Partnering for the Future of Automotive Technology

Office of Advanced Automotive Technologies
1999 Program Highlights

Message from the Director

As we journey into the 21st century, our citizens enjoy an unparalleled degree of transportation freedom. To safeguard this freedom, we must ensure the continued flexibility provided by automobiles and other personal-use vehicles. Given our mounting concerns for energy security, improved air quality, and industrial competitiveness, this objective represents one of our greatest challenges. Over the next several years, the nation will implement new federal and state automobile emissions regulations; encounter more volatile global energy markets; and face increased economic competition in the international market for clean, advanced automotive technologies.

Together, government and industry have made great strides in developing technologies for advanced vehicles. Through the collaborative efforts managed by the Office of Advanced Automotive Technologies, we have witnessed advances in many technology areas — from the development of microchannel fuel processor technologies that allow a fuel cell system to work with a range of fuel types to a breakthrough manufacturing technique that could potentially reduce the production cost of lightweight carbon fiber by 40 percent. This report provides highlights of accomplishments achieved in FY99, together with overviews of technological challenges and future directions in each technology area.

If dramatically advanced, fuel-efficient, low-emission cars are to become a major part of this country's highway transportation fleet, much research and development (R&D) remains to be done. Our current research efforts represent a collaboration of industry, government, national laboratories, and universities working to enable production of vehicles with radically improved fuel economy and reduced emissions. Our collective goal is to drive advanced automotive technologies to the point of maturity so that auto manufacturers can incorporate them into the everyday family car. We are confident that our programs will provide the vital advanced technologies to meet our nation's critical need for personal, light-duty highway transportation, while also markedly reducing America's consumption of energy for transportation and providing a cleaner environment for future generations.

In addition, it is imperative that we look at the implications of our work in a global context. Toward that end, in April 2000 the Department of Energy is sponsoring the first in a planned series of biennial Future Car Congresses. This international conference, held in Arlington, Virginia, showcases accomplishments in advanced automotive technologies and highlights the achievements of government-industry partnerships. It also serves as a forum to validate current and future directions of R&D, addresses issues related to environmental impacts from vehicles, and promotes industry-university dialogue on ways to educate, recruit, and train an advanced transportation technologies work force for the 21st century.

Robert Kirk
Acting Director
Office of Advanced Automotive Technologies
Office of Transportation Technologies

Message from the PNGV Coordinator

This is an exciting time for automotive technology research and development. Earlier this year the three major U.S. automakers unveiled their state-of-the-art hybrid-electric family sedan concept vehicles capable of achieving up to 80 miles per gallon. These high-tech vehicles represented the second major milestone of an unprecedented government-industry partnership — the Partnership for a New Generation of Vehicles (PNGV). The next PNGV milestone calls for completion of production prototypes of these high-fuel-economy vehicles by 2004.

Since 1993, the U.S. Department of Energy's Office of Advanced Automotive Technologies has been working with other federal agencies, Ford, DaimlerChrysler, General Motors, hundreds of suppliers, universities, and national laboratories to develop this next generation of family vehicles. Researchers are working on advanced engines, propulsion materials, fuel cells, power electronics, lightweight bodies and chassis, and cutting-edge battery technologies. This partnership is yielding dramatic results in a range of automotive technologies, pointing the United States toward global leadership in the development and production of affordable, fuel-efficient, low-emission automobiles.

We are encouraged by the PNGV program's recent technological breakthroughs, some of which are highlighted in this report. Results of PNGV activities in materials and engine technologies are already being incorporated into production vehicles. Other technologies, such as fuel cells, are receiving public attention through media coverage and the display of concept vehicles at international auto shows. For PNGV to succeed in meeting its goals, however, research must continue on reducing component costs, improving system efficiencies, and minimizing emissions. We look forward to continuing our joint R&D efforts and seeing the future car become a reality.

Edward Wall
PNGV Coordinator
Office of Advanced Automotive Technologies
Office of Transportation Technologies

Partnering for the Future of Automotive Technology

1999 Program Highlights

Office of Advanced Automotive Technologies
Office of Transportation Technologies
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

The Office of Advanced Automotive Technologies

Can you imagine driving for more than 1,000 miles in a hybrid electric vehicle before needing to fill up your gas tank? Or can you picture yourself picking up the kids from school in a fuel-cell-powered minivan? Not too long ago, these transportation technologies were only possible in our imagination. Now they may be just a few years from arriving in showrooms near you — made possible, in part, through the research and development activities supported by the U.S. Department of Energy's (DOE) Office of Advanced Automotive Technologies (OAAT) within the Office of Transportation Technologies.

Under the leadership of the Office of Energy Efficiency and Renewable Energy (EERE), DOE is sponsoring the research, development, and validation of cutting-edge vehicle technologies to enable fuel-efficient and environmentally friendly light-duty vehicles. Because transportation accounts for more than 65% of the oil consumed by the United States — more than domestic production — these efforts are sharply focused on developing vehicle technologies to decrease our nation's reliance on petroleum. The technologies are also providing breakthroughs in combating air pollution and global climate change by reducing light-duty vehicle emissions.

Technologies developed by OAAT will significantly benefit the U.S. automotive industry, U.S. economy and the environment:

- ✓ **Enhance U.S. automotive industry competitiveness**
- ✓ **Reduce U.S. reliance on petroleum**
- ✓ **Reduce harmful exhaust gases**

OAAT works with other agencies, DOE laboratories, industry partners, and universities across the United States, to conduct high-risk research and development of technologies for use in cars, minivans, pickup trucks, and sport-utility vehicles. Supported research addresses fuel cells, cleaner burning fuels, electric and hybrid electric systems, energy storage solutions, and lightweight and other advanced materials. The development of advanced automotive technologies will help 21st century vehicles run cleaner and go farther on a gallon of fuel. This document highlights the exciting FY 1999 research and development accomplishments in major transportation technology programs and identifies areas in which additional technical challenges will be addressed in the coming years.

Partnering for Success

The DOE automotive technology R&D program plays a major role in the Partnership for a New Generation of Vehicles (PNGV). With the U.S. Department of Commerce as the government lead, PNGV was established in 1993 to bring together the resources of the automotive industry and government in a historic effort to triple the fuel efficiency of today's passenger vehicles. PNGV-selected technologies include advanced propulsion systems, energy storage, and lightweight materials. Over the life of the program, engineers at DOE national laboratories, automotive suppliers, and universities work in partnership with Ford, DaimlerChrysler, and General Motors to research, develop, and validate new vehicle components that will enable a family sedan to achieve up to 80 miles per gallon. By 2004, the automakers will have assembled what each considers to be their best mix of technologies in the form of three breakthrough production prototype vehicles.

By 2004, the PNGV program aims to:

- ✓ **Develop manufacturing techniques to reduce the time and cost of automotive development**
- ✓ **Improve fuel efficiency and emission performance of conventional vehicles**
- ✓ **Develop a vehicle with triple the fuel efficiency of today's mid-size cars while maintaining or improving safety, performance, emissions and price**

The year 2000 marks a major milestone of the PNGV program — the unveiling of the proof-of-concept vehicles that demonstrate up to 80-mpg fuel economy. Earlier this year, the three U.S. automakers presented their PNGV vehicles — Ford and General Motors at the North American International Auto Show in Detroit, and DaimlerChrysler in Washington, DC. All three vehicles (Prodigy, Precept, and ESX3) feature advanced hybrid propulsion systems, high-efficiency diesel engines, and extensive use of lightweight materials. At the unveiling of these vehicles, Ford Motor Company Chairman William Clay Ford, Jr., General Motors Vice Chairman Harry Pearce, and DaimlerChrysler Senior Vice President Bernard Robertson credited DOE's contribution to developing the advanced technologies showcased in their vehicles.

In addition to its PNGV-related activities, OAAT conducts an Electric Vehicle (EV) Battery program in conjunction with the U.S. Advanced Battery Consortium (USABC). USABC was formed in 1991 by the three major U.S. automakers and DOE to address the development of effective long-range, rechargeable batteries – the key technology required for the successful commercialization of electric vehicles. The specific goal of the USABC partnership is to develop lithium-based battery technologies by 2002 that will enable electric vehicles to achieve driving ranges comparable with those of conventional vehicles. More information on the USABC partnership is presented in the Electric Vehicle Batteries section.

Ford P2000 Prodigy

PHOTO COURTESY FORD MOTOR COMPANY

DaimlerChrysler ESX3

PHOTO COURTESY DAIMLERCHRYSLER CORPORATION

General Motors Precept

PHOTO COURTESY GENERAL MOTORS CORPORATION

OAAT at a Glance

OAAT is divided into three management teams – Energy Conversion, Energy Management, and Vehicle Systems – that provide the technical, financial, and programmatic management of R&D activities. Each team manages technology areas represented by separate budget areas of the OAAT appropriation. Following a master R&D plan, all teams work together toward meeting the OAAT program goals of developing technologies to improve fuel efficiency and reduce emissions.

- The Energy Conversion Team focuses on research and development in advanced **technologies** for compression-ignition direct-injection (CIDI) engines, fuel cells, propulsion system materials, and fuels utilization. The Energy Conversion Team also conducts programs designed to access innovative expertise at small businesses and universities.
- The Energy Management Team manages R&D activities bearing on high-energy battery **technologies** for electric vehicles, high-power battery technologies for hybrid-electric vehicles and advanced power electronics and electric machine technologies.
- The Vehicle Systems Team reviews and evaluates the integration of components developed by the other two teams. The Vehicle Systems Team also develops advanced propulsion subsystems, hybrid direct-injection engines, advanced lightweight materials, and simulation **technologies**.

Each technology area is highlighted in this report, including overviews of technical challenges, FY 1999 accomplishments, and future program directions.

Advanced Combustion & Emission Control

The goal of the Advanced Combustion and Emission Control program is to develop technologies enabling the introduction of highly efficient engines that meet stringent federal emissions standards. The PNGV program identified compression-ignition, direct-injection (CIDI) engines as one of the most promising technologies for meeting the partnership's fuel economy goals. Therefore, activities of the Advanced Combustion and Emission Control program currently focus on the development of CIDI engine and emission control technologies for use in a hybrid vehicle. Program activities also explore the fundamentals of the processes involved in combustion that contribute to emission formation. The program is aimed at developing engine technologies that will enable automakers to produce light-duty vehicles with up to three times the fuel economy (80 mpg) of today's conventional vehicles.

Challenges

Today's CIDI engines achieve impressive thermal efficiency. However, in order to meet future emissions standards, advancements in clean combustion, emission control technology, and fuels are necessary, including:

- Reducing and controlling unwanted oxides of nitrogen (NO_X) and particulate matter in the exhaust by 85% below current-technology diesel engine emissions.
- Decreasing emissions without jeopardizing fuel economy.

Advanced Diesel Engines Promise High Fuel Efficiency.

Recent Accomplishments

Laboratory tests of a new catalyst technology demonstrated the potential to remove 95% of NO_X emissions over a broad range of temperatures; this achievement received a National Laboratory CIDI R&D Award for outstanding achievement in research and development with respect to CIDI engine exhaust emissions control.

Two industry cost-shared programs were initiated with engine manufacturers and catalyst suppliers to develop and demonstrate emissions control systems for PNGV CIDI engines that will enable compliance with U.S. Environmental Protection Agency (EPA) Tier 2 emissions standards.

Lean Burn NOx Catalyst May Remove 95% of NO_X Emissions.

R&D Magazine awarded a 1999 R&D 100 Award for "Clean Diesel Technology: Simultaneous reduction of NO_X and particulates from diesel engines by three-way optimization of oxygen purity in the intake air, fueling rate, and timing."

A Presidential Early Career Award was presented to a national laboratory researcher for plasma-activated catalysis research.

Future Directions

By 2002, complete component-level validation to achieve PNGV CIDI intermediate targets of 0.2 g/mile NO_X and 0.025 g/mile particulate matter emissions.

By 2004, demonstrate technology that will achieve tailpipe emission levels commensurate with EPA Tier 2 standards.

Optimize the effects of fuel formulation on emission control device performance.

More information on this program can be found in *1999 Annual Progress Report: Advanced Combustion and Emission Control.*

Hybrid Direct-Injection Engine

Although its high thermal efficiency makes the CIDI engine the principal combustion engine candidate for the PNGV program, the spark-ignited direct injection (SIDI) engine appears to have many attractive features. Compared to CIDI engine technology, the SIDI engine technology has lower particulate emissions, better power-to-weight ratio, the ability to use certain alternative fuels, and greater compatibility with known emissions control technologies. In addition, because it uses gasoline fuel, the SIDI engine may receive greater U.S. market acceptance than the diesel-fueled CIDI engine. The Hybrid Direct-Injection Engine program is focused on evaluating and developing improved SIDI engine technologies.

The Optically Accessible SIDI Engine Allows Researchers to Look Inside a Working Engine.

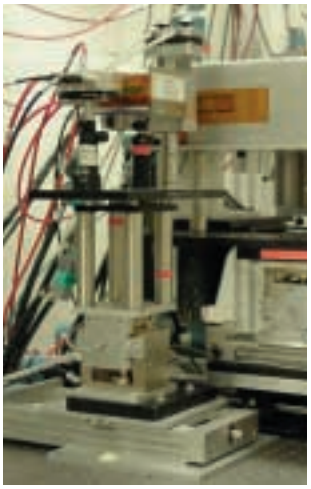
Challenges

Because of their good fuel economy, SIDI-powered vehicles have achieved strong market success in both Europe and Japan. These engines, however, have not been able to meet the stringent U.S. Tier 2 emissions standards for particulate matter, NO_x, and hydrocarbons. OAAT efforts are focused on addressing these challenges:

- Precise control of timing, volume, dispersion, and in-cylinder fuel charge locations, as well as required air-fuel ratio, is critical to obtaining complete combustion and low emissions.
- Reducing the overall cost of the engine components for successful commercialization.

Recent Accomplishments

- Developed an x-ray technique to allow researchers to image the dense liquid core of the fuel spray, furthering understanding of critical fuel spray properties.
- Developed and conducted diagnostic evaluations using a specially-made transparent SIDI engine that lets researchers look inside a working engine.
- As a part of the engine design process, researchers conducted three-dimensional computer modeling to perform full-cycle dynamic simulation of SIDI injections and combustion.



Experimental Test Setup for X-Ray Measurements Using SIDI Injection System.

Future Directions

- Develop a low-cost SIDI injection system that will enable attainment of EPA Tier 2 emissions standards while achieving at least 35% efficiency.
- Develop exhaust gas sensors and perform combustion modeling through industry-laboratory partnerships.
- Continue fundamental combustion research to improve understanding and control of in-cylinder phenomena.

More information on this program can be found in *1999 Annual Progress Report: Hybrid Direct-Injection Engine.*

Fuel Cell Technologies

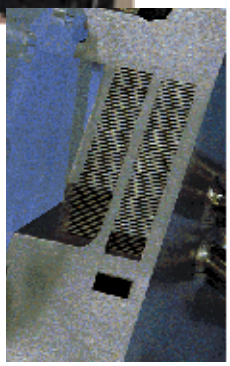
Fuel cells can power the car of tomorrow: quieter, cleaner and more efficient than internal combustion engines, while providing equivalent range and performance. Except for ordinary water, fuel cells produce zero emissions when fueled directly with hydrogen and extremely low emissions when running on such fuels as methanol, ethanol, natural gas, or gasoline. In addition, fuel cells produce electricity without the use of moving parts, thereby making little or no noise. While fuel cells represent the power source of tomorrow, they are the focus of the automotive industry's demonstrations today: every major automobile company is evaluating the technology and most have demonstrated fuel cell test vehicles operating on hydrogen or methanol. OAAT's Fuel Cell R&D program is working to bring this technology closer to realization through research and development on fuel-flexible proton exchange membrane (PEM) fuel cells. Program objectives include reducing the size, cost, and weight of fuel cells and working to enable fuel cells to operate on readily available fuels such as gasoline.

Challenges

The successful early introduction and acceptance of automotive fuel cells is dependent on fuel-flexible fuel cell systems — systems that run on both conventional and alternative fuels. In addition to developing new fuel systems, we must:

- Make fuel cells cost-competitive by developing new materials, advanced manufacturing processes, and systems with higher operating efficiencies.
- Improve overall performance, weight, size, and durability.

Researchers Received the Vice President's PNGV Medal for Achievements in Fuel Processor Technologies.



The Microchannel Fuel Processor Received an R&D 100 Award.

Recent Accomplishments

- Successfully integrated a fuel cell stack that uses a fuel-flexible fuel processor operating on low-sulfur gasoline, methanol, ethanol, naphtha, and other fuels.
- Developed a new microchannel fuel processor to reform gasoline into a fuel stream with a high concentration of hydrogen. The processor was identified by *R&D Magazine* as one of the 100 most technologically significant new innovations of the year.
- Identified new fuel cell catalysts that will allow fuel cells to tolerate a higher level of carbon monoxide from reformed fuel without reducing the performance of the fuel cell stack.
- Achieved cost-reducing advances in the manufacture of fuel cell membrane-electrode assemblies and bipolar plates.

Integrated Fuel Cell Systems: Energy Partners (below) and International Fuel Cells (left)

Future Directions

- Complete development, testing, and evaluation of an integrated, automotive-size fuel cell power system capable of operating on petroleum-based and alternative fuels and able to meet cost targets.
- Complete development and demonstration of a fabrication process for low-cost (i.e., $10/kW) advanced membrane-electrode assemblies (MEAs).

More information on this program can be found in *1999 Annual Progress Report: Fuel Cells for Transportation*.

Advanced Petroleum-Based & Alternative Fuels

In order for PNGV-selected powertrains and energy conversion technologies to maximize their energy efficiency potential while maintaining low emissions, advanced fuels are needed. The Advanced Petroleum-Based Fuels program supports research in the evaluation of new petroleum-based fuel formulations that will allow hybrid engines and fuel cells to succeed in meeting emissions requirements. Activities in the Alternative Fuels program are directed at the use of alternative fuels in high-efficiency direct-injection engines.

Challenges

- Advanced petroleum-based or alternative fuel blends must be developed because current fuels have physical properties and impurities that may cause combustion inefficiencies and poison emission control catalysts. These inefficiencies can result in excessive NO_x and particulate matter emissions when used in high-fuel-economy engines.
- Use of alternative fuels in advanced direct-injection engines and fuel cells requires addressing such issues as high-pressure storage. Additional challenges include reducing the costs of pressurized gas tanks on board the vehicle, reducing the costs and improving the reliability of pressurized refueling equipment, and extending fuel cell vehicle range.

Recent Accomplishments

New Microreactor Tests Different Fuels for Use in Fuel Cells.

- Completed testing and evaluation of an advanced, PNGV-scale CIDI engine that uses a blended, low-sulfur diesel fuel resulting in a reduction of up to 10% in particulate emissions.
- Determined the implications of fuel formulations on fuel cell reformer performance by using a microreactor to test the effect of different hydrocarbons (and therefore, different fuel types).
- Completed development of a prototype fuel injection system pump that allows clean-burning dimethyl ether to be used in a six-cylinder diesel engine.

Future Directions

Fuel Pump Allows a Diesel Engine to Use Dimethyl Ether Fuel.

- By 2004, in collaboration with the automotive and fuel industries, identify advanced fuel formulations that will enable direct-injection and fuel cell engines to exceed EPA Tier 2 Bin 5 (similar to California LEV) emissions standards.
- For alternative fuels, evaluate pressurized on-board fuel storage technologies.

More information on this program can be found in *1999 Annual Progress Report: Advanced Petroleum-Based and Alternative Fuels.*

Lightweight Vehicle Materials

One of the most practical ways to increase fuel efficiency and reduce emissions is to reduce the weight of the vehicle. While steel continues to be the most widely used material for structural components in automobiles, a number of alternative materials, such as aluminum and composites, are moving from the laboratory to the manufacturers. High costs and other critical issues continue to constrain widespread use of these newer materials. The Lightweight Vehicle Materials program addresses these issues through the development and validation of advanced lightweight materials that can significantly reduce vehicle body and chassis weight without compromising other vehicle attributes such as safety, performance, recyclability, and cost. Cost reduction, manufacturability, design data and test methodologies, joining, recycling, and repair are the focus of activities that support the PNGV goals.

Challenges

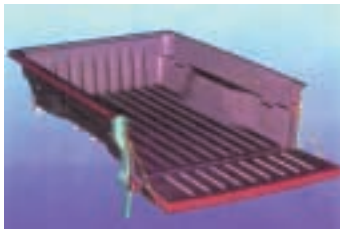
High cost is the greatest single barrier to using lightweight materials in automotive applications. The development of new materials, forming technologies, and appropriately scaled manufacturing processes offer the potential to reduce these costs. In addition, new technologies must be able to meet standards for safety, durability, performance, and recyclability.

P-4 Preformer Will Potentially Reduce Production Costs of Carbon-Fiber Components.

Recent Accomplishments

- Developed carbon fiber techniques with the potential to reduce production costs by 40% and production times by a factor of almost ten.
- Developed aluminum alloy sheet with the potential to reduce production costs by 10-25%.
- Improved aluminum casting models to reduce component weight by over 50%.
- Decreased barriers to use of recycled wrought aluminum through an advanced technique for color sorting of aluminum alloys.
- Validated a concept with the potential to cut magnesium production costs while also reducing environmental impact.

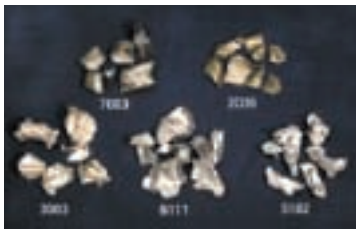
Conversion to Cast Aluminum Lowers Weight of Control Arm from 16.3 lb to 7.9 lb.



Researchers Developed a Glass Fiber Composite Truck Bed.

Future Directions

- Demonstrate the feasibility of cost-competitive carbon fiber production for automotive applications.
- Validate lightweight technologies that will enable 60% reduction in automobile body and chassis weight.
- Validate crash absorption models for carbon fiber composite-intensive automobiles.



Chemically Etching Wrought Aluminum Scrap Pieces Allows for Easy Color Identification of Different Alloys.

More information on this program can be found in *1999 Annual Progress Report: Lightweight Vehicle Systems Materials.*

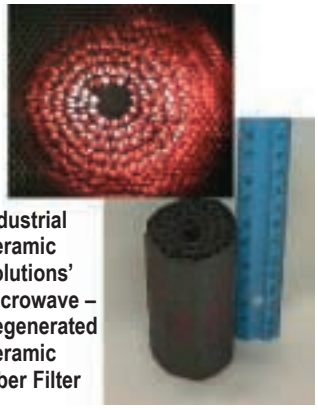
Propulsion Materials

Automotive propulsion system materials research is key to PNGV program success. This research is aimed at improving the materials used in propulsion systems components and subsystems — systems such as power electronics, fuel cells, combustion engines, and emissions control. New propulsion system materials will facilitate higher efficiencies, lower emissions, improved alternative fuel capabilities, and lower specific weight and volume, without compromising cost, safety, and recyclability. In the development of these enabling technologies, the Propulsion Materials program focuses on the use of all types of advanced materials — metals, ceramics, composites, and novel material systems such as "smart" materials. Currently, the program addresses materials concerns that directly affect the commercial viability of advanced propulsion systems — concerns in the area of thermal management, emissions, and reduced manufacturing costs.

Challenges

As technology enablers, propulsion system materials will help other OAAT programs overcome their own technological challenges.

- Power Electronics — Heat generated by advanced power electronics modules is the greatest challenge to their successful operation. Advanced materials are required to dissipate heat, preventing damage to sensitive semiconductor circuits.
- Fuel Cells — The successful development of fuel cell technology for automotive applications requires breakthroughs in cost, durability, size, and performance. Materials research for fuel cell stacks can help to reduce costs while improving durability and performance.
- Combustion Emissions Control — Wherever there are moving parts within a system, new materials can reduce the amount of friction between these parts and improve efficiency, overall durability, and operating life. In addition, propulsion materials can help engines reduce emissions through the development of advanced filters and other emission control devices.



Industrial Ceramic Solutions' Microwave – Regenerated Ceramic Fiber Filter

Recent Accomplishments

- Power Electronics — Developed high heat-conductivity carbon foam for heat exchangers and heat sinks, helping to increase heat transfer from advanced power electronics devices fourfold, reduce volume by a factor of ten, and reduce system costs by 20 to 25 percent.
- Fuel Cell — Produced a new molding compound for fuel cell bipolar plates that exhibited reduced cure times, extended shelf life, and enabled a more uniform flow – leading to lower-cost production of stacks for PEM fuel cell systems.
- Combustion & Emissions Control — Developed a microwave regenerative (self-cleaning) exhaust filter for diesel engines that is capable of capturing more than 90% of carbon particulates.

In 1999, the OAAT-supported Near-Frictionless Coating (NFC) technology was presented with a National Laboratory Director's Award.

Future Directions

- Many of the advanced technologies will be moved from the laboratory over to industry for testing or commercialization.
- New propulsion system materials projects will include the development of smaller, lighter, and more efficient radiators and the fabrication and testing of small, high-temperature, low-loss capacitors.

More information on this program can be found in *1999 Annual Progress Report: Propulsion Materials.*

Electric Vehicle Batteries

Electric vehicles offer an attractive alternative to vehicles powered by internal combustion engines because they do not produce harmful emissions. However, the successful commercialization of electric vehicles requires the development of advanced energy storage and related systems technologies. Through high-energy battery research, the Electric Vehicle Battery program focuses on advanced energy storage technologies that will enable full-range electric vehicles to travel at least 200 miles on a single battery charge. Working closely with U.S. automakers as part of the U.S. Advanced Battery Consortium (USABC), the Electric Vehicle Battery program seeks to develop the next generation of nickel-metal hydride (NiMH), lithium-ion and lithium-polymer battery technologies.

Challenges

Electric vehicle battery systems must simultaneously meet such extraordinary requirements as high power demand, fast rechargeability, long life, safety, low heat, and low cost. Barriers include high cost, inadequate performance and life, reliability, system safety, and disposal issues.

- Electrode and Electrolyte Performance — Battery electrodes and electrolytes need greater efficiency and capacity.
- Abuse Tolerance — Battery designs still face a challenge in tolerating abuse with respect to heat and chemical composition.
- Materials Manufacturing — Technologies are required that reduce the cost of manufacturing cell materials for automotive battery applications.

SAFT America Began Delivery of NiMH Batteries for Use in the Chrysler EPIC Electric Minivan.

Recent Accomplishments

- Completed nickel-metal hydride battery research activities with the delivery of production modules from SAFT America to DaimlerChrysler for use in their EPIC Electric Minivan and from GM Ovonic to General Motors for use in the EV-1 and S-10 electric vehicles.
- Demonstrated life of more than 500 cycles in laboratory tests of a lithium-polymer electrochemical cell cohort group representing an entire EV battery pack.
- Developed a comprehensive series of tests to characterize the abuse tolerance of advanced batteries developed under the USABC and PNGV programs. These test procedures were published in July 1999 and have been recognized and adopted by the Society of Automotive Engineers (SAE) as the industry standard (J2464).

SAFT NiMH Battery Pack and Module

Future Directions

- Beginning in FY 2000, Phase III of the DOE-USABC cooperative agreement will focus on the development and validation of lithium-ion and lithium-polymer batteries.
- Between FY 2002 and FY 2005, researchers will validate full-size battery packs for first- and second-generation lithium-based batteries with low-cost components.

More information on this program can be found in *Advanced Battery Technology for Electric and Hybrid Vehicles* and *1999 Annual Progress Report: Energy Technology Research.*

High-Power Energy Storage

A lightweight, compact, high-power energy storage device is one of the critical component technologies for hybrid propulsion systems. In contrast to the high-energy requirement of electric vehicle batteries, the energy storage device for hybrid vehicles must have high power — about 10 times greater than the requirement for electric vehicles. The High-Power Energy Storage program currently focuses on lithium-ion and nickel-metal hydride technologies — considered to be the only energy storage devices currently able to meet the schedule and performance requirements of the PNGV program. Research is conducted both in coordination with the USABC and through the DOE national laboratory Advanced Technology Development (ATD) program. Activities include the development, evaluation, and demonstration of both nickel-metal hydride and lithium-based high-power battery technologies.

Challenges

- High-power lithium-ion batteries are not intrinsically tolerant of short circuits, overcharging, and other abuses. Low-cost, fail-safe electrical and mechanical safety devices need to be developed.
- If manufactured at a level of 100,000 batteries/year, the cost of today's high-power battery technology ($3,000/kWh) is still three times the estimated cost required for successful market introduction.
- To reduce overall system costs, current battery calendar life, based on power, must be increased from 3-4 years (lithium-based batteries) and 6+ years (nickel-metal hydride batteries) to 10 years.
- Proven fabrication and assembly techniques do not exist for manufacturing thin electrode assemblies at high rates and assembling them into compact, lightweight packages (cells, modules, and batteries).

SAFT High-Power Battery Module

High-Power Batteries Will Enable PNGV Vehicles to Meet Performance Requirements.

Recent Accomplishments

- SAFT built and delivered four 50-volt, 12-ampere hour (A•h) lithium-ion modules for testing, meeting PNGV performance targets for power-assisted hybrid electric vehicles.
- Developed a viable first generation high-power cell for fabrication, identified lower-cost materials and created a new electrolyte for a second-generation high-power cell.
- Manufactured 300 high power cells of ~1 A•h each, and developed packaging designs that have the potential to reduce cell packaging cost from $15/10 A•h cell to less than $1/A•h cell.

Future Directions

- Select one of two currently developed battery technologies and develop a 200-volt battery aimed at satisfying the PNGV high-power energy storage requirement for hybrid vehicles.
- Focus on overcoming the main barriers to the successful development and commercialization of high-power lithium-ion batteries.

More information on this program can be found in *1999 Annual Progress Report: Advanced Technology Development* and *Partnering for the Future of Automotive Technologies: 1999 Accomplishments Report.*

Advanced Power Electronics

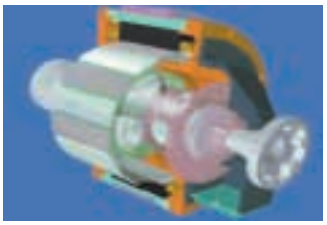
Advanced power electronics are required to manage the energy flow between the batteries and the electric motors in hybrid-electric vehicles. Current electric vehicles are driven by induction motors, which are difficult to optimize for power and efficiency. Replacing them with permanent-magnet, switched-reluctance, or other advanced motors will help attain the higher efficiency and power density needed for hybrid electric and electric vehicles while reducing weight and cost. The goal of the Advanced Power Electronics program is to develop these advanced power electronics and electric machinery technologies that are reliable, efficiently packaged, and affordable.

Challenges

- Materials, processing, and fabrication technologies for both power electronics and electric machinery are too expensive for automotive applications.
- Existing power electronics and electric machinery are bulky and difficult to package for automotive applications. Also, current heat management techniques are inadequate to dissipate heat in high-power-density systems.
- Integration of power electronics and motors into a single propulsion unit is required to promote space savings, reduced cost, and higher efficiency and reliability with fewer connectors, hoses, and cables.
- Existing power electronics converters and motor controllers that meet requirements for size and weight are not sufficiently rugged or reliable for a 150,000-mile vehicle lifetime.

Recent Accomplishments

- Organized and held the first Power Electronics Peer Review meeting to provide an opportunity for industry program participants to help focus R&D efforts and learn of laboratory capabilities/accomplishments in the area of power electronics R&D.
- Initiated an effort to integrate power electronics and motors into a single integrated propulsion unit to improve packaging density, reduced cost, and achieve higher reliability and efficiency.
- Began an effort to research, develop, and demonstrate an automotive electric motor drive including the design, fabrication, and testing of an axial gap DC brushless motor and the building of an advanced AC induction motor for series and parallel configuration.



The Automotive Electric Motor Drive Will be Developed Over the Next Three Years.

Future Directions

- Continue the development of an advanced integrated power module and the automotive electric motor drive. Results of these efforts are expected over the next three years.
- Future activities will place increased emphasis on advanced capacitor research and development, including advanced materials.

Advanced Integrated Power Electronics Will be Key to Successful Development of Hybrid Electric Vehicles.

More information on this program can be found in *1999 Annual Progress Report: Advanced Power Electronics and Electric Machines.*

Vehicle Systems Technologies

The goal of the Vehicle Systems Technology program is to facilitate development of competitive, consumer-acceptable automotive propulsion systems through the definition of technology requirements, and development and validation of necessary component technologies. Activities under the Vehicle Systems Technology program include the development and validation of advanced hybrid-electric vehicle propulsion systems, design of advanced modeling and evaluation tools, development of facilities for testing vehicle systems, and development of advanced automotive accessories to ensure that these systems can be made more efficient and can work with the advanced propulsion systems under development.

William Powers, Ford Motor Company's Vice President for Research, Delivers Ford P2000 LSR Hybrid Electric Vehicle to Secretary Richardson.

Advanced Powertrain Test Facility Validates Complete Vehicle Systems.

Variable-Compression-Ratio Engine Promises High Efficiency at Low Engine Power Levels.

Challenges

The main challenge of the Vehicle Systems Technology program is to predict how individual technology components will perform when assembled together in an automobile.

Recent Accomplishments

- Completed development and testing of 50-mpg parallel hybrid propulsion systems for mid-size vehicles and continued development activities aimed at 80-mpg fuel economy.
- Completed testing, mapping, and characterization of a Toyota hybrid vehicle.
- Investigated the potential for variable-compression-ratio (VCR) technology to significantly improve spark-ignition engine efficiency without compromising proven emission control technology.
- Continued to enhance advanced vehicle systems modeling capabilities through the Advanced Vehicle Simulator (ADVISOR) software and Virtual Vehicle model.

Future Directions

- Continue to focus on testing component technologies and overall vehicle systems validation through both testing and computer modeling.
- Begin identification of technology requirements for incorporating PNGV-supported technologies in a future high-fuel-economy sport utility vehicle (SUV).

More information on this program can be found in *1999 Annual Progress Report: Vehicle Systems Technologies.*

Cooperative Automotive Research for Advanced Technologies (CARAT) Program

Small businesses, colleges, and universities have an abundance of creativity, resourcefulness, entrepreneurial spirit, and good-old American "know-how." OAAT's Cooperative Automotive Research for Advanced Technologies (CARAT) program, established in 1998, allows these organizations to realize their potential by establishing partnerships with industry to research, develop, and validate advanced automotive technologies.

Recent Accomplishments

- Completed 26 Phase 1 projects designed to prove the feasibility of advanced technologies in six research topic areas.
- Selected seven small-business and university projects to continue to Phase 2 activities, in which engineering prototypes will be built to meet specific performance targets. In addition, preliminary economic analyses will be completed that will assess each technology's potential to meet high-volume, low-cost fabrication targets.

Future Directions

- Complete review of the new Phase 1 CARAT participants to determine their potential for continuation into Phase 2 in late 2000.

Graduate Automotive Technology Education (GATE)

The Graduate Automotive Technology Education (GATE) program began in 1999. Its purpose is to develop centers of excellence at U.S. universities for the training of engineers in advanced automotive technologies. GATE centers promote cross-cutting curricula addressing technologies critical to the development and production of future automobiles, including fuel cells, hybrid-electric drivetrains, lightweight materials, direct-injection internal combustion engines, and high-power energy storage.

Recent Accomplishments

- Opened ten centers of Automotive Technology Excellence at the following U.S. universities: University of California, Davis (two centers); Virginia Tech; University of Maryland, College Park; University of Tennessee, Knoxville; Ohio State University; West Virginia University; Michigan Technical University; University of Michigan, Dearborn; and Pennsylvania State University.

Future Directions

- Continue support of curriculum development and student fellowships to spur growth of the centers and increase in industry sponsor funding. Each center is expected to be self-sustaining at the end of its DOE-funded support period.

More information on the CARAT program can be found in *Snapshots of CARAT* Projects. More information on the GATE program can be found in *Partnering for the Future of Advanced Automotive Technologies: 1999 Annual Accomplishments Report.*

Student Competitions

To give tomorrow's engineers first-hand experience with the technical challenges facing the PNGV program, DOE and U.S. Council for Automotive Research teamed up with students from 13 universities for the FutureCar Challenge student competitions. Based upon the same criteria as the PNGV program, student teams were given either a Dodge Intrepid, Ford Taurus/Mercury Sable, or Chevrolet Lumina for conversion into a "FutureCar" capable of getting up to 80 miles per gallon while maintaining the affordability, utility, safety, and performance currently available.

Recent Accomplishments

- Completed the fourth and final year of the FutureCar Challenge competitive series. Thirteen major engineering colleges faced the challenge of converting a mid-size, American family sedan into a "super" fuel-efficient vehicle.
- The University of Wisconsin, Madison, won the 1999 competition with a hybrid-electric-powered Mercury Sable that achieves more than 62 miles per gallon over-the-road fuel economy without compromising performance.
- Virginia Tech, the second-place overall finisher, became the first team in the world to successfully convert a mid-size production car to use fuel cell power.

"The Aluminum Cow" – University of Wisconsin's First-Place Winner in the 1999 Future Car Challenge.

Future Directions

- Focus activities on the FutureTruck 2000 competition, sponsored by DOE and General Motors. Fifteen university teams will start with a Chevy Suburban and reengineer it to reduce greenhouse gas emissions by two thirds, without sacrificing performance. In 2002-2003, Ford Motor Company will assume the role of co-sponsor.

Students From Virginia Tech Celebrate With Their Fuel Cell Vehicle.

More information onthis program can be found at the FutureCar Challenge and FutureTruck 2000 web sites: www.uscar.org/futurecar/index.htm and home.att.net/~futuretruck/

1999 OAAT Program Participants

U.S. Automakers

DaimlerChrysler Corporation
Ford Motor Company
General Motors Corporation

Suppliers

3M Corporation
Air Products & Chemicals, Inc.
Albany Research Center
ALCOA Technology Center
AlliedSignal Automotive
Analytic Power
Arthur D. Little
Aspen Systems, Inc.
Baltimore Gas & Electric
BOC Gases
BCS Technologies
Cape Cod Research
CeraMem Corporation
Chesapeake Automotive Enterprises
Computer Systems Management, Inc.
Cummins Engine Company
Daug
Delco Propulsion System
Delphi Automotive Systems
Delphi Electronics
Desert Research Institute (DRI)
Detroit Diesel Corporation
Directed Technologies, Inc.
Dow Chemical
DuPont Lanxide Corporation
EIMEx
Electric Power Research Institute
Electrochem, Inc.
Electrolyser Corporation Ltd.
Electrosource, Inc.
Energetics, Inc.
Energy Conversion Devices, Inc.
Energy Partners, Inc.
Engineering Society of Detroit
EPYX
FEV Engine Technology
Foster Miller, Inc.
Gas Research Institute
General Electric Corporation
Giner, Inc.
GNB Industry Battery Company
Goodyear Tire & Rubber Company
H Power
Hexcel Corporation
Hydrogen Burner
Impco Technologies
Industrial Ceramic Solutions
Institute of Gas Technology
International Fuel Cells
Johnson Controls, Inc.
Life Enhancement Technologies, Inc.
Lincoln Composite
Lynntech
Materials & Electrochemical Research
McDermott Technologies, Inc.
McNeil Technologies, Inc.
Mechanical Technology, Inc.
Meruit
Milford Fabricating
Mooradian Associates
NexTech Materials, Inc.
Onan Corporation
Ovonic Battery Company
Physical Sciences, Inc.
Plug Power
PolyStor, Inc.
Praxair, Inc.
PSI Technologies
Ravenswood Aluminum Company
Ricardo, Inc.
SAFT America, Inc.
Santa Fe Alloys
SatCon Technology Corporation
Silican Power Company
Spectra Corp
Southern California Gas Company
Southwest Research Institute
Symyx Technologies
Tecogen
TMS, Inc.
Teledyne
Thiokol Corporation
Thixomat
T/J Technologies, Inc.
Vairex Corporation
VARTA Autobatterie
Virgina Power Technologies
Visual Computing Systems
Washington Gas Company

Universities

Boston University
Case Western Reserve University
Florida Atlantic University
Illinois Institute of Technology
Iowa State University
Johns Hopkins University
Michigan State University
Michigan Tech University
Norfolk State University
Ohio State University
Pennsylvania State University
Princeton University
Texas A&M University
University of California - Davis
University of Connecticut
University of Illinois - Urbana
University of Maryland - College Park
University of Miami
University of Michigan - Ann Arbor
University of Michigan - Dearborn
University of South Mississippi
University of Tennessee
University of Texas - Austin
University of Toledo
University of Wisconsin
Virginia Polytechnic Institute
West Virginia University

Organizations / Consortia

American Society
for Engineering Education
Electric Vehicle Association
of the Americas
Electrochemical Society
Consortium for Fossil Fuel Liquification
International Energy Agency
Northwest Alliance for
Transportation Technologies (NATT)
U.S. Advanced Battery Consortium
U.S. Advanced Materials Partnership

Federal Agencies

National Aeronautics
and Space Administration
National Science Foundation
U.S. Department of Commerce
U.S. Department of Transportation
U.S. Department of Defense
U.S. Environmental Protection Agency

National Laboratories

Ames National Laboratory
Argonne National Laboratory
Brookhaven National Laboratory
Idaho National Engineering
and Environmental Laboratory
Lawrence Berkeley National Laboratory
Lawrence Livermore National
Laboratory
Los Alamos National Laboratory
National Renewable Energy Laboratory
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
Sandia National Laboratories

For More Information

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Recent OAAT Publications

Office of Advanced Automotive Technologies R&D Plan / March 1998

1999 OAAT Annual Accomplishments Report / forthcoming

1999 Annual Progress Report:
Energy Conversion Team / January 2000
- Advanced Combustion and Emissions Control
- Fuel Cells for Transportation
- Advanced Petroleum-Based and Alternative Fuels
- Propulsion Materials

1999 Annual Progress Report:
Energy Management Team
- Advanced Battery Technology for Electric and Hybrid Vehicles / October 1999
- Advanced Power Electronics and Electric Machines / forthcoming
- Advanced Technology Development / forthcoming
- Energy Technology Research / forthcoming

1999 Annual Progress Report: Vehicle Systems Team
- Lightweight Vehicle Systems Materials / February 2000
- Vehicle Systems Technologies / forthcoming
- Hybrid Direct-Injection Engine / forthcoming

Snapshots of CARAT Projects / January 1999

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Related Web Sites

Office of Advanced Automotive Technologies
www.ott.doe.gov/oaat

Office of Transportation Technologies
www.ott.doe.gov

Office of Energy Efficiency and Renewable Energy
www.eren.doe.gov

U.S. Department of Energy
www.doe.gov

Partnership for a New Generation of Vehicles
www.uscar.org/pngv/index.htm
www.ta.doc.gov/pngv

Hybrid Electric Vehicle Program
www.hev.doe.gov

United States Council for Automotive Research
www.uscar.org

FutureCar Challenge
www.uscar.org/futurecar/index.htm

FutureTruck 2000
home.att.net/~futuretruck

Clean Cities
www.ccities.doe.gov

Alternative Fuels Data Center
www.afdc.doe.gov

Office of Advanced Automotive Technologies
Office of Transportation Technologies
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy