Lead Feature

by Scott Fosgard

Physicists Help Build the Next Generation

> Early in the next century a partnership between government, academia and the Big Three automakers will unveil high-performance vehicles that get up to three times the fuel economy of today's automobiles

When the U.S. set a national goal to land a man on the moon in the 1960s, it took a total commitment by the government to win a major technological battle of the cold war and become the dominant power in the race into space. By comparison, today's national technological objective–to develop a new generation of automobiles–may seem somewhat mundane. Yet the stakes are high, the economic rewards potentially higher and the technical challenges it presents to physicists, engineers and other scientists are, in some respects, as daunting. NASA, after all, did not have to offer space travel that the average American could afford to buy or, for that matter, would want to buy.

"Making this next generation of vehicles affordable will be the biggest challenge we face," explains William F. Powers, a NASA veteran, member of the operating committee for the U.S. Council for Automotive Research (USCAR) and an executive at Ford Motor Co. USCAR, an industry umbrella organization made up of Ford, the Chrysler Corp. and the General Motors Corp., is working on the project in partnership with the federal government to develop the new-generation automobile.

Powers sits on USCAR's Operation Council with Bernard I. Robertson, of Chrysler, and Kenneth R. Baker, who is with General Motors. Physicists by training and inclination, these three men oversee the work of hundreds of physicists, engineers and technicians working on projects for the 14 cooperative research consortia of USCAR.

The government-industry partnership–an historic alliance between the federal government and the U.S. automotive industry, represented by USCAR and the United Auto Workers–is known officially as the Partnership for a New Generation of Vehicles (PNGV). President Clinton has requested $385 million in the fiscal-year 1996 budget for PNGV-related activities.

The quest for the "supercar" began in 1993 with the creation of PNGV. As recently as a decade ago the PNVG's goals–to develop an attractive, affordable mid-sized automobile that can meet or beat Tier-II federal emission standards while complying with other Clean Air Act requirements and delivering good performance and achieving fuel efficiency three times that of comparable vehicles–would have been considered virtually impossible. This level of performance represents the equivalent of getting 80 mpg in a 1995 Chrysler Concorde, Ford Taurus or Chevrolet Lumina that can accelerate from 0 to 60 mph in twelve seconds.

PNGV's timetable calls for making a production prototype of this vehicle by the year 2005. That gives the partnership a little more time than NASA had to put a man on the Moon: eight years. But consider that the average person is still a long way from being able to afford a moonwalk!

Nevertheless, the nation has received a huge return on its space investments–new technologies, industries, products and processes–a $100 billion return, by government estimates. The potential rewards from successful development of a new generation of vehicles are even greater because the stakes are higher: survival as the global leader in one of the world's most vital industries. Chrysler, Ford, GM and their suppliers and dealers employ 2.3 million people in the U.S., including 45,000 scientists and engineers. New car sales account for 4.4% of the U.S. Gross National Product.

As the search intensifies for new materials, power sources, energy storage methods and electrical and electronic devices, PNGV also promises to have an even greater impact on the development of new technologies.

"In the 1960s," recalls Powers, "I was lucky to be part of the Apollo space program, in which government, industry and university worked closely together to achieve a very clear goal. We maximized the resources of the nation. My vision for PNGV is similar: We have created some of the same kinds of ties to achieve our objectives and meet our timetables, which are also clear."

Reinventing the wheel

Advanced lightweight materials and structures

- ◊ Design optimization
- ◊ High-strength steel
- ◊ Polymer matrix composites
- ◊ Metal matrix composites
- ◊ Ceramics
- ◊ Engineering plastics
- ◊ Aluminum, titanium, magnesium
- ◊ Joining technolgies and adhesives
- ◊ Recycling
- ◊ Accelerated process/cycle time in manufacturing

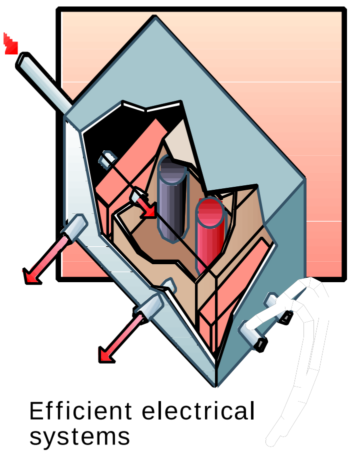
Advanced manufacturing

- ◊ Agile manufacturing (programmable machines and tools; near net-shape casting)
- ◊ High-speed data communication and data management
- ◊ Rapid prototyping and virtual manufacturing; high-performance computing; complex visualization techniques
- ◊ Supercomputing
- ◊ Advanced forming technologies
- ◊ Advanced joining technologies

Energy conversion

- ◊ Four-stroke, direct-injection engines
- ◊ Turbines
- ◊ Fuel cells

FUEL CELL:

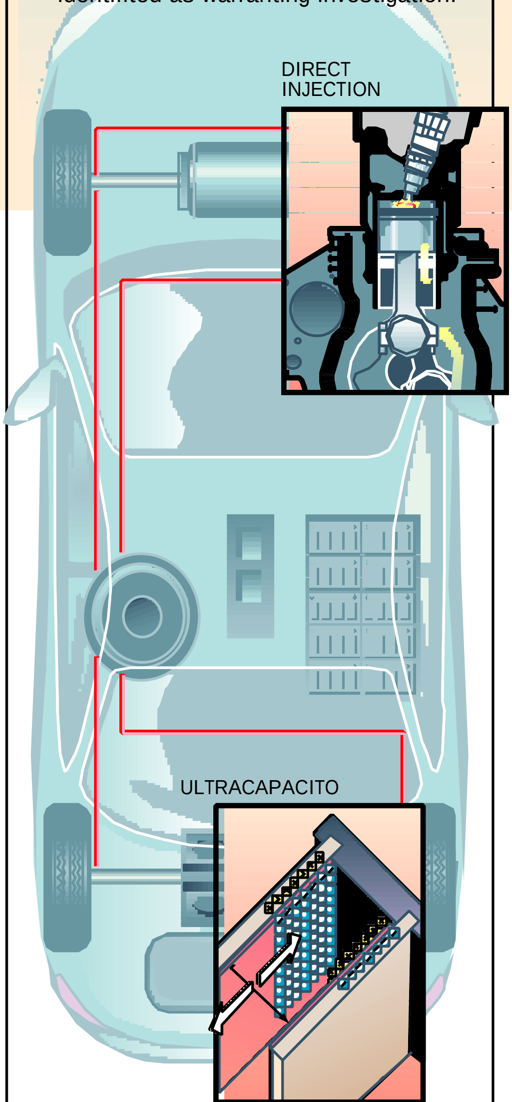


Efficient electrical systems

- ◊ Advanced electric motors
- ◊ Power electronics
- ◊ Efficient electric controllers (for regenerative braking, power management, signal distribution)

Inventions needed for PNGV

Major improvements or innovations are needed in these technology areas. Within each of the areas, specific candidate technologies have been identifited as warranting investigation.



Energy storage devices

- ◊ Advanced high-power batteries
- ◊ Flywheels
- ◊ Ultracapacitors

Waste heat recovery

- ◊ Thermoelectric systems

Advanced analysis and design methods

- ◊ Simulations
- ◊ Fluid dynamics
- ◊ Structural mechanics
- ◊ Virtual prototyping
- ◊ Trade-off studies

Reduction of mechanical losses

- ◊ Advanced lubricants
- ◊ Low-friction materials

Aerodynamics/rolling resistance improvements

- ◊ Simulation tools
- ◊ New materials

Improved efficiency of internal combustion engines

- ◊ Stratified charge/lean burn engine
- ◊ Direct injection
- ◊ Transient fuel control/fuel injection

Emissions control

- ◊ Advanced NO_x exhaust catalysts
- ◊ On-board diagnostics (evaporative systems, catalyst diagnostics, engine misfire)
- ◊ Advanced particulate traps

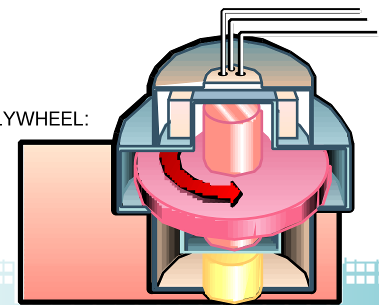
Fuel preparation, delivery and storage

- ◊ Pressure vessels
- ◊ Hydrogen storage alternatives
- ◊ Reformers/fuel processors

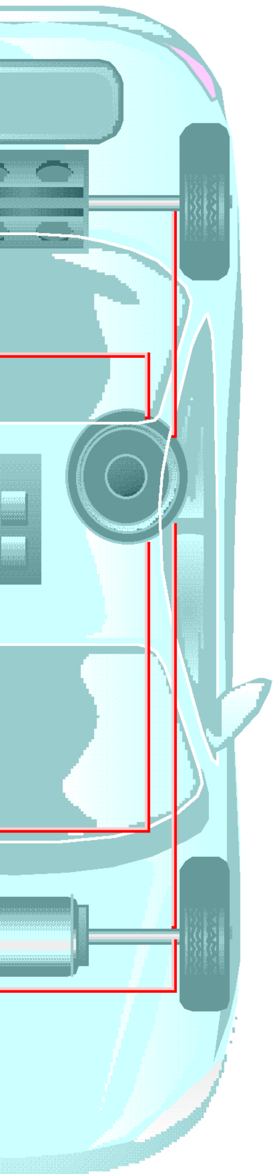
Interior thermal management

- ◊ Low-emissivity windows
- ◊ Efficiency heating, ventilation and air conditioning

FLYWHEEL:



GRAPHICS/ROBERT E. GRAHAM



Needed technologies

PNGV has three primary goals:

- Improve U.S. competitiveness in automotive manufacturing significantly.
- Apply innovations to conventional vehicles when they are commercially viable.
- Develop a vehicle that gets up to 80 mpg while maintaining the performance, utility and costs of today's cars.

To achieve these goals, PNGV leaders have identified thirteen technology areas in which "breakthrough" advances must be made (see table). In each of the technology areas, an executive committee of the PNGV technical task force has identified candidate technologies with the most potential. In energy conversion, for example, the emphasis is on four-stroke, direct-injection (4SDI) engines, gas turbines and fuel cells, while advanced high-power batteries, flywheels and ultracapacitors are the primary focus of the search for new energy-storage devices.

The technology strategy of PNGV is based on the assumption that major advances must be made in a multitude of different technologies to realize the demanding goals for the new generation of vehicles. To meet the 80-mpg target, PNGV strategy is to reduce energy demand of the vehicle by 50 %, improve the conversion and delivery of input energy to the power train, recover 50-70% of the braking energy with regenerative systems and implement a strategy for systems energy management.

To reduce energy demand, vehicle weight must be slashed by up to 40%, and aerodynamic drag, rolling resistance and accessory load must each be reduced 30%. To improve input energy usage, fuel conversion must achieve up to 55% thermal efficiency, and power and transmission losses must be reduced by one-third. Realizing the braking-energy recovery goals will require about 95% mechanical and electrical conversion and 90% recovery of the energy lost in breaking with high-power storage systems. The energy management goals are to implement a system that has 90% efficiency, reduces demands on energy source or consumer amenities such as air conditioning, radio, power windows and so on by about 30%, eliminates standby idling and coasting losses and recovers waste heat.

Technology teams

Ten "technology teams," composed of engineers, physicists and other scientists from the Big Three, are exploring potential technologies. These teams are, in turn, supported by scientists from the federal laboratory system and the seven federal agencies that have budgeted funds supporting PNGV. The teams are directed by Ron York, GM's technical director for PNGV, Bob Mull of Ford and Peter Rosenfeld of Chrysler.

The teams are studying fuel cells, flywheels, high-power batteries, manufacturing, materials and structures, gas turbines, super-efficient electric systems, direct-injected internal-combustion engines and vehicle systems. They are also helping to define technical plans, establish how to measure progress, set milestones and create road maps; recommending budget levels and priorities and reviewing government programs to ensure they are relevant to the technical targets; and conducting workshops and symposia as needed to promote communication.

Lightweight materials

An important goal for physicists and other scientists participating in PNGV is to find ways to produce cost-effective lightweight components, an important route to dramatic fuel economy gains. For every 10% reduction in a vehicle's mass, its fuel economy increases 6-8%. But the challenge is to decrease the weight without compromising passenger comfort or safety, and without sacrificing handling, performance or reliability.

To reduce a vehicle's mass, researchers are considering materials such as aluminum, titanium and magnesium; polymer matrix and metal matrix composites; ceramics and engineering plastics; and joining methods and adhesives. While they all offer significant weight-reduction benefits, these advanced materials pose critical production, cost and application problems. For example, PNGV researchers must find a practical method for joining aluminum sheet components, create affordable manufacturing methods for polymer-based composites and overcome a lack of high-volume production processes for the composites.

PNGV technical teams are working on viable methods for clinching or riveting aluminum, for nonresistive "spot welding" and for workable adhesive bonding. To reduce the manufacturing costs of polymer-based composites, they are investigating high-modulus fiber materials and high-strength, high-stiffness resins. To manufacture composites in high volume, they are exploring fast molding and rapid curing of composite materials that are later formed into molded parts, to convert slow hand-built methods into high-production methods.

Energy conversion

The familiar 4SDI gasoline engine is still an appealing power source for the new generation of vehicles. The auto industry is very familiar with the technology; it is reliable and relatively inexpensive to mass produce and it has widespread customer acceptance. However, this engine has only 23% thermal efficiency. Engineers will, therefore, have to make the 4SDI substantially more efficient if it is to achieve 80-mpg fuel consumption in a mid-sized sedan.

Diesel engines, on the other hand, have a 30-35% baseline thermal efficiency, up to 30% improved fuel economy, 10-20% lower CO_2 emissions, almost no evaporative emissions and low cold-start emissions. While diesels have limited market acceptance in the U.S., Europeans have grown used to operating diesel passenger cars.

Diesels do, however, have high NO_x and particulate emissions and therefore require exhaust gas after-treatment. To remain in contention as a new-generation engine, a system for exhaust-gas recirculation must be developed for the diesel. Potential technologies include NO_x catalysts (perhaps a zeolite) for lean-burn engines, a compact plasma generator for electrical after-treatment of exhaust gas, a device to cool exhaust gas before recirculation or some means of providing inert gas instead of exhaust-gas recirculation.

Researchers need to find additional solutions if the diesel 4SDI is to emerge as a feasible alternative. Some possible avenues include: cost-effective, high-pressure components (including injector tips); improved thermal efficiency; and advances in accelerated mixing and combustion and fuel-injection spray-pattern timing.

Fuel cells have been used for years in the space program. They provide reliable high power; operate efficiently on a variety of hydrogen fuels, including natural gas; have zero or near-zero emissions because they don't use combustion; and are much quieter than conventional automotive power trains.

The automotive applications of fuel cells, however, are constrained by their size, weight and cost. Performance and other limitations also include slow response rates and start-up times; fuel storage, conditioning and delivery problems, including fuel crossover in direct methanol fuel-cell designs; the need to integrate the fuel cell, energy storage system and electric drive and controls; and low power and energy density.

Because of their high power density, high reliability, low emissions and ability to run on a variety of fuels, gas turbines are potential automotive power sources. But they pose a number of problems related to cost, thermal efficiency, high temperatures, structural ceramics, emission controls, heat recovery and insulation.

To solve these problems with the gas turbine engine, researchers are studying a low-friction, low-wear interface between regenerator core and seals; moveable blade tips that reduce the gap between blades and casing; high-temperature elastomers that remain compliant above 600°F; nonelastomer-based springs and pads capable of operating at high temperatures; and high-temperature graphite that can operate at temperatures above 1,200°F.

Energy storage devices

Braking accounts for a significant portion of a vehicle's energy losses. A major goal of the PNGV program is to recover and store a vehicle's braking energy for later use. Energy lost when the vehicle is idling or decelerating also could be saved and stored to increase efficiency. To accomplish this we need to develop high-power energy-storage systems that are lightweight, compact and cost-efficient. Potential technologies include high-power batteries, ultracapacitors and flywheels, all of which would allow the primary power source to run at more nearly optimum performance when efficiency is greatest.

Cost is the biggest problem with each of these storage systems. The performance of present-day batteries is inadequate, ultracapacitors have low energy densities, and friction losses make currently available flywheels inefficient. Potential solutions to these problems include cost-effective, high-power bipolar batteries (such as lithium/iron disulfide), advanced materials for ultracapacitors to increase their charge storage capability, improved bearings and an inexpensive, no-leak vacuum bottle for flywheels.

Because a vehicle's electrical system is key to its fuel economy and overall economy, an important objective is to improve this system's efficiency. More effective battery charging, electric steering assist, active suspension, variable-speed compressors for air-conditioning, electric propulsion and regenerative braking can all help to improve electrical system efficiency. Gains may also be made through reductions in weight and energy loss and integration of the functions and technologies that control the various electrical components.

Among the solutions being explored are improved power conductors, drive motors and actuators; high-power-density electronics for power conditioning and control; development of an on-demand power steering system; and methods for reducing the climate control load and energy requirements.

Production timetable

By 1997 the list of candidate technologies will be narrowed to those able to meet PNGV goals within the established time frame. However, basic research is expected to continue on technologies that need a longer development cycle. To evaluate the feasibility of these technologies, each of the Big Three will begin developing concept vehicles by 2000. The next step is to build production prototypes, in which the new technologies are incorporated into working vehicles that can be mass produced.

William Powers compares the impact of these new technologies to that of computers, which began to be built into automobiles in the 1970s. Although consumers may not have noticed a radical change in the appearance of the cars of that time, computers, bringing with them such refinements as cold-weather starting and anti-lock brakes, made a significant impact on auto performance. "PNGV's work will be equally dramatic over time." predicts Powers. "While the car may look the same, it will be radically different to those who understand its workings."

Scott Fosgard is communications director for the U.S. Council for Automotive Research.