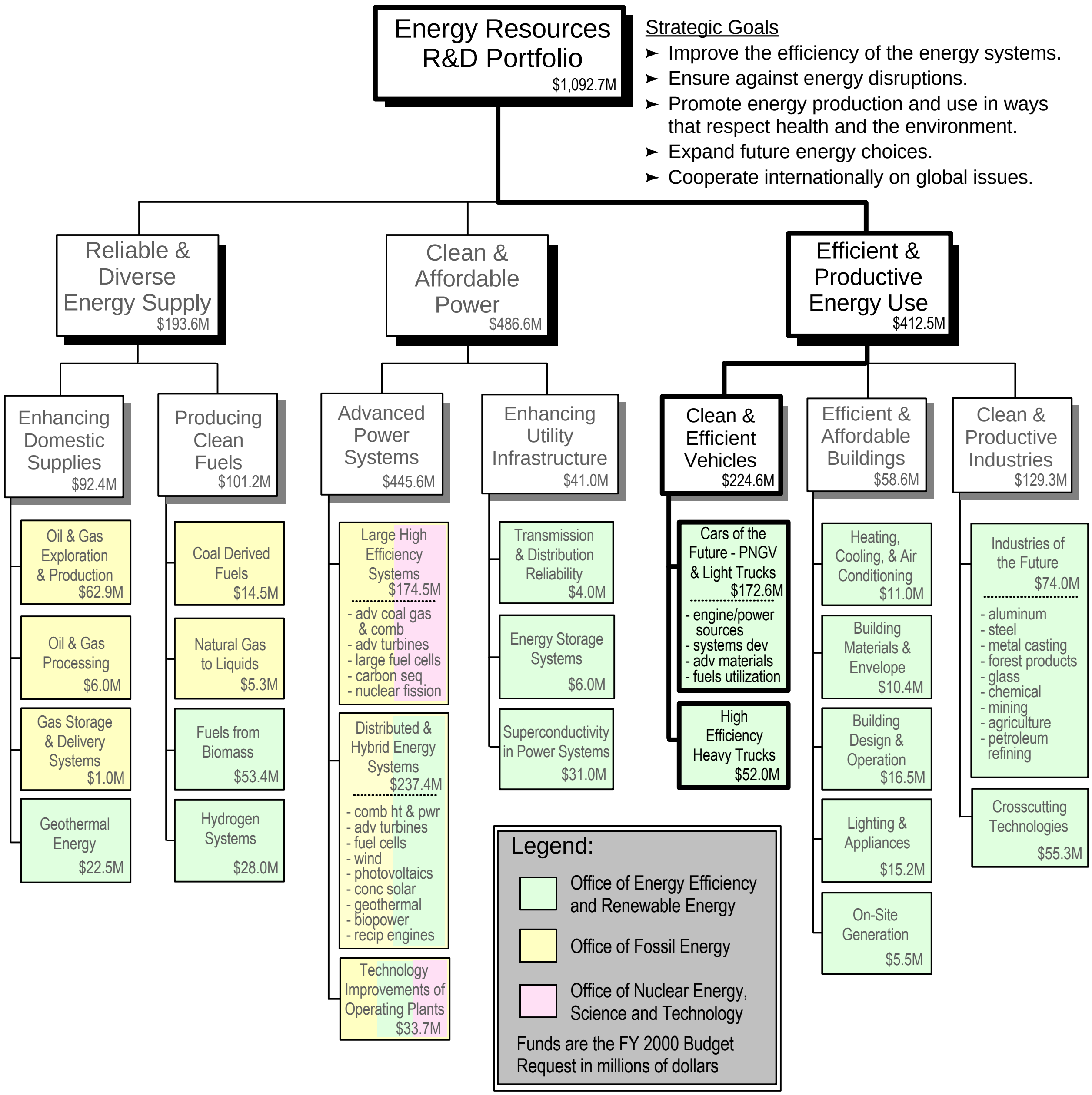
Chapter 7
Clean and Efficient Vehicles



Chapter 7
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Overview

Definition of Focus Area

Highway vehicles currently account for approximately 50 percent of daily domestic petroleum consumption (about 9.2 million barrels per day). Through significant efficiency increases in passenger cars and trucks, and development of cost-effective alternative fuels, the clean and efficient vehicles R&D portfolio seeks to reduce the growth of highway vehicle petroleum consumption.

National Context and Drivers

The U.S. transportation sector is dependent on petroleum for nearly 97 percent of its energy. In 1997, the transportation sector consumed 12.1 million barrels per day (MBPD) of petroleum products; highway vehicles account for 75 percent of transportation energy use with passenger vehicles alone using nearly 60 percent of the total. Without advanced, energy-efficient technologies, the Energy Information Administration projects that by 2020, the energy demand in the transportation sector will increase by 45 percent to 17.6 MBPD.

Transportation accounts for 65 percent of the U.S. annual petroleum consumption and uses 88 percent more petroleum than the United States produces. Currently, about half of the petroleum used in the United States is imported with U.S. dependence on imported petroleum growing. Annually, the cost of oil imports is one of the largest components of the U.S. balance of trade deficit. In 1997, oil imports were 34 percent of the merchandise trade deficit. The United States also remains vulnerable to future oil price shocks and manipulation by oil-producing countries, which, since 1972, has cost the U.S. economy $4 trillion.

The explosive popularity of low fuel-economy pickup trucks, vans, and sport utility vehicles used for personal transport, coupled with a growing economy, falling fuel prices, increasing numbers of drivers, and increasing miles traveled by each vehicle is pushing transportation fuel consumption higher. This situation will not change without a major advance in vehicle fuel efficiency. This could occur through regulatory or tax policies on vehicles or fuels and/or through technology improvements in the Nation's vehicles.

The Department of Energy's (DOE's) clean and efficient vehicles portfolio is the technological cornerstone for the Nation's initiative to significantly improve transportation energy efficiency.

Linkage to CNES Goals and Objectives

Technological developments from the clean and efficient vehicles R&D portfolio will contribute to meeting objectives contained within four of the five major CNES goals.

- CNES Goal I, Objective 2 - Significantly increase the energy efficiency in transportation, industrial, and buildings sectors by 2010.

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply.

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(pursuing research aimed at major improvements in vehicle efficiency, resulting in major reductions in greenhouse gas emissions, while meeting significantly improved emissions standards)*

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options. *(expanding long-term energy options such as hydrogen-based vehicle systems, enabling educational research opportunities, and building capabilities at educational institutions)*

By meeting OTT's goals and objectives, the Nation will reduce its dependence on oil and achieve energy savings as well as reduced carbon emissions. DOE, in the Quality Metrics Program Analysis, has estimated that by 2010, 1.8 quads of primary oil will be displaced, increasing to 3.7 quads by 2020. (For reference, 3.7 quads equals 638 million barrels of oil; highway vehicles currently use about 19 quads of energy annually). This will result in energy cost savings of nearly $10 billion in 2010 and over $20 billion by 2020; carbon reductions are estimated at 25 and 60 million metric tons in 2010 and 2020. (Motor gasoline use in the United States produces about 302 million metric tons of carbon per year).

Uncertainties

The technologies needed for the Cars of the Future and Heavy Trucks programs offer technical challenges identified in the technical roadmaps that provide the approach, milestones, and tasks needed to resolve the technical uncertainties. In addition to the uncertainties in technology development (the risk of being able to resolve technical barriers in a timely fashion), market and political uncertainties also exist. With low oil prices, fuel economy ranks low on the list of vehicle attributes that new car buyers desire. Consequently, one of the technical challenges is a result of market uncertainty—with an uncertain market for energy-efficient transportation technologies, efficiency needs to be produced with little to no incremental cost. In addition, there are some political uncertainties. For example, the regulatory process may establish extremely strict emissions standards that could preclude the adoption of some energy-efficient technologies.

Investment Trends and Rationale

Because 75 percent of transportation energy use is consumed by highway vehicles, virtually all of the DOE transportation technology R&D budget is directed at cars and trucks. And with 80 percent of highway vehicle energy use being passenger vehicles, the majority of the R&D budget is in the Cars of the Future (the major effort being the Partnership for a New Generation of Vehicles) and Light Trucks (which includes pickup trucks, vans, and sport utility vehicles). The area of heavy trucks accounts for the remainder of the DOE transportation R&D investment.

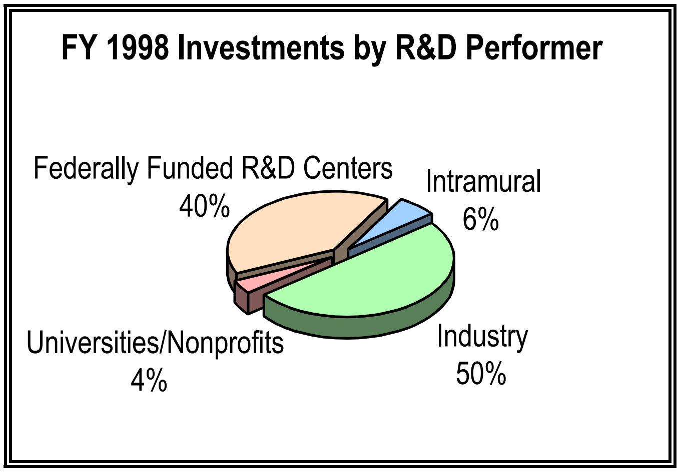
The Office of Transportation Technologies and its predecessor organizations have worked with the U.S. auto industry and engine manufacturers for over two decades to develop energy efficient technologies. Often the research was driven by Congressional mandates and various Administration priorities. Since the advent of the Partnership for a New Generation of Vehicles, DOE has worked even closer with the industry during the planning process to develop common technical roadmaps that would enhance the probability of commercial success. Technical roadmaps were developed first for the auto area and later for the heavy truck sector. Research and development plans were produced by OTT's Office of Advanced Automotive Technologies (OAAT) and the Office of Heavy Vehicle Technologies (OHVT). These plans underwent extensive external review. To assure the quality of the automotive R&D plan, the National Research Council (NRC) conducted an independent, comprehensive review of the OAAT plan last year, while the OHVT plans will be reviewed by the NRC this year.

Major program thrusts are developed in cooperation with industry in order to maximize the likelihood of commercialization of the energy-efficient technologies. Consequently, budget changes tend to be characterized as "mid-course corrections" rather than radical adjustments. One area of increased emphasis is compression-ignition, direct-injection (CIDI) engines, commonly called diesel engines. CIDI engines have the highest thermal efficiency of any internal combustion engine and offer the greatest near-term potential for reducing transportation energy use and greenhouse gas emissions. The primary focus of DOE's R&D is reducing emissions of particulates and oxides of nitrogen, which are the major technical challenges for CIDI engines.

One way that risk can been reduced is to explore a broad range of technologies. For this reason, the Office of Transportation Technologies has a diverse research portfolio. Periodically, a technology selection process is used to evaluate research progress against established milestones and reduce the number of technologies to the most promising ones. The most recent example occurred with the Partnership for a New Generation of Vehicles at the end of 1997. Program diversity also occurs with respect to time horizons, research stage, and research performers.

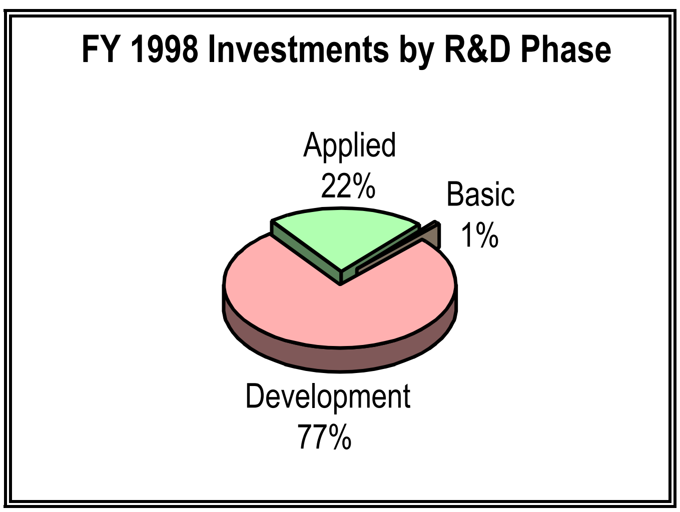
By design, the OTT research programs have been long-term, i.e., typically ten years or longer. DOE transportation research in the 1980s on alcohol fuels has resulted now in commercially available flexible-fueled (gasoline or alcohol) vehicles. Current research into energy storage, fuel cells, and hybrid vehicle systems also has a long-term horizon, although industry will often "harvest" DOE-supported technologies before the technology development for an integrated vehicle system has been completed. Consequently, it is difficult to delineate with any precision whether the research fits within a near-, mid-, or long-term horizon for anticipated commercialization.

The portfolio consists of two main entities, Cars of the Future, which includes PNGV and light trucks, and High Efficiency Heavy Trucks. FY 1998 funding for Cars of the Future totaled 84 percent of the portfolio, with High Efficiency Heavy Trucks supporting the remaining 16 percent. As shown in the figure below, half of the research is performed by the private sector, either funded directly or through DOE laboratories. Approximately 40 percent of the research is performed by the DOE laboratories themselves. A relatively minor amount of research is performed by other government agencies (6 percent) or universities (4 percent).



Research is often classified by stage—basic research, development, and applied research. Very little basic research is performed by the clean and efficient vehicles portfolio. Development is defined in the OMB Circular No. A-11 as, "...systematic application of knowledge toward the production of useful materials, devices, and system or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements."

As the next figure shows, the bulk of the research dollars are devoted to development with the majority of the balance spent on applied research, and a minute portion on basic research.



Given the limitations of Federal resources, the clean and efficient vehicles portfolio is allocating its budget consistent with the opportunities for having the greatest impact on transportation energy use (cars, light trucks, and heavy trucks) and with the technical priorities established with DOE's cost-sharing partners.

Federal Role

The primary government R&D role is to support long-range, high-risk activities where breakthroughs offer large potential payoffs to the Nation, but are not reflected in current market pricing. This support includes funding, as well as access to unique R&D capabilities within the Federal laboratory system. With fuel prices at historic lows, the transportation sector has little or no incentive to undertake high risk research on its own to achieve breakthrough efficiency improvements. The DOE role is to conduct R&D, with cost-sharing industry partners, that would achieve the national goals of:

- Reducing the Nation’s dependence on petroleum.
- Decreasing vehicle exhaust emissions, thereby improving urban air quality.
- Having a positive economic impact on the Nation’s transportation sector, which accounts for one out every seven American jobs.

Key Accomplishments

The auto industry is already beginning to use many of the technologies developed in the Cars of the Future, Partnership for a New Generation of Vehicles (PNGV), and Light Truck Programs. This was dramatically demonstrated by the recent unveiling of several hybrid and other advanced vehicles at the 1998 North American International Auto Show, where concept vehicles showcasing DOE-supported technologies included the Chrysler ESX2, Ford P-2000, and the General Motors EV-1 platforms. OAAT-supported technologies that were integrated into these concept vehicles included advanced compression-ignition, direct-injection (CIDI) engines, parallel-hybrid vehicle configurations, a proton exchange membrane (PEM) fuel cell, a methanol reformer, and a nickel-metal hydride battery. While considerable R&D remains to make these technologies commercially viable, these public demonstrations clearly demonstrate the interests of the U.S. auto companies in bringing these DOE-supported technologies to market.

Cars of the Future, PNGV, and Light Trucks:

Budget: FY98-$139.1M, FY99-$150.4M, FY00-$172.6M

Background

The Partnership for a New Generation of Vehicles (PNGV) is a cooperative research and development (R&D) program between the Federal government and the United States Council for Automotive Research (USCAR) that was announced by President Clinton and the CEO's of Chrysler Corporation, Ford Motor Company, and General Motors Corporation (GM) on September 29, 1993. The three major domestic automakers are working with the Federal government, labor, suppliers, and universities, to develop efficient, low-emission vehicles for the 21st Century.

The PNGV has 3 goals:

- To develop manufacturing techniques to reduce the time and cost of automotive development.
- To improve fuel efficiency and emission performance of conventional vehicles.
- To develop a new family of vehicles with up to triple the fuel efficiency (i.e., 80 miles per gallon) of today's mid-size cars (i.e., Ford Taurus, Chrysler Concorde, and Chevrolet Lumina) while maintaining or improving safety, performance, emissions, and price.

The initiative represents a priority approach of the Administration to protecting the environment, improving the competitiveness of U.S. companies, and reducing the economic and geopolitical risks that result from this Nation's rising dependence on petroleum. Government is working with industry to develop the required technologies, and industry will make the choices necessary to meet America's transportation needs. Together, they will achieve important social and economic objectives for the Nation. Seven Federal agencies participate in the Partnership for a New Generation of Vehicles under the leadership of the Department of Commerce.

Currently the Administration is discussing expansion of the Partnership for a New Generation of Vehicles to include multi-purpose vehicles (Class 1 and 2 trucks which include pickups, vans, and sport utility vehicles). Sales of multi-purpose vehicles have increased dramatically in the past 13 years from approximately 3 million vehicles in 1983 to over 6.9 million in 1997 (from 25 percent to over 45 percent of the foreign and domestic sales in the United States). Consequently, the industry is shifting substantial manufacturing emphasis to light trucks.

Sales in the light truck segment are shifting towards the heavier Class 2 trucks, reducing the average fuel economy for this segment. As a result, the U.S. auto manufacturers are having difficulty meeting current light truck Corporate Average Fuel Efficiency (CAFÉ) standards. Both GM and Chrysler failed to meet the 20.6 mpg standard for the 1995 model year. GM's truck fleet must exceed the CAFÉ standard of 20.7 over the next 3 years or face a prospective penalty for its 1995 shortfall.

Linkage to CNES Goals and Objectives

The R&D goals of DOE's programs in advanced vehicle technologies are to research, develop, and validate technologies that enable development of production prototypes of light-duty vehicles (automobiles, pickups, vans, and sport utility vehicles) which have (1) for automobiles, up to 3 times the fuel economy of comparable conventional vehicles; (2) for light trucks, 35 percent improvement in fuel efficiency (engine replacement only); (3) fuel flexibility; (4) emissions that at least comply with the most stringent statutory limits projected to be in the marketplace; and (5) other attributes, such as price, safety and performance, that render them competitive with conventional products.

This effort supports objectives contained in four of the five CNES goals:

- CNES Goal I, Objective 2 - Significantly increase the energy efficiency in transportation, industrial, and buildings sectors by 2010. *(developing more efficient transportation technologies)*

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply. *(helping reduce the consumption of petroleum)*

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(pursuing research aimed at major improvements in vehicle efficiency, while meeting significantly improved emissions standards)*

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options. *(expanding long-term energy options such as hydrogen-based vehicle systems, enabling educational research opportunities, and building capabilities at educational institutions)*

Program Description

Seven Federal agencies are collaborating with the U.S. auto companies in pre-competitive research to significantly improve automotive fuel economy. DOE's R&D program, which represents the majority of the Federal effort in PNGV, is conducted in partnership with the U.S. auto industry and the U.S. diesel engine industry. Research to overcome barriers to automotive technology development and utilization draws upon the unique capabilities of a dozen National Laboratories, combined with research facilities at universities, the major automakers and their suppliers. Coordination and prioritization of research portfolios is undertaken by technical teams comprised of representatives from industry, government, and National Laboratories. The technical areas include fuel cells, electrochemical energy storage, system analysis, manufacturing, four-stroke direct injection engines, materials and structures, electrical and electronics, and vehicle engineering.

Through consensus, each team develops a technical roadmap to overcome the barriers in its particular technology area. The teams review research progress and results, and recommend priorities for further research.

Research in the Cars of the Future, PNGV and Light Trucks Program Area can be grouped into four programs:

Engine/Power Sources

Budget: FY98-$68.3M, FY99-$96.1M, FY00-$123.2M

Advanced engine and power systems are critical to dramatic improvements in the fuel economy of automobiles and light trucks. Because the government does not manufacture vehicles, development of these technologies (which include advanced combustion engine R&D, fuel cells, high-power batteries, power electronics and electric machines, and electric vehicle batteries) will occur through a process that focuses on the research, development, and validation of hardware or prototypes to meet performance and cost goals. This collaborative process between the U.S. automakers, diesel engine manufacturers, and DOE follows technology roadmaps that have been developed, and are periodically updated, for each technology area.

Advanced Combustion Engine R&D

Budget: FY98-$14.8M, FY99-$34.2M, FY00-$46.8M

Description, Objectives, and Performers. The Advanced Combustion Engine R&D effort seeks to significantly improve the fuel efficiency of conventional piston engine technologies while cost-effectively meeting projected emissions regulations. The primary focus is on developing and validating compression-ignition, direct-injection (CIDI) engine technologies. In its 1997 technology selection, the PNGV identified direct injection engines as the most promising near-term energy conversion technology. Additional resources were requested in the FY 1999 and FY 2000 budgets to overcome the significant barriers that remain for this technology to meet anticipated emissions requirements. With the stringent emissions regulations proposed for particulates and nitrogen oxides, a secondary focus will be to enhance the performance of spark-ignition, direct-injection (SIDI) technology as a power system alternative to meeting the PNGV goals.

CIDI (diesel) engines have the highest thermal efficiency of any proven heat engine (brake thermal efficiency of 32-42 percent) and are excellent propulsion system candidates for both conventional drive systems and hybrid configurations. However, the use of CIDI engines in the automobile and light truck markets has been limited by shortcomings in performance, weight, size, noise, cost, and emissions. The greatest barrier to the future viability of CIDI engines for light-duty vehicles is the lack of effective, affordable emissions control technologies.

SIDI engines are being developed to support Goals 2 and 3 in the PNGV program. The status of current development and the potential of the SIDI engine suggest that it is a likely candidate for the incremental improvement of passenger car fuel economy (Goal 2), and a potential enabling technology for a three-times more fuel-efficient vehicle (Goal 3). The SIDI engine appears to be a viable alternative to the CIDI engine if, for a variety of reasons such as emissions, refueling, and service infrastructure, the latter is determined to be unable to achieve all the PNGV requirements.

R&D Challenges. Current NO_x emissions exceed the target (0.2 g/mile) by a factor of two and the proposed research target (0.05 g/mile) by a factor of eight. NO_x catalysts that operate with lean-burn engines are not available. Catalyst materials must be developed that operate in the presence of oxygen in the exhaust and that can perform over a wider temperature range. Other aftertreatment technologies are underdeveloped, costly, and do not have proven reliability and durability. Current particulate emissions exceed the research target (0.01 g/mile) by a factor of six. Particulate traps are costly (as much as 30 percent of the engine cost), energy-intensive (about 10 percent of fuel consumption), and have unproven reliability. Other aftertreatment devices (e.g., non-thermal plasma) are not adequately developed. In addition to the emissions problem, CIDI engines are about twice as expensive as conventional, port-injected, spark-ignition engines, principally because of the sophisticated fuel injection equipment. Higher operating temperatures and pressures also increase the cost of the engine structural components. Additional emissions controls (in-cylinder or aftertreatment) will simply add to the cost of the CIDI engine.

The key challenges for SIDI include reduction of NO_x, plus the reduction of unburned hydrocarbons (HC), and further reduction in particulates. The remaining challenge for SIDI is to improve the thermal efficiency (36-37 percent), which is better than the current port fuel injection engines (25-30 percent), but lower than CIDI engines.

R&D Activities. CIDI engine technology R&D focuses on in-cylinder and aftertreatment methods to reduce NO_x and particulate emissions as the primary barriers. NO_x reduction will target in-cylinder combustion control, catalysts, low-temperature plasma, and fuel modification and additives. Particulate reduction will target combustion control (such as variable air composition), traps, low-temperature plasma destructive technologies, and fuel and lubricant modifications. Research utilizes standard U.S. diesel fuel, low-sulfur California diesel fuel, and ultra-low sulfur European diesel fuel. Additional fuels that may have potential, such as dimethyl ether, are being evaluated. Design teams are focused on a 55 kW engine for hybrid applications in automobiles and a 150-200 kW engine for light trucks. The SIDI development effort is similar in approach, but smaller in scope.

Accomplishments. Program accomplishments include:

- In a joint DOE/industry hybrid propulsion program, two different CIDI engines were designed and developed. One engine was developed by Ford Motor Company and FEV Engine Technology, the other by Chrysler and Detroit Diesel Company.

- Initiated benchmark testing at the National Laboratories of state-of-the-art CIDI and SIDI engines.

- Completed initial performance specifications of critical enabling technologies, as well as cost goals, for the high efficiency diesel engine to replace the lower efficiency spark ignition gasoline engine for light truck applications (sport utility vehicles, vans, pickup trucks).

- Completed initial testing of first generation light truck engine systems. The efficiency improvement goal of 35 percent was met with one development team and exceeded by another, achieving 60 percent improvement. However, these tests did not meet the projections for 2004 emission standards.

Fuel Cells

Budget: FY98-$22.6M, FY99-$33.5M, FY00-$41.4M

Description, Objectives, and Performers. Fuel cells have emerged in the last decade as a potential replacement for the internal combustion engine in vehicles because they are clean, energy efficient (with a part-load system efficiency goal of over 50 percent and a full-load system efficiency goal target of 45 percent), and fuel flexible. Fuel cells offer the desirable attributes of low emissions, quiet and continuous operation, and modularity. Any hydrogen-rich material can serve as a potential fuel source for this rapidly developing technology. This includes fossil-derived fuels, such as natural gas, methanol, petroleum distillates, liquid propane, and gasified coal, or renewable fuels, such as ethanol or hydrogen (produced from renewable energy sources). The proton exchange membrane (PEM) fuel cell is the focus of current development efforts because it is capable of higher power density and faster start-up than other types of fuel cells.

R&D Challenges. Stack systems, fuel-flexible fuel processors, hydrogen storage, and power system integration are technical barriers for fuel cell development. Although fundamental scientific breakthroughs are not required to meet the program goals, substantial improvements are also needed in the areas of catalyst carbon monoxide (CO) tolerance and low-cost fabrication. Long-term durability and the efficiency of the integrated power system have not yet been demonstrated.

R&D Activities. Particular emphasis is placed on research to achieve high efficiency, quick start-up, long life, and low manufacturing costs. The R&D is focused towards development of low cost fuel cell components, fuel processor subsystem development, and integration of stacks, fuel processors, and balance of plant components. Methanol, ethanol, natural gas, and gasoline are being evaluated as fuels for on-board reforming. Industry teams led by Plug Power, International Fuel Cells, Allied Signal, and Energy Partners are completing development of 50 kW fuel flexible fuel cell systems under cost-shared contracts.

Accomplishments. Program accomplishments include:

- Conducted the world's first gasoline-fueled proton exchange membrane (PEM) fuel cell power demonstration with Epyx Corporation, Plug Power, and Los Alamos National Laboratory, integrating fuel-flexible fuel processing technology with carbon monoxide clean-up and fuel cell stacks to produce power from both ethanol and gasoline.

- Under a program with Ford Motor Company and International Fuel Cells, completed laboratory validation tests on hydrogen-fueled 50 kilowatt (commercial-scale) PEM fuel cell propulsion systems including testing under automotive drive cycle requirements.

- Under a program with General Motors Corporation and Ballard, completed testing of a 30 kW methanol fuel cell system that demonstrated extremely low emissions.

High-Power Batteries for Hybrid-Electric Vehicles

Budget: FY98-$8.6M, FY99-$12.8M, FY00-$15.0M

Description, Objectives, and Performers. A lightweight, compact, high-power energy storage device is one of the critical component technologies for a viable hybrid propulsion system. The primary functions of this device are to load-level the demand on the prime power source to maximize efficiency and minimize engine weight, volume, and cost; recapture the vehicle kinetic energy through regenerative braking; and capture the energy from the prime power source during braking and idle periods. In contrast to the high-energy requirement of electric vehicles, the energy storage device for hybrid vehicles must have high specific power (about ten times greater for hybrids than for electric vehicle batteries). Technologies that have the potential to meet the requirements for hybrid vehicles include: advanced high-power batteries, ultracapacitors, and flywheels. Currently only high-power batteries are considered sufficiently developed to have the potential to meet the schedule requirements of PNGV.

R&D Challenges. Batteries with power-to-energy ratios greater than 20kW/kWh and also have long cycle life, are needed. Electric and mechanical safety devices are needed to prevent overcharge or over-discharge. The candidate batteries all have operating temperature ranges that do not cover the entire operating temperature range required for automotive applications. Cost is too high by several factors, calendar life is unknown, and recyclability of the components is not known (the target is 80 percent recyclability at the vehicle level).

R&D Activities. Through a cooperative agreement between the United States Advanced Battery Consortium (USABC) and DOE, the USABC is focusing on the development of high-power batteries for PNGV. Two candidate battery chemistries have been identified as the most likely to succeed in meeting the requirements—nickel-metal hydride and lithium ion. The first of these offers relatively good power capability as a result of the good ionic conductivity of the aqueous potassium hydroxide electrolyte. The second offers excellent energy density that can be traded for higher power. Both chemistries are being investigated under the USABC program, initially to establish the basic performance and life capabilities in small laboratory cells, and then to demonstrate the best of these technologies in full-size modules. Ultimately, full-capacity battery energy storage subsystems will be engineered for delivery and operation with technology-validation test-bed vehicles.

Four USABC subcontracts to establish baseline cell chemistries and electrode designs were completed in 1997 and two of the contractors were awarded follow-on subcontracts (one for lithium-ion cells and the other for nickel-metal hydride cells) to develop and demonstrate their high-power battery technologies at the nominal 50-V module level with electronic and thermal management. In addition, the USABC awarded two other subcontracts to further explore alternative lithium-ion technologies. Performance and cycle life testing of deliverable cells are being conducted by selected National Laboratories under a Cooperative Research and Development Agreement (CRADA) with USABC.

Accomplishments. Program accomplishments include:

- Fabricated 50-volt nickel metal hydride high power modules and initiated life cycle testing.
- Scaled up high power energy storage lithium-ion technology from one to 12 ampere-hour full-sized, cells required for integration into 50-volt modules.
- Developed abuse test requirements and protocols, and completed assessment of the high-power energy storage lithium-ion safety performance envelope.

Power Electronics and Electric Machines

Budget: FY98-$4.4M, FY99-$6.9M, FY00-$9.0M

Description, Objectives, and Performers. Power conditioning for motor controllers, chargers, and other interface electronics is a key enabling technology for hybrid electric vehicles. Development of electronic components and systems for vehicle applications has progressed from replacing mechanical systems to making features available that can only be realized through interactive controls and devices. Currently, the application of power electronics in conventional vehicles is aimed at integrated powertrain controls, integrated chassis system controls, multiplexing, and navigational and communications systems. In addition to these requirements for conventional vehicles, hybrid vehicle electric powertrains will require control devices with faster semiconductor chip operation, higher power density, and more power dissipation per device.

Electric machines in use today are typically driven by induction motors, which are inherently difficult to optimize for power and efficiency. Replacing them with permanent-magnet, switched-reluctance, or other advanced machines will result in lighter weight, more cost-effective systems with higher efficiency and power density needed for hybrid electric vehicles. Research and development is therefore needed to produce power electronics and electric machines for automotive applications that are efficiently packaged, lightweight, low-cost, and reliable.

R&D Challenges. The primary barriers include: (1) Cost - materials, processing, and fabrication technologies for both power electronics and electric machinery are too expensive (by factors of 3 to 4) for automotive applications; (2) Volume - power electronics and electric machines are too large for automotive use; (3) Weight - electric machinery and power electronic controllers are too heavy and the extra component weight requires additional structural mass; and (4) Reliability and Durability - controllers have not been developed that meet 150,000 mile vehicle lifetime targets and existing electric machinery is not sufficiently rugged to operate in an automotive environment.

R&D Activities. For power electronics, OAAT is focused on developing technologies for automotive integrated power modules (AIPM) suitable for automotive applications. Baseline requirements for automotive controllers incorporating this power module architecture have been developed through close coordination with Chrysler, Ford, and General Motors. Additionally, OAAT is supporting development in the industry with the competitive award of 2 contracts at $10 million each to develop AIPM. OAAT work in this area is leveraged through an interagency agreement with the Office of Naval Research to jointly develop Power Electronic Building Blocks for use in automotive as well as military applications. The government-funded component development and testing is primarily being performed by DOE National Laboratories and U.S. Navy laboratories. In the electric machines area, OAAT is also supporting research to develop advanced technologies. Presently, industrial development is focused on induction motors, but weight, volume, efficiency, and cost goals are more likely to be met by switched-reluctance or permanent-magnet technologies if the existing technical barriers are resolved. OAAT plans for a similar solicitation effort to aid industry development of electric machinery for traction drives. A specification has been developed in a coordinated effort with Ford, GM, and Chrysler for traction drives. OAAT is also supporting laboratory R&D to improve materials useful in attaining the PNGV goals for power electronics and electric machinery.

Accomplishments. Program accomplishments include:

- Developed novel inverter topologies capable of meeting size, weight, reliability, and performance requirements for PNGV.

- Developed dc-dc converters with enhanced performance, size, and weight necessary in fuel-cell powered vehicles.

Electric Vehicle Batteries

Budget: FY98-$17.8M, FY99-$8.8M, FY00-$11.0M

Description, Objectives, and Performers. The California zero-emission vehicle requirements formulated in 1990, strengthened the interest of the auto industry in developing and introducing electric vehicles (EVs) into the automotive market. The key to market success of EVs has always been battery technology. Vehicle range is limited by battery performance, and battery cost remains high. For the past eight years, DOE's EV battery research and development has been conducted under a cooperative agreement with the USABC. Currently, research is directed toward completing the nickel-metal hydride technology (that doubles the range of EVs) and the lithium-ion technology, as the most promising mid-term technologies, and toward the lithium polymer technology for the long term.

R&D Challenges. While the technical barriers are specific to the type of battery being developed for electric vehicle application, the general areas are similar, and include for the long-term lithium-polymer battery: power density (which needs to be improved from 250 to 450 W/l), specific power (targeted at 300 W/kg versus the current 200), energy density (which needs to reach 195 Wh/l compared to the present 110) and specific energy (from the current 75 Wh/kg to a goal of 135). Cost, safety, recycling/disposal, and manufacturability are also barriers.

R&D Activities. The development of advanced batteries involves battery developers and suppliers, small businesses, National Laboratories, and universities. These activities are coordinated by DOE through the EV Battery Exploratory Technology Research Program and by USABC through its Technical Advisory Committee. Key barriers (and attendant research) for lithium batteries are large cell safety, overcharge damage, electrolyte oxidation, and cathode limitations. The technical barriers requiring research for the development of the lithium polymer battery include material degradation, electrode and electrolyte performance, projected battery performance and cost, thermal and electrical management, safety, disposal, and manufacturability.

Accomplishments. Program accomplishments include:

- Initiated extensive laboratory testing of lithium-polymer electric vehicle batteries which will provide 3 to 4 times the range, and significantly greater performance and life, compared to conventional lead-acid batteries. These batteries will be commercially introduced by 2003.

- Nickel-metal hydride battery packs, provided by two separate developers, are currently powering electric vehicles in introductory market programs.

Systems Development

Budget: FY98-$45.6M, FY99-$24.8M, FY00-$23.9M

Description, Objectives, and Performers. Systems development provides the focus and guidance for the OAAT vehicle systems research and development activities. Work in this area provides development and validation of required propulsion subsystem technologies; validation of vehicle system component and subsystem technologies in the context of a vehicle operating environment; feedback to enhance predictive models; and validation at the vehicle level of the achievement of objectives.

In this context, the systems development objectives are:

- By 1998, develop and validate production-feasible propulsion subsystem technologies that will enable the achievement of 50 mpg in test-bed six-passenger sedans that meet EPA Tier 2 emissions requirements, and retain all the attributes of comparable competitive production vehicles.

- By 2004, develop and validate propulsion subsystem technologies and validate technologies that will enable the achievement of 80 mpg in test-bed six-passenger sedans that retain all the attributes of comparable competitive vehicles, including emissions controls.

- By 2011, develop and validate production-feasible vehicle subsystem technologies that will enable the achievement of 100 mpg in test-bed six-passenger sedans emphasizing non-petroleum-based fuels and zero emissions, and which retain all the attributes and features of competitive vehicles.

R&D Challenges. The technical barriers are defined for the engine/power sources, materials, and fuels programs. In the systems development program, the technologies produced in the other programs are brought together as a system, i.e., into a testbed vehicle or propulsion system in the laboratory.

R&D Activities. To overcome the technical barriers, technology requirements were first defined. Requirements were developed through coordination with industry and derived from a common vehicle systems perspective. A vehicle system computer modeling capability (ADVISOR) was developed in the first phase of the program. The propulsion subsystem performance models embedded within the vehicle system models are being validated and refined using data generated by the test and evaluation activities of both the Hybrid Program (50/50 cost-shared contracts with Chrysler, Ford, and General Motors) and the vehicles developed in the advanced vehicle competitions by a number of university engineering schools. Technology validation will occur within a total vehicle systems context. This activity can involve either actual testing and evaluation of technology-representative point designs in complete test-bed vehicles or simulation of the operation of such point designs using subsystem/component models embedded in a total automobile system model.

Accomplishments. Program accomplishments include:

- Completed the validation of the hybrid vehicle ADVISOR model against data from the four existing university-developed hybrid vehicles from the Advanced Vehicle Competition.

- Completed the Ford P 2000 rolling chassis, demonstrating the achievement of the target 2000 lbs curb weight with a conventional drivetrain. Preliminary tests show the fuel economy goal of 50 mpg will be exceeded by both the conventional and hybrid configurations.

- Concluded in 1998, the GM hybrid propulsion development program demonstrated the achievement of a Stirling-powered series hybrid configuration in a mid-size Chevrolet Lumina. Because of its series hybrid configuration, the vehicle also demonstrated a zero emissions capability for errands and short commutes. Compared to prior technologies, substantial improvements were achieved in developing affordable battery packs specifically designed for hybrid vehicles, and reducing the cost of the electric motor and the complexity of the motor's power electronics, as well as improving thermal control for the battery pack.

- A major success for the Chrysler hybrid propulsion development program in FY 1998 was the rapid design, development, and testing of the first generation parallel hybrid propulsion configuration. The program began in March 1996, and in just over 18 months succeeded in demonstrating a production based test-bed vehicle and an advanced lightweight concept vehicle, the ESX-2. The concept vehicle is an operational parallel hybrid system using an advanced three cylinder diesel engine. Both vehicles are paving the way for Chrysler's 2nd generation of hybrids that will address issues of manufacturing, cost, weight, accessory power requirements, emissions, durability, and reliability. Initial tests show the fuel economy and emissions targets will be exceeded.

- Launched the CARAT program which provides small businesses and universities an opportunity to solve critical technology barriers as part of the PNGV. Received 133 competitive proposals and have awarded 26 Phase 1 CARAT cooperative agreements.

- Initiated the GATE program with a solicitation for proposals. From the proposals, nine universities were selected to receive support in the development of multi-disciplinary graduate student automotive engineering programs that emphasize technologies critical to the development and production of cars of the future. Advanced technology areas include: fuel cells, advanced energy storage, lightweight and propulsion materials, direct injection engines, and hybrid electric drivetrain and control systems.

Advanced Materials

Budget: FY98-$20.9M, FY99-$22.7M, FY00-$17.0M

Description, Objectives, and Performers. The advanced materials research conducted by OAAT has two closely coordinated elements. The first is propulsion subsystem materials, which is focused on developing materials for propulsion components and subsystems to facilitate higher efficiencies, lower emissions, improved alternative fuel capabilities, and lower specific weight and volume, without compromising other factors such as cost, safety, and reliability. Research activities in this area are defined under the appropriate engine/power source. The other research element encompasses lightweight vehicle systems materials, where reduction of body and chassis weight is the focus of the research activities.

Both the propulsion subsystem materials work and the lightweight vehicle system materials research are closely coordinated with materials R&D for heavy vehicle technologies.

The major goals in the lightweight vehicle systems materials area are to develop and validate cost-effective lightweight material technologies that could significantly reduce vehicle weight without compromising vehicle cost, performance, safety, or recyclability. Research objectives include:

- A 25 percent reduction in the weight of the body and chassis by 2000.
- A 50 percent reduction in the weight of body and chassis components contributing to a 40 percent reduction in vehicle weight by 2004.
- A 60 percent reduction in the weight of body and chassis components, necessary to achieve 100 mpg fuel economy, by 2011.

R&D Challenges. Cost is the single greatest barrier to the use of lightweight materials in automotive applications. In terms of life-cycle cost, aluminum is about 50 percent (or less) as expensive as steel and polymer composites are 3 times (or less) as costly. Methods for high-volume production of automotive components from lightweight materials have not been adequately developed, and design data and test methodologies are inadequate. High-volume, high-yield joining technologies for lightweight and dissimilar materials do not exist. Technologies for cost-effective recycling and repair of advanced materials are lacking.

R&D Activities. The DOE research is focused on specific classes of materials using representative, nonproprietary components. As technical barriers are removed, the technologies are made available for industry to take in-house to perform proprietary, application-specific research. The technology development areas and individual projects have been identified through workshops, white papers, planning studies, and assessments. The lightweight materials of interest include aluminum, magnesium, titanium, and carbon-fiber and metal matrix composites.

Accomplishments. Program accomplishments include:

- Demonstrated a four-minute cycle time for glass-fiber preforms to enable high-volume production of glass-reinforced composite automotive components.
- Developed test methodologies for characterizing the Mode II response of adhesive bonding joints for automotive applications. Standardized test procedures and fracture-based guidelines were developed and have been transferred to industry.
- Demonstrated the technical feasibility of producing carbon fiber using microwave radiation with significantly reduced processing times and costs.

- Demonstrated new processing technology for the fabrication of pump components using particulate reinforced aluminum alloys, resulting in weight savings and improved performance.

- Developed non-heat treatable aluminum sheet with yield strength exceeding 35,000 psi.

- Developed a unique lightweight (0.5 g/cm^3), high conductivity (100 W/n•K) carbon foam that is being utilized for thermal management of electronics such as heat sinks and heat exchangers.

- Developed lightweight carbon composite bipolar plate materials in the laboratory that meet fuel cell requirements, and transferred a material recipe and manufacturing process to industry for scale-up.

Fuels Utilization

Budget: FY98-$4.3M, FY99-$6.8M, FY00-$8.5M

Description, Objectives, and Performers. DOE supports fuel R&D in two major areas: (1) alternative fuels for conventional engines, and (2) fuels for advanced engines in support of the PNGV program. Alternative (i.e., non-petroleum) fuels have the potential to displace significant amounts of petroleum, providing energy security benefits, and reduced emissions. Alternative fuels are at varying stages of development for use in vehicle engines, and the additional research needed to increase their viability for conventional vehicles varies accordingly. Research is also being conducted to address the potential of new fuels to ensure compliance with emissions regulations in high-efficiency advanced engines. Fuel composition changes may facilitate the effective use of aftertreatment/cleanup devices and enable advanced engines to minimize emissions while maximizing fuel economy objectives.

R&D Challenges. *Compressed Natural Gas (CNG):* The most critical barrier to retail consumer acceptance of the CNG vehicle is the high initial vehicle cost, due primarily to the high fuel tank cost. In addition, refueling infrastructure expansion is hindered due to the high cost of compressors and auxiliary equipment, resulting in CNG fueling stations that cost five times as much as gasoline stations. The third technical barrier is limited vehicle range (about half that of conventional vehicles) due to the mass and volume of the on-board gas storage tanks.

Ethanol: This renewable fuel has the potential to displace imported oil and reduce the transportation sector's contribution to criteria pollutants and greenhouse gases. The current ethanol R&D needed for long-term biomass production is described in the Producing Clean Fuels chapter of this document.

Dimethyl Ether (DME): Although not currently used as a transportation fuel, dimethyl ether is being considered because of its high cetane number and inherently low particulate emissions, which make it attractive for high-efficiency compression-ignition engines. The principal technical barriers for DME exist because its supporting fuel systems (fuel storage, fuel delivery/injection) are in a very preliminary design stage; therefore the costs, reliability, durability, and safety are not known. Further, large-scale production, distribution, and refueling infrastructures do not exist.

R&D Activities. For CNG, several interrelated tasks will develop lower-cost, lighter-weight materials for the different types of CNG storage tanks and integrate these improvements into acceptable vehicle storage systems. The cost and reliability of fueling stations will be improved through compressor and auxiliary component technology development, with an emphasis on materials and design concept refinements. Vehicle range will also be addressed through improvements to achieve a high-efficiency engine. Research into the use of dimethyl ether will require development of fuel storage, fuel delivery, and fuel injection systems. Fuel infrastructure issues will also be evaluated.

In the future, the Fuels Utilization program for light duty vehicles and trucks will increase focus on development and evaluation of advanced petroleum based fuels to be used in direct injection engines and fuel cells. A major concern for these advanced engines is to be able to meet future emission requirements and efficiency goals. It will be necessary to work with energy and automotive companies to develop fuels that will meet these goals and that can be effectively introduced into the market. Testing of various fuels with advanced direct injection engines is underway. Future programs will evaluate the effect of oxygenates as an additive to diesel fuel to help with reducing particulate matter (PM) emissions, analysis of PM with regard to toxicity, and determining the impact that lubrication oil has on the formation of PM in the exhaust. Fuels for fuel cells will also be a major part of the program. Projects to identify major contaminants in advanced petroleum based fuels and their impact on fuel cell performance is underway. The tolerance level of these contaminants will be determined in future programs. In addition, testing of fuels in fuel processors to optimize the use of fuel constituents will be started.

Accomplishments. Program accomplishments include:

- Completed tests on 7 fuels (DMM, Fischer-Tropsch neat, Fischer-Tropsch 20, biodiesel, EPA-2D, CARB diesel, regular diesel) in an advanced direct injection, diesel engine, aimed at determining emission effects. Positive effects were observed on particulate emissions with up to 50 percent reduction gained from DMM blended with low-sulfur diesel.

- Demonstrated the Generation I integrated storage system (ISS), utilizing lower-cost, lighter-weight, Type II compressed natural gas tanks.

- The Ethanol Vehicle Challenge, involving 14 U.S. and Canadian engineering schools, demonstrated 30 percent better fuel economy than gasoline vehicles as well as comparable cold-starting (at 0^{O} F) and driveability.

- Thirteen U.S. and Canadian engineering schools participated in the FutureCar Challenge (with vehicle goals similar to those in the PNGV program). The highest on-road efficiency was 75 mpg compared to 37 mpg with a control conventional vehicle.

High-Efficiency Heavy Trucks

Budget: FY98-$30.9M, FY99-$30.8M, FY00-$52.0M

Background

The health and continued growth of the U.S. economy are dependent on maintaining the energy security and profitability of the trucking industry, now and into the foreseeable future. Trucks are the mainstay for trade/commerce and economic growth. The gross domestic product (GDP), and hence, economic activity, is linked to freight transport. Total highway freight transportation expenditures (local and intercity trucks) were over $348 billion, accounting for 79 percent of the Nation's freight bill and approximately 4.8 percent of the GDP (1995). Meeting energy demand for movement of goods is, therefore, critical to the economy.

Linkage to CNES Goals and Objectives

The goals for heavy truck technology have been established according to truck class because of the vastly different use patterns across the weight classes.

(1) For class 7-8 trucks, the tractor trailer long-haul rigs, the goal is to develop by 2004, the technology for a fuel efficiency of 10 mpg (at 65 mph) meeting prevailing emission standards, using either diesel or a liquid alternative fuel.

(2) For class 3-6 trucks, predominantly urban delivery vehicles, the goal is to achieve double the fuel economy of today's vehicles, using conventional or natural gas fuels, in combination with a hybrid electric propulsion system.

(3) To support the alternative fuel requirements above, there are goals to develop alternative fuel engines with fuel flexibility and a thermal efficiency of 55 percent with liquid alternative fuels, as well as gaseous fuels.

This effort supports objectives contained in three of the five CNES goals:

- CNES Goal I, Objective 2 - Significantly increase the energy efficiency in transportation, industrial, and buildings sectors by 2010. *(developing more efficient transportation technologies)*

- CNES Goal II, Objective 1 - Reduce the vulnerability of the U.S. economy to disruptions in oil supply. *(helping reduce the consumption of petroleum)*

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(pursuing research aimed at major improvements in vehicle efficiency resulting in major reductions in greenhouse gases)*

Program Description

Research and development plans developed by OTT's Office of Heavy Vehicle Technologies (OHVT) were extensively reviewed by industry partners (truck manufacturers, diesel engine manufacturers, and their suppliers), fuel suppliers, other DOE organizations, other Federal agencies, National Laboratories, and other Federal research centers. The OHVT plans and programs were reviewed by an independent industry/government peer review panel and will undergo National Research Council review during 1999. Consequently, the research activities described in this portfolio are the result of rigorous planning processes and can be referenced in the OHVT Technology Roadmap and in the Multi-Year Program Plan. Research and development for the Office of Heavy Vehicle Technologies is carried out largely in cooperative programs between the DOE laboratories and industry, by universities, and by independent research institutions.

The High Efficiency Heavy Truck efforts can be grouped into four major categories:

Heat Engine R&D

Budget: FY98-$3.5M, FY99-$3.5M, FY00-$9.0M

Description, Objectives, and Performers. Heavy trucks rank closely behind passenger cars and light trucks in the Nation's annual fuel utilization. Their relatively high fuel consumption per vehicle provides an incentive to utilize more efficient technology as it becomes available, even in times of low fuel prices. Engine R&D for heavy vehicles focuses on advancements in fuel economy for petroleum savings and on emissions control technology to maintain compliance with increasingly stringent regulations. Mainstream R&D activities in engine technology are carried out in cooperative agreements with the major domestic engine manufacturers, with enabling technology R&D conducted in the National Laboratories. Targeted engine efficiency is 55 percent or higher, with the direct-injection diesel engine being the incumbent, and still most viable candidate, for highway truck applications. Engine efficiency improvement is a major contributor to overall goals of increasing class 7-8 truck fuel economy from nominally 7.5 mpg to over 10 mpg at 65 mph. Innovative and improved designs for higher cylinder pressures, improved exhaust heat utilization, and lower engine friction are key aspects of the technology roadmap. Emissions control R&D emphasizes a three-pronged approach: combustion systems, aftertreatment, and fuel formulation. Engine compatibility and optimization for non-petroleum diesel fuels is an additional objective to augment petroleum savings. These efforts are shared and coordinated with the fuels R&D projects in heavy vehicles.

R&D Challenges. Best current engines have efficiencies of nominally 46 percent. In order to achieve the fuel economy targets for heavy trucks, engine efficiency must be on the order of 55 percent or higher, requiring a 20 percent advancement. Improvements, focused on the direct injection, "diesel-cycle" engine, are needed in a number of integrated technology areas including increased peak cylinder pressure, additional exhaust heat recovery through improved turbo systems, improved thermal management, less heat rejection, reduced parasitic friction loss, and improved combustion.

The greatest barrier for this high efficiency engine class is emission control, particularly NO_x and particulate matter (PM). Emissions reduction requires a systematic approach encompassing three areas of activity: (1) in-cylinder processes (combustion, air handling), (2) exhaust aftertreatment, and (3) fuels properties.

Success is dependent on advancements in basic engine design, in key subsystems such as turbocharging and fuel injection, and in supporting technologies like materials.

R&D Activities. Tasks are in progress to improve fuel injection systems, along with more fundamental research to improve the understanding of key parameters of the in-cylinder processes. New models of how NO_x and particulates form in engines have been developed. Research and development on exhaust aftertreatment includes particulate filters, NO_x catalysts, and plasma systems, plus improvement in the measurement and analysis tools needed to accurately determine what compounds the devices are reducing and what byproducts they may be producing.

Accomplishments. Program accomplishments include:

- A new type of particulate filter has been developed through the prototype stage.
- Small prototypes of NO_x catalysts have exceeded 50 percent reduction of NO_x and non-thermal plasmas devices have exceeded 70 percent reduction on a small scale.
- To date, engine efficiency of approximately 52 percent has been achieved in test engines, compared to 44 percent in production engines when the program began, and 46 percent today.
- The program has assisted manufacturers in reducing NO_x emissions by over 50 percent and PM by over 80 percent in production engines.
- New prototypes of diesel engines for sport utility vehicles have been built and are undergoing evaluation in test cells as well as in vehicles. Fuel economy improvements are expected to exceed 50 percent compared to gasoline engines.

Systems Development

Budget: FY98-$1.7M, FY99-$1.5M, FY00-$12.0M

Description, Objectives, and Performers. For class 7-8 highway trucks, systems R&D encompasses the reduction of aerodynamic drag and rolling resistance in heavy trucks, as well as reduction of parasitic losses related to auxiliaries and operating modes. In order to achieve the truck fuel economy goals, for example, aerodynamic drag coefficients will need to be lowered from today's typical value of 0.60 to less than 0.50. The challenge is to make the cab and trailer modifications cost effective, while not hindering maintenance, reducing payload, nor violating regulations that govern the overall size of the unit. A detailed plan on aerodynamic drag has been developed with industry participation, and a similar activity is underway on rolling resistance. One part of the aero effort will be to advance the computational tools used for cab/trailer development. In particular the trailer has received much less attention in aerodynamic development. It will be the focus of near-term analysis using existing computational tools.

R&D Challenges. The trucking industry is reluctant to accept new technology unless it meets all State and Federal regulatory standards, standard trucking practices, and the return on the investment is realized within 2 years.

R&D Activities. DOE is fostering a proof-of-principle project to reduce truck idling that can save up to 3 billion gallons of fuel per year (reducing petroleum consumption by nearly 200,000 barrels per day). Several industry firms have agreed to make cab heater/cooler units available to truck operators who will record data on time in use and fuel consumed. The data will be disseminated in order to encourage the use of the devices. A substantial improvement in local air quality could also result.

For class 6 and lighter trucks (urban delivery trucks), the primary focus in systems R&D is on hybrid-electric technology. In a conventional vehicle powered by an internal combustion engine, the engine must deliver short bursts of high power for acceleration and also long duration steady-state power at lower levels for constant speed highway cruising. The variability in power requirement causes vehicle manufacturers to provide engines that are sized to meet the maximum power requirement. These "oversized" engines are less fuel efficient at low loads and idling and they produce higher emissions. Also, in conventional vehicles, mechanical friction braking is used to slow the vehicle when necessary, resulting in the conversion of kinetic energy into heat.

The use of a hybrid electric propulsion system allows the vehicle to have a smaller prime power source that can be optimized for efficient, clean operation while the hybrid system can still meet the high power requirements for acceleration. Also, regenerative braking can be easily incorporated into the hybrid system. Hybrid electric propulsion systems are ideally suited for use where the power demand is non-constant, such as in city driving where frequent starts and stops are required. The hybrid electric propulsion system is a natural replacement for the gasoline engine in medium duty urban delivery trucks. The attainment of a fully cost-effective technology is one of the hybrid's greatest challenges. Hybrid systems are being developed in the PNGV program for cars, and these systems should be applicable to light trucks.

Accomplishments. Program accomplishments include:

- A detailed R&D plan on heavy vehicle aerodynamic drag has been developed with industry. Efforts are started to improve computational tools for aerodynamic design of the tractor/trailer.

- A program has been started to compile data on the fuel savings from use of truck cab heaters/coolers to avoid truck idling. The presentation of the data is expected to promote the use of these fuel-saving devices.

Advanced Materials

Budget: FY98-$13.0M, FY99-$14.8M, FY00-$16.0M

The major program elements in heavy truck advanced materials are (1) propulsion system materials, (2) high strength weight reduction materials, and (3) the High Temperature Materials Laboratory.

Propulsion System Materials

Description, Objectives, and Performers. The purpose of the Heavy Vehicle Propulsion System Materials Program is to develop enabling materials technology to support fuel flexible low emission, high efficiency diesel engines for medium and heavy duty trucks.

The design of advanced components for high efficiency diesel engines has, in many cases, pushed the performance envelope for engine materials past the point of reliable operation. Higher mechanical and tribological stresses and higher temperatures of advanced designs limit the engine designer. Advanced materials allow the design of components that may operate reliably at higher stresses and temperatures, thus enabling more efficient engine designs. Advanced materials also offer the opportunity to improve emissions, noise, vibration, harshness (NVH), and performance of diesel engines for pickup trucks, vans, and sport utility vehicles.

R&D Challenges. Component cost and reliable cost-effective processes and manufacturing procedures for advanced materials present substantial barriers to their commercialization.

R&D Activities. New forms of materials, such as nanophase structures in both metals, ceramics, and alloys in the amorphous condition, are being investigated to determine if their unique properties such as high hardness, strength, corrosion resistance, and low coefficient of friction can stand up to the rigors of the new power plants.

Accomplishments. Program accomplishments include:

- Development and commercialization of scuff-resistant ceramic components for Cummins Engine Company fuel injectors that allow Cummins to meet EPA standards for particulate emissions.

- Successful development and testing of durable ceramic valves for a Detroit Diesel Corporation heavy duty engine.

High Strength Weight Reduction Materials

Description, Objectives, and Performers. The objective of the High Strength Weight Reduction Materials Program is to develop advanced materials and materials processing technologies leading to reductions in vehicle weight that enable heavy vehicles (trucks and buses) to be more energy efficient. The focus is on body and chassis components which are light weight while still meeting performance requirements in a cost effective way. Weight reductions will be achieved through the increased use of improved conventional materials and new, advanced materials and by developing low-cost, high volume manufacturing processes. When implemented, these materials technologies will reduce the weight of unloaded heavy duty tractor-trailer units by 20-30 percent, resulting in 10-18 percent reduction in fuel use and emissions. These goals are achieved through partnerships between government laboratories, industry, and universities.

R&D Challenges. High costs and component reliability and durability are major issues in the commercial truck market.

R&D Activities. Development of the technology to cast ultra-large aluminum components; application of metal compression forming to produce high integrity structural cast aluminum components; and the development of metal matrix composites are other avenues of attention for heavy vehicles.

Accomplishments. Program accomplishments include:

- Design of all major components of the Ultra-large Casting System including primary and holding furnaces, press, mold system, and caster cell was completed and fabrication of a major component is nearing completion. Installation and initial trials are scheduled for early FY 1999. Successful development will result in low-cost, high-volume production of single large components, thereby reducing the number of parts and corresponding assembly steps.

- Demonstrated a new casting process for aluminum alloys and metal matrix composites (MMC) which will enable the substitution of low cost cast components with significantly less weight than cast iron components while offering considerable cost savings over forged aluminum components.

High Temperature Materials Laboratory

Description, Objectives, and Performers. The High Temperature Materials Laboratory (HTML) is a national user facility, offering opportunities for American industries, universities, and other Federal agencies to perform in-depth characterization of advanced materials under the auspices of its User Program. Available are electron microscopy for microstructural and microchemical analysis, equipment for measurement of the thermophysical and mechanical properties of materials to elevated temperatures, x-ray and neutron diffraction for structure and residual stress analysis, high speed grinding machines, and measurement of component shape, tolerances, surface finish, and friction and wear properties.

The User Program began in 1987, and has expanded over the intervening years from a few user projects per year to a current range of 80 to 110 project per year. In the eleven years between 1987 and 1998, a total of 819 projects were performed, with users from several hundred industries, colleges and universities, and other Federal agencies. The HTML focuses on materials for transportation, especially structural materials, with work being performed on engine and fuel system materials, chassis materials, and brake system materials. Cummins Engine Company, Detroit Diesel Corporation, and Caterpillar Inc. are frequent users. HTML also supports their suppliers, and especially catalyst materials developers and suppliers, since catalysts will play such an important role in the success of diesels in the future. Automobile manufacturers similarly work with HTML, especially Ford Motor Company. Projects involving non-transportation research are also undertaken at HTML, as long as they have a relationship to energy efficiency or renewable energy.

R&D Challenges. The HTML attempts to resolve materials issues at the atomic level. The primary barrier to that approach is the capability of the available equipment to provide adequate analysis.

R&D Activities. This year, HTML researchers and users spent considerable effort on characterization of catalyst materials, including use of transmission electron microscopy to evaluate several-atom clusters of Os species on substrates, and novel catalysts from Ford Motor Company. Much of the catalyst examination was performed via remote microscopy, wherein the user simply logs onto the HTML computer controlling the microscope and runs it from his/her home institution. This process is extremely cost-effective, avoiding the expenditure of both the user’s travel time and money. Research was also directed at development of advanced materials for diesel engine fuel injection systems.

Accomplishments. Program accomplishments include:

- In an on-going HTML User project with Ford Research Laboratory, conducted via remote microscopy, Dr. C. K. Narula used the Hitachi HF-2000 transmission electron microscope to study experimental catalysts comprising Pt clusters on alumina, titania, and mixed Al-Ti oxide support materials.

- A basic catalyst research HTML user project has been initiated with Professor Bruce Gates and his students at the University of California at Davis. Professor Gates is preparing and studying catalysts comprising clusters of heavy atom species on a variety of substrates.

- Several Cooperative Research and Development Agreements (CRADAs) are now underway with major U.S. diesel engine manufacturers to apply the unique capabilities of the HTML to specific materials problems.

Fuels Utilization

Budget: FY98-$12.7M, FY99-$11.0M, FY00-$15.0M

Description, Objectives, and Performers. DOE has both near term and long range objectives and efforts in fuel utilization. For class 7-8 trucks, the most viable alternative substitute fuel in the near term is liquefied natural gas (LNG). Several LNG trucks are undergoing field trials, and have demonstrated NO_x and PM levels over 80 percent lower than similar vehicles operating on standard diesel fuel. A challenge remains to elevate the efficiency and power of the natural gas engines closer to that of the diesel engines they replace.

Natural gas engines, because of their demonstrated low PM and NO_x, are particularly attractive for urban delivery vehicles in class 3-6 trucks. These vehicles provide an excellent application for natural gas since most are operated as fleets with central refueling. Natural gas engines in class 3-6 need significant improvements in part-load efficiency since they normally operate with a lighter load factor than larger highway trucks. Urban delivery vehicles are prime targets for hybrid vehicle technology with the potential for up to 3 times today's fuel economy. Hybrid vehicles, for lowest emissions, will need a natural gas engine designed especially for the hybrid system.

R&D Challenges. Cost - the industry is reluctant to accept any new engine/fuel system which is not clearly cost attractive; Infrastructure - unavailability of an adequate number of fueling stations is a significant barrier to widespread use of alternative fuels; Operation, Maintenance and Reliability - the diesel engine is noted for its reliability and durability, and the industry is cautious about use of new fuels and engines due to concerns that reduced reliability will adversely impact operations.

R&D Activities. To meet this challenge, DOE, the Gas Research Institute, and the South Coast Air Quality Management District have jointly instituted projects with major engine manufacturers. The project teams will work to make incremental improvements to today's natural gas engines to help maintain a market for the technology. The teams will also develop stretch technology like direct injection natural gas engines to achieve efficiency goals of up to 55 percent.

The program strategy includes research and development of natural gas storage to complement these engines. One specific project focuses on the development of onboard high pressure fuel delivery systems for direct natural gas fuel injectors. Other projects include testing of conformable tanks, developing smart tank technologies, developing low pressure storage, studies on natural gas storage for heavy vehicle market penetration, and demonstrating the advantages of LNG/CNG refueling. Performance measures for this activity are developing safe, reliable, cost efficient components for heavy vehicle fuels storage. Performance goals are as follows:

1. Use conformable tanks to achieve 40 percent more onboard storage than conventional compressed gas cylinders.

2. Reduce life cycle cost by 25 percent for natural gas storage for heavy vehicles.

3. Increase hold times, reliability and reduce boil-off for LNG storage.

4. Conserve 15 percent of the energy fuel value of natural gas by improving storage tank design, fuel delivery systems and fuel integration strategies.

The second major fuel thrust for heavy vehicles is alternate-feedstock liquid diesel fuels. Fuels with excellent qualities for high-efficiency compression ignition engines can be produced from biomass, natural gas, and in the long term, other vast resources such as coal and oil shale. These fuels have value in displacing petroleum consumption, and their typically low levels of sulfur and aromatic hydrocarbons, offer some inherent benefit for engine emissions. The low sulfur content may enable use of certain aftertreatment technologies (e.g. NO_x traps) for near-zero emissions. Oxygenated fuels such as biodiesel and dimethoxymethane are proven for lowering PM and are generally miscible with conventional diesel fuel. Even without optimizing an engine for the specific fuel, Fischer-Tropsch diesel fuel has been found to lower PM by over 30 percent. Most of these diesel-like fuels are also advantageous in being compatible with today's fuel distribution infrastructure.

Compression-ignition fuels can possess similar physical properties (density, viscosity) yet vary widely in chemical composition (aliphatic/aromatic ratio, oxygen content). Compression ignition engines also have particular design features depending on the manufacturer and application of the engine. Correlations relating fuel properties to engine efficiency and emissions are empirical and not very accurate, making the optimization of fuel and engine properties difficult. A two pronged approach has been initiated to remedy the situation and help fully exploit new fuels. First, research has been started to improve the fundamental understanding of the effects of fuel properties on emission formation. Optical access research engines and combustion vessels are being used to characterize how fuel properties affect spray and atomization, soot formation, and NO_x. For the present, we must continue to rely on test programs with experimental matrices of fuel parameters and engine designs. This program element is called the "Performance and Emissions Data Base for New Diesel Cycle Fuels," and was planned with participation of the engine manufacturers as well as fuel producers.

In addition to improving the utilization of conventional and alternative fuels in a diesel cycle engine, the program includes activities to improve the understanding of the effects of diesel engine emissions on air quality and human health. This will largely be accomplished by (1) participation and support for studies of diesel emissions and their health effects, (2) identification of major air quality problems affected by fuel-related sources, (3) examination of emissions from heavy vehicles run on diesel, biodiesel, CNG, LPG, methanol, ethanol, and other fuels of interest, and (4) the study of the transport and fate of the pollutants and/or their precursors.

The Office of Transportation Technologies (OTT) is also collaborating with Fossil Energy and its Federal Energy Technology Center (FETC) to advance the development and deployment of cost competitive fossil-based replacement fuels. Four types of activities are being conducted under this collaboration: (1) production, characterization, and testing of Fischer-Tropsch diesel fuel and additives made from syngas for petroleum diesel blending; (2) small-scale, high-efficiency Liquified Natural Gas (LNG) production technology for remote site natural gas production and fleet LNG fuel production; (3) incorporation of renewable feed streams to refinery systems for carbon reduction; and (4) process economics to identify technical and market barriers for the deployment of replacement fuels additives. These activities are being coordinated by the OTT Fuels Crosscut Coordinating Team (FCCT).

Accomplishments. Program accomplishments include:

- Assisted industry in introducing and certifying alternative fuel heavy-duty engines in numerous applications. Includes natural gas engines for urban buses and alcohol-fueled engines for trucks and buses.

- Demonstrated LNG powered trucks with 80 percent less NO_x and PM than conventional diesel powered vehicles.

- Developed and demonstrated a multi-cylinder heavy duty diesel engine operational on M85 and diesel fuel interchangeably.

- Characterized the performance and emissions from diesel engines operating on advanced petroleum-like fuels such as biodiesel and Fischer-Tropsch diesel fuel.

Summary Budget Table (000$)

Clean and Efficient Vehicles Research Areas	FY 1998 Appropriated	FY 1999 Appropriated	FY 2000 Request
Cars of the Future - PNGV and Light Trucks	**139,066**	**150,356**	**172,580**
Engine/Power Sources	68,280	96,121	123,180
- Advanced Combustion Engine R&D	*14,818*	*34,175*	*46,800*
- Fuel Cells	*22,614*	*33,501*	*41,380*
- High-Power Batteries for Hybrid-Electric Vehicles	*8,620*	*12,750*	*15,000*
- Power Electronics and Electric Machines	*4,410*	*6,875*	*9,000*
- Electric Vehicle Batteries	*17,818*	*8,820*	*11,000*
Systems Development	45,582	24,815	23,900
Advanced Materials	20,855	22,655	17,000
Fuels Utilization	4,349	6,765	8,500
High Efficiency Heavy Trucks	**30,890**	**30,840**	**52,000**
Heat Engine R&D	3,500	3,500	9,000
Systems Development	1,700	1,500	12,000
Advanced Materials	13,015	14,820	16,000
Fuels Utilization	12,675	11,020	15,000
Total	**169,956**	**181,196**	**224,580**