here.

OTA makes no attempt here to catalog all federal research that might be in some way relevant to advanced vehicles. Instead, the emphasis is on describing the R&D programs that are explicitly targeted on the advanced light-duty vehicle fleet. Several R&D areas are considered beyond the scope of this report: R&D aimed at incremental improvements to conventional vehicles, whether in the areas of safety, reduced friction, or emissions control are excluded, as is R&D on alternative fuels for internal combustion engines. The area of intelligent vehicle highway systems

(IVHS) is also excluded, although there is a case to be made for integrating advanced vehicle technologies more closely with the broader systemwide concerns of IVHS.

THE FEDERAL ROLE IN ADVANCED VEHICLE R&D: A HISTORICAL PERSPECTIVE-1970-1995

The federal government has played an active role in R&D of advanced automotive technologies for more than 20 years. Fuel efficient, low-emission vehicles have long been seen by both federal and state governments as crucial to achieving the twin goals of reduced U.S. dependence on imported oil and improved urban air quality. Key pieces of federal legislation that have promoted advanced vehicle R&D are shown in table 5-1.

Reduced Oil Use

Beginning with the first oil shock in 1973, reducing U.S. dependence on imported oil became a major focus of U.S. transportation policy. In an effort to stimulate the development and commercialization of more fuel-efficient vehicles, Congress passed a series of laws beginning with the Energy Policy and Conservation Act of 1975, which mandated a doubling of the fuel economy of the new car fleet from 14 to 28 mpg. The Electric and Hybrid Vehicle Research, Development, and Demonstration Act was passed in 1976, which launched the Department of Energy's (DOE's) Electric and Hybrid Vehicle Program.[3] Congress continued to promote the reduction of transportation oil use through the Automotive Propulsion Research and Development Act of 1978, the Alternative Motor Fuels Act of 1988, and the Energy Policy Act of 1992.

Air Quality

The desire for cleaner air, particularly in urban centers whose air quality falls below federal standards, has also been a major motivator for government involvement in advanced vehicle technologies. In fact, the Public Health Service (and later, the Environmental Protection Agency--EPA) began finding research on cleaner-burning hybrid vehicles in the period 1969 to 1974.[4] But perhaps no regulation has had a greater impact on R&D than California's Low Emission Vehicle Program--LEV (adopted in September, 1990), which was devised to ensure compliance with the federal Clean Air Act Amendments of 1990.

In particular, California's requirement that 2 percent of vehicles sold in the state in 1998 (about 40,000 vehicles) must have zero emissions, rising to 10 percent--or 200,000 vehicles--by 2003, has greatly stimulated research on battery electric and fuel cell electric vehicles, the only

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[3] The EHV Program had three parts, including R&D funding, vehicle procurement for market demonstrations, and loan guarantees to promote the involvement of small and medium-sized companies.

[4] Victor Wouk, "Hybrids: Then and Now," IEEE Spectrum, July 1995, p. 16.

technologies currently known that have zero tailpipe emissions of criteria pollutants.[5] The California LEV program (and its proposed adoption in several northeastern states) has not only stimulated joint research by the Big Three on advanced batteries and electric vehicles (EVs), it also spawned a myriad of small companies aiming to produce EVs (either converted from gasoline vehicles or purpose-built) to meet the 1998 requirements. Japanese manufacturers interviewed by OTA indicated that they had largely abandoned EV research until the California mandate forced them to renew it in earnest.

Perspectives on the Federal Role

The fact that the federal government has been involved with development of advanced automotive technologies for more than **20 years** might suggest that these technologies are now mature and ready for the market, but this is far from true. The principal reason is that there has been no market pull on these advanced technologies to provide a coherent market vision. Manufacturers have been able to meet government mandates for higher fuel economy and lower emissions through relatively inexpensive improvements to conventional vehicles, and, with falling real prices for gasoline, consumers place a very small premium on the high fuel economy offered by advanced technologies. These factors, combined with the high risk of investing in advanced technologies, have meant that industry cost sharing of government R&D contracts has been rather low--typically less than 20 percent.

There are additional reasons, however, that 20 years of government programs have failed to further develop the vehicle state of the art: government support has been inconsistent, poorly coordinated, and lacking in well-defined goals. As one example, figure 5-1 reveals the budget history of the DOE Electric and Hybrid Vehicle Program (for more detail, see box 5-l). This figure clearly shows the "rollercoaster" nature of federal R&D finding during the period 1976 to 1995. These budget fluctuations have made it impossible to sustain a coherent development program. For instance, after an initial flurry of activity on hybrid vehicles at DOE from 1978 to 1980, the hybrid effort was shelved until 1992.

The federal R&D effort has also suffered from agency parochialism. DOE has focused on the oil import reduction problem, with some attention to reducing the emission of greenhouse gases. The DOE view, however, has been that concerns about emission of criteria pollutants regulated under the Clean Air Act Amendments of 1990 are the purview of EPA, and there has been very little coordination between DOE and EPA' on advanced vehicle R&D.[6] The Department of Defense (DOD), particularly the Advanced Research Projects Agency (ARPA), has also been conducting research on electric and hybrid vehicles, which, until recently, was not well integrated with DOE research.

Since the advent of PNGV in September 1993 (see below), however, interagency coordination has improved. For example, DOE has established the Interagency Coordination Task Force for

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[5] Tom Cackette, "California's Zero Emission Vehicle Requirements and Implications for Hybrid Electric Vehicles,"
[6] Ken Heitner, U.S. Department of Energy, Office of Transportation Technologies, personal communication, Apr. 24, 1995.

Electric and Hybrid Vehicle Technologies to coordinate federal R&D in these technologies, and signed a Memorandum of Understanding with ARPA in June 1994 to lay out common interests and objectives and to minimize duplication.[7]

Finally, there has been little attempt to link R&D goals for advanced automotive technologies to specific national goals for imported oil reduction and emissions reduction from the transportation sector. DOE has proposed no specific overall goals or timetables for technology development in this areas In the absence of a coherent strategic plan by the administration, programs are driven by fragmentary congressional guidance contained in various pieces of legislation over the past 20 years. As one example, the Energy Policy Act of 1992 established the goal of displacing 10 percent of petroleum-based fbels with alternative fuels (ethanol, methanol, propane, natural gas, electricity, hydrogen) by 2000 and 30 percent by 2010. These goals, however, are not well integrated with the stated goals of current R&D initiatives such as PNGV, which does not address alternative fuels.

Partnership for a New Generation of Vehicles

The centerpiece of the current federal effort in advanced automotive R&D is PNGV, (see Box 5-2). Initiated by the Clinton administration together with the Big Three automakers in September 1993, PNGV is conceived as a joint government-industry R&D program aimed at the following three goals:

1. reducing manufacturing production costs and product development times for all car and truck production;

2. pursuing advances that increase fuel efficiency and reduce emissions of conventional vehicles; and

3. developing a manufacturable prototype vehicle in 10 years that gets up to three times the fuel efficiency of today's comparable vehicle, without sacrificing safety, affordability, comfort, or convenience.

Goal 3 is deliberately chosen to require technological breakthroughs in the vehicle power source, drivetrain, and structural materials (see chapter 3 for a discussion of candidate technologies). The PNGV timetable for Goal 3 is to select component technologies by 1997, produce a concept vehicle by 2000, and have a manufacturable prototype by 2004.

PNGV is actually a "virtual" program, in the sense that it coordinates and refocuses the various existing agency programs and resources toward the PNGV goals. NO "new" federal appropriations per se are planned for PNGV although the underlying agency programs that address PNGV goals may receive increases. PNGV has helped to bring greater coherence to the federal advanced vehicle R&D effort, by bringing representatives of the various government

[7] U.S. Department of Energy, "Electric and Hybrid Vehicle Program: 18th Report to Congress for Fiscal Year 1994," April 1995.
[8] Ken Heitner, see footnote 6.

agencies and industry together around the same table. However, while the defining goal of PNGV--developing midsize vehicles with fuel efficiencies up to 80 mpg--is clearly relevant to national goals of reducing oil consumption and greenhouse gas emissions, it appears to have been chosen because of the technical challenges that must be overcome to achieve it, rather than because of any relationship to specific national goals.

PNGV does bring one new dimension to the federal role in advanced automotive R&D that departs from past programs--an explicit federal interest in promoting the international competitiveness of the U.S. auto industry. According to the president's Budget for FY 1996, for example, "The PNGV initiative is a partnership with U.S. industry to ensure the global competitiveness of the U.S. automobile industry and its suppliers and improve environmental quality." In this new economic partnership, the federal government has given the U.S. industry (and particularly the Big Three) an unprecedented degree of control over the technology development agenda. This emphasis on competitiveness in turn has lent a proprietary flavor to PNGV that was not a characteristic of past programs. For example, foreign-based auto manufacturers are excluded from participating in PNGV (although foreign-based suppliers may participate under certain conditions).

OVERVIEW OF MAJOR ADVANCED AUTOMOTIVE R&D PROGRAMS

This section provides an overview of the major R&D programs and institutions involved in advanced automotive technology development in the United States, Europe, and Japan. It is based on published information as well as visits by OTA staff and contractors to European, Japanese, and U.S. manufacturers and government laboratories.

United States

According to a survey of federal program managers conducted by the PNGV secretariat, a total of $270 million was budgeted in 1995 for technological development in 14 key areas judged critical to the goals of the Partnership for a New Generation of Vehicles (see table 5-2). For FY 1996, the Clinton Administration requested an increase to $386 million or about 43 percent.

These budget figures are controversial, however. Industry sources contacted by OTA believe these estimates are inflated--that much of the government R&D included by agency program managers is not actually relevant to PNGV.[9] Depending on the accounting criteria used, the total figure for federal spending on technologies relevant to advanced automobiles could be higher or lower (see box 5-3).

[9] According to one PNGV participant, the *total* (government plus industry) R&D effort may approach $270 million in FY 1995.

Major Automotive R&D Programs in Federal Agencies

The discussion below characterizes the major advanced automotive R&D programs underway in the federal agencies, together with their finding levels and strategies for commercializing advanced vehicles.

Department of Commerce (DOC)

DOC's National Institute of Standards and Technology (NIST) is the focal point for the agency's advanced automotive research. NIST is a world-class center for physical science and engineering research with long experience in areas such as automated manufacturing processes, advanced materials, and development of measurement standards and techniques.

Overall, NIST's ongoing research is predominantly in the area of advanced manufacturing, followed by advanced composites and design methods. In the future, NIST's capabilities in the area of standards development could become very important for advanced vehicles--for example, standards for product data exchange, standards for measuring the performance of composite materials, or for information exchange between an electric vehicle and a charging station during rapid charging.

Although NIST's advanced vehicle-related R&D is scattered among several programs, the bulk of the finding is provided through the Advanced Technology Program (ATP), a 50-50 cost-shared R&D program with industry. ATP solicits research proposals from industry in several areas related to automobiles, including advanced composites, materials processing for heavy manufacturing, and automotive manufacturing. For example, in FY 1995 ATP initiated eight new projects, all related to the use of composite materials in vehicles, with annual finding of about $8.5 million (matched by an equal industry contribution).

DOC's advanced vehicle budget request shows an apparent decrease from nearly $20 million in FY 1995 to $9 million in FY 1996. The $9 million figure, however, includes only the cost of continuing projects started in earlier fiscal years. In fact, ATP expects to initiate $30 million in new auto-related contracts in FY 1996, but negotiations on these contracts are not yet completed. Thus, instead of being cut in halt the actual NIST budget for PNGV-related technologies would nearly double to $39 million in FY 1996. [10]

Department of Defense

DOD has numerous projects under way to improve the readiness and fighting capability of military vehicles. Many of these involve the same advanced technologies that are also being considered for the civilian light-duty vehicle fleet under PNGV DOD research is sponsored by a number of institutions, including research laboratories of the Army, Navy, and Air Force, as well as ARPA. In addition to sponsoring its own research, ARPA is the coordinator of the Technology Reinvestment Project (TRP), which promotes the development of "dual use" technologies that have both civilian and military applications. DOD's participation in PNGV is coordinated by the

[10] However, ATP funding is controversial in Congress, and significant cuts are being debated.

U.S. Army Tank Automotive Research, Development, and Engineering Center, which is the world's largest producer of military ground vehicles.

DOD's PNGV-related budget request shows an apparent increase from about $24 million in FY 1995 to over $42 million in FY 1996. In fact, this increase does not measure increased R&D activity, but rather reflects different accounting methods used in the two years.[11] In FY 1996, additional projects were included in the PNGV inventory that had been excluded in FY 1995. Indeed, actual DoD finding for auto-related R&D could fall substantially in FY 1996, if ARPA finding is cut as anticipated.

The ***Advanced Research Projects Agency, views*** its role in advanced vehicle development as a supporter of research on both medium-duty and heavy-duty drivetrains for military vehicles (e.g., buses, "humvees," and Bradleys); in the future, these technologies could be scaled down to light duty vehicles. ARPA contrasts this with the DOE approach, which is aimed primarily at the light-duty vehicle fleet. ARPA funds research on electric and hybrid vehicles through two mechanisms: the Electric/Hybrid Vehicle and Infrastructure (EHV) Program, and the TRP. The EHV Program was a congressional add-onto the budget in FY 1993, which grew to $45 million in FY 1994, but dropped to $15 million in FY 1995 and is zeroed out in the FY 1996 budget request.

All of the finding of the EHV Program is channeled through seven regional consortia (see table *5-3)* that provide at least 50 percent cost-sharing of ARPA finds. The consortia involve universities, state and local governments, small businesses, defense contractors, Big Three automotive suppliers, federal laboratories, transit agencies, environmental groups, utilities, and military departments.

ARPA's EHV Program has been a major source of finding for small companies interested in conducting advanced vehicle research that is not channeled through the Big Three automakers. The consortium approach has helped to keep contract management costs low while stimulating cross-fertilization of ideas among consortium members through triannual meetings. It is unclear what impact the elimination of the EHV Program will have on these consortia.

ARPA also manages the TRP, a program launched in 1993 to conduct joint govemment/industry research both to "spin off" defense technologies to the commercial sector and to "spin-on" state-of-the-art commercial technologies for military applications. TRP finds are currently supporting seven research projects with industry contractors, some of which are relevant to advanced vehicles, such as a project on developing computer simulation tools for concurrent engineering and vehicle design. Advanced vehicle powertrains were designated as a TRP "focus area" for 1995, with anticipated funding of around $25 million; however, these finds have been rescinded by Congress, and the future of the entire TRP is in doubt.

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[11] According to information provided by the PNGV Secretariat.

DOE's involvement in advanced automotive research dates back to its inception in 1976 and before that in its predecessor agency, the Energy Research and Development Agency. Many elements of DOE's mission are directly relevant to advanced vehicles, especially the goals of improving efficiency of energy use, diversifying energy sources, and improving environmental quality.

DOE's 10 national laboratories are heavily involved in advanced vehicle research and have been encouraged to form Cooperative Research and Development Agreements (CRADAS) with industry and with the U.S. Council for Automotive Research (USCAR) consortia to develop jointly automotive technologies. In these CRADAS, DOE finds the laboratory efforts, while the industry funds its share of the work. A master CRADA has been developed to be the model for all such efforts by PNGV which eliminates the need to renegotiate the terms for each new agreement. Focal areas of DOE research include advanced engine technologies such as gas turbines, hybrid vehicles, alternative fuels, fuel cells, advanced energy storage, and lightweight materials.

DOE has the lion's share of PNGV-related federal R&D with $159 million of the total of $270 million (59 percent) in FY 1995. As noted above, the Office of Transportation Technologies (OTT) programs are the centerpiece of PNGV Major OTT R&D programs are described below.

The **Electric and Hybrid Vehicle Propulsion Program is** the cornerstone of DOE's transportation fuel efficiency research. Established under the Electric and Hybrid Vehicle Research Development, and Demonstration Act of 1976 as amended, this program recently released its 18th annual report to Congress. The three components of this cost-shared program with industry consist of Advanced Battery Systems, Fuel Cell Systems, and Propulsion Systems Development, including hybrid vehicles.

Advanced Battery Systems and High Power Energy Storage Devices. In October 1991, DOE joined with the Big Three and the Electric Power Research Institute to fund the U.S. Advanced Battery Consortium (USABC), a 12-year, 50-50 cost-shared, $260 million program to develop batteries with acceptable energy and power densities for electric and hybrid vehicles. USABC has identified both mid-term and long-term goals for battery performance. As of early 1995, the program involved six industrial contractors and six CRADAs with national laboratories. Three of the development contracts are for batteries that can satisfy the mid-term criteria, and three are for longer term technologies that could make EVS competitive with conventional gasoline-powered cars. In FY 1995, DOE provided $26.9 million to the joint USABC program, as well as $1.8 million for exploratory research on new battery technologies at several national laboratories. Requested finding for FY 1996 is $20 million for USABC and $2 million for exploratory research. The decrease in USABC funds from FY 1995 to FY 1996 reflects a focus on fewer batteries and the completion of mid-term battery development.

In FY 1996, roughly $10 million is requested to let cost-shared contracts through USABC for development of high-power energy storage devices, implementing a program begun in FY 1994. Development contracts for storage devices will be competitively selected among batteries, ultracapacitors, and flywheels. These will be used in hybrid and fuel cell propulsion systems.

Fuel Cell Program. There has been widespread consensus that proton exchange membrane (PEM) fuel cells are the most suitable type for light-duty vehicles, though the best method of supplying the hydrogen needed by the fuel cell is less clear. Currently, the two principal fueling options being explored are: on-board reforming of hydrogen-containing liquids, especially methanol; and on-board storage of hydrogen that is generated externally.[12]

In 1991, DOE contracted with GM's Allison Gas Turbine Division to develop a proof-of-feasibility methanol-fueled PEM fuel cell for light-duty vehicles. The first phase ended in FY 1993 with the testing of a 10 kW fuel cell system. In 1994, DOE signed contracts with teams headed by Ford and Chrysler/Pentastar Electronics to develop fuel cell systems using on-board hydrogen storage.

In parallel, DOE has been supporting a team headed by H-Power to develop a municipal bus powered by 50 kW phosphoric acid fuel cells. DOE is also conducting feasibility studies on fuel cell-powered locomotives.

In FY 1995, DOE was finding fuel cell contracts for light-duty vehicles at $16.1 million, for buses at $2 million, and for locomotives at $1.5 million. Additional exploratory fuel cell research on advanced electrodes and membranes was funded at $3.5 million, conducted at national laboratories such as Los Alamos, Brookhaven, and Lawrence Berkeley. Requested funds for FY 1996 increase to $28 million for light-duty vehicles, and supporting research at national laboratories increases to over $9 million, with level finding for bus and locomotive research. Cost-sharing of contracts by industry is expected to be around 20 percent.

Hybrid Propulsion Systems. DOE has supported hybrid vehicle research for well over a decade. In the late 1970s and early 1980s, General Electric (GE) developed a prototype hybrid vehicle that achieved up to 50 percent improvement in fuel economy compared with a similar conventional vehicle. The vehicle, however, was complicated, heavy, and expensive, and the effort was discontinued in 1984. In addition, in 1984, DOE began a cost-shared contract with Ford and GE to develop modular electric powertrains. Ford fabricated nearly a dozen 56 kW (75 hp) electric drivetrains that were tested in 1994 and inserted in Ford Ecostar vans.

DOE's current program for hybrid vehicles began in FY 1992 and is structured as a five-year, 50 percent cost-shared cooperative program with industry to achieve two-fold fuel economy improvement with low emissions and performance comparable to conventional vehicles. Contracts have been signed with teams, headed by Ford and GM, who are working primarily on series hybrid configurations. DOE finding of $35.4 million was provided for these contracts in FY 1995. In addition, DOE supported $1.5 million in "enabling" technology for hybrids, and $1.3 million for the Hybrid Challenge, a student competition in which university teams build hybrid vehicles that are then tested against one another.

In FY 1996, a finding increase to $52 million is requested for cost-shared hybrid vehicle contracts, which includes contracting with a third development team (from Chrysler) "enabling" R&D increases to $3 million.

12= oxidation of methanol fuel, without reforming, is a long-term option being explored in exploratory research programs.

The **Heat Engine Technologies Program** encompasses both light-duty and heavy-duty engine technologies, including research on turbine engines, automotive piston engines, diesel engines, and supporting combustion and emissions research.

Light-Duty Engine Technologies. DOE's gas turbine research programs have focused on the use of ceramic components to achieve the highest possible operating temperatures (around 2,500 'F) and efficiencies. Whereas early efforts were directed at turbines as the only power source for the vehicle (100 kW), direct drive with turbines is now recognized to be impractical, owing largely to the inefficiency of gas turbines at part load. Nevertheless, the prospect of using a small gas turbine (30 to 50 kW) as the auxiliary power source (operating continuously at high load) in a hybrid vehicle has given the turbine a new lease on life in the automotive context. Current programs, which are managed for DOE by the National Aeronautics and Space Administration, are focused on these scaled-down turbines. Funding in FY 1995 was about $7 million, with a requested increase in FY 1996 to $8.5 million.

In FY 1994, DOE began an effort called the Automotive Piston Engine Technologies program to accelerate the commercialization of lean-bum engines to enable the U.S. auto industry to regain market share from foreign competitors. This program works with industry through 50 percent cost-shared CRADAs with USCAR and other companies in such areas as lean-bum engine catalysts. It was funded in FY 1995 at $3 million, with a FY 1996 request at $4.5 million. In addition, DOE requested new activities in FY 1996 on improved internal combustion engines for hybrids, including spark ignited and compression ignited, for a total of $2 million. Combustion research was requested to increase from $2 million to $3 million in FY 1996.

Heavy Duty Engine Technologies. Although this program focuses on diesels for heavy-duty applications, successful technology will probably be scaled down to light-duty diesels. The program is developing ceramic coatings to allow much higher operating temperatures and pressures, as well as for better performance and reduced fiction in cam rollers, turbochargers, valves, and fuel injectors. Thermal efficiencies of over 50 percent have been demonstrated in truck-sized engines. Funding in FY 1995 was $6 million, requested to stay level in FY 1996.

The **Transportation Materials Program** has two distinct parts: propulsion system materials (primarily ceramics for heat engines) and vehicle system materials (lightweight metals and composites for vehicle bodies):

Propulsion System Materials. The thrust of this program is to develop cost-effective methods for manufacturing ceramic components for heat engines in the near term. During the past 10 years, there have been dramatic improvements in the processing and properties of ceramic materials (especially silicon nitride) for heat engines. So impressive have been these improvements that DOE officials interviewed by OTA feel that processing and reliability problems have been solved, and that the principal remaining challenge is to reduce the cost of ceramic components. Funding for FY 1995 was about $17 million, with a 2 percent increase requested in FY 1996.

Vehicle System Materials. This program seeks to develop lightweight, cost-effective materials for autos, including low-cost carbon fiber composites, as well as advanced alloys of magnesium and aluminum. Some of the work is performed in the national laboratories, and some in cooperation with USCAR's Automotive Materials Program. Funding in FY 1995 was $12 million with a requested increase in FY 1996 to $17 million. Much of the increase would go toward development of improved composite manufacturing technologies.

Related programs that are not part of PNGV include:

Alternative Fuels Utilization Program (AFUP), The Energy Policy Act (EPACT) of 1992 is the major impetus behind DOE's efforts to accelerate the commercial deployment of alternative fuel vehicles (AFVs).[13] EPACT defines AFV acquisition mandates for four major classes of fleets--federal, fuel provider, state, and privat/local fleets. Each has a well-defined schedule for the number or percent of acquisitions that must be AFVs. By FY 1995, about 15,000 AFVs had been purchased for the federal fleet, with 12,500 more purchases planned for FY 1996.[14] AFUP supports two major R&D thrusts--basic research on combustion and emission characteristics of various alternative fuels and demonstration programs of the performance of AFVs in daily use. The fleet test program includes a cross-section of over 2,000 cars, trucks, and buses. In FY 1995, overall finding of $52.6 million was apportioned as follows: AFV procurement subsidy to federal agencies, $20 million; data acquisition $13.2 million; AFV deployment, $9.6 million; engine R&D $7.8 million; atmospheric reactions, $2.0 million.

Pursuant to EPACT Title VI, the AFV deployment budget includes the Infrastructure Development and Demonstration Program, a $2 million, 50 percent cost-shared program with electric utilities and universities to test and evaluate electric and hybrid vehicle components and associated support equipment. The program provides an early market for evaluation of new electric vehicle technology.

Biofuels Research. DOE has a separate effort to develop alternative fuels from biomass, a domestic, renewable source, led by the National Renewable Energy Laboratory. If renewable fuels can be produced at a competitive cost, this would not only reduce U.S. reliance on imported energy, it would also reduce greenhouse gas emissions from the transportation sector. The largest effort in the program is to produce ethanol from agricultural and forestry residues, waste paper, and low-value industrial waste streams. Funding for development of transportation biomass fuels in FY 1995 was $35 million, with a requested increase to $38 million in FY 1996.

Hydrogen Program. Hydrogen is the preferred source of energy for automotive fuel cells. DOE's Hydrogen Program was initiated in the mid-1970s following the OPEC oil embargo and its resultant energy supply shocks. Congress has encouraged additional DOE activity through the Matsunaga Hydrogen Research, Development, and Demonstration Act of 1990, the Clean Air Act Amendments of 1990 (Title IV), and EPACT. The Matsunaga Act required the development of a five-year management plan to develop hydrogen technologies, while the EPACT required DOE to initiate work with industry to produce hydrogen from renewable energy sources and evaluate the feasibility of modifying natural gas pipelines to transport hydrogen and natural gas mixtures. A

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[13] Fuels of interest to the program include electricity, ethanol, hydrogen, methanol, natural gas, and propane.

[14] Executive Office of the President, Office of Management and Budget, *FY96 Budget Highlights* (Washington, DC: [Printing O]ffice, 1995), p. 22.

Hydrogen Technical Advisory Panel has been established to provide oversight of the federal program.

The current DOE hydrogen program is located in the Office of Utility Technologies. The program is a comprehensive effort that involves development of technology for hydrogen production, storage, transport, and utilization. This infrastructure will also be required for the use of hydrogen as a transportation fuel Funding in FY 19 95 was $9.5 million, with a decrease to $7.4 million requested for FY 1996.[15]

Department of Interior (DOI)

Current activities are quite limited (only $495,000 in FY 1995), but include research to improve titanium and aluminum matrix composite casting processes, and recycling strategies for nickel-metal hydride batteries. A budget increase to $2.5 million is proposed for FY 1996.

DOI's Bureau of Mines has developed considerable experience in tracking materials and energy flows through product life cycles. Life-cycle assessment of advanced vehicles and components can help to anticipate problems with raw materials availability, environmental impacts, and recyclability. This includes the worldwide availability of raw materials, environmental impacts of industrial processes, and strategies for recycling of materials. No other agency appears to be ***looking*** seriously at these issues.

Department of Transportation (DOT)

Since 1982, when DOT research on fuel-efficient engines was terminated by the Reagan Administration, DOT has not done significant research on light-duty vehicle propulsion systems. However, DOT's Federal Transit Administration (FTA) has been supporting fuel cell research for transit buses that is likely to be relevant to fuel cell-powered light-duty vehicles. In 1987, FTA initiated a jointly funded program with DOE to develop a fuel cell-powered bus test bed, which was demonstrated in April 1994. The 30-foot bus is powered by a 50 kW phosphoric-acid fuel cell with a nickel cadmium (NiCd) battery that supplies peak power. TWO similar buses are to be tested starting in spring of 1995. FTA's participation in that project has ended (no finds were allocated in FY 1995), but a new project is beginning that is expected to involve 40-foot buses powered by an advanced phosphoric acid or PEM fuel cell.

DOT has designated the National Highway Traffic Safety Administration (NHTSA) as the coordinator for all DOT activities relating to PNGV NHTSA is responsible for conducting safety research and promulgating federal standards for motor vehicles. As such, much of the ongoing research on crashworthy structures, improved restraint systems, rollover protection, biomechanics, crash modeling, and crash avoidance for conventional vehicles is also highly relevant to advanced vehicles. NHTSA's FY 1995 budget request for crashworthiness research

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[15] On February 1, 1995, the House Committee on Science held hearings on H.R. 655, "The Hydrogen Future Act of 1995," which would authorize increases in the Hydrogen Program to $25 million in FY 1996,$35 million in FY 1997, and $40 million in FY 1998.

(including safety systems and biomechanics) contracts was about $10 million, with an equal amount requested for crash avoidance research.

In FY 1996, NHTSA has requested $5 million in PNGV-relevant R&D Of this, $3.5 million will be used to develop computer models to evaluate the crashworthiness of lightweight automotive structures; 1.5 million is requested to study the impact of advanced vehicles on consumers, the U.S. economy, and the U.S. transportation system. NHTSA will administer a congressionally earmarked program involving joint efforts between West Virginia University and its industrial partners to demonstrate the use of advanced materials (e.g., metal foams, composites, and sandwich structures) to improve crashworthiness.

Environmental Protection Agency (EPA)

EPA's main interest in advanced vehicles relates to their emissions, both criteria pollutants such as nitrogen oxides (NO_x) and hydrocarbons, and greenhouse gases. EPA had one Of the earliest R&D programs on advanced propulsion systems, dating back to a program under the Public Health Service in 1971. After the formation of DOE in 1976, the program moved to that agency and evolved into what is now DOE's Office of Transportation Technologies.

There are two current thrusts at EPA relevant to advanced vehicles: one involves cleaner alternative fuels the other seeks to reduce criteria pollutants from highly efficient, hybrid vehicles (those having small ICES engines). The requested increase in EPA's PNGV budget from $7.6 million in FY 1995 to $12.5 million in FY 1996 will go to support the latter thrust. Industry has identified four-stroke, direct injection engine technology as a "gap area" that needs additional federal finding. Reducing the emissions from these engines is a major challenge, especially if the vehicle-operating strategy calls for the engine to be turned on and off repeatedly over the driving cycle (see hybrid discussion in chapter 3).

EPA also has a small program to develop testing and certification standards for electric and hybrid vehicles. This effort in FY 1995 involved less than one full-time equivalent employee, but will probably have to be expanded to provide a solid basis for evaluating these vehicles as they are developed.

National Aeronautics and Space Administration (NASA)

NASA has experience installing many advanced technologies in aircraft and spacecraft that are now being considered for light-duty vehicles. These include components such as gas turbines, fuel cells, lightweight metals and composites, as well as broader system experience with efficient electric power management and optimization of complex systems. A focal point of these technologies is the Lewis Research Center, which has managed the advanced gas turbine program for DOE and fuel cell programs for DOE and DOD.

Recent workshops with U.S. automakers identified several NASA technologies that can be introduced into vehicles in the near term: sensors to measure cylinder pressure and hot exhaust characteristics; insulating and high-temperature ceramics for improved catalytic converters; thermoelectric materials to generate electricity from exhaust heat; and optical inspection technology for cylinder liners. NASA's indicated PNGV-related budget ($5 million in FY 1995 increasing to $7 million in FY 1996) probably understates the amount of R&D that would be of interest to the auto industry.

In the future, NASA plans to launch a significant thrust directed at improved electric drivetrains. The overall concept will include management of the primary power source, energy storage, and power management systems, as well as the development of a high-speed 80-120 kW dynamometer for system development. This is expected to reduce significantly powertrain losses during acceleration and braking transients. The basis for this activity is the NASA technology for space power systems, high-capacity actuators for launch vehicle thrust control, and power-by-wire systems for advanced aircraft. NASA will also lead an industry/government team to conduct tradeoff studies to evaluate candidate concepts and technology that could meet the PNGV 80 mpg goal.

National Science Foundation (NSF)

NSF conducts research on the enabling technologies that may provide the basis for major breakthroughs and advances. NSF identified around $54 million in FY 1995 projects that are related to advanced vehicles, with a requested increase to nearly $57 million in FY 1996. Invariably, however, this research is basic or generic research in areas such as materials synthesis and behavior, engineering, manufacturing, sensors, and computer organization and operation. Although this basic research could be critical in solving such challenges as lubrication of high-temperature ceramic engines, virtually none is targeted on advanced vehicles per se.

Collaborative Private-Sector R&D Activities

United States Council for Automotive Research (USCAR)

Collaborative research among the Big Three has been under way since 1988. USCAR was formed in 1992 to help coordinate administrative and information services for existing and future research consortia aimed at addressing common technological and environmental concerns. USCAR is an umbrella research organization of the Big Three that currently covers 14 research consortia. It is also the administrative coordinator for the industry's participation in PNGV The USCAR consortia support a broad range of research, much which is funded privately. A portion of the research is jointly funded by the federal government, however, and eight CRADAs are in force between USCAR and various national-laboratories. Highlights of the activities of several of the key consortia are described below.

The mission of the ***U.S. Advanced Battery Consortium*** (USABC) is to develop EV batteries that will significantly improve range and performance. Although several battery types are available today (e.g., lead acid and nickel-cadmium), USABC does not believe that they offer sufficient long-range performance potential. As of early 1995, USABC had awarded six major research contracts to develop mid-term (nickel-metal hydride and sodium sulfur) and long-term (lithium iron disulfide and lithium polymer) batteries. USABC is currently funded under a 12-year, $260 million budget that is shared equally between DOE, USCAR and the electric utility industry. DOE finding in FY 1995 was $26.9 million.

The ***Automotive Materials Partnership*** (USAMP), which now includes the former Automotive Composites Consortium, conducts joint research to develop lightweight materials for improved fuel economy. Materials included are: polymer composites; light metals (aluminum, magnesium, titaniu, and metal composites); engineered plastics, cast iron, steel, and ceramics. At this writing, all research on polymer composites had been on the less expensive, but lower performing glass-fiber reinforced materials, rather than the more expensive carbon-fiber materials. Life cycle assessment of materials use is also being investigated under USAMP.

The ***Low Emission Technologies R&D Partnership*** (LEP), in addition to research funded exclusively by the Big Three aimed at such areas as 100,000-mile in-use emission compliance and evaporative emissions control systems, has a number of ongoing projects with the national laboratories on emission control technologies, the largest of which is on the development of a lean NO_x catalyst. LEP is also working with NASA in the areas of advanced sensor technology and thermoelectric materials for generating electricity from exhaust heat.

The activities of the ***Supercomputer Automotive Applications Partnership*** include development of technology to reduce drastically design time through computer visualization, and to analyze crashworthiness, especially for modeling the behavior of composite materials.

The ***Vehicle Recycling Partnership is*** working on recycling technologies for numerous automotive components and materials, and also on strategies for material sorting and identification, as well as material selection and design criteria for improving the recyclability of cars.

Utilities

Suppliers of alternative fuels for alternative vehicles (e.g., natural gas and electricity) have an inherent interest in supporting research, development, and demonstration programs that would expand transportation markets for those fuels. A further incentive is that energy utilities come under the procurement mandates of the Energy Policy Act of 1992, which require that they increase purchases of alternative fuel vehicles for their own fleets. Thus, utilities are assuming a leadership role in fleet demonstration programs and in developing the necessary refueling infrastructure to support wider use of their own fuels.

DOE coordinates 13 institutions participating in the *Site Operator Program,* they are located in various regions of the country, and test electric vehicles under many different conditions of weather, climate, and terrain. In FY 1994, these institutions, which include universities, electric utilities, and military installations, were testing approximately 190 electric vehicles, and more than 40 additional vehicles were on order. Cost sharing of DOE contracts among the site operators is generally more than 90 percent.

The Electric Power Research Institute, which is the principal research arm of the electric utility industry, established the ***Infrastructure Working Committee*** (IWC) in 1991. IWC brings together representatives of the auto industry, utilities, universities, regulators, and others to work in five key areas: establishing standards for safe, efficient electrical connectors and charging stations; addressing health and safety codes (e.g., for ventilation, and electro magnetic field exposure); examining the impact of EVS on load management, power quality, transmission, and distribution systems; educating customers about the EV infrastructure; and developing protocols for communication between the EV and the electric utility during recharging. The Department of Energy works closely with IWC.

In addition, the Electric Vehicle Association of the Americas, the Edison Electric Institute, the Electric Transportation Coalition and the Electric Power Research Institute have jointly initiated the "EV America" program, which seeks to place incrementally as many as 5,000 roadworthy EVS in a controlled market demonstration.

European Union

Several countries in Europe have major programs underway to develop electric and hybrid vehicles as well as their supporting technologies and infrastructure. These include France, Germany, and Sweden. There is considerable cooperation in development activities across national borders among auto manufacturers and suppliers.

The European Union (EU) supports these efforts through precompetitive research programs. Funding is provided primarily through the Framework Program. The nature of precompetitive research is such that the specific programs are of interest to several different industries, which makes it difficult to determine a specific finding level for the auto industry. It is estimated that EU support of technologies of interest to the auto industry was about ECU 100 million ($125 million) in 1994. [16] About 80 percent of the awards support R&D activities; the remaining 20 percent support demonstration projects to create the necessary standards and prove the technologies ready for commercialization.

Auto manufacturers in the European Union have stepped up their collaborative R&D efforts in advanced technology, at least in part as a competitive response to U.S. consortia under USCAR and programs such as the PNGV In May 1994, the European car industry formed the European Council for Automotive Research and Development (EUCAR), a consortium of nine European automakers including Ford of Europe and Adam Opel AG, the German subsidiary of General Motors. EUCAR will facilitate collaborative-research projects (especially on traction batteries)[17] and give the manufacturers a unified voice on matters relating to R&D In June, EUCAR released a proposed "Automotive Research and Technological Development Master Plan" for consideration under the Fourth Framework Program (1994 to 1998). The Master Plan proposes to focus on three areas:

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16 According to the European Union, a significant portion of these monies are spent on such areas as intelligent vehicle technologies and intelligent highway systems.

17 EUCAR Working Group, "Traction Batteries," Second Progress Report, July 1994.

- product-related research on advanced powertrains, materials, and so forth,
- manufacturing technologies to match the new vehicle concepts, and
- the total transport picture, including the integration of the vehicle into a multimodal transport system.

Total finding for the proposed EUCAR program is estimated at ECU 2,430 million over five years, of which about ECU 570 million (about $715 million) is estimated to involve projects of a specifically automotive nature. Although the goals of the Master Plan bear some resemblance to the PNGV goals, the plan describes research that is not so close to the market (with no mention of a timetable for prototype vehicle development, for instance) and broader in scope (encompassing such issues as worker training and broader “sustainable transportation” concerns).

EU officials indicated to OTA that only a fraction of these projects would be funded, and that the primary source of finding would be the five-year Framework IV program, which is currently soliciting proposals. [18]

To stimulate R&D on advanced vehicles using traction batteries, the EU has announced, beginning in 1995, a Task Force called “Car of Tomorrow” that will pursue the following objectives:

- identify research priorities in consultation with industry, including small companies and users,
- ensure coordination among R&D programs of the EU and with other national and international initiatives, and
- encourage the use of additional financial resources (e.g., venture capital) for advanced automotive R&D

France

France is considered by many observers to be a promising market for advanced vehicles, particularly EVs. One official cited three reasons that France, as opposed to the United States in general (and California in particular), offers greater market opportunities for EVs: more compact urban areas result in shorter commute distances; 90 percent of electricity generation in France is nuclear or hydro, so that power plant emissions associated with EV use are low; and gasoline is expensive. [19]

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[18] Awards are expected to be made during the period April through June 1995.

[19] Jean-Yves Helmer, Executive Vice President, Peugot Citroen, memorandum distributed at a press conference in Anaheim, CA, Dec. 2, 1994.

Government-Funded Programs

Active interest of French automakers in electric and hybrid vehicles dates back to the late 1960s. It is estimated that support of battery and fuel cell research by the French government has exceeded $35 million to date.[20] As in Germany (see below), much of French government finding for advanced vehicles supports EV demonstration programs and infrastructure development.

In July of 1992, an agreement was signed by government officials, Electricite de France (EDF), and two major automobile groups (Renault and PSA Peugeot) to develop supporting infrastructure for EVs and equip at least 10 battery charging sites by 1995.[21] In 1993, La Rochelle, a city of 120,000 on the Atlantic coast, became the first often cities to participate in a two-year EV demonstration program. Fifty vehicles are involved in the Phase 1 La Rochelle trial. The project envisions providing 20 to 50 EVs and supporting infrastructure to each participating city, along with vehicle financing and driver training. PSA Peugeot Citroen is manufacturing the vehicles for the La Rochelle site. EDF is actively involved in the program.[22]

The city of Paris and EDF formed a partnership in 1993 to promote the use of EVs in Paris.[23] Paris, with approximately 1,000 EVs in use, has installed 50 municipal recharge stations throughout the city, and plans to have 200 by the end of 1995. The city of Paris and EDF have committed to acquiring EVs for their vehicle fleets and hope to have as many as 260 in operation during 1995. The combined cost of the project to the two partners is estimated at around FFR $48 million ($1O million).

Industry R&D

The PSA Group (Peugeot and Citroen) have developed an EV city car they claim could be in production (with a subsidy from the French government) by the end of the decade. The price difference between the electric and gasoline versions of the Peugeot 106 (assuming production volumes of 10,000 units) is estimated to be $4,000 to 5,000, not including the batteries. Peugeot also announced plans to convert 10,000 gasoline-powered vans to electric power.

Renault is also active in the development of EVs It has delivered EVs to Sweden for participation in its three-city demonstration project and hopes to launch an electric version of the Clio in 1996 with annual production of 1,000 units. It is cooperating with Matra in the development of a purpose-built EV.[24] EDF operates approximately 500 EVs primarily small vans.

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[20] U.S. General Accounting Office, *Electric Vehicles: Likely Consequences of U.S. and Other Nations' Programs and Policies,* GAO/PEMD-95-7(ashington, DC: December 1994), p. 69.

[21] Ibid, p. 65.

[22] Noel Bureau, "Electric Peugeot 106 and Citroen AX Vehicles in Customers' Hands in La Rochelle," *The 12th International Electric Vehicle Symposium (EVS-12),* vol. 1, (San Francisco, CA: Electric Vehicle Association of the Americas, 1994), pp. 11-17; P.Beguin and C. Peyiere, 'Gearing Up for Industrial Production of Peugeot 106 and Citroen AX Electric Models," *The 12th International Electric Vehicle* Symposium *(EVS*-12), vol. 1, (San Francisco, CA: Electric Vehicle Association of the Americas, 1994), pp. 111-115; and C.A. Bleijs et al., "Analysis of the Results Obtained with EDFs Electric Fleet and the La Rochelle Program," *The 12th International Electric Vehicle Symposium (EVS-12),* vol. 1, (San Francisco, CA: Electric Vehicle Association of the Americas, 1994), pp. 171-180.

[23] Patrick LeFebvre and Jean-Paul Camous, 'A Partnership in Paris for the Development of the Electric Vehicle," *The 12th International Electric Vehicle Symposium (EVS-12), vol. 2, (San* Francisco, CA: Electric Vehicle Association of the Americas, 1994), pp. 247-256.

[24] That is, a vehicle designed "fire the ground up" to be an EV, not just a converted gasoline-fueled vehicle.

Germany

Government-Funded Programs

Contemporary research in Germany on EVs began in 1971.[25] By 1978, a fleet of 140 electric vans were in operation, supported by thirteen battery transfer stations. At present, there are about 4,000 to 5,000 EVs on the road in Germany.[26] Government financial support of advanced battery research since 1974 has exceeded DM 97.5 million ($66 million), and support of fuel cell research to date has exceeded DM 35 million ($24 million).[27]

Recently the German government has concentrated on supporting projects that seek to demonstrate and evaluate EVs.[28] Three major programs are currently underway. The most important is a four-year EV demonstration and evaluation program on the island of Rugen. The project began in October 1992, and aims to test EV performance under a full range of driving conditions. It is ultimately expected to involve 60 vehicles. The German government is providing half of the estimated budget of DM 40 to 50 million ($23 to $30 million). A second program, dubbed Project Telecom, is expected to last three years and involve forty electric and hybrid vehicles.[29] Finally, the German Postal Service began a two year test of 20 to 25 zinc-air battery vehicles and their supporting infrastructure. In December 1994, it was announced that an additional 50 vehicles would be purchased and that the test program would be extended through 1996. The budget for the Postal Service Test is about DM 25 million ($18 million).[30]

In Germany, EVs are free from taxes for five years, but otherwise receive little direct support at the national level.[31] However, some local regions are actively supporting them. For example, Bavaria and Baden subsidize as much as 30 percent of the purchase price of EVs.

Industry R&D

German automakers have been investigating advanced vehicle concepts for more than 20 years. Volkswagen alone has built and tested over 400 electric and hybrid vehicles. German automakers can take credit for some remarkable achievements. For example, in 1994, Daimler Benz announced the development of a prototype van powered by a PEM fuel cell, the result of an R&D investment reportedly over $lbillion. Also in 1994, VW's Audi division marketed the A8, a luxury car featuring a novel aluminum space frame design, the result of a 10-year development effort with Alcoa.

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25 U.S. Department of Energy, *Electric and Hybrid Vehicle Program: The Second Annual Report to Congress for Fiscal Year 1978, DOEICS-0068* (Washington DC: January 1979), p. 60.

26 Dietrich Naunin, "Survey on the Drive Systems, Battery Technology, Charging and Infrastructure Systems for German Electric Vehicles," *The 12th international Electric Vehicle Symposium, (EVS-12), vol. 2,* (San Francisco, CA: Electric Vehicle Association of the Americas, 1994), pp. 768-776.

27 Ibid.

28 U.S. General Accounting Office, see footnote 20, p. 72.

29 Ibid, pp. 63-65.

30 Yehuda Harats et al., "Electric Fuel and the Deutche Bundespont Postdienst: A Joint EV Demonstration Program," *The 12th International Electric Vehicle Symposium (EVS-12)*, vol. 2, (San Francisco, CA: Electric Vehicle Association of the Americas, 1994), pp. 226-235.

31 U.S. General Accounting Office, see footnote 20, p. 47.

In May 1994, OTA staff visited four German automakers: Volkswagen, BMW, Porsche, and Mercedes Benz, and one supplier, Robert Bosch, to discuss advanced vehicle R&D Some of the results are illuminating. There was uniform optimism about the future of direct-injection diesel engines, which can achieve a 40 percent increase in fuel efficiency compared to current gasoline engines. Considerable skepticism was expressed, however, about the ability of pure electric and hybrid vehicles to meet the performance and cost expectations of consumers. Although some German automakers have designed advanced vehicles from the ground up (e.g., BMW's E-1 electric car), most prototypes involve conversions from production gasoline or diesel vehicles with batteries and electric motors added. This approach reduces financial risk, while enabling companies to test alternative concepts.

Sweden

Government-Funded R&D

Swedish government support for contemporary research on electric and hybrid vehicles began in the mid 1970s. Owing to concerns about the performance and range of pure EVs the Swedish research program has primarily focused on hybrids. The Swedish National Board for Industrial and Technical Development (NUTEK) and the Swedish Transport and Communications Research Board (KFB) have begun three complementary electric and hybrid vehicle programs.[32] These are:

1. Beginning in 1993, a six year electric and hybrid vehicle research program funded by NUTEK with an annual budget for the first three years of $1 million.

2. A four-year KFB-led electric and hybrid vehicle demonstration program with government finding of $16 million and matching finds from participants.

3. A technology procurement program was established in 1992 by NUTEK to create demand pull for electric and hybrid vehicles. In 1994, two purchasing groups formulated specifications for vehicle performance and price. Eight to 10 prototypes are to be delivered in 1995 for evaluation. Members have committed to purchase 220 vehicles, if their specifications are met.

The three largest cities in Sweden (Stockholm, Gothenburg, and Mamlo) have EV and hybrid demonstration projects under way. Major participants include Renault, Volvo, the national government, and regional electric power producers. The city of Gothenburg has taken the lead with its "Start" Project, involving 10 vehicles and at least one electric charging station, funded at $1.25 million per year. Recently, KBF has signed four-year agreements with Gothenburg and Mamlo that will enable them to deploy a wider variety of vehicles and to increase each of their electric and hybrid vehicle fleets to more than 50 vehicles.[33]

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[32] B. Essle and A. Lewald, "Swedish National Programs for Electric and Hybrid Electric Vehicles," *The 12th International Electric Vehicle Sympo.m @J&12)*, vol. 1, (San Francisco, CA: Electric Vehicle Association of the America% 1994), pp. 698-706.

[33] Ibid.

Industry R&D

In 1992, Volvo unveiled its Environmental Concept Car, which used a gas turbine with an electric drivetrain. More recently, it has announced plans to market a hybrid electric vehicle in the United States in 1997 or 1998. The hybrid will be based on its 850 sedan using a four-cylinder gasoline engine, and will meet California ULEV requirements. The vehicle is expected to cost 30 percent more than a gasoline vehicle of comparable performance, have 25 percent better fuel efficiency, and have a range of more than 160 miles.[34]

Japan

Government-Funded Programs

The major ongoing Japanese government/industry collaborative programs relevant to advanced vehicle R&D are shown in table 5-4. Japan was the first country to pursue the development of electric vehicles through a collaborative research program. MITI's Agency for Industrial Science and Technology launched a modest program with Japanese manufacturers to advance the state of the art of EVs that ran from 1971 to 1977, with total finding of $19 million. The program did not develop any successful vehicles, but did lead to improved EV components. A follow-on 10-year program to promote EVs intended to have 250,000 on-road and off-road EVs in the fleet by 1986, but actually only 1,200 on-road and 10,000 off-road vehicles (mostly golf carts) were produced in that year.

Under the recently launched New Sunshine Program, an umbrella for MITI's ongoing energy programs, are several R&D programs relevant to advanced vehicles. The "Eco-Station 2000" program intends to convert 2,000 Japanese service stations (of a total 60,000 stations) into "Eco-Stations" by the year 2000. Eco-Stations will provide motorists with access to a range of alternative fuels including methanol and natural gas, as well as electric charging facilities. The program is funded at a total of 3.66 billion yen FY 1993 to 1995), and there are currently several Eco-Stations established in the Kanto, Chubu, and Kinki areas.

Another collaborative MITI program, the Dispersed-Type Battery Energy Storage Technology program which runs from 1992 to 2001 with total finding of 14 billion yen, aims to develop long-life lithium batteries for small-scale load-leveling systems for home use and high-energy density lithium batteries for EVs

MITI's New Energy and Industrial Technology Development Organization has supported research on PEM fuel cells from 1992 to 1995, aimed at development of 1 kW modules. Funding is reported at an annual average of 200 million yen. The program involved eight companies, including Sanyo, Fuji, Mitsubishi, Toshiba, and Asahi Glass.[35] A follow-up program is now being planned, with the goal of developing PEM stacks in the tens of kW range. Industry sources interviewed by OTA stressed that, although the Japanese PEM program got a slow start, it is

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[34] Jack Keebler, "Volvo Hybrid EV Slated for U.S. Sale," *Automotive News*, Dec. 19, 1994, p. 43.

[35] Kenneth Dircks, Ballard Power Systems, personal communication, Apr. 19, 1995.

rapidly catching up to North American programs and PEM fuel cells are being actively developed and tested by some of the most powerful companies in Japan.

Japan has also had a massive fuel cell development program aimed at energy production since 1981, with cumulative finding of 61.4 billion yen (1981 to 1995). These fuel cells, including molten carbonate, solid oxide, and phosphoric acid electrolytes, are intended for electric power generation plants and are not directly applicable to vehicles, but industry sources interviewed by OTA suggested that the experience gained from these investments should be applicable to development of automotive PEM fuel cells.

MITI has also been supporting ceramic gas turbine development in a program from 1988 to 1996, funded at 16 billion yen. The turbines, however, are 300 kW units intended for electric power generators, not automobiles. Numerous past ceramic technology programs, together with private industry investments, have given Japanese companies the most advanced ceramic capability in the world. For example, the best ceramic turbocharger rotors, widely considered to be the closest analog of automotive ceramic gas turbine rotors, are made by Japanese companies such as Kyocera, NGK Insulators, and NGK Sparkplug.

Industry Programs

Japanese auto manufacturers have been involved in research on electric vehicles for more than 20 years. Nevertheless, OTA's interviews with the automakers suggested that much of this work had been put on the back burner owing to continuing problems with traction battery performance and doubts about the broad consumer appeal of EVs This attitude changed, however, with the adoption of California's zero emission vehicle (ZEV) regulations. Currently, all of the major Japanese manufacturers (often in collaboration with electric utilities) have developed electric cars in anticipation of the California ZEV regulations that go into effect beginning in 1998. Nevertheless, these efforts may fairly be described as defensive. The automakers appear to believe that many of the environmental and energy efficiency concerns with current ICE cars can be solved by improvements to ICES and intelligent vehicle-highway systems, rather than by resorting to exotic technologies such as EVs hybrids, and fuel cells. Thus far, the Japanese industry has not been inclined to develop collaborative R&D programs that rival USCAR and PNGV

OTA staff visited with engineers from Honda, Nissan, Toyota, and Mitsubishi in Japan to discuss advanced automotive R&D Despite the fact that the Japanese government has sponsored research in the past, and Japanese companies have in-house research programs on advanced technologies, it appeared clear that much of this work had been allowed to lapse until the California ZEV regulations revived their EV programs.

Japanese companies agreed with OTA staff conclusions that substantial improvements in fuel economy are possible through lightweighting and more aerodynamic design, but thought some of the gains projected in OTA's scenarios were too optimistic (for example, one company suggested that maximum weight reduction with aluminum would be 24 percent of curb weight, while OTA projects that a **30** percent reduction is possible), Like the German automakers, the Japanese were skeptical about the future cost and performance characteristics of traction batteries for EVs and about the fuel efficiency potential of hybrids. In contrast to the Europeans, the Japanese companies appeared relatively uninterested in compression-ignited (diesel) engines for passenger cars. They have, moreover, aggressive programs to introduce cleaner and more efficient spark-ignited engine technologies such as lightweight aluminum lean-bum engines and lean NO_x catalysts. Actually, recent model Toyotas and Hondas using conventional engines are poised to meet California's ultralow emission vehicles (ULEV) standards in 1998, which is an achievement that could undermine the desirability of more expensive vehicles that bum "cleaner" alternative fuels such as alcohols and natural gas.

ANALYSIS OF ADVANCED AUTOMOTIVE R&D PROGRAMS

U.S. Competitive Status in Advanced Automotive Technologies

"Leapfrog" Technologies

All of the world's major auto manufacturers began investigating electric and hybrid vehicle technologies during the late 1960s and early 1970s. Over the years, each manufacturer has developed and tested prototype EVs and hybrids with varying design configurations, and there have been some notable achievements. Mercedes Benz has deployed a prototype fuel cell-powered van. General Motors has developed the Impact, a prototype EV sports car that goes from zero to 60 mph in eight seconds. If current plans hold, Volvo will be the first manufacturer to offer a gasoline engine/electric drive hybrid car in the United States in 1997 or 1998.

Despite significant improvements in the cost and performance of advanced vehicle technologies, though, automakers interviewed by OTA remain skeptical about the ability of leapfrog vehicles to compete with steadily improving conventional vehicles in the near term, at least without government subsidies. For example, Volvo's hybrid is expected to cost 30 percent more than a comparable conventional vehicle, and have a range of only 160 miles.[36] Japanese manufacturers credit the California ZEV mandates with forcing the revival of R&D on EVs that had been allowed to lapse.

Despite the problems with the federal R&D programs discussed above, the U.S. R&D effort on leapfrog automotive technologies appears to be more comprehensive in both scope and content than similar efforts in other industrialized countries. No other country has collaborative R&D organizations comparable to USCAR the DOE national laboratories, and PNGV nor the regulatory aggressiveness of California's (and potentially several northeastern states') ZEV regulations. Using the PNGV secretariat's budget estimate of $270 million in FY 1996--no other government comes within a factor of two of these levels. While other countries have specific areas of relative strength (e.g., the Japanese industry's expertise in advanced ceramics and a growing

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[36] Keebler, see footnote 34.

fuel cell effort), a continuation of the more comprehensive U.S. approach is likely to put U.S. companies in a strong position technologically. Whether this technological lead will be translated into early commercialization in the United States will depend on government policies as well as the way in which the vehicles perform and how much they cost relative to steadily improving conventional vehicles of the same generation.

"Advanced Conventional" Technologies

The U.S. car industry's competitive position in "advanced conventional" automotive technologies--those that promise significant but evolutionary improvements in fuel efficiency and reduced emissions--does not appear to be as strong. For example, German automakers have developed advanced, direct injection diesel engines that offer a 40 percent increase in fuel efficiency, while reducing the noise, vibration and particulate emissions that formerly have been associated with diesels. A significant fraction of new passenger car sales in Germany are diesel-powered, whereas diesel passenger cars have disappeared from the U.S. market. In OTA's view, if NO_x emissions from these engines can be reduced through the use of improved catalysts, diesel-powered cars could make a comeback in the U.S. market. Based on their experience with building small, efficient diesels for passenger cars, European automakers may also be in an excellent position to exploit the use of compact diesel powerplamts in hybrid electric vehicles. This is a promising option currently being evaluated by the PNGV partners.

Japanese manufacturers apparently believe they can achieve many of the benefits of leapfrog technologies through evolutionary improvement in conventional technologies, at much lower cost. One example is the lean-bum gasoline engine (see previous chapters), which offers fuel efficiency improvements of 10 percent at relatively low cost. This has been a technology targeted by Japanese manufacturers, especially Honda. If NO_x emissions from lean-bum engines can be reduced through catalysts or other means, these vehicles will be able to meet California's ULEV standards. To date, no U.S. automaker has announced its intention to market a lean-bum engine vehicle.

Another "advanced conventional" technology that can improve fuel economy is the use of lightweight aluminum instead of steel in the vehicle structure. This is another case where some foreign manufacturers have been more aggressive than U.S. automakers, at least in introducing actual production vehicles. In 1991, Honda introduced its aluminum-intensive sports car, the NSX. In 1994, Audi (working with Alcoa) unveiled the A8 luxury coupe, which has an innovative aluminum space frame structure. Although neither of these vehicles is particularly lightweight (or cheap), they demonstrate a near-term technology that could be used for fuel efficiency gains.

These examples are not offered to suggest that U.S. automakers are ignoring these technological opportunities. Rather, they reflect differences in automakers' assessments of the cost-effectiveness of these technologies, given current fuel prices and consumer preferences in the United States. In fact, the Big Three have extensive in-house research programs on lean NO_x catalysts, and will build direct injection diesels for the European market through their subsidiaries in Europe. Furthermore, Federal finding for compact diesels, lean NO_x catalysts, and aluminum manufacturing technologies is requested to increase substantially in the FY 1996 budget (see below). The principal lesson from this experience for leapfrog technologies is that even when the feasibility of these technologies is proven, commercialization will depend on the manufacturers' judgments of cost effectiveness and market acceptance.

U.S. R&D Program

The U.S. R&D program for leapfrog automotive technologies is technologically diversified and includes a mix of near term and long-range options. For example, batteries, ultracapacitors, and flywheels are being researched in parallel as energy storage devices, as are gas turbines, diesels, and advanced gasoline engines for hybrid powerplants. Near term prospects, such as advanced lead acid traction batteries and aluminum body structures, are being investigated, along with longer term technologies such as fuel cells and advanced composites. At this writing, it is very uncertain which powertrains, drive systems, body designs, and materials will combine to give the best package of cost and performance in advanced light duty vehicles of the future. Indeed, depending on the desired vehicle function, location, and driving conditions (e.g., fleet or private, cold or warm climate, urban or rural), different combinations of technologies may be most appropriate. The federal R&D program is conscious of these uncertainties, and is structured to pursue several options in parallel, so as not to pick a timer prematurely.

The current research program involves a large number of participants, including eight government agencies, the national laboratories, and the Big Three and their suppliers and contractors. Government officials interviewed by OTA noted that mechanisms such as the Interagency Hybrid and Electric Vehicle Task Force, PNGV technical meetings, and ARPA-sponsored meetings of regional consortia were stimulating an unprecedented level of information sharing. Industry officials also expressed satisfaction with the new climate for collaborative research and noted enthusiastic cooperation from the agencies and laboratories with which they were associated. Industry cost-sharing of government contracts is growing, ranging from 50 percent or more for nearer term technologies (e.g., piston engines for hybrids) to around 15 to 20 percent for longer term technologies (e.g., fuel cells).

Key Budgetary Changes in FY 1996

FY 1996 is significant because it is the first real opportunity for the PNGV program to influence the budget priorities of the participating federal agencies. Table 5-5 gives a summary of some of the larger budget changes requested in FY 1996 for the agency programs discussed above. In the analysis section below, the impact of these proposed changes is assessed.

As might be anticipated, the largest increases in FY 1996 are in DOE's Electric and Hybrid Vehicle Program, the cornerstone of the PNGV effort; specifically, in high-power energy-storage devices, fuel cells, and hybrid systems. Small piston engines and turbines for hybrids are requested for a significant increase at DOE, as are materials for lightweight vehicles; however, hybrid vehicle and composite materials programs in NIST and ARPA may confront large cuts.

The priorities reflected in the federal budget request for FY 1996 appear generally consistent with the results of OTA's technical analysis, presented in previous chapters. Research needs identified by OTA including the need for more cost-effective ceramic and composite manufacturing processes, improved high-power energy-storage systems, and cost reduction of fuel cell systems, are all targeted for increases by DOE.[37] The opportunity noted by OTA for using a small, efficient direct injection diesel in a hybrid vehicle is also part of additional finding requested by DOE in FY 1996, and the challenge of reducing the emissions from these vehicles is being addressed by EPA.

The finding priorities also tend to support recent statements by observers of PNGV that the most likely configuration of the PNGV prototype vehicle is a hybrid, powered in the near term by a piston engine, and in the longer term perhaps by a fuel cell. Funding for advanced battery research is steady or declining, while there are significant increases for contracts on power storage devices, hybrid systems (including a new hybrid development team at Chrysler), and fuel cells. Interestingly, while two out of three of DOE's fuel-cell contracts (with Ford and Chrysler) call for on-board storage of hydrogen fuel the budget request for DOE's Hydrogen Research and Technology Program is down by 22 percent from FY 1995.

R&D Areas Likely to Require Increased Support

By its own acknowledgment, PNGV is a technology development program focused primarily on component and vehicle hardware to achieve its 80 mpg goal. At this stage, less attention is being given to several issues--including safety, infrastructure, standards development, and life-cycle materials management--that must be addressed before successful commercialization of an advanced vehicle. In each of these areas, the private-sector role is dominant, but government also has an important role to play. The result is that, as the initial hardware problems with advanced vehicles are solved, substantial additional federal resources will have to be allocated to address these issues.

safety. Advanced vehicles raise numerous new safety concerns stemming from both their lightweight structures and exotic propulsion systems. These include the lack of experience with crash behavior of complex new vehicle designs and composite materials, as well as the question of how safety regulations may have to be modified to account for a fleet that contains a mixture of heavier conventional steel vehicles and lighter aluminum or composite vehicles.

In addition advanced propulsion systems will also introduce new safety concerns. Advanced batteries may pose new safety risks, not only from their large mass, but also owing to corrosive electrolytes, toxic materials, high operating- temperatures, and potential for electric shock of passengers.[38] Flywheel power-storage devices that must spin at many tens of thousands of revolutions per minute pose obvious risks in crash situations. The manufacture, transport, servicing, and disposal of these materials and components raise additional safety issues.

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[37] Note, however, that the contemplated cuts in NIST's Advanced Technology Program and ARPA's Electric and Hybrid Vehicle program hit some research areas, such as composites manufacturingg, particularly hard. If these programs are eliminated, they will more than offset proposed increases by DOE in composites processing finding.

[38] An overview of in-vehicle safety issues for electric vehicles can be found in J. Mark, National Renewable Energy Laboratory, "Environmental, Health, and Safety Issues of Sodium-Sulfur Batteries for Electric and Hybrid Vehicles, Volume IV: In-Vehicle Safety," NREL/TP-463-4952, November 1992.

Of course, the primary responsibility--and liability--for vehicle safety lies with the automakers. Government, however, has the responsibility to understand the issues and set appropriate safety peformance standards. NHTSA, under the Department of Commerce, is responsible for safety regulations for motor vehicles. NHTSA has received comments on new and amended Federal Motor Vehicle Safety Standards collected under an Advanced Notice of Proposed Rulemaking, but has not drafted any final rules. NHTSA has determined that EVs should comply with the intent or purpose of all existing standards," although it recognizes the need to modify existing regulations that apply to ICE vehicles as appropriate.

DOE's National Renewable Energy Laboratory (NREL) has conducted a number of studies on EV safety issues,[39] and since 1990 has chaired the Ad Hoc EV Battery Readiness Working Group, a government/industry advisory body.[40] While NREL and the Working Group have made a good start, much remains to be done. Examples include: the need for better data from a more extensive testing and demonstration program; developing "systems" approaches to EV safety (as opposed to battery or component-oriented approaches); comprehensive risk assessment to place particular risks in perspective; and the need to broaden the focus to include additional technologies, such as flywheels and ultracapacitors.

As discussed in the section on crashworthiness of vehicle materials and structures, preliminary tests have demonstrated that vehicles made of aluminum and polymer composites can meet safety standards. Designers and regulators, however, do not currently have the tools to predict accurately the behavior of these advanced vehicle structures in crash situations, especially for composites. In FY 1996, NHTSA has requested $3.5 million to model the crashworthiness of advanced, lightweight vehicles. Much more experience with the crash behavior of these materials is likely to be required before designers and regulators develop the confidence they currently have in steel.

Infrastructure. Advanced vehicles cannot operate in a vacuum; they require a supporting infrastructure comparable to the existing conventional vehicle infrastructure. As used here, infrastructure refers not only to fuel production, distribution, storage, and transfer to the vehicle, but also to manufacturing issues such as materials availability, manufacturing expertise, and capabilities for servicing, repair, and recycling vehicles.

Depending on the specific vehicle design, fuel and structural materials, this infrastructure could look very different from those of today, although a major transformation of the infrastructure will not occur rapidly. It is more likely that advanced vehicles for the mass market will be designed to function within the existing infrastructure--at least initially--than that the massive petroleum-based fuel infrastructure will be changed to accommodate new vehicle technologies.[41] Eventually, vehicle technologies and supporting infrastructure may evolve together incrementally into new forms.

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39 Studies have included safety issues associated with shipping, in-vehicle safety, and recycling/disposal of a number of EV battery types, including sodium sulfur, nickel-metal hydride, lithium polymer, and lithium ion.

40 C.J. Hammel, Engineering Society of Detroit, "Electric Vehicle Environmental, Health, and Safety Program and Battery Readiness Working Group," January 1994.

41 Examples would be hybrids that can run On dual fuels such as gasoline and methanol, or fuelcells that run on reformed gasoline or diesel fuel

The current federal R&D program focuses almost exclusively on developing advanced vehicles; at most, a few million dollars--perhaps 1 percent of the hardware budget--has been set aside for infrastructure considerations. DOE has a $2 million program to work with the electric utility industry to develop infrastructure for EVs and finding for studies to determine infrrastructure needs for fuel cell vehicles has been requested in FY 1996.

There are undoubtedly many reasons for the lack of federal attention to infrastructure issues. One is the chicken-or-egg problem: it is risky to invest in infrastructure development for vehicles whose numbers and requirements are not yet clearly defined. Another has been the belief that the private sector has the responsibility for infrastructure development. A third reason has been a lack of follow-through on the part of government. For example, although $40 million was authorized by Congress in the Energy Policy Act of 1992 for electric vehicle infrastructure development and demonstration programs, no money was ever appropriated.

U.S. experience with programs aimed at promoting the use of alternatively fueled vehicles has shown that the lack of a convenient refueling infrastructure is a critical constraint. The infrastructure issue is certain to constrain advanced vehicle development as well. Ultimately, the cost of developing a national infrastructure for advanced vehicles is the responsibility of fuel providers and the automakers. Experience with AFV programs, however, has shown that the government has an important role to play in such areas as national standards development, federal fleet procurement, coordinating with states and localities to ensure an adequate concentration of vehicles in a given area, demonstration programs, and so forth. As the technological uncertainties of advanced vehicles are resolved, the federal government will have to pay increased attention to this area to ensure the national availability and reliability of infrastructure to support these vehicles.

Standards. Today's light-duty vehicle fleet is largely uniform in terms of the structural materials and propulsion system technologies. Although there are slight variations among models--such as in their use of plastics or size of engine, for the most part the fleet is composed of steel vehicles using gasoline internal combustion engines. The standards and specifications for these materials and engines are well established.

With the prospect of a fleet of vehicles made of exotic structural materials, mix-and-match powertrains, operation algorithms, and alternative fuels and fueling systems, manufacturers, consumers and regulators must each be assured of the safety, reliability, and performance of these vehicles and subsystems. This is certain to -become a critical area of government involvement (along with standards organizations and private companies) for complex new vehicle technologies. Standards associated with crashworthiness and infrastructure have already been mentioned above. In addition, however, much more work will be needed in the areas of vehicle testing, component testing, and material testing. With an increasingly global automobile industry, harmonization of U.S. standards with international standards is also essential.

Again, the primary responsibility for development of these standards will be private-sector organizations such as the Society of Automotive Engineers. The government, however, must also be able to set such standards as are necessary to fulfill its regulatory functions (examples include emissions testing standards, fuel economy standards, and standard procedures for handling emergency situations).

As one example, emissions testing of hybrid vehicles presents a complex problem. Depending on the relative sizes of the engine and battery (or other energy storage device), the control algorithm that determines when the power sources turn on and off, and the fuel type, the emissions from the hybrid over the test cycle may range from zero to a significant level. How the test procedures are established and how emissions limits are set could have a major impact on what kinds of hybrids are produced as well as their cost. Yet, EPA currently has less than one full time equivalent employee working on this problem. In the future, important roles can be seen for NIST (for materials and manufacturing standards), EPA (for environmental performance standards), DOE (for component testing and certification standards, and refueling standards), and NHTSA (for safety standards).

Life Cycle Materials Flows. Light-weight vehicles with advanced powertrains will utilize a very different set of materials than do current autos. Because the auto industry is such a prodigious user of materials, any significant change would have wide-ranging ramifications for the entire life cycle of materials use, from extraction of raw materials to final disposal. As one example, if 10 percent of all new vehicles sold in California in 2003 are electric vehicles, and most of these use advanced lead acid batteries, the auto industry's demand for lead will increase significantly. While the lead mining industry may be able to handle the increased demand, a significant impact is expected on the battery-recycling industry. In fact, significant increases can be expected in releases of lead residues to the environment from battery-recycling processes.[42] To the extent that battery recycling facilities are not located in California, the net effect of the California ZEV regulations would be to "export" lead pollution to other states where recycling is performed. Similar life-cycle impacts on the economy and environment may result from use of other advanced materials in other propulsion systems or structural components.

DOE conducted some studies of materials flows associated with battery EV's in the early 1980s.[43] These appeared to concentrate primarily on questions of materials availability, rather than environmental impacts on the entire materials cycle. These studies must be updated to reflect modem technologies and regulations. The Department of the Interior Bureau of Mines has developed considerable expertise in recent years in the areas of life-cycle materials flows, and might be an effective agency for preliminary studies.

Future Role of Federal R&D Programs

At this writing, Congress is debating the appropriate federal and private-sector roles in supporting scientific research and technology development across a broad range of areas. Advanced vehicle R&D and especially the joint public/private partnership concept of PNGV is part of that debate. Below, OTA discusses several issues that Congress should consider in its deliberations.

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42 Lester Lave et d., "Environmental Implication of Electric Cars," *Science, vol. 268,* May 19, 1995, p. 993.

43 See, for example, U.S. Department of Energy, "Electric and Hybrid Vehicle Program: First Annual Report to Congress," December 1977, p. 29.

Issue 1: Should Congress continue to support advanced vehicle K&WY

During the past 20 years, government policies at the federal and state levels have been the principal drivers for leapfrog vehicle development. Auto manufacturers and their suppliers are anxious not to be blindsided by new technologies, but have had little market incentive to invest in developing leapfrog technologies on their own.[44] The rationale for this government involvement has been that the benefits offered by these vehicles--improved air quality, enhanced U.S. energy security--are social benefits that do not command higher prices in the marketplace.

Government policies to stimulate advanced vehicle R&D have been of two types: "carrots" such as R&D contracts or procurement subsidies for advanced vehicles; and "sticks" such as higher regulatory standards for emissions control and fuel economy. Regardless of one's view of California's ZEV regulations, for instance, it is undeniable that they have stimulated extensive research on batteries and fuel cells that would not have occurred in their absence. In addition numerous small, entrepreneurial companies producing small numbers of electric vehicles and fuel cell prototypes are dependent on the ZEV regulations for their continued existence. The automakers, however, have fought bitterly against these regulatory mandates, claiming that they are forcing technologies into the marketplace before they are ready.

This lack of market demand for advanced vehicles seems unlikely to change in the foreseeable future, absent a major oil price shock or other unforeseen developments. With real gasoline prices at historic lows and urban air quality improving, car buyers care more about such attributes as good acceleration performance and carrying capacity than about increased fuel economy and reduced emissions. This is especially true if these attributes carry a higher price, as OTA's analysis suggests. Thus, if government wishes to continue to pursue the goal of superefficient vehicles, it will likely need to continue its involvement, whether through R&D finding, mandates, or other incentives.

*Issue 2: Is **the federal advanced vehicle R&D effort coherent and consistent with national needs?***

Government policies toward advanced vehicles have been driven by a diverse set of concerns, including the desire to improve urban air quality, reduce oil imports and, more recently, to avoid global climate change. This diverse set of concerns has led to a patchwork of legislation and programs that attempt to address the concerns through different technical and economic approaches. The result has been a federal effort that has been poorly coordinated and that lacks clearly defined relationships to national needs.

Traditionally, for example, R&D on controlling vehicle emissions to address air quality issues such as those addressed in the Clean Air Act have been the province of EPA, while R&D on improving fuel economy to address energy security issues has been the province of DOE.

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[44] Historically, industry cost-sharing on government R&D contracts to develop risky, long-term technologies (e.g., gas turbines, fuel cells) has generally been less than 20 percent. In some recent programs, such as the DOE R&D contracts with the automakers on advanced batteries and hybrid vehicles, industry cost-sharing is around 50 percent.

Although fuel economy and emissions characteristics are closely related in actual vehicle operation, R&D programs at EPA and DOE have not been well coordinated.

Many other examples might be cited. During the past 20 years, finding for R&D programs such as DOE's Electric and Hybrid Vehicle Program has fluctuated wildly, making it impossible to sustain a coherent effort to develop hybrid vehicles. And, although Congress outlined clear goals for bringing alternatively fueled vehicles into the fleet in the Energy Policy Act of 1992, federal tax policies favor some fuels at the expense of others, without regard for the fuels' relative energy content or desirability from an environmental point of view.

PNGV is clearly an attempt to address some of these issues, by coordinating government and industry R&D efforts toward achieving commonly accepted goals; principally, the development of an **80** mpg prototype vehicle by 2004. Nevertheless, the 80 mpg target appears to have been chosen more for the technological innovations that will be required than for any direct relationship to national goals for reduced oil imports or reduced greenhouse gas emissions. Although a superefficient vehicle would clearly contribute greatly to these goals, little thought has apparently been given about whether the 80 mpg target is the most cost-effective approach. For example, the same amount of imported oil might be displaced more cheaply through a combination of a 50 mpg target with a more aggressive alternative fuels program.

The point here is not that a high fuel economy target is wrong, but that appropriate planning and analysis are lacking that would enable an evaluation of the entire federal R&D program in the context of broader national goals for air quality, energy security, and reduced potential for global climate change. This analysis becomes especially important in a tight budget environment in which PNGV-inspired R&D programs may be competing with other continuing programs (e.g., alternative fuels heavy-duty vehicle research) for the same resources.

Issue 3: ***Is the federal R&D relationship with industry structured to encourage maximum innovation?***

There is an ongoing debate about how federal R&D funding can best catalyze the emergence of advanced vehicle technologies. On the one hand, there are advantages to supporting work by the major automakers and their suppliers, since the automakers are in a position to commercialize rapidly a successful innovation in mass-market vehicles. On the other hand, many observers are concerned that federal efforts to develop leapfrog vehicle technologies rely too heavily on the existing industry, which they argue has a considerable stake in maintaining the status quo. In their view, more agile small and medium sized companies are best able to commercialize novel technologies, particularly in niche markets that initially maybe too small to attract the attention of the major automakers.

OTA's investigations for this study suggest that many small and medium-size U.S. companies have developed innovative advanced vehicle technologies not currently being displayed by the automakers.[45] Most of these companies recognize that successful commercialization of these innovations will require working in concert with a large company in the industry. The automakers

[45] Examples include superior regenerative braking systems and thermal management systems to enhance EV battery capacity in cold climates.

for their part recognize that small entrepreneurial companies have important contributions to make in solving the many challenging problems. These considerations suggest that the federal advanced vehicle R&D program should maintain a balance between small and large company participation to ensure the most successful outcome.

Traditionally, DOE advanced vehicle technology programs have worked primarily with large companies--defense contractors, automotive suppliers, or the Big Three themselves. To the extent that small or medium-size companies have participated, it has generally been as part of a subcontractor team. CRADA agreements with federal labs are also difficult for small companies to participate in, owing to the 50 percent cost sharing requirements. PNGV which is structured to work as a partnership under the leadership of the Big Three, seems likely to reinforce the large company orientation of the federal effort.[46]

Recently, other government programs, such as NIST's Advanced Technology Program, and ARPA's Electric and Hybrid Vehicle Program and Technology Reinvestment Project have begun to provide significant finding to contractors outside the traditional auto industry, especially to small and medium-sized companies. The Administration, however, has requested no finding for EHV in FY 1996, and substantial cuts in TRP and ATP are being debated in Congress. If these cuts are made as threatened, the federal program would become even more dependent than it currently is on the traditional industry.

Conclusions

The 20-year plus federal involvement with advanced vehicle R&D provides an important perspective on current efforts to commercialize advanced automotive technologies. First, from the earliest days of these programs, the amount of time that would be required to commercialize advanced vehicle technologies was severely underestimated. For example, according to a projection made in the first annual report to Congress of DOE's Electric and Hybrid Vehicle Program, dated December 1977: "The technology of electric and hybrid vehicles is such that . . . advanced vehicles with advanced energy storage systems are not likely to appear before the early to mid-1980 s." In fact, many of the technical challenges cited in those early reports, such as battery energy storage capacity, power density, and lifetime continue to be major challenges today.

Although most of the technologies involved in advanced vehicles (batteries, flywheels, motors and controllers) have received government finding for decades, this funding has been highly variable,[47] and only in the last five years has there been a concerted attempt by both the auto industry and government to develop viable commercial vehicles. Thus, although the technologies are by no means "new," we still have little experience with the way they perform as an integrated system in on-the-road vehicles, or with rapid, cost-effective manufacturing processes. At this

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[46] The PNGV steering committee has recognized the need to find ways to bring innovative ideas from entrepreneur and small companies into the program, and has published a document titled "Inventions Needed for PNGV."

[47] For example funding for DOE's Electric and Hybrid Vehicle program roae to a peak of $37.5 million in 1979, but dropped to $8.4 million in 1985. By 1995, it had risen again to about $90 million.

writing, government finding for advanced vehicle R&D appears once again poised for a downturn owing to budget cuts. PNGV has begun to define the R&D priorities for some of these technologies, particularly for hybrid vehicles; however, it will be difficult, if not impossible, to address these priorities and solve the many remaining problems without sustained, and even increased, finding.

BOX 5-1: DOE's Electric and Hybrid Vehicle Program

DOE funding rose rapidly from startup in 1976 to a peak of $37.5 million in 1980. During this period, several prototype vehicles were constructed that established the "state of the art." General Electric developed a hybrid prototype vehicle with Volkswagen and the Jet Propulsion Laboratory. GE also developed a battery EV prototype with Chrysler. In the early 1980s, however, government and industry interest in the program began to wane, owing to three factors-the Reagan Administration's negative attitude toward what it viewed as government intervention in private-sector activities; a rapid decline in energy costs; and economic recession.[1] By FY 1995, program funding reached a low of $8.4 million. After cuts forced the elimination of government loan guarantees, small companies dropped out of the program, and after testing the GE vehicle, the hybrid development activity was shelved.

Most of the activity during the mid-1980s involved battery and electric drivetrain development (e.g., transistorized motor controllers, induction motors) with Ford, GE, and Eaton. Cost-sharing in the contracts by industry was generally from 10 to 20 percent, reflecting the high risk of these technologies as perceived by industry. Following the passage of the California Low Emission Vehicle program regulations in 1991, however, and the establishment of the U.S. Advanced Battery Consortium in the same year, government and industry funding turned a corner. The Big Three, which had made only a modest investment in advanced technologies during the 1980s, were forced to become more actively involved. A new five-year hybrid development program began in 1992, and fuel cell vehicle development contracts were negotiated with each of the Big Three. DOE funding for the Electric and Hybrid Vehicle program rose to about $90 million in FY 1995, with industry cost-sharing as much as 50 percent.

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[1] Ken Barber, Department of Energy Office of Transportation Technologies, personal communication, May 15, 1995.

BOX *5-2:* The Partnership for a New Generation of Vehicles PNGV

PNGV was conceived as a model government/industry research program that would provide a template for government/industry cooperation in other industries in the future. The program combines a "stretch" goal (up to a threefold increase in fuel economy) with a clear timetable for achieving it (10 years).

Considerable care was taken to define clearly both government and industry roles in the partnership. The federal role in PNGV is to provide resources for technology development from relevant defense work and from the national laboratories, particularly for the longer term goal 3. PNGV research is to be jointly funded by industry and the federal government, with industry funding proportionally greater for near-term, low-risk projects (goals 1 and 2), and federal funding greater in long-term, high-risk areas (goal 3). Industry will shoulder increasing responsibility for goal 3 as the program nears the concept vehicle and production prototype stages. In the first two years of the program, cumulative federal funding is estimated at around $500 million, with $200 million contributed by private industry. ' Over the 10 years, it is expected that government and industry spending on the program will be about equal.

The Big Three manufacturers were given a leadership role in resource allocation decisions, particularly in regard to the commercial viability of various technologies. This was consciously done to correct the government-led model that characterized federally funded automotive R&D previously, in hopes that the prototype vehicles that emerge from the program will be commercially attractive.

PNGV is directed jointly by a government and an industry steering group. The government group consists of representatives of the eight participating agencies (Departments of Commerce, Defense, Interior, Transportation, Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation) and other executive branch organizations, chaired by the under secretary of commerce for technology. The industry group is led by the vice presidents for research of the Big Three auto manufacturers, together with a representative of the U.S. Council for Automotive Research (USCAR)--the umbrella organization under which joint research is conducted by the Big Three (see below). Separate technical task forces have also been organized on both the government and industry side.

PNGV released its first Program Plan in July 1994, outlining its organizational structure and plans. At the invitation of DOC, the National Research Council formed a review committee to evaluate PNGV and its first report was released in November 1994.[2] The report found that PNGV had made a good start, but that many issues (especially in project management) would have to be resolved if the program were to succeed.

The existence and structure of the PNGV program raise some important issues for policymakers. For some, PNGV represents a classic "technology push" approach that attempts to develop technology and then find a market for it. According to this view, the government involvement will waste both public and private funds in an attempt to skew the production of cars toward characteristics that are not demanded by consumers. A second type of criticism, heard from some small companies and environmental groups, is that PNGV is skewed too heavily toward the existing industry--that the technologies are promising, but that the Big Three cannot be expected to wholeheartedly pursue new technologies that undermine their extensive investments in internal combustion engines and installed plant and equipment. In this view, the central role of the Big Three crowds out smaller, more innovative companies that are not constrained by the baggage of existing investments.

PNGV's 10-year time frame for goal 3 is also a source of potential concern. This timetable has advantages in providing a concrete target and structure for the program. The 1997 date for beginning technology selection for the prototype will, however, exclude promising longer term technologies that could contribute to goal 3 (such as composites and fuel cells) but which, according to OTA's analysis, will not be available in this time frame. If these technologies are excluded from subsequent PNGV funding on that basis, long term efforts to improve fuel economy may be harmed. Finally, what will happen after 2004 is unclear. Participation in PNGV involves no commitment on the part of the Big Three to produce commercially any vehicles that result from the research.

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[1] "Clinton Budget Boosts Clean-Car Funding 23%," *Automotive News, Feb.* 13, 1995, P- 8.

[2] National Research Council, Research *Program of the Partnership for a New Generation of Vehicles,* (National Academy Press, Washington, *DC: 1994).*

BOX *5-3:* Federal Spending on Advanced Auto R&D

The federal government conducts a wide range of R&D that is relevant to advanced vehicles, from basic science to vehicle deployment programs. This makes it difficult to define precisely a total budget for automotive R&D The federal R&D effort can be described by analogy to an onion. At the core of the onion are projects that are clearly related to advanced vehicles; an example would be DOE's Electric and Hybrid Vehicle Program (see below). As one moves away from the core, successive layers include projects that are less and less closely identified with vehicles per se.

One of the first initiatives of PNGV **was** to conduct an inventory of **all** federal R&D that might be relevant to PNGV goals.[1] All eight federal agencies involved were asked to nominate projects that relate to 14 technology areas judged by PNGV to be critical to achieving its goals. Although the general technology areas were specified, however, no common criteria were given for the agencies to determine which program to include or exclude. As a result, different agencies used different criteria, and sometimes the criteria changed in subsequent rounds of the inventory. For example, DOD projected an increase in funding for PNGV-relevant projects from FY 1995 to FY 1996 (from $24 million to $42 million); however, this "increase" did ***not*** involve increased R&D activity, but instead the inclusion of a number of ongoing projects in FY 1996 that had been excluded in the FY 1995 inventory.[2]

In early agency responses to the inventory effort, the agencies listed both "directly relevant" research, as well as "indirectly relevant, or "supporting" research. An example of supporting research might be the National Institute of Standards and Technology's project on ceramic machining, which is intended to develop cost-effective techniques for machining ceramics within specified tolerances. These techniques eventually might be used to machine ceramic gas turbine rotors to their final dimensions, or they might be used for very precise ceramic spray painting nozzles or ball bearings. Funding for such basic research cannot be accurately allocated 100 percent to advanced vehicles, as it serves much broader purposes.

Typically, the agencies reported spending four or five times as much on "supporting" research as on "direct" research. Yet, this supporting research is not currently included in the budget totals for PNGV In addition, many vehicle-related federal programs are also excluded from the PNGV budget because they are not considered part of PNGV's scope. PNGV defines itself as being concerned only with the rolling stock-that is, not with infrastructure, policy, marketing, or other "systems" considerations. Thus, DOE's battery electric vehicle program, its alternative fuels fleet demonstration program, its biofuels research program, and its hydrogen technology development program are not generally included *in* PNGV even though the results of these efforts could have a direct impact on the commercialization of a PNGV prototype vehicle. Depending on one's point of view, total federal spending on R&D relevant to advanced vehicles could fall anywhere in the range of about $170 million to $500 million.

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1 The inventory process is being repeated and improved.

2 According to information supplied by the PNGV Secretariat in the Department of Commerce.

TABLE 5-1: Key Legislation Affecting Automotive Research and Development

Title	Public law number	Major provisions	Comments
Clean Air Act Amendments of 1966	PL 89-675	Provides Department of Housing, Education, and Welfare (HEW) funding to support the development of technologies to assist in improving air quality.	Legislative history emphasizes that a balanced research program is to be followed regarding automobile-related air pollution, including supporting research to develop cleaner internal combustion engine-powered vehicles and the development of electric vehicles.
Clean Air Act Amendments of 1970	PL 91-604	Provides the secretary of HEW with the authority to set and enforce national air quality standards, including for automotive emission control, motor vehicle testing and certifications, and for automotive and other fuels	Directs the secretary to test, as he deems appropriate, any new motor vehicle or engine as it comes off the assembly line to determine whether it conforms to applicable standards, and to conduct R&D activities with respect to low-cost instrumentation techniques to facilitate the measuring of automotive emissions.
Energy Reorganization Act of 1974	PL 93-48	Gives Energy Research and Development Agency (ERDA) responsibility for accelerating the commercialization of electric and hybrid vehicles.	Responsibility for this was transferred to DOE under the Department of Energy Reorganization Act of 1977, PL 95-91.
Non-Nuclear Energy R&D Act of 1974	PL 93-577	instructs ERDA in Sec. 6.(3)(A)(iii) to advance energy conservation technologies in the near term through “improvements in automobile design for increased efficiency and lowered emissions, including investigation of the full range of alternatives to the internal combustion engine . . .“	ERDA initiated a near-term Electric Vehicle Program.
Electric and Hybrid Vehicles Research, Development and Demonstration Act of 1976	PL 94-413	Authorizes Department of Energy (DOE) to, *inter alia*, “encourage and support accelerated research into, and development of, electric and hybrid vehicle technologies. ”	Launched DOE’s Electric and Hybrid Vehicle Program. Subsequently amended by PL 95-238.
Department of Energy Act of 1978 --Civil Applications.	PL 95-238	Directs the Department of Energy to undertake research and development of new automotive propulsion systems to achieve improved fuel economy, which can be adapted to various alternative fuels.	Amended PL 94A13. Launched DOE’s Automotive Technology Development Program, which currently consists of two major engine-related projects: (1) the Advanced Turbine Technology Applications Project and (2) the Heavy-Duty Transport Project. [n addition, basic ceramic materials and alternative fuels technologies for all engine projects are being developed under the Advanced Materials Development Project and the Alternative Fuels Utilization Program.

Alternative Motor Fuels Act of 1988	PL 100-494	Directs DOE to prepare studies on alternative motor fuels such as methanol, ethanol, and natural gas, and established Interagency Commission on Alternative Motor Fuels to coordinate federal activities and report to Congress.	Relies mainly on plarming, information exchange, and coordination, rather than mandates, to encourage production of alternative fuels.
Clean Air Act Amendments of 1990	PL 101-549	Provides increased standards for vehicle emissions. Phase 1 standards were to be implemented in 1993. Phase 2 standards, which reduce acceptable emissions to half of their 1993 levels, are to be implemented in 2003.	Phase 1 standards were achievable with 1990 technology for most vehicles. It was recognized at the time that further R&D would be required to meet Phase 2 standards.
Energy Policy Act of 1992	PL 102-486	Directs secretary of DOE to determine feasibility of replacing 10 percent of petroleum fuels with alternative fuels by 2000 and at least 30 percent by 2010. Mandates a schedule for purchase of AFVs by public and private fleets. Section 1913 provides a 10 percent tax credit (up to $4,000) for electric vehicles. Title VI authorizes up to $50 million for electric and electric hybrid vehicle demonstrations between 1993 and 2002, as well as $40 million for electric vehicle infrastructure development between 1993 and 1997.	Target schedule for acquisition of AFVS considered very difficult to meet, and costs and benefits are uncertain.

SOURCE: Office of Technology Assessment, 1995.

TABLE 5-2: PNGV-Related FY 1995 Appropriations by Technical Area and Agency ($ millions)

Technical area	DOC[a]	DOD[b]	DOE	DOI	DOT	EPA[c]	NASA	NSF	TOTAL
Lightweight materials	6.83	7.03	47.42	0.50				19.24	81.02
Energy conversion			70.47			2.75		0.85	74.07
Energy storage	0.04		0.47			2.00		2.69	5.20
Effi[illegible]		1.20					1.00	15.41	17.61
Exhaust energy recovery			1.04				0.20		1.24
Analysis and design methods	1.50	1.89	2.71				2.20	1.85	11.24
Reduction of mechanical losses	0.25							25	50
Aero and rolling improvements			0.78						0 8
Advanced manufacturing	10.46	2.75	23.64					4 6	4 46
Improved internal combustion	0.58	11.02	7.04			2 90	0 25	3 02	24 8
Emissions control			3.78				35	2 0	20
Fuel prep, delivery, storage								0.15	0.15
Efficient heating, cooling, etc.			0.50					2.81	3.31
Crashworthiness								0.14	0.14
TOTAL	10.66	23.08	158.85	0.50	0.00	7.65	5.00	54.09	269.73

[a]In addition to the base of $19.7 million, DOC through the National Institute of Standards and Technology's Advanced Technology Program has selected relevant projects with requested funding of $30.1 million. Contracts are not yet in place for these selected proposals.
[b]DOD numbers are based on program personnel contact and are still tentative.
[c]EPA numbers still in discussion.

NOTE: Numbers indicated in the table are specific to PNGV and identified as such. DOT program personnel indicate that an additional $20 million each year is spent on R&D related to PNGV with dual purpose; in FY96, $1 million of the $20 million will be targeted specifically for PNGV.

KEY: DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; DOI = Department of the Interior; DOT = Department of Transportation; EPA = Environmental Protection Agency; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; PNGV = Partnership for a New Generation of Vehicles; R&D = research and development.

SOURCE: PNGV Secretariat.

TABLE 5-3: Regional R&D Consortia Supported by the Advanced Research Projects Agency (ARPA)

Consortium	Members	Activities	Comments
Hawaii Electric Vehicle Demonstration Project	24 members including companies, university% utilities, and local government.	Developing technology and infrastructure for electric cars and buses.	Began in 1993 with $5 million from ARPA, matched by local sources.
Calstart	Over 100 members including GM, defense and electronic companies, small companies, utilities, universities, and local government.	Technology development for electric, hybrid, and natural gas vehicles and infrastructure.	Has operated more than 15 technology programs, with a budget of over $60 million--mostly private funding sources.
Sacramento Electric transportation Consortium	Over 30 members led by the Sacramento Municipal Utility District and local Air Force installations.	Development of "dual use" advanced vehicle technologies, including flywheels and fuel cells.	Joint finding from ARPA and local sources.
Electricore, the Mid-America Electric Vehicle Consortium	Over 36 groups from 17 states, including GM subsidiaries.	Electric vehicle (EV) development and deployment, including a strong emphasis on public awareness.	Joint projects over $18 million, cost-shared by ARPA and local sources.
Southern Coalition for Advanced Transportation	Over 45 utilities, universities, and manufacturers.	Development of advanced EV technologies for civilian and military vehicles, including rapid charging,	Joint projects over $24 million, including EV fleet for 1996 Olympics in Atlanta.
Northeast Alternative Vehicle Consortium	Over 60 organizations, led by defense-oriented companies.	Technology development, cost studies.	Begun in 1993, now has more than $25 million in joint projects.
Mid-Atlantic Regional Consortium for Advanced Vehicles	Organizations in 7 states.	Development of high efficiency EV components.	Newest consortium.

SOURCE: Advanced Research Projects Agency, "Progress Report," vol. 1, No. 1, Winter 1994.

Table 5-4: Government-Funded Advanced Automotive R&D in Japan

Agency	Project	Comment
MIT/New Sunshine Program	Fuel cell power-generation Technology	R&D on many fuel cell types including some 700 million yen for 1 kW proton exchange membrane modules (1992-1995).
	Ceramic gas turbine	1988-1996 at about 1.8 billion yen per year; focus is on 300 kW turbines for power generation, though past public and private R&D have given Japan the lead in automotive ceramics.
	Dispersed-type battery energy storage technology	1992-2001, with total funding of 14 billion yen, focus is on high-energy-density, long-life batteries for stationary or vehicle applications.
	Lean NO_x catalysts	1993-2000, to develop better catalyst compositions to remove NO_x from the exhaust of lean-bum engines. Japan is a world leader in this technology.
	Hydrogen energy system	1993-2020, currently in planning stages, includes R&D on use of hydrogen for all stationary and mobile needs.
MITI/JEVA	Electric vehicle (EV) popularization	5-year program begun in 1992, total funding is 1.1 billion yen. The goal is to demonstrate optimum load-leveling measures and charging systems for the mass introduction of EVs
MITI/Agency of Natural Resources and Energy	Eco-Station *2000*	1993-2000, goal is to have a nationwide network of 2,000 refueling stations with multiple alternate fuels by the year *2000.*

SOURCE: Office of Technology Assessment, 1995.

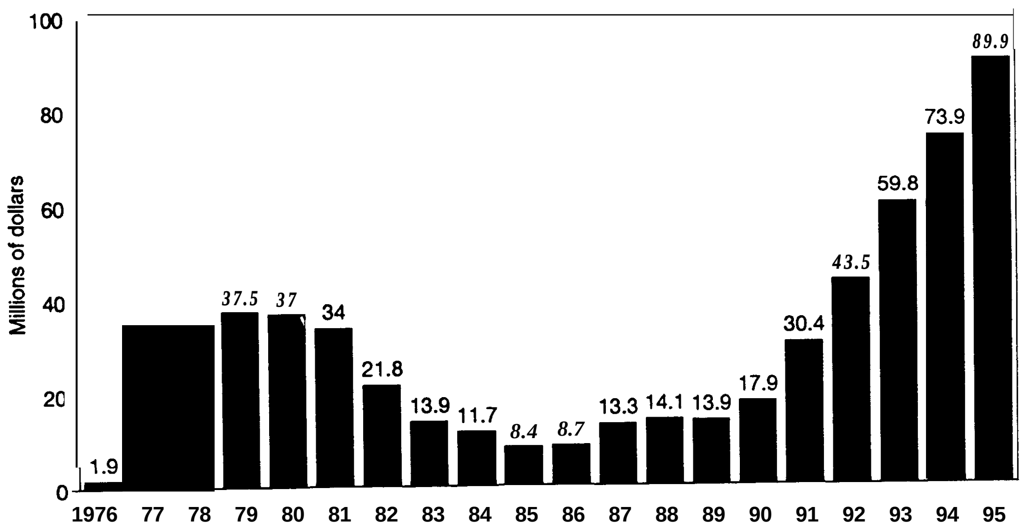
TABLE 5-5: PNGV Budgetary Changes in FY 1996

Agency/program	R&D area	FY 1996 dollars in millions, requested change (in percent)	Comments
DOC/NIST/ATP	8 new projects on composite manufacturing initiated in FY 1995.	-lo *(50%)*	Requested budget does not include an expected $30 million in new auto-related contracts to be negotiated in FY 1996. However, funding for ATP is controversial in Congress, and substantial cuts have been proposed.
DOD/ARPA/EHV	Hybrid and electric vehicle development	-15 (loo%)	Congressional add-on to ARPA budget in FY 1993, provides funds to seven regional consortia including small businesses. Funding zeroed out in President's FY 19% budget request.
DOD/ARPA/TRP	Advanced vehicle drivetrains	?	Supports development of "dual use" technologies; focus area on vehicle drivetrains designated in FY 1995. Funding for TRP is controversial in Congress, and large cuts have been proposed.
DOE/OTT/material technology	Composite and light metal manufacturing processes, recycling, and crashworthiness	+5 (42%)	Joint work with USAMP and national laboratories.
DOE/OTT/heat engine technologies	Develop gas turbine, spark-ignited piston, and diesel engines as hybrid vehicle APUs	+6 (48%)	Cost-shared work with industry, national labs.
DOE/OTT/electric and hybrid propulsion	Battery and other energy storage device development	+3 (lo%)	A $9 million increase for power storage devices for hybrids is offset by a $6 million decrease for advanced batteries.
DOE/OTT/electric and hybrid propulsion	Automotive fuel cell development	+19 (84%)	Increase equally divided between 15 percent cost-shared contracts with Big Three, and enabling research at national labs.
DOE/OTT/electric and hybrid propulsion	Hybrid vehicle development	+17 (45%)	Adds a third contractor team to existing teams at Ford and General Motors (presumably at Chrysler).
DOE/UT/hydrogen research and development	Production, storage, distribution, and conversion of hydrogen as fuel	-2 (22%)	Reduction comes from stretch-out of joint industry/lab efforts on near-term natural gas reforming and storage system.
EPA	Reducing emissions from four-stroke, direct-injection engines	+5 (65%)	Addresses a key problem with hybrids.

KEY: APUs = auxiliary power unit; ARPA = Advanced Research Projects Agency; ATP = Advanced Technology Program; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; EHV = Electric and Hybrid Vehicle program; EPA = Environmental Protection Agency; NIST = National Institute of Standards and Technology; OTT = DOE's Office of Transportation Technologies; TRP = Technology Reinvestment Project; USAMP = U.S. Advanced Materials Partnership; UT = DOE's Office of Utility Technologies.

SOURCE: Office of Technology Assessment, 1995; and U.S. Department of Energy, FY1996 ***Congressional*** Budget ***Request,*** vol. 4, DOE/CR-0030 (Washington, DC: February 1995).

Figure 5-1: DOE Electric and Hybrid Vehicle Program Budget History, FY 1976-95



SOURCE: Ken Barber, Department of Energy, personal communication, May 1995.