# 1.0 Program Overview

The Program Performance & Accountability Framework (PPAF) shown in Figure 1-1 is a visual representation of the relationships between critical components of program planning. The PPAF is intended to assist personnel in understanding the relative positions and linkages between program planning components. This tool will be used to explain the various components of the FreedomCAR and Vehicle Technologies (FCVT) Program and their relationships. The PPAF visually lays out the mission, vision, performance goals, strategic goals, outputs, and outcomes of the Program. The PPAF also delineates between aspects for which the Program is accountable (through performance measurement) and those that are outside of the Program's control.

**PPAF**

| | Accountable | Not Accountable |
|---|---|---|
| Endstate | Mission | Vision |
| Planning | Performance Goals | Strategic Goals |
| Results | Outputs | Outcomes |

**Figure 1-1.** The Program Performance & Accountability Framework

Internal processes (mission, goals, and outputs) for which the Program can be held accountable are shown in the left column. External processes (vision, strategic goals, and outcomes) that are part of the Program's planning processes but for which the Program is not ultimately accountable are shown in the right column. Although desirable outcomes, strategic goals, and vision are defined by the Program based upon its internal processes, accomplishment of these is dependent upon other factors such as business commercialization decisions and is outside the Program's control. In addition, the PPAF shows how outputs align with the mission and performance goals, while outcomes align with the vision and strategic goals. The framework also displays parallels between the mission and vision, performance goals and strategic goals, and outputs and outcomes.

The PPAF will be used throughout Section 1 and Section 2. The area(s) shaded in yellow will indicate the aspect covered in the corresponding subsection.

## 1.1 External Assessment and Market Overview

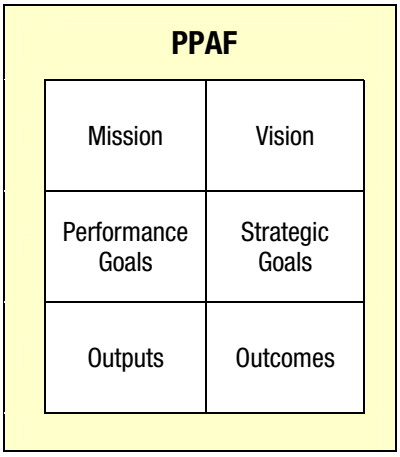



**Figure 1-2.** Section 1.1, External Assessment and Market Overview

### Current and Potential Market

The United States faces a host of global and national challenges at the beginning of the 21st Century. Our nation's energy security is largely dependent on the efficiency of and fuel choices made for its transportation system. The transportation sector significantly influences the nation's economic and environmental wellbeing. As Figure 1-3 shows, the transportation sector consumes more oil than is produced domestically. In fact, highway vehicles alone use more petroleum products than our country produces, and as energy use for transportation continues to grow, the situation will only worsen. Another part of the challenge is keeping our environment healthy. Transportation accounts for over 30 percent of all greenhouse gas emissions, for over 80 percent of carbon monoxide emissions, for over 55 percent of nitrogen oxide emissions, and for over 40 percent of volatile organic compound emissions. The motor vehicle, for all of its obvious benefits, is a major contributor to these challenges. Removing the energy and environmental impact of the motor vehicle can result in significant progress on each of these fronts.

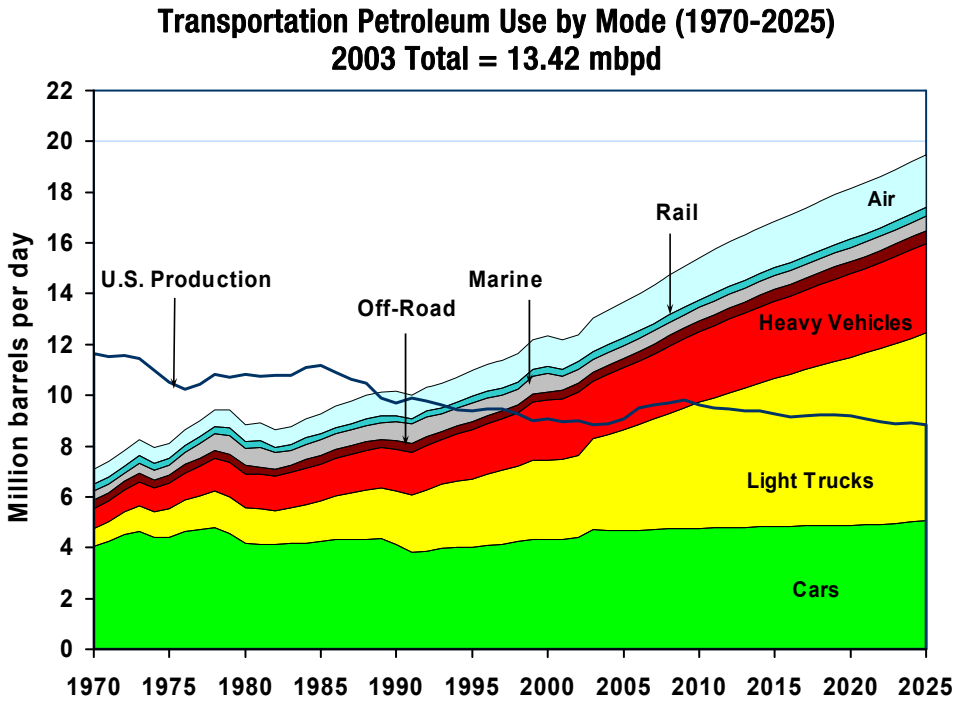
### International Environment

Domestic oil production has been steadily declining for over two decades, and oil imports are expected to reach 70 percent of all oil consumed in the United States by 2025. Oil imports have been a growing problem because petroleum resources are distant from most of the world's consumers and unevenly distributed globally. Because of this, oil imports impact our energy and economic security. Not only is the U.S. oil demand growing, but global demand, (as indicated by vehicle registration growth in Figure 1-4), in both industrialized and developing countries is increasing rapidly. Particularly in countries such as China and India, the growth of motor vehicles is far outpacing that of the United States.

Worldwide petroleum depletion and environmental impacts must be faced with the international community. Energy security and local air pollution must be addressed largely within the United States.

### Competing Technologies

The advanced transportation technologies being developed by FCVT are competing with the cars and trucks already on the road today. The technologies that go into these vehicles are known; they are reliable, dependable and have a reasonable, 15 year service life. The components current vehicles are manufactured with have been developed and refined for over 100 years.




**Note:** The sharp increase in values between 2003 and 2004 are caused by the data change from historical to projected values.
**Source:** Transportation Energy Data Book: Edition 24, ORNL-6973, December 2004, and EIA Annual Energy Outlook 2005, February 2005.

**Figure 1-3.** The Historical Ad Projected Oil Consumption by Transportation Sector and U.S. Oil Production

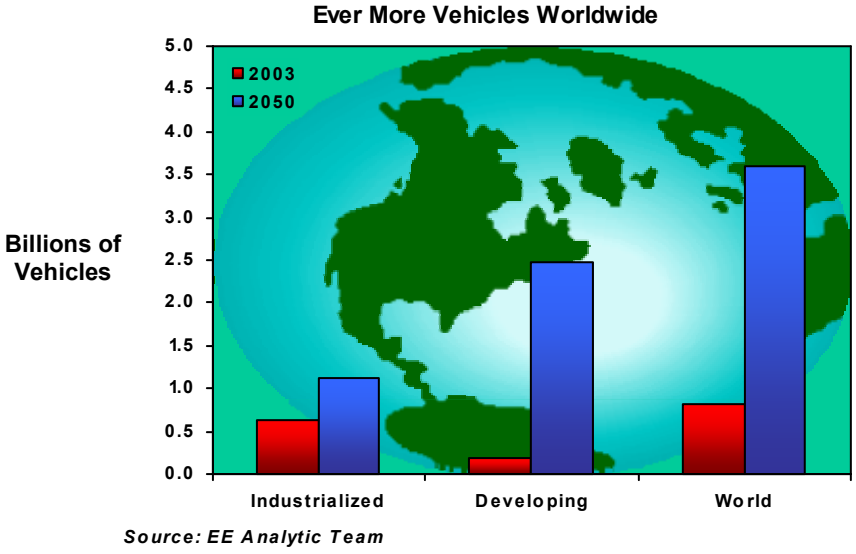



**Figure 1-4.** Motor vehicle registration growth

**Market Barriers at the Program Level**

Many technical and economic barriers exist for affordable, mass-produced, high-fuel-economy vehicles, including fuel cell hybrid automobiles fueled by hydrogen. In addition to technology barriers, market barriers must be addressed. Too often, research projects result in a technology success, but never impact the economy or our energy efficiency because the market barriers were not factored into the planning. Within the transportation industry, key market barriers include a lack of market drivers, price, risk aversion, and lack of infrastructure.

Due to the fluctuation of energy prices, there is a lack of consistent market drivers. The market incentives are not yet sufficient to drive vehicle manufacturers to make the high investments necessary to develop and produce new energy saving technology. In many cases, consumers have insufficient knowledge about the new technology – often to the point that the consumer is not aware that an energy-efficient technology is even available. A minority of consumers can be classified as "early adopters", but market acceptance of technologies that are revolutionary rather than evolutionary is generally very limited. In addition, consumers have become accustomed to the performance of today's technologies and expect the same performance attributes in alternative technologies. An energy-efficient technology may meet consumers' needs, but it must also meet their expectations to be accepted.

Another market barrier is the price that industry and the market establish for energy-efficient technologies. Instead of scaling up production, suppliers would rather maintain higher profitability per unit. Thus energy-efficient technologies penetrate higher margin vehicles, but will not benefit from economies of scale and become available in all vehicle segments. Markets other than highway transportation may place a higher value on the technology. Developing a low cost lightweight material for the automotive industry could easily result in the aircraft industry monopolizing the material and none of it getting into highway vehicles. The value of the lightweight material in an aircraft is one to two orders of magnitude greater than its value in an automobile. As an example, if low cost ($3/lb) carbon fiber for automotive applications also meets the performance requirements for aircraft applications where the selling price maybe $35/lb, the supplier may choose to sell its product to the aircraft industry at something less than $35/lb, but at a margin considerably greater than he would receive from the auto industry. Energy-efficient technologies may have a lower life cycle cost, but the initial price paid by the consumer is likely to be higher. Many consumers are not willing to pay more for an alternative technology, even when that technology will save them money over the life of the product.

There are several pathways within the highway vehicle market that products may take in getting to the consumer. These various pathways have different profit margins. For example, dealer-installed options provide a higher profit than factory-installed options. An original equipment manufacturer (OEM) may offer an option that enhances energy efficiency. But if it is comparably priced to a nearly equivalent,

but less efficient dealer installed option, the dealer is more likely to choose the product that provides him with the greater margin.

Manufacturers' and consumers' risk aversion is an additional market barrier. The manufacturer may be concerned regarding future warranty or litigation impact. Until the technology is "tried and proven" there is a risk to the future profitability of the company. Current vehicle technologies in the marketplace have a long history of competitive development that sets high standards for new technologies. They also have known value retention. A conservative consumer will let others try the technology first. This consumer will not buy into the new technology until it has established similar history. The consumer may be concerned as to whether the new technology is fully comparable to highly-developed technology currently established in the marketplace. This consumer may be concerned that the benefits of the new technology were achieved through a trade off or a sacrifice of other performance characteristics of the traditional technology.

Lack of infrastructure is also a barrier to the introduction of many energy-efficient technologies. New technologies require infrastructure investment to supply and distribute them. Also, there is investment required to maintain technologies in the marketplace. This investment is in the form of training technicians to repair/maintain the technologies and to stock replacement parts for the new product.

FCVT has developed a plan to address the market barriers, which includes cost reduction and education and outreach. The market will determine the price of the product, but FCVT is performing research and development (R&D) on technologies that will reduce the manufacturer's cost of producing, introducing and maintaining energy-efficient technologies. The technologies are being made available to industry to enhance competition in the marketplace, which in turn will reduce the price.

Education and outreach is also necessary to increase awareness of the benefits of energy-efficient technologies. Student competitions, for example, aid in training future scientists and engineers and show them what is possible. Their knowledge not only expands the possibilities of technologies, but also the consumer base desiring those technologies. Web sites provide information on energy-efficient alternatives for the consumer and enable the consumer to make a more knowledgeable choice.

## 1.2 Internal Assessment, Program History and Progress

**Program History.**
FCVT's extensive and layered history began in 1968 under the Department of Health, Education and Welfare. The driving force to this was the increasing awareness of air pollution and its associated health issues due in part to vehicle emissions. The two studies that emerged to spur the vehicle technology effort along were on heat engines and electric vehicle technologies. Subsequently, there was a 10-year plan developed that incorporated the results of both studies to assist in pollution control.

The Program was transferred to Energy Research & Development Administration (ERDA), the Department of Energy's (DOE) predecessor, in 1975. It was named the Transportation Energy Conservation Program. Under ERDA, its primary mission/focus changed from air pollution reduction to total energy and petroleum savings.

| PPAF | |
|---|---|
| Mission | Vision |
| Performance Goals | Strategic Goals |
| Outputs | Outcomes |

**Figure 1-5.** Section 1.2, Internal Assessment, Program History and Progress

The Electric Vehicle & Hybrid Electric Vehicle RD&D Act of 1976 (EV & HEV RD&D Act) technically broadened the focus of the Program by placing more emphasis on hybrid vehicles. It also required a significant demonstration to be conducted. A series of legislation gave additional emphasis to the Program including heat engines and fuels and other alternatives as well as beneficial enabling technologies like advanced materials. This series included the Non-Nuclear Energy R&D Act of 1974 and the Department of Energy Act of 1978 - Civil Applications. In 1990 the Biomass Office was split into the Office of Power Technology and the Office of Transportation Technology allowing more specific focus. The Energy Policy Act of 1992 was enacted which increased the technology focus on energy and petroleum savings.

The earliest R&D, driven by air pollution concerns, was on key enabling technologies for electric vehicles such as the battery and for an alternative heat engine to replace the gasoline internal combustion engine (ICE). Brayton cycle, Rankine cycle and Stirling engine technologies were the heat engine focus. The barriers for Stirling engines, for example, were lack of proof-of-concept in vehicles, large radiator volume, high cost, and lack of methods of control required by vehicles. At the time, batteries were not powerful enough for adequate acceleration. They did not store enough energy for adequate range and were not durable enough for an adequately long life. They were also too costly. In addition to traditional technologies, battery research efforts were focused on such technologies as high-temperature NaS and LiS battery couples. There were no modeling and simulation tools for electric or hybrid vehicles and components, and few analysis tools or techniques to calculate benefits and impacts for the total life cycle.

Under DOE, focus shifted slightly to petroleum savings and petroleum independence for transportation as a primary goal for energy security. Also under DOE, the R&D efforts that had existed as independent technology based advanced efforts were integrated in 1996 into a single transportation program with light-duty (Office of Advanced Automotive Technologies) and heavy-duty vehicle (Office of Heavy Vehicle Technologies) components. In 2002, the offices were regrouped again into the Office of FreedomCAR and Vehicle Technologies (OFCVT) and the Office of Hydrogen, Fuel Cells and Infrastructure Technologies (OHFCIT). An integrated systems research approach has encompassed a wide range of vehicle technologies to include fuels and lubricants, vehicle systems, engines and power sources, materials,

environment and health, safety (trucks), hybrid propulsion, energy storage, power electronics and electrical machines.

Since the beginning, the Program effort has been guided by studies, analyses, expert opinion, legislation, R&D results, and mission/focus. These have shifted the Program's emphasis as follows:

- Early emphasis on specific enablers in batteries and Stirling Engines.
- Broadened energy storage technology base and engine base (included Gas Turbine).
- Ground-up systems proof of concept for: electric vehicles supported with battery and propulsion R&D; hybrid propulsion proof of concept with supporting R&D, fuel cell and engine R&D. Ground-up EV system effort developed modeling tools and demonstrated importance of aerodynamic drag, rolling resistance, weight, as well as the efficiencies of the propulsion, power, and battery subsystems.
- Commercialization projects for electric vehicles and hybrid vehicles with an advanced technology project (including fuel cells).
- Integration of all vehicle technology R&D efforts aimed at fuel economy goals for the vehicle (1993).
- Integration of vehicle technology R&D efforts aimed at priority component performance goals as key enablers across platforms to more energy-efficient and petroleum independent vehicles (2002).

Over the past four years, the FCVT effort has implemented a fundamental shift in goals from an emphasis on fuel economy at the system level to R&D aimed at technology and component level performance goals. Motivated in part by the need for broader implementation of vehicle efficiency technologies and by the President's hydrogen vision, the FreedomCAR and Fuel Partnership was announced and the 21st Century Truck Partnership (21st CTP) was revamped in 2002.

The Program goals stated in the FY 2002 Congressional Budget Request were broad, vehicle level goals addressing the reduction of oil use in highway vehicles, improvement of the efficiency of light- and heavy-duty vehicles, adoption of lightweight materials, and the production of renewable domestic fuels. Today, these goals would be considered outcomes rather than outputs of the FCVT Program.

In the FY 2003 Budget Request, the Program Strategic Performance Goals were categorized by subprogram and had a technology specific focus. In the FY 2005 request, weight reduction of a tractor-trailer was incorporated into the heavy vehicle goal in order to cover a greater portion of commercial vehicle activities. The reduction of heavy vehicle parasitic losses was adopted as a goal that is being realized in FY 2006, as well as the reduction of high power battery costs.

The Advanced Combustion R&D and Fuel Utilization R&D Subprogram goals in the FY 2003 and FY 2004 requests were focused on emissions reduction. In FY 2005, the focus was shifted to improving efficiency to better coincide with the FreedomCAR goals. The 2010 goal for passenger vehicle engine efficiency changed from 43% in the FY 2005 request to 45% in the FY 2006 request due to a higher FY 2005 appropriation than requested. The commercial vehicle engine efficiency goal of 55% was moved back from a 2012 target in the FY 2005 request to a 2013 target in the FY 2006 request. This was due to a reduced FY 2006 request from the current appropriation in the Advanced Combustion Engine R&D subprogram.

The Program goal for Materials Technologies R&D set in 2003 to reduce the production cost of carbon fiber remained the same through the FY 2005 request. The goal was broadened in FY 2006 to include all materials and manufacturing technologies in order to include a greater portion of the activities being performed by the FCVT Program.

Electric Vehicle, Fuel Cell, and the Clean Cities goals appearing in the FY 2003 request were not present in subsequent FCVT requests. The Electric Vehicle R&D Subprogram was rolled up into the Hybrid and Electric Propulsion Subprogram in FY 2004, where it remains today. Fuel Cell R&D and the Clean Cities Subprograms split from the FCVT Program in FY 2004. Fuel Cell R&D is under the purview of the Hydrogen, Fuel Cells, and Infrastructure Technologies Program. Clean Cities moved to the Weatherization and Intergovernmental Program.

Other changes in recent years include specific project completions and terminations. Priority selections and 'neck-down' decisions are implemented during the normal conduct of the Program and details are covered in each of the Program element areas in the technical portions of the Plan. Effort completions on a broader scale include the following: Light Truck Engine Research was successfully completed with the achievement of 50 percent improvement in fuel economy while meeting Tier 2 Bin 5 vehicle emissions standards; Non-Petroleum Based Fuel natural gas efforts on medium and heavy truck engine research as well as infrastructure development were brought to completion because these technologies were judged to be mature and ready for commercialization after years of R&D; and Environmental Impacts assessment was terminated because it was deemed not within the mission of DOE. The FCVT Program incorporates continual evaluation of priorities and concordant recommendations of adjustment of resources to Congress and additional changes are likely in coming years. Additional emphasis on plug-in hybrids and on non-petroleum fuels is currently under examination.

**Major Program Accomplishments**

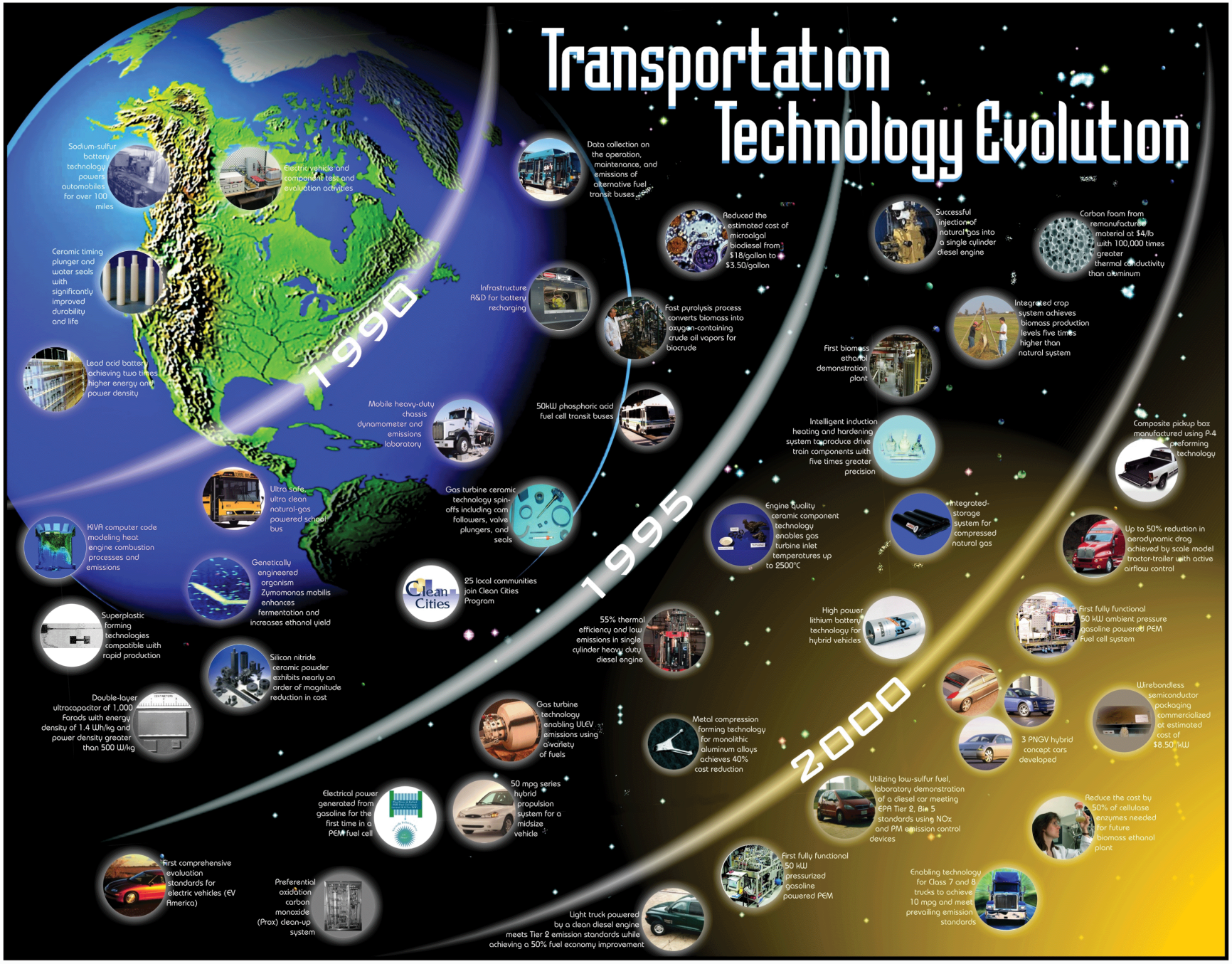
Since the beginning of the Partnership for a New Generation of Vehicles (PNGV) in 1993, the DOE national laboratories supporting FCVT have received 19 R&D 100 Awards, 3 *Discover* Magazine awards, and 6 Federal Laboratory Consortium (FLC) awards for Excellence in Technology Transfer. In 2003, a member of FCVT's national laboratory staff was named one of the top 50 research leaders by *Scientific*

*American* magazine. FCVT and its predecessor organization, the Office of Transportation Technologies, have a track record of success, having funded research on now commercial technologies, such as nickel-metal hydride batteries, light-weight tie rods for heavy trucks, and new metal-forming technologies. Its focus has always been on research for long-term, high-risk technologies. Such research has been highly regarded. It provides a substantial base for furthering energy efficiency in transportation because it avoids potential conflicts in the commercialization process. Numerous computer codes have been developed to aid tasks from component performance to vehicle systems simulation and are widely used by both industry and academia. It provides specialized facilities at the national laboratories which are used by government, industry, and academia for fundamental research and development of transportation technologies. These specialized facilities include the Advanced Powertrain Research Facility, the Renewable Fuels and Lubricants Laboratory, the High Temperature Materials Laboratory, and the National Transportation Research Center. FCVT and its partners also make extensive use of the Office of Basic Energy Sciences' Combustion Research Facility.

There has been significant progress in R&D and the commercialization of technologies which enable fuel efficient vehicles. In 1991, under a cooperative agreement with the DOE and the U.S. Advanced Battery Consortium (USABC), the development of nickel metal hydride (NiMH) battery technology was initiated. This technology is a key component of today's hybrid ICE vehicle. DOE successfully completed its NiMH R&D effort in 1999.

In additional examples, research from the DOE effort with its industrial partners has helped foster the development of the Ford Escape Hybrid sport utility vehicle (SUV) and the General Motors Silverado/Sierra Full-Size Hybrid Pickup Truck–both of which are now available to consumers. They are targeted at the personal truck market, where sales are highest and the need for improved fuel economy is greatest. These and other DOE industry partners were able to apply and expand on the results from DOE-sponsored, pre-competitive hybrid research as they developed their proprietary technologies and products to meet the specific needs of their customers.

DOE and the National Renewable Energy Laboratory (NREL) in 1994 began working with industry partners to develop a sophisticated systems analysis tool that answers crucial questions about specific component and vehicle designs. This tool, ADVISOR (Advanced Vehicle Simulator), uses basic physics calculations and measured component performance to model conceptual vehicles. It greatly reduces testing time to evaluate various vehicle powertrain alternatives. It provides a shared simulation tool for government and industry and assists the automotive industry to develop fuel-efficient vehicles and components. This tool has been transferred to industry and is now being commercialized. The following figures (Figures 1-6 and 1-7) display the achievements of major government cost-shared transportation technology over the last 15 years.


Transportation Technology Evolution
1990
1995
2000
Sodium-sulfur battery technology powers automobiles for over 100 miles
Electric vehicle and component test and evaluation activities
Ceramic timing plunger and water seals with significantly improved durability and life
Lead acid battery achieving two times higher energy and power density
Mobile heavy-duty chassis dynamometer and emissions laboratory
Ultra safe, ultra clean natural-gas powered school bus
KIVA computer code modeling heat engine combustion processes and emissions
Genetically engineered organism Zymomonas mobilis enhances fermentation and increases ethanol yield
Superplastic forming technologies compatible with rapid production
Silicon nitride ceramic powder exhibits nearly an order of magnitude reduction in cost
Double-layer ultracapacitor of 1,000 Farads with energy density of 1.4 Wh/kg and power density greater than 500 W/kg
First comprehensive evaluation standards for electric vehicles (EV America)
Preferential oxidation carbon monoxide (Prox) clean-up system
Electrical power generated from gasoline for the first time in a PEM fuel cell
50 mpg series hybrid propulsion system for a midsize vehicle
Light truck powered by a clean diesel engine meets Tier 2 emission standards while achieving a 50% fuel economy improvement
Data collection on the operation, maintenance, and emissions of alternative fuel transit buses
Infrastructure R&D for battery recharging
50kW phosphoric acid fuel cell transit buses
Gas turbine ceramic technology spin-offs including cam followers, valve plungers, and seals
25 local communities join Clean Cities Program
55% thermal efficiency and low emissions in single cylinder heavy duty diesel engine
Gas turbine technology enabling ULEV emissions using a variety of fuels
Metal compression forming technology for monolithic aluminum alloys achieves 40% cost reduction
Reduced the estimated cost of microalgal biodiesel from $18/gallon to $3.50/gallon
Fast pyrolysis process converts biomass into oxygen-containing crude oil vapors for biocrude
Engine quality ceramic component technology enables gas turbine inlet temperatures up to 2500°C
Intelligent induction heating and hardening system to produce drive train components with five times greater precision
High power lithium battery technology for hybrid vehicles
First fully functional 50 kW pressurized gasoline powered PEM
Successful injection of natural gas into a single cylinder diesel engine
Carbon foam from remanufactured material at $4/lb with 100,000 times greater thermal conductivity than aluminum
Integrated crop system achieves biomass production levels five times higher than natural system
First biomass ethanol demonstration plant
Integrated-storage system for compressed natural gas
Composite pickup box manufactured using P-4 preforming technology
Up to 50% reduction in aerodynamic drag achieved by scale model tractor-trailer with active airflow control
First fully functional 50 kW ambient pressure gasoline powered PEM Fuel cell system
3 PNGV hybrid concept cars developed
Wirebondless semiconductor packaging commercialized at estimated cost of $8.50/kW
Utilizing low-sulfur fuel, laboratory demonstration of a diesel car meeting EPA Tier 2, Bin 5 standards using NOx and PM emission control devices
Reduce the cost by 50% of cellulase enzymes needed for future biomass ethanol plant
Enabling technology for Class 7 and 8 trucks to achieve 10 mpg and meet prevailing emission standards

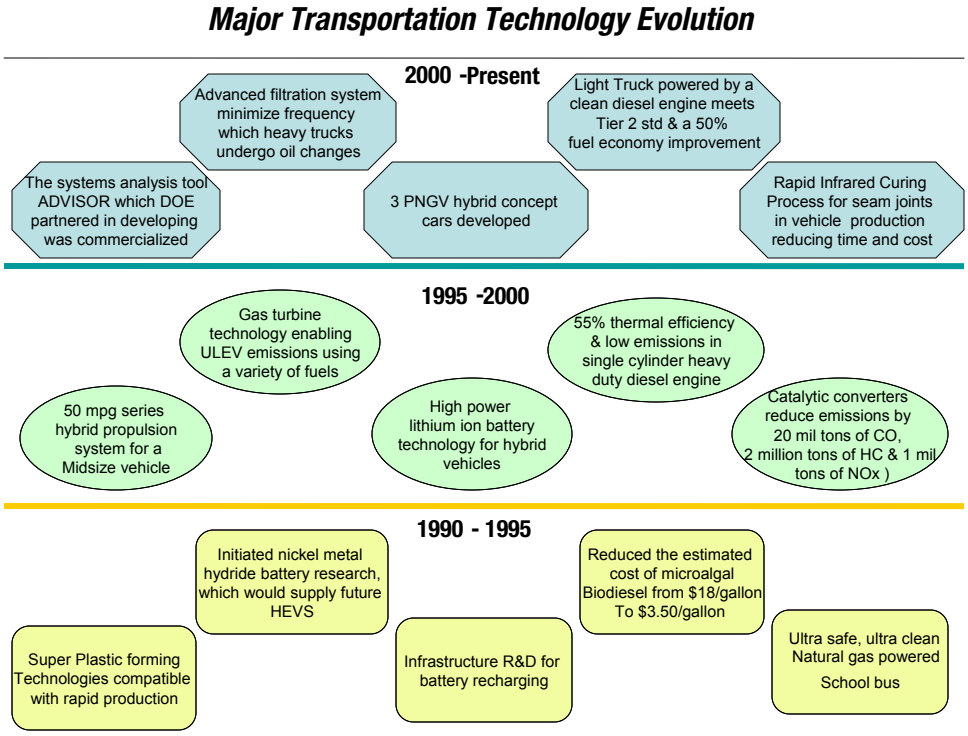



**Figure 1-7.** Technology Achievements of the Last 15 Years

## 1.3 Program Justification and Federal Role

### National Need

*The number one priority of DOE's EERE (Energy Efficiency and Renewable Energy) is the reduction or removal of dependence on foreign oil.* With increasing uncertainty regarding international relations, the need to reduce our dependence on imported oil is becoming more important. The FCVT Program will be the major contributor for R&D in this area from now until at least 2030 (depending on the successful advancement of certain technologies). FCVT supports R&D that will lead to new technologies to reduce foreign oil dependency, as well as decrease emissions and help transition motor vehicles from conventional fuels and powertrains to hydrogen and hybrid fuel cell vehicles. The FCVT Program provides the base for greater energy efficiency through technologies such as energy storage, electric drives, and lightweight materials needed to make hybrid fuel cell vehicles a reality in the future.

This document maps out the plan to accomplish the FCVT Program's priorities. In collaboration with government, industry, national laboratories, and academia, the Program supports R&D of advanced vehicle technologies and fuels. The Program is helping the U.S. transition to a more secure energy future that offers economic and

environmental benefits for generations of Americans. Its developments will dramatically reduce and later possibly eliminate petroleum demand. They will also decrease emissions of criteria air pollutants and greenhouse gasses.

Research, development, and validation activities are focused on technologies to reduce oil use in highway vehicles such as cars, light trucks, and heavy vehicles (composed of medium and heavy trucks and buses). The Program promotes the development of fuel-efficient motor vehicles and trucks, researches options for using cleaner fuels, and implements efforts to improve energy efficiency. Locomotives and off-highway vehicles like those used in construction, mining, and agriculture may benefit from these efforts as well because they have engines similar to the heavy-duty trucks. Overall, the FCVT Program concentrates on higher-risk, longer-term technology developments, leaving commercialization and near-term applications to industry.

**Federal Government Support**

The government has a long history of supporting science and fundamental research. High risk and the long payback periods make much of this research unattractive for the private sector to conduct. In fact, much of this research would never be done without the government providing the foundation.

The government's role in applied R&D has evolved over time. There has been concern that its involvement will interfere with technology commercialization. However, there are times when national needs provide a compelling case for the judicious support of applied R&D. Energy security is just one example. Foreign governments, dealing with similar national concerns, continue to fund advanced transportation research at high levels to address the issues. In the case of DOE vehicle research, which specifically addresses the national issues of energy and the environment and the increasing pressures of global competition, the FCVT Program has involved the affected industries in planning the research agenda and identifying technical goals that, if met, will provide the basis for commercialization decisions. The government's approach allows *industry-wide collaboration in pre-competitive research, then competition in the marketplace.*

**Unique/Critical Aspects**

The FCVT Program is the only program developing technologies to save and/or displace petroleum in the transportation sector for passenger vehicles in the near and mid term and for commercial vehicles in the near-, mid- and long-term. Partnering with industry through the FreedomCAR and Fuel Partnership and the 21st Century Truck Partnership, DOE is leading the nation's long-term research effort to develop technologies for (1) moving from petroleum-fueled personal vehicles (cars, pickup trucks, sport utility vehicles, and minivans) to those powered by fuel cells that run on hydrogen made from diverse domestic resources, and (2) doubling the fuel economy of new commercial vehicles (long-haul freight trucks and buses), which, for the foreseeable future, will continue using engines that run on improved liquid fuels, including those from renewable and non-conventional sources. Moving to hydrogen

is widely seen as the most promising long-term means of eliminating the transportation sector's dependence on petroleum.

Because it may be decades before fuel cell vehicles make a substantial impact, it is important to find other ways to start reducing oil use sooner. DOE has a Transition Strategy:

http://www1.eere.energy.gov/vehiclesandfuels/features/fcvt_feature_driving_technology.html

to help improve energy security until fuel cell vehicles can dominate the market. The Transition Strategy involves developing advanced personal and commercial vehicle technologies that will help dramatically reduce oil consumption as soon as possible (while also helping achieve the nation's long-term goal of driving fuel cell vehicles). These new technologies include components for hybrid electric vehicles (batteries, electric drivetrains, and controllers), lightweight materials, improved fuels, advanced combustion engines, and other improvements that make today's hybrids more efficient and that will serve as "core components" in tomorrow's fuel cell vehicles. FCVT is the only DOE program that is developing technologies to improve the fuel economy of personal vehicles (during the Transition period) and commercial vehicles (in the mid- and long-term). These technologies will help maintain freedom of mobility, a wide range of vehicle choices, and reliable freight transport, and they are essential as a foundation for efficient fuel cell vehicles. Reducing oil consumption can have a beneficial impact on oil prices and help increase our nation's gross domestic product (GDP), which in turn will expand the job market.

**Other Federal Programs Complemented by the FCVT Program**

The FCVT Program leads DOE's partnerships with industry to develop advanced technologies for both personal and commercial vehicles. FCVT's sister program, the Hydrogen, Fuel Cells & Infrastructure Technologies (HFCIT) Program, leads DOE's development of fuel cells, as well as hydrogen production, storage, and distribution infrastructure. These two DOE programs work together as part of a single continuum of technologies, leading toward a future in which the vehicles we drive will not be dependent on petroleum and will have zero or near-zero emissions.

The Advanced Power Electronic and Electric Machine activity complements and is complemented by power electronics research in eight of the other eleven EERE programs, the Office of Electricity, and the Office of Science. In addition to the internal complementary activities, this technology area is also complemented by research activities in the Defense Advanced Research Projects Agency (DARPA) and National Aeronautics and Space Administration (NASA). The interaction between these groups has been enhanced by the formation of a FCVT led Power Electronics Crosscut group which meets regularly and shares in the cost of crosscutting research projects.

The Advanced Combustion R&D and Fuels Technology element is complemented by research in the Biomass Program, Office of Science and Office of Fossil Energy.

While the Biomass Program is developing fuels from renewable sources and the Office of Fossil Energy is developing fuels from fossil sources, FCVT is determining the properties those fuels must exhibit to maximize efficiency and minimize the emissions of future engines. The Basic Energy Sciences Office within the Office of Science has constructed and maintains the Combustion Research Facility at Sandia National Laboratory – Livermore. This facility is used by FCVT and its industrial partners for much of the fundamental research in combustion. The Office of Fossil Energy funds engine research at the National Energy Technology Laboratory. Engine research information and plans are regularly exchanged between the Offices.

Materials research is performed in many Federal programs and much of it is complementary to the transportation materials research funded by FCVT. The Office of Science, DARPA, and the National Science Foundation perform basic materials research which often forms the basis of applied research funded by FCVT. The applied research activities are often complemented by activities in the Industrial Technologies Program, NASA, and National Institute of Standards and Technology (NIST). Automotive crash modeling is an area of complementary and cooperative research with the Department of Transportation (DOT). While DOT is focused on crash testing of vehicles with some activity in the area of crash modeling, FCVT is characterizing new materials, incorporating them into crash models and sharing that information with DOT. The Office of Science–procured massively parallel computers are used within the Program for vehicle crash modeling.

## 1.4 Program Vision

The FCVT vision is that *transportation energy security will be achieved through a U.S. highway vehicle fleet of affordable, full-function cars and trucks that are free from petroleum dependence and harmful emissions without sacrificing mobility, safety, and vehicle choice*. This vision builds on the successful transportation R&D and propels the research on new technologies for transportation. Realization of this vision will require not only success in the R&D, but also success in the many external endeavors necessary to get the business decisions and produce and support the advanced technologies required.

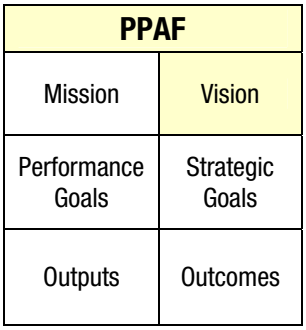



**Figure 1-8.** Section 1.4, Program Vision

## 1.5 Program Mission

The mission of the FCVT Program is summarized in the statement: *develop more energy-efficient and environmentally friendly highway transportation technologies that enable America to use less petroleum.* The long-term aim is to develop "leapfrog" technologies

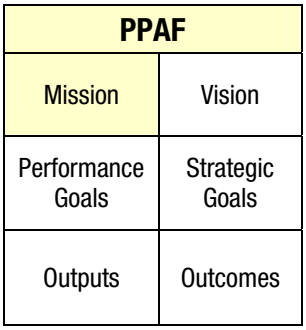



**Figure 1-9.** Section 1.5, Program Mission

that through improvements in vehicle energy efficiency will provide Americans with continuing freedom of mobility and greater energy security, at lower costs and with lower impacts on the environment than current high efficiency vehicles. The Program focuses its research and development investments specifically on potential technology improvements that have uncertain or long-term outcomes, yet have significant public benefit if achieved. The high risks associated with these projects make it unlikely that they would be pursued by industry alone.

## 1.6 Program Approach

FCVT has developed various integrated means and mechanisms to perform its mission and achieve its vision and goals. "Means" include operational processes, resources, information, and the development of technologies; and "mechanisms" include Program R&D, policy, and management and legislative initiatives. Various external factors, including market barriers, may impact the ability to achieve the Program's goals. Collaborations are integral to the planned investments, means and mechanisms, and to addressing external factors. Two government-industry partnerships serve as implementing mechanisms for major portions of the Program: the FreedomCAR and Fuel Partnership, which implements much of both the President's Hydrogen Fuel Initiative and the Department's FreedomCAR budget, and the 21st Century Truck Partnership.

The Program focuses its technology research and development investments specifically on areas that would not be pursued by industry alone due to high risks and uncertain or long-term outcomes. Program activities include research, development, testing, technology validation, technology transfer, and education. These activities are aimed at developing technologies that could achieve significant improvements in vehicle fuel efficiency and displacement of oil by other fuels which ultimately can be produced domestically in a clean and cost-competitive manner.

The FCVT Program has implemented approaches for achieving the goals for passenger light-duty vehicles and commercial heavy-duty vehicles. For passenger light-duty vehicles, FCVT, in conjunction with industry through the FreedomCAR and Fuel Partnership, has established performance goals (Subsection 1.7). The long-term approach is to perfect the technologies that will enable a timely transition to a transportation hydrogen economy. There are also significant reductions in oil use possible from R&D to improve highway transportation technologies in the interim. Taking advantage of these interim opportunities to significantly reduce oil use (thus benefiting both our economy and our energy security) is a key outcome sought by FreedomCAR and Fuel Partnership activities.

The 21st CTP has identified desirable technology goals in five general areas: engine systems, hybrid heavy-duty powertrains, parasitic losses, truck safety, and idling reduction. The FreedomCAR and Fuel Partnership has identified nine challenging goals for government and industry R&D. The FCVT Program has exclusive responsibility for the four goals in the technology areas of electric propulsion, energy

storage, materials, and ICE powertrain systems. The FCVT Program and HFCIT Program share responsibility for the goal relating to hydrogen fueled ICE powertrains. The partners are jointly developing technical roadmaps that outline the pathways for achieving long-range technology-specific R&D goals (including cost targets) and the milestones required to demonstrate progress. Each partner will consider these goals in implementing its respective R&D programs.

The truck industry and government partners have developed a common vision "that our Nation's trucks and buses will safely and cost-effectively move larger volumes of freight and greater numbers of passengers while emitting little or no pollution and dramatically reducing the dependency on foreign oil." Ultimately, 21st CTP seeks safe, secure, and environmentally friendly trucks and buses that use sustainable and self-sufficient energy sources, thereby helping enhance America's global competitiveness.

The FCVT carries out its mission by targeting Federal investments in technology research and development in strategic partnerships with auto manufacturers, commercial heavy-duty vehicle manufacturers, equipment suppliers, fuel and energy companies, other Federal agencies, state government agencies, universities, national laboratories, and other stakeholders. These partnerships, that are integral and critical to the overall FCVT approach, insure the best R&D is undertaken, facilitate the technical coordination of activities, attract cost sharing to provide leveraged benefits for the American taxpayer, and help attain the maximum benefit from the Program.

The approaches outlined above will result in significant cost savings and a significant reduction in the consumption of gasoline and diesel fuels, thus cost effectively reducing America's demand for petroleum, lowering carbon emissions, and decreasing energy expenditures–thus putting the taxpayers' dollars to more productive use.

The FCVT approach supports several pathways for securing energy independence in America's transportation system. The FreedomCAR and Fuel Partnership is designed to reverse America's growing dependence on foreign oil. This path focuses on developing the needed technologies for hydrogen-powered hybrid fuel cell vehicles by the middle of next decade. The FCVT Program is developing technologies to save petroleum in the current combustion engine vehicles. It is establishing a technology transition from current vehicles to hybrid fuel cell vehicles, as well as possible alternative paths, which will apply fuel cells when they become viable for the transportation industry.

The research on hybrid fuel cell vehicles is not expected to be completed for another 10 to 12 years. Many technical and economic barriers still exist for affordable, mass-produced hydrogen hybrid fuel cell automobiles. And once research is completed, a business case will have to be made for the shift to a new fuel and new propulsion system. In the interim, FCVT will support the development of advanced technologies that will be more energy-efficient in the mid-term and later provide the technology

base for the eventual commercialization of hybrid fuel cell vehicles. These near-term improvements will focus primarily on improved combustion and reduced parasitic loses for heavy-duty vehicles. Because of the more demanding requirements for such vehicles, research will focus on increasing their efficiency and reducing their emissions.

Figure 1-10 shows one possible path to a hydrogen future for transportation. It displays how FCVT-supported technologies may be commercialized. The first stage in this transition is hybridization. FCVT and its predecessor organizations in DOE have supported the development of hybrid vehicles for years, and they are now being introduced in limited numbers to the U.S. market. Further improvements are expected with advanced combustion techniques and cleaner fuels. Improvements in energy storage and power electronics technologies will continue to make hybrid vehicles, and eventually hybrid fuel cell vehicles, more affordable.

Hydrogen ICEs can assist in the transition to a hydrogen transportation system. Auto companies can continue using existing engine plants, while the hydrogen ICEs will encourage hydrogen production and distribution, as well as advances in hydrogen storage. Then with a hydrogen infrastructure in place and a public that has become comfortable with hydrogen as a fuel for personal vehicles, hybrid fuel cell vehicles can be introduced in the mass market.

The FCVT Program is also researching other technologies, like lightweight materials, that may be introduced at any time during the transition. They are not limited to any particular propulsion system. These technologies may be commercialized in a different order; many different paths exist to a future that provides personal and transport mobility with hydrogen hybrid fuel cell vehicles. The path and timing will vary for the different types of vehicles. Long-haul trucks, for example, that use the high energy content of diesel fuel and large fuel tanks to minimize refueling times, may adopt fuel cell technology at the latest dates. But regardless of the timing, research on different aspects of vehicle systems is needed to make the future of hydrogen vehicles a reality.

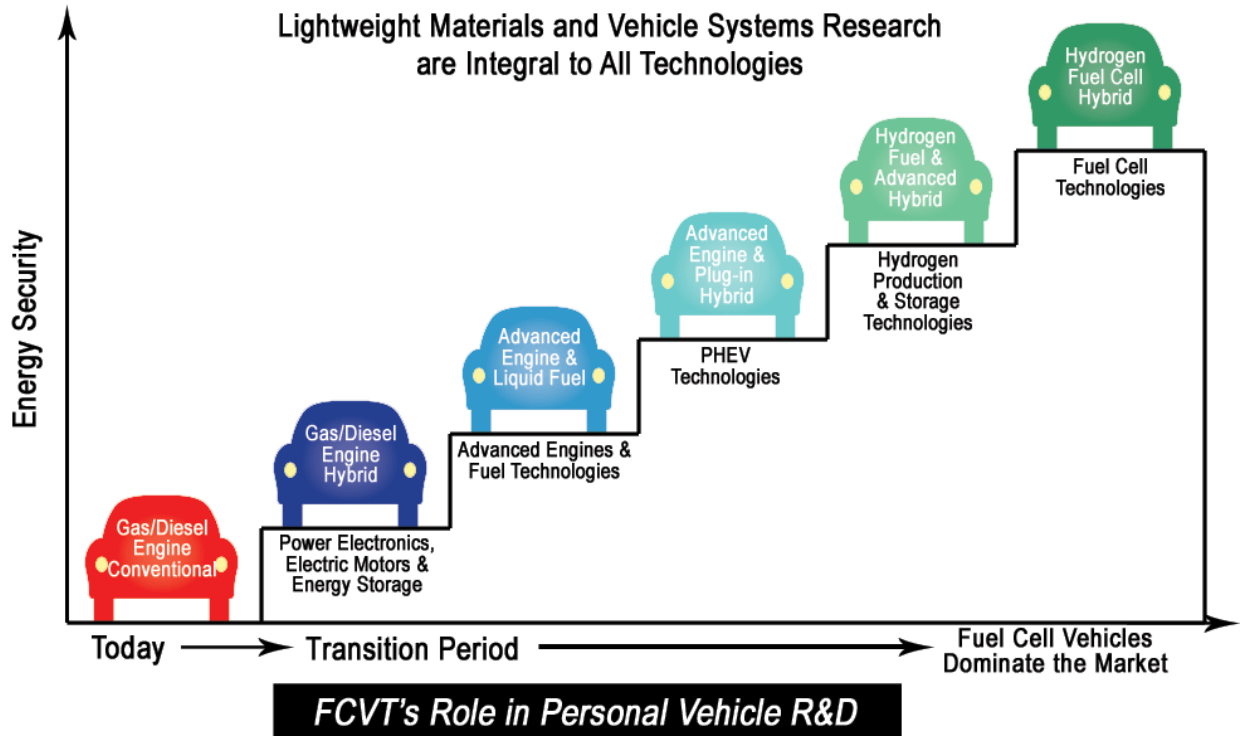



**Figure 1-10.** One Possible Pathway to Energy Security

## 1.7 Performance Goals

The FreedomCAR and Fuel partners have identified nine high-level technical goals for government and industry R&D efforts. The FCVT Program plays a key role in this Partnership by conducting R&D through the continued development of advanced technologies. The Program aims to achieve the nearer-term goals of the Partnership by dramatically reducing the fuel consumption and emissions of all petroleum based, light-duty personal vehicle classes. Achieving these goals is of paramount importance because they will provide the necessary technologies for the long-term hydrogen fuel cell vehicles.

| PPAF | |
|---|---|
| Mission | Vision |
| Performance Goals | Strategic Goals |
| Outputs | Outcomes |

**Figure 1-11.** Section 1.7, Performance Goals

As noted in Subsection 1.6, the 21st CTP has identified desirable technology goals in the five general areas: engine systems, hybrid heavy-duty powertrains, parasitic losses, truck safety, and idling reduction. The partners are jointly developing technical roadmaps that outline the pathways for achieving long-range technology-specific R&D goals (including cost targets) and the milestones required to demonstrate progress.

The FCVT Program is exclusively responsible for the following goals which are directly related to the Partnership goals:

- **Vehicle Systems Element:** Reduce heavy truck parasitic losses (e.g. aerodynamics, ancillary systems) from 39 percent of engine output in 1998 to 24 percent in 2006.
- **Hybrid and Electric Propulsion Element:** By 2010, reduce the production cost of a high power 25 kW battery for use in passenger vehicles from $3,000 in 1998 to $500 (with an intermediate goal of $750 in 2006) to enable cost competitive market entry of hybrid vehicles. By 2010, develop an integrated electric propulsion system that costs no more than $12/kW peak ($660 per system compared to the cost of $1,900 in 1998) and can deliver at least 55 kW of power for 18 seconds and 30 kW of continuous power. Additionally, the propulsion system will have an operational lifetime of 15 years.
- **Advanced Combustion R&D Element and Fuel Technology Element:** Improve the efficiency of ICEs from 30 percent (2002 baseline) to 45 percent by 2010 for light-duty passenger and from 40 percent (2002 baseline) to 55 percent by 2013 for commercial heavy-duty vehicle applications while utilizing an advanced fuel formulation that incorporates a non-petroleum based blending agent to reduce petroleum dependence and enhance combustion efficiency.
- **Materials Technology Element:** By 2012, develop material and manufacturing technologies that if implemented in high volume could cost effectively reduce the weight of passenger vehicle body and chassis systems by 50 percent with safety, performance, and recyclability comparable to 2002 vehicles.

The Program performance goals are aimed at enabling cars and trucks to become highly efficient through R&D that provides clean power technologies and improved domestic fuel specifications that work with advanced power systems. The Program R&D will focus on reducing the cost and improving the attributes of advanced vehicle technologies so they will become both performance- and cost-competitive. Details on measures and status for these goals are given in Section 2 of this Multi-Year Program Plan (MYPP).

## Goal Cascade

The linkage from the National Energy Policy down through Department goals and EERE goals to the FCVT Program goals is shown in Figure 1-12.

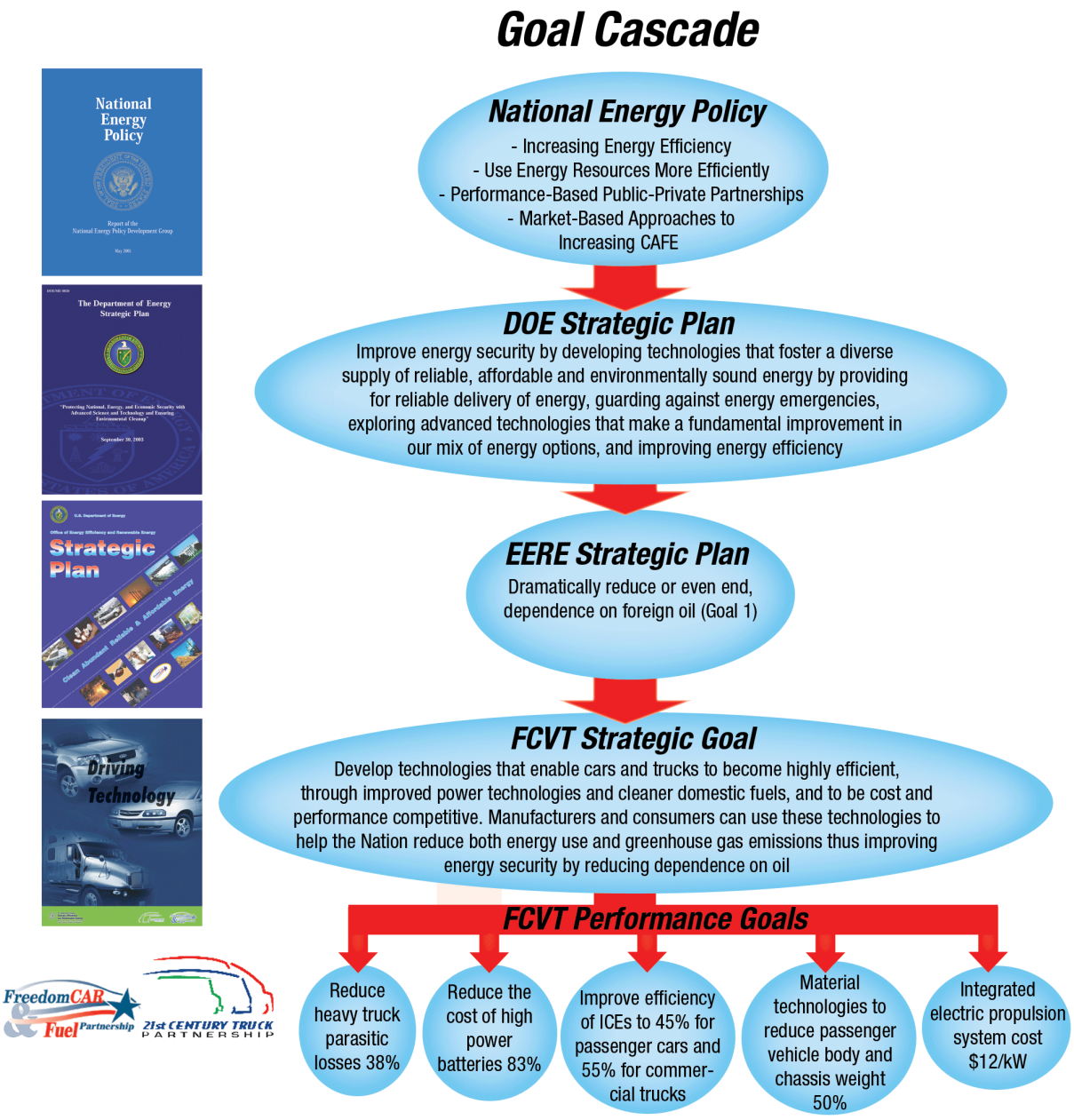



**Figure 1-12.** Linkage of FCVT Performance Goals through EERE and DOE Strategic Plans to the National Energy Policy

## 1.8 Program Strategic Goals

The Department's Strategic Plan identifies four strategic goals (one each for defense, energy, science, and environmental aspects of the mission) plus seven general goals that tie to those strategic goals. The FCVT Program supports the following Energy Strategic Goal:

*To protect our national and economic security by reducing imports and promoting a diverse supply of reliable, affordable, and environmentally sound energy.*

| PPAF | |
|---|---|
| Mission | Vision |
| Performance Goals | Strategic Goals |
| Outputs | Outcomes |

**Figure 1-13.** Section 1.8, Program Strategic Goals

In addition, the FCVT Program supports General Goal 4, Energy Security:

*Improve energy security by developing technologies that foster a diverse supply of reliable, affordable and environmentally sound energy by providing for reliable delivery of energy, guarding against energy emergencies, exploring advanced technologies that make a fundamental improvement in our mix of energy options, and improving energy efficiency.*

The FCVT Program has one strategic program goal which contributes to General Goal 4 in the "goal cascade":

*Develop technologies that enable cars and trucks to become highly efficient, through improved power technologies and cleaner domestic fuels, and to be cost and performance competitive. Manufacturers and consumers can then use these technologies to help the Nation reduce both energy use and greenhouse gas emissions thus improving energy security by reducing dependence on oil.*

## 1.9 Program Outputs

The FCVT Program outputs are the validated technologies required to enable improved energy efficiency in the transportation sector. These technologies are validated to attain the performance goals specified in the Program. Working with industry, opportunities and barriers to energy-efficient technologies are identified. Funding from FCVT is used in a four phase research and development process, as presented in Figure 2-3 of Section 2.2, to overcome those barriers. As the technology matures and moves through each phase, industry's involvement and cost share is increased. The involvement of industry facilitates the technology transfer process and provides an immediate path for commercialization. Industry might harvest the new technologies from any phase of the R&D process. However, after government involvement through validation of technology many steps must be taken

| PPAF | |
|---|---|
| Mission | Vision |
| Performance Goals | Strategic Goals |
| Outputs | Outcomes |

**Figure 1-14.** Section 1.9, Program Outputs

by industry to realize the outcomes and benefits presented in Section 1.10 below. Industry must make its business decisions, develop products and prototypes, build its production lines, and establish its supporting infrastructures to move the technology into the marketplace. Working in partnership with the appropriate industries from early stages of research aids movement of the technology through these steps.

Typical outputs from the FCVT Program are listed below:

- Vehicle Systems
  - Vehicle models such as ADVISOR (Advanced Vehicle Simulator) and PSAT (Powertrain System Analysis Toolkit)
  - Improved ancillary systems including
    - High efficiency air conditioning
    - Electrically driven auxiliaries
  - Validated technologies
- Hybrid and Electric Propulsion
  - Lower cost, longer life batteries with higher energy and power density
  - Lower cost power electronics that also are lighter weight and require less volume
  - Lower cost electric machines that have higher efficiency while being lighter and requiring less volume
  - Power electronics that have greater temperature tolerance
- Advanced Combustion R&D and Fuel Technology
  - Combustion technologies for high efficiency and low emissions
  - Engine control strategies for high efficiency and low emissions
  - Fuel characteristics required for advanced engines to achieve their potential performance
- Materials Technologies
  - Lower cost, lightweight materials
  - Lower cost processing technologies for materials that contribute to vehicle weight reduction
- Technology Introduction
  - Status reports on Energy Policy Act (EPAct) required replacement of petroleum fuel use
  - Sustainable workforce of Engineers and Scientists with specialized training
  - Validation of vehicle systems technology

## 1.10 Program Outcomes

The FCVT Program pursues its mission through integrated activities designed to improve the energy efficiency and productivity of our economy. These improvements should reduce susceptibility to energy price fluctuations and potentially lower energy bills; reduce Environmental Protection Agency (EPA) criteria

| PPAF | |
|---|---|
| Mission | Vision |
| Performance Goals | Strategic Goals |
| Outputs | Outcomes |

**Figure 1-15.** Section 1.10, Program Outcomes

pollutants; reduce greenhouse gases; enhance energy security by increasing the diversity of domestic fuel use; and provide greater energy security and reliability by reducing reliance on imported oil. In addition to these "EERE business-as-usual" benefits, realizing the Program goals would provide the technical potential to reduce conventional energy use even further if warranted by future energy needs.

Estimates of annual non-renewable energy savings, energy expenditure savings, carbon emission reductions, and oil savings resulting from the realization of Vehicle Technologies Program benefits are shown through 2050 in the Table 1-1. These benefits are achieved by targeted Federal investments in technology research and development in partnership with auto manufacturers, commercial heavy-duty vehicle manufacturers, equipment suppliers, fuel and energy companies, other Federal agencies, state government agencies, universities, national laboratories, and other stakeholders. These partnerships facilitate the technical coordination of activities and attract cost sharing to provide leveraged benefits for the American taxpayer.

The assumptions and methods underlying the modeling efforts have significant impact on the estimated benefits, and results could vary significantly if external factors, such as future energy prices, differ from the "baseline case" assumed for this analysis. EERE's baseline case is essentially the same as the Energy Information Administration (EIA) "business-as-usual" case presented in its Annual Energy Outlook. In addition, possible changes in public policy and disruptions in the energy system which may affect estimated benefits are not modeled. The external factors such as unexpected changes in competing technology costs could also affect the Program's ability to achieve its goals.

A summary of the methods, assumptions, and models used in developing these benefit estimates that are important for understanding these results are provided at:

http://www.eere.energy.gov/ba/pba/gpra.html.

Uncertainties are larger for longer term estimates. The results shown in the long term benefits tables are preliminary estimates based on initial modeling of some of the possible Program production technologies; nonetheless, they provide a useful picture of growing national benefits over time.

| FCVT Benefits | 2010 | 2015 | 2020 | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Primary nonrenewable energy savings (Quads) | 0.1 | 0.7 | 2.1 | 4.0 | 7.7 | 14.2 | 18.9 |
| Energy bill savings (Billion 2002 $) | ns | 7 | 31 | 61 | 28 | 95 | 177 |
| Carbon emission reductions (MMTCE) | 2 | 15 | 42 | 76 | 148 | 272 | 365 |
| Oil savings (MBPD) | 0.0 | 0.3 | 0.9 | 1.8 | 3.6 | 6.6 | 8.8 |

**Table 1-1.** FY 2006 GPRA (Government Performance Results Act) Benefits Estimates for the FCVT Program[a]

The vehicles in the model increase their market share over time as their incremental cost relative to conventional vehicles declines and as their efficiency relative to

[a] Benefits reported are annual, not cumulative, for the year given. Estimates reflect the benefits that may be possible if all of the program's technical targets are met and funding continues at levels consistent with assumptions in the FY 2006 Budget.

conventional vehicles increases. Some of the efficiency gains are attained by using lightweight materials while maintaining the safety of the vehicles. By 2025, about 1.8 million barrels per day of oil (relative to base consumption) is projected to be saved as compared with the reference projection without these technologies. This accounts for more than 8 percent of projected transportation oil use in 2025 (more than 5 percent of total U.S. oil use). By 2050, the projected oil savings grows to 8.8 mbpd, which is about 35 percent of the amount of oil use projected for transportation in that year (more than 25 percent of total U.S. oil use). The primary non-renewable energy savings are expressed in Quads of energy and they are nearly equal to the oil savings since oil is a non-renewable energy source. The energy bill savings from 2010 through 2025 are the savings in fuel costs by vehicle users due to the increased efficiency of their advanced vehicles. The energy bill savings from 2030 through 2050 includes the fuel cost savings by vehicle users and the incremental expenditures the vehicle users made to purchase their advanced vehicles. Carbon savings are based on the amount of carbon that the petroleum products would have released if they had been used.

In addition to energy independence and petroleum depletion, development of the new technologies addresses the challenges of greenhouse gases, local emissions and economic competitiveness. FCVT R&D will improve the environment globally and enable U.S. automotive and truck industries to be more competitive.

- **Improved Environment:** On a per-vehicle basis and in terms of the total energy cycle, hybrid vehicles can reduce greenhouse gas emissions by nearly 50% compared with conventional vehicles, providing additional environmental benefits during the transition to the ultimate goal–hybrid fuel cell vehicles operating on hydrogen. In addition, the fuel economy improvements achieved by heavy-duty vehicles will contribute to a reduction in greenhouse gas emissions, as carbon emissions from petroleum fuel are directly related to fuel economy.
- **Economic Competitiveness**: The global automotive and truck markets are extremely competitive because of the economic benefits of high-wage manufacturing jobs and spillover benefits to the broader manufacturing sector. FCVT activities in advanced technology development are conducted jointly with U.S. Council for Automotive Research (USCAR), a consortium of U.S. car makers. An even more diverse consortium representing the heavy-duty truck industry is another research partner with FCVT. One of the direct benefits of FCVT research will be to enable U.S. companies to be more competitive with lower-wage countries by leading in the development of advanced technologies. In addition, the reduction of petroleum use in transportation will reduce the nation's dependence on oil imports from sensitive regions of the world, lessening the opportunities for oil price shocks and the attendant economic consequences.

Success in developing and marketing advanced energy-efficient technologies in America's cars and trucks will provide significant benefits for the nation. Meeting the

goals for both the FreedomCAR and Fuel Partnership and the 21st CTP will provide the pathway for the United States to dramatically change its energy use and petroleum dependence, greatly reducing emissions and the transportation sector's contribution to greenhouse gases, while sustaining mobility and the freedom of vehicle choice. This is a vision that will benefit all citizens. The pursuit of cleaner, more-efficient vehicles today and emissions-free, petroleum-free vehicles tomorrow is a national goal set by the President and is important to the nation's energy, environmental, and economic future. The research agenda in this plan leads to this vision of the future.

This page intentionally left blank.