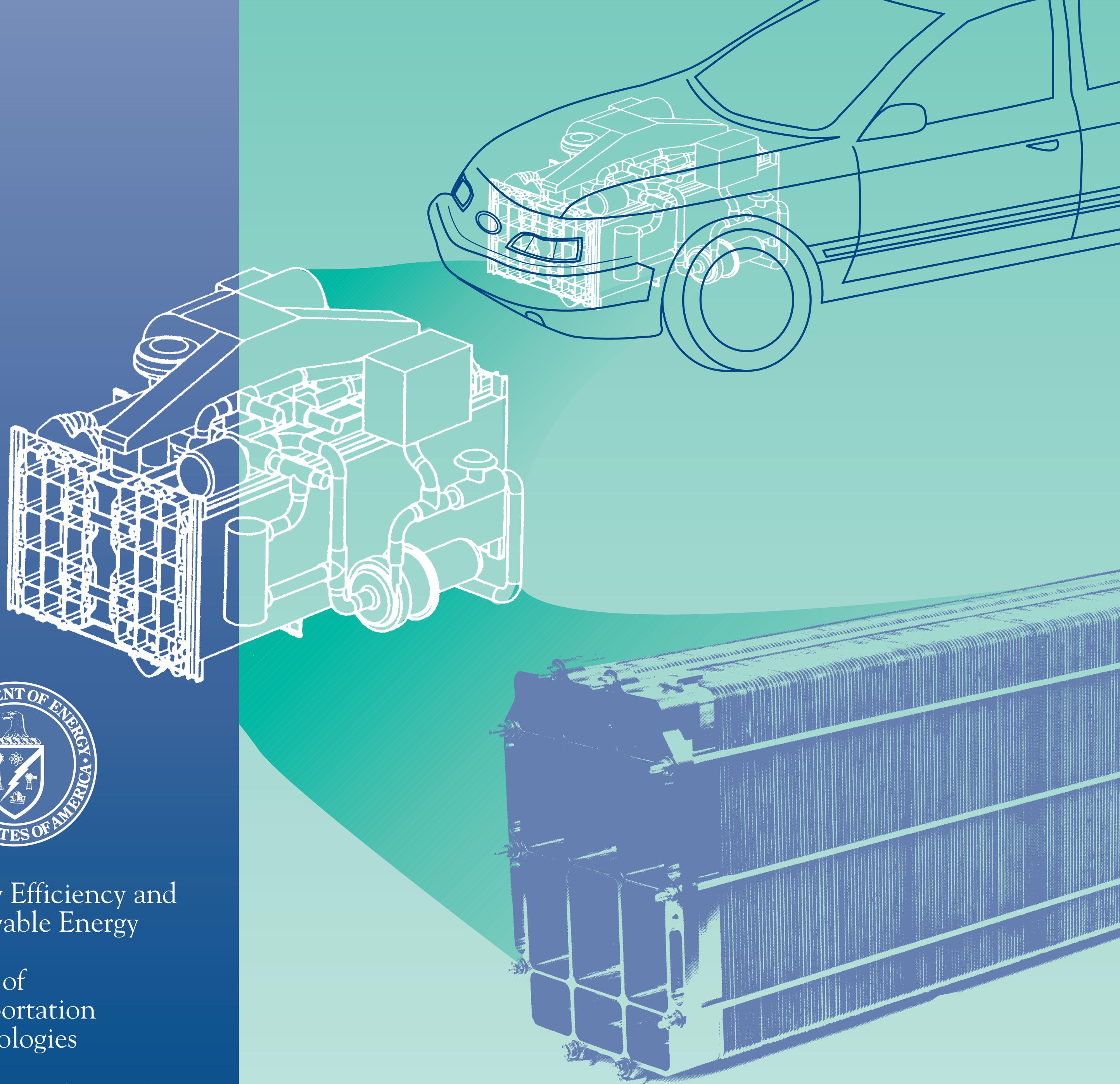
# FUEL CELLS

## FOR TRANSPORTATION



Energy Efficiency and
Renewable Energy

Office of
Transportation
Technologies

Office of Advanced
Automotive
Technologies

## PROGRAM IMPLEMENTATION STRATEGY

# Foreword

This document describes the implementation strategy for the Fuel Cells for Transportation Program, which supports the U.S. Department of Energy (DOE) Research and Development Plan for the Office of Advanced Automotive Technologies. The Program Implementation Strategy was developed by DOE based on several recent government/industry workshops that identified research and development priorities. The DOE fuel cell program managers are: Patrick Davis, JoAnn Milliken, Donna Lee, and Steven Chalk. DOE is especially grateful to the following for their willingness to participate in the April 1996 workshop and for their many valuable comments and contributions to the development and review of this strategy.

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## Introduction

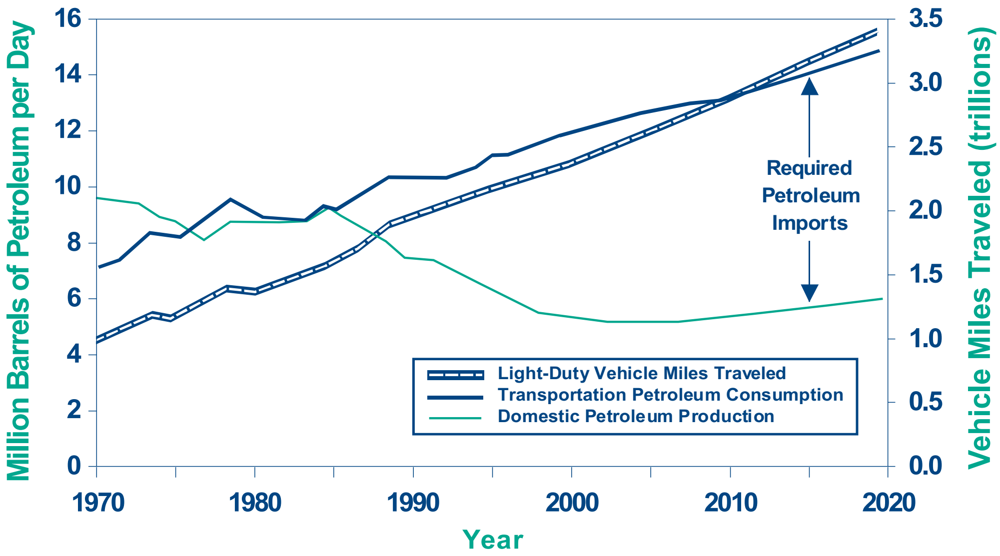
Fuel cells have emerged, in the last decade, as a potential replacement for the internal combustion engine (ICE) in vehicles. Fuel cells could revolutionize the way in which electrical power is generated, because they possess the potential for high efficiency, low emissions, fuel flexibility, quiet and continuous operation, and modularity. Any hydrogen-rich material can theoretically serve as a source of hydrogen for fuel cells. Leading candidates include fossil-derived fuels such as natural gas, methanol, and petroleum distillates, as well as renewable fuels such as methanol, ethanol or hydrogen (produced from renewable energy sources). Recognizing the benefits of this rapidly developing technology, the United States and other countries have assigned a high priority to developing fuel cell technology for both transportation and stationary applications. Fuel cells are one of the three power system technologies currently being considered for an 80 miles per gallon vehicle under the Partnership for a New Generation of Vehicles (PNGV).

### FUEL CELL POWER SYSTEMS ARE REVOLUTIONARY

- Energy Efficient
- Clean
- Fuel Flexible

### THE TRANSPORTATION SECTOR IS THE KEY ELEMENT OF A NATIONAL STRATEGY TO REDUCE PETROLEUM DEPENDENCY AND AIR POLLUTION

The transportation sector is the single largest user of petroleum in the United States, consuming approximately two-thirds of the total. About three-quarters of this amount is used by automobiles, trucks, and buses. Nearly half of all petroleum consumed in this country is imported and oil consumption by automobiles and light-duty trucks now exceeds domestic production. The number of vehicles on our roads and the total miles driven each year continue to increase steadily.




America is increasingly dependent on imported oil. This heavy reliance on petroleum contributes to air pollution, and has made the United States economically and strategically vulnerable to disruptions in the supply of imported petroleum. America's dependence on imported oil is also resulting in a massive transfer of wealth from the United States to oil exporting countries ($48 billion in 1995).

![AAT advanced automotive technologies]

## PROGRAM OBJECTIVES

### BY 2000

Develop and validate fuel cell stack system technologies that are:

- 51 percent energy efficient at 40 kW maximum net power
- 100 times cleaner than EPA Tier II emissions
- Operational on gasoline, methanol, ethanol, natural gas, and hydrogen.

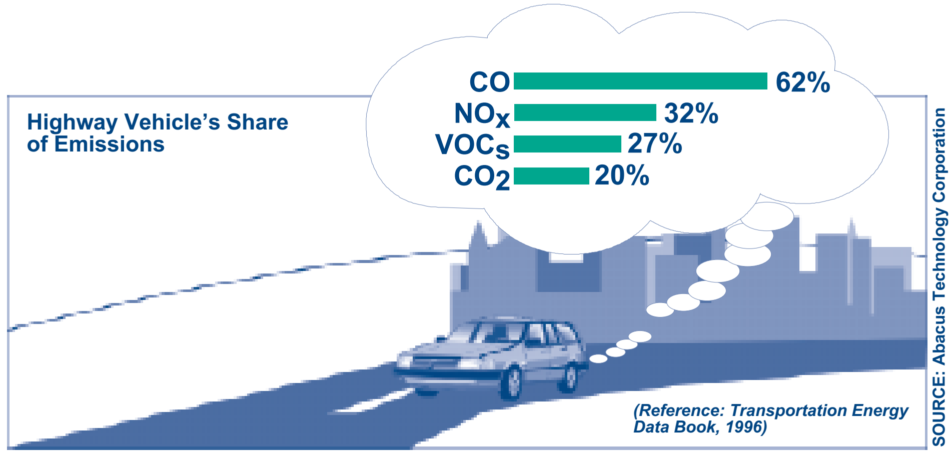
### BY 2004

Develop and validate fuel cell power system technologies for competitiveness with ICEs:

- Cost
- Performance
- Range
- Safety
- Reliability

### EPACT

Congress has defined the government's role in the development of fuel cell vehicles in Sections 2025(j) and 2026 of the Energy Policy Act of 1992, Public Law 102-486 (EPACT), which calls for a comprehensive program of research, development, and




This increased use of petroleum is contributing to U.S. air pollution. The poor air quality in many of our cities and increasing levels of greenhouse gases in the atmosphere are national health concerns. Eighty million Americans live in areas that regularly violate Federal air quality standards. Despite significant progress in vehicle exhaust reduction, emissions from transportation sources remain a major problem.

Global competition in the transportation market is another concern. Improvement in the nation's balance of trade and American job opportunities will result as the United States continues its development of innovative technologies and gains an increasing share of the emerging global market for clean, energy-efficient vehicles.

### THE OFFICE OF ADVANCED AUTOMOTIVE TECHNOLOGIES IS SUPPORTING DEVELOPMENT OF HIGHLY EFFICIENT, LOW, OR ZERO EMISSION FUEL CELL POWER SYSTEMS AS AN ALTERNATIVE TO INTERNAL COMBUSTION ENGINES

In order to effectively address these challenges, the Fuel Cell Program is integrating the efforts of the automotive industry, fuel cell and fuel processor developers, national laboratories, universities, and fuel suppliers in a customer-focused national program.

The Program is developing more fuel efficient, cleaner, and cost-effective vehicle power systems that meet the most stringent emission standards while retaining the same high performance as today's engines. Vehicles using these power systems will have triple the fuel economy of comparable conventional vehicles, enhanced fuel flexibility, and will enter the global marketplace by 2010.

The research, development, and validation of fuel cell technology is integrally linked to the Energy Policy Act (EPACT) and other major U.S. policy objectives, such as the PNGV. Established in 1993, PNGV is a research and development initiative involving seven Federal agencies and the three U.S. automobile manufacturers to strengthen U.S. competitiveness. The PNGV will develop technologies for vehicles with a fuel efficiency of 80 miles per gallon, while maintaining such attributes as size, performance, safety, and cost.

# Program Benefits

Fuel cell vehicles have the potential to reduce harmful emissions and consumption of non-renewable energy sources because they are clean and efficient. Fuel cells are a technology that could change our future – a device that could power automobiles with little or no tailpipe emissions, provide energy to homes and factories with virtually no smokestack pollution – and use renewable, domestic energy at high efficiency while creating thousands of jobs.

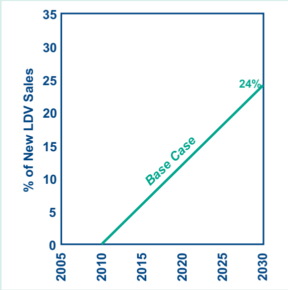
Program implementation will provide significant energy, environmental, and economic benefits at national, regional, and local levels. These include:

- Reducing dependence on foreign oil, thereby reducing trade deficits and increasing economic, political, and military security;
- Minimizing the environmental impacts of transportation while maintaining a high level of mobility;
- Increasing jobs in the automotive industry and strengthening the competitiveness of the United States in international markets including the utility, construction, and industrial sectors;
- Providing benefits to the entire domestic economy which include savings to consumers in the form of reduced expenditures for fuel.

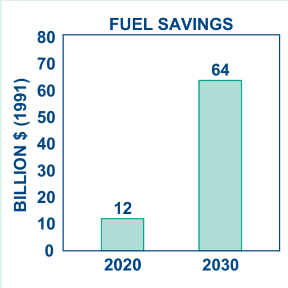
The potential market penetration of light-duty fuel cell vehicles (FCVs) provides a *base case* for a benefits analysis of fuel savings and emissions reduction[1]. The *base case* assumes a 24 percent cumulative market share of new light-duty vehicles sold in the United States by the year 2030. Light-duty vehicles (LDVs) include passenger cars, light trucks, vans, etc. This estimate is based on relatively conservative assumptions, such as projected oil and natural gas prices. The potential benefits of deploying FCVs, measured in terms of reduced consumer outlays for motor fuel, could total $64 billion by the year 2030. The potential benefits of deploying FCVs, measured in terms of the value of reduced air emissions, could total $23 billion by the year 2030. These are present value 1991 dollars under the *base case* assumptions.

The deployment of FCVs will also mean a shift from petroleum-based fuels and a reduced demand for crude oil. Under the *base case*, annual oil demand reductions will reach 220 million barrels by 2020 and 849 million barrels in 2030, or a cumulative total savings of 6.3 billion barrels from 2000 through 2030.

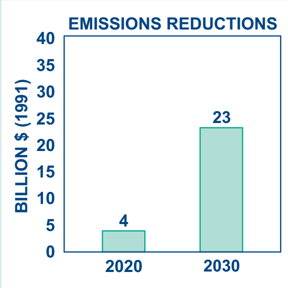
[1] Jason Mark, James M. Ohi, and David V. Hudson, Jr., National Renewable Energy Laboratory, *Fuel Savings and Emissions Reductions from Light Duty Fuel Cell Vehicles*, April 1994, p. viii.



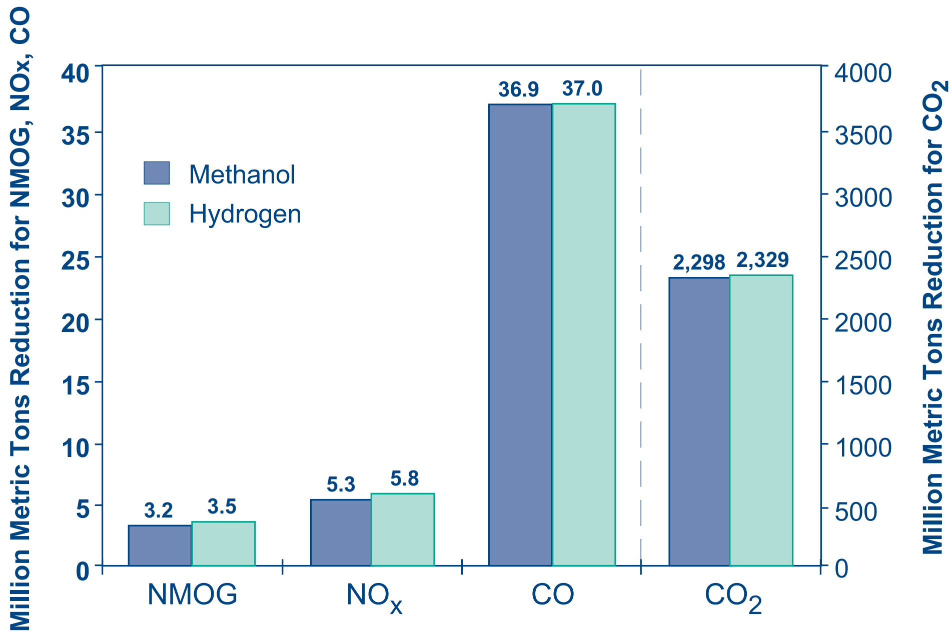

**Fuel cell vehicle market penetration based on steady expansion of sales.**




**Present value of fuel cost savings from the deployment of light-duty fuel cell vehicles projected to 2030.**




**Present value of emissions reduction (including $CO_2$) from development of light-duty fuel cell vehicles projected to 2030.**




**Cumulative Emissions Reductions from the Use of FCVs for the Period 2010-2030 (Base Case Market Penetration)**

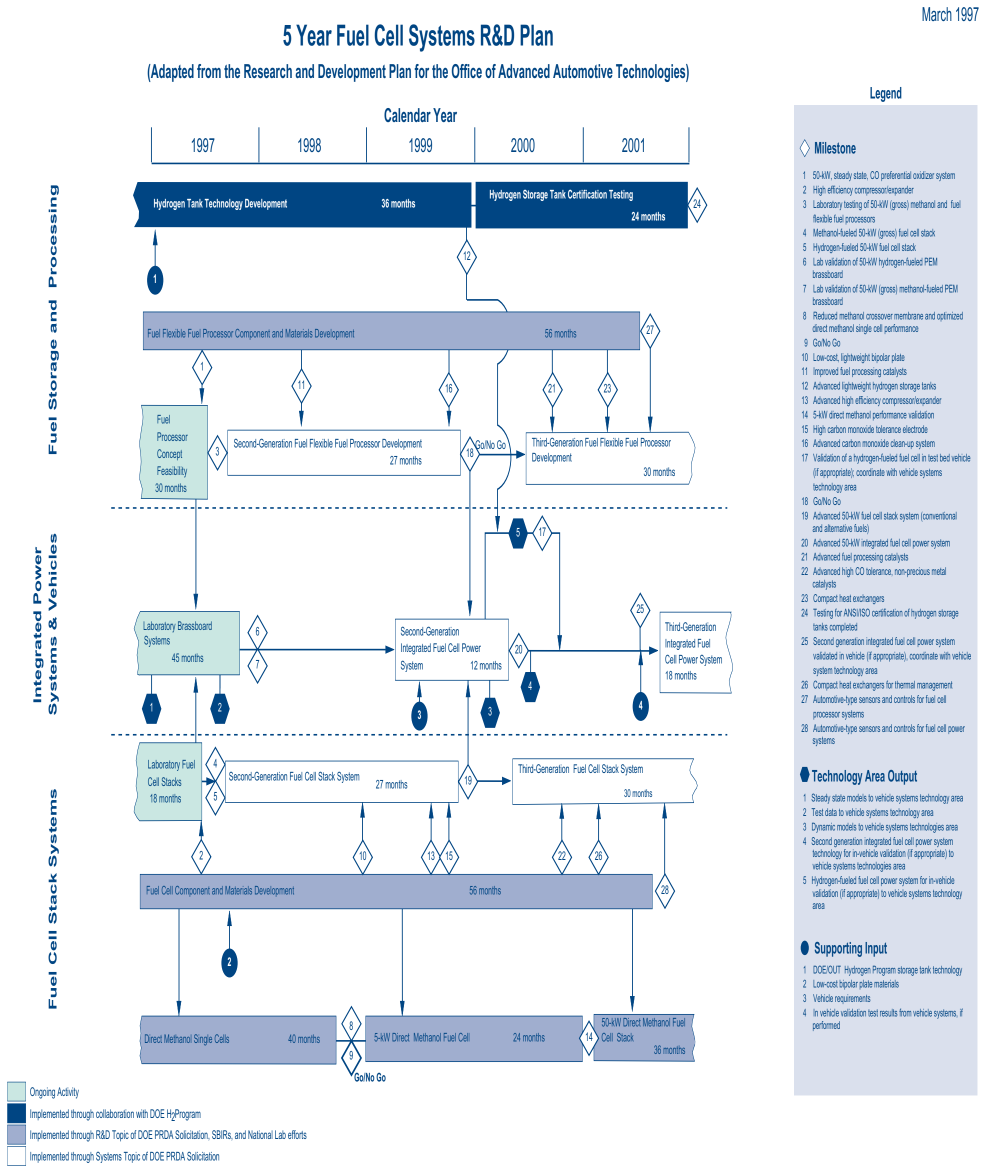
Environmental benefits will result from reductions in the emission of pollutants that affect local air quality. These pollutants include non-methane organic gases (NMOG), nitrogen oxides ($NO_X$), and carbon monoxide (CO), as well as carbon dioxide ($CO_2$). Nearly one-third of the U.S. population resides in an area of ozone non-attainment, reflecting the large scale of the urban air pollution problem. Reducing emissions of NMOG and $NO_X$ will help reduce ozone formation, and lower CO emissions will result in additional air quality benefits.

Although tailpipe emissions are the primary component of transportation emissions, air emissions associated with producing and distributing fuel are not small. The estimate of environmental benefits accounts for the total fuel cycle of emissions from fuel production and distribution. For the *base case*, deploying FCVs will result in a total avoided emissions of approximately 2300 million metric tons of air pollutants and carbon dioxide (greenhouse gas) between 2010 and 2030 for FCVs.

# Technology Description

## FUEL CELLS USE AN ELECTROCHEMICAL PROCESS TO CONVERT HYDROGEN AND OXYGEN TO ELECTRICITY

The fuel cell is a device that converts the chemical energy of a fuel directly into usable electricity and heat without combustion. Fuel cells are similar to batteries in that both produce a DC current by means of an electrochemical process. In both systems, two electrodes – an anode and a cathode – are separated by an electrolyte. Unlike batteries, however, fuel cells use reactants that are stored externally and operate continuously as long as they are supplied with fuel.



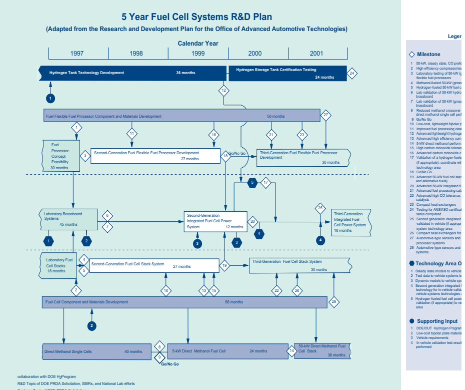

**Fuel cells combine features of both batteries and engines. Individual fuel cells are connected into groups called stacks to achieve a useful voltage and power output.**

## FUEL UTILIZATION

Fuel cells consume only hydrogen and oxygen and operate best on pure hydrogen (oxygen is obtained from air). In order for fuels other than hydrogen to be utilized by fuel cells, they must be processed or reformed to provide a hydrogen-rich gas mixture. Catalysts are used to facilitate the chemical reactions. Alternative fuels being considered for use in fuel cell vehicles include methanol, ethanol, hydrogen, and natural gas. These fuels can be derived from a spectrum of energy sources. Two approaches are currently being considered to supply the fuel cell stack with hydrogen at required purity levels:

- **Hydrogen for Fuel Cells Can Be Stored On-board a Vehicle**

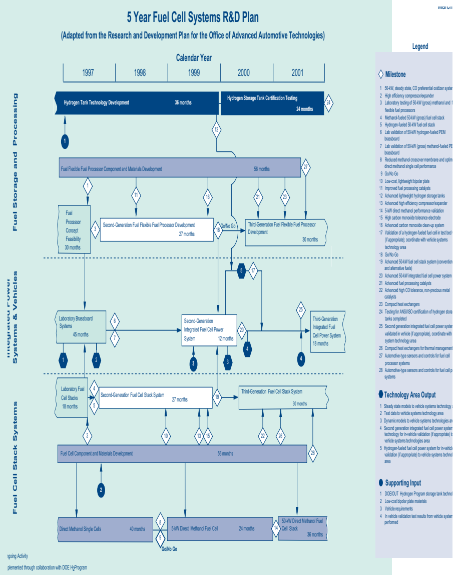
Storing hydrogen on-board a fuel cell vehicle greatly simplifies the propulsion system design and increases overall system efficiency by eliminating on-board fuel processing. Studies have shown that hydrogen storage systems can be engineered to the same safety levels as conventional fuel systems. Because hydrogen is a lightweight gas, however, a relatively large volume or weight is required to contain enough energy to provide the same driving range as today's automobiles. Currently, two methods of storing hydrogen are receiving the most investigation: compressed gas in storage tanks at high pressure and liquid hydrogen in insulated storage tanks at low temperature and pressure. Other storage methods based on metal hydrides, solid adsorbents, and glass microspheres have potential advantages but are not as well developed. On-board hydrogen storage development is a thrust of DOE's Hydrogen Program.




EDO/LLNL Carbon Fiber High-pressure Hydrogen Storage Tank

- **Fuel Processors Can Reform Common Transportation Fuels into Hydrogen**

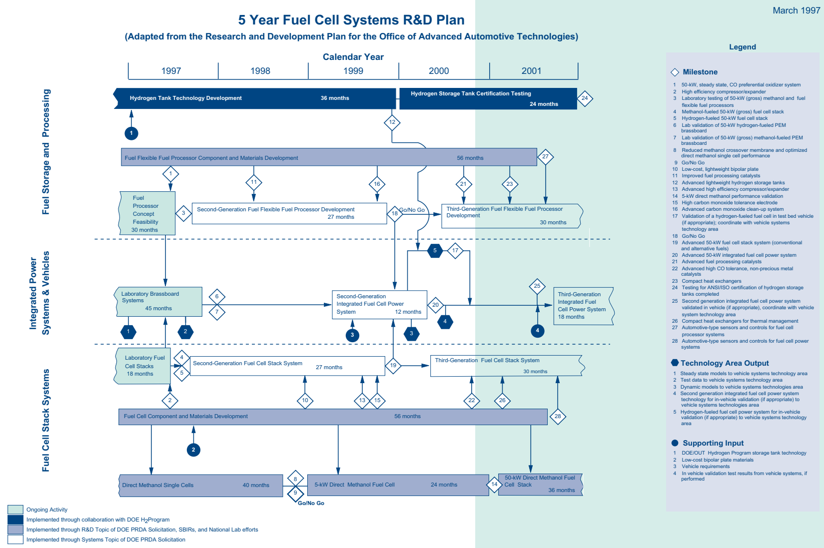
On-board fuel processing can reform conventional fuels (i.e., gasoline) and alternative fuels to produce the required hydrogen. The primary types of reformers currently being developed for transportation are steam reformers and partial oxidation reformers. Designs combining elements of both types are also being investigated. Fuel cells can be poisoned if impurities (primarily carbon monoxide) are present in the reformer product gas stream. Carbon monoxide must be prevented from forming, or removed after reforming. Carbon monoxide removal can be achieved with water-gas shift reactors, preferential oxidation reactors, or hydrogen separation membranes. On-board reformation adds significant complexity to the system; however, it has the advantage of using a fuel for which the distribution infrastructure is already developed.




Partial Oxidation Fuel Processor Developed by Arthur D. Little

# Technology Status and Challenges

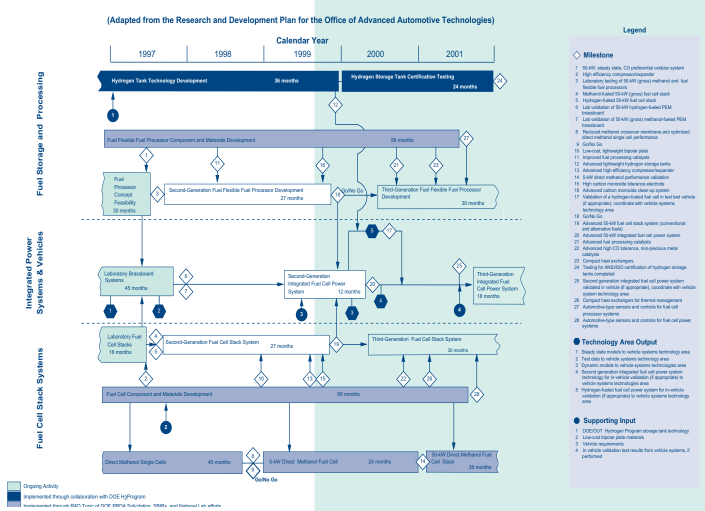
Researchers have achieved impressive performance gains in fuel cells for transportation during the last decade. The technology has advanced to the point where in-vehicle demonstrations are proceeding in the United States, Europe, and Japan. With funding from DOE, South Coast Air Quality Management District (California), and the Department of Transportation, H-Power Corporation successfully built and tested three fuel cell powered buses. These thirty foot long, twenty-five passenger buses are efficient, clean, quiet, comfortable, and meet all applicable standards for transit buses. Each bus uses a 50 kW phosphoric acid fuel cell to supply all its energy needs and operates on methanol fuel at over 42 percent thermal efficiency. The fuel economy of the buses over the standard Transit Coach Duty Cycle is 2.3 mi/gal on methanol, or 5.35 mi/gal diesel equivalent, about twice that of conventional buses with diesel engines. The buses have carbon monoxide and nitrogen oxide emissions levels that are more than 30 times lower than the 1998 Federal heavy-duty diesel emission standards and virtually zero hydrocarbon or particulate emissions.




The DOE fuel cell bus, the world's first liquid-fueled fuel cell vehicle, was developed in partnership with industry and is virtually pollution-free.

## CURRENT DEVELOPMENT EFFORTS EMPHASIZE THE PROTON-EXCHANGE-MEMBRANE FUEL CELL FOR AUTOMOTIVE APPLICATIONS

The proton-exchange-membrane (PEM) fuel cell is capable of high power density and quicker startup than other fuel cell types. The Program is focused on PEM development because of its superior performance potential. The PEM fuel cell is a strong long-term candidate to replace ICEs in transportation applications; significant progress has been made during the past five years. International Fuel Cells, Energy Partners, Mechanical Technology Incorporated, Delphi Automotive, and Ballard Power Systems are all currently developing PEM fuel cells for automotive applications. DOE is focusing PEM fuel cell development efforts on light-duty vehicles because this market segment offers the greatest potential energy and environmental benefits.




Prototype 50 kW Automotive Fuel Cell Power Plant Under Development by International Fuel Cells advanced automotive technologies

International competition is keen in the race to develop PEM power systems for automobiles -- extensive efforts are underway in North America, Europe, and Japan. In May 1996, Daimler-Benz unveiled a six-passenger van (NECAR II) powered by a 50 kW hydrogen-fueled Ballard PEM fuel cell. A 20 kW PEM fuel cell has been demonstrated by Mazda. Toyota and Honda are also actively engaged in the development of fuel cell vehicles. Toyota unveiled its first fuel cell electric vehicle with a 20 kW PEM fuel cell in October 1996.

## PEM FUEL CELL DEVELOPMENT MUST ADDRESS TECHNICAL CHALLENGES BEFORE SUCCESSFUL TRANSPORTATION APPLICATIONS ARE POSSIBLE

**Significant technical challenges must be met for PEM fuel cell power systems to reach their potential, including:**

- **Size and weight reduction**
- **Manufacturing cost reduction**
- **Rapid start and operation**
- **Durability and reliability**
- **Fuel storage, conditioning, and delivery.**

Despite significant recent advances, PEM fuel cell technology must progress beyond the current state-of-the-art before it can be considered a viable alternative to the ICE. The technical challenges include the fuel cell stack, the fuel processor, and balance-of-plant components.

***Size and Weight Reduction.*** The size and weight of current fuel cell systems must be reduced substantially to meet the performance requirements for automobiles. This applies not only to the fuel cell stack, but also to the ancillary components and major subsystems (e.g., fuel processor, compressor/expander, and energy storage device) making up the balance of the power system. Size and weight reduction are being addressed both in basic fuel cell technology and in power system development. For instance, the program is developing:

- Fuel cell stacks using lighter weight materials, operating at higher current densities, and/or near atmospheric pressure.
- Compact, lightweight, on-board fuel processors.
- Improved on-board hydrogen storage systems.
- Integrated, compactly packaged heat exchangers, compressor/expanders, condensers, radiators, etc.

***Manufacturing Cost Reductions.*** Cost reductions must be achieved before fuel cell power systems are competitive with ICE technology. Currently the costs for automotive ICE power plants are about $25-35/kW; fuel cell system costs need to be less than $50/kW for the technology to be competitive. Further cost reductions are being sought by developing:

- Fuel processor and stack designs specific to the transportation sector, reduced catalyst loading, and selection of appropriate materials conducive to high-volume manufacturing.
- Fuel cell stack technology with higher power density.
- Low cost components and materials such as bipolar plates, membrane electrode assemblies (MEAs), carbon paper, and catalysts.

***Rapid Start and Operation.*** Start-up time for automotive applications must be less than a few seconds to reach full power. Until faster-starting fuel cells are developed, vehicles can be designed so that energy stored in on-board batteries can be used during the first few minutes of operation while the fuel cell system reaches required power levels. In addition, improved transient response of the complete fuel cell system, including the fuel processor subsystem and other components, must be developed and demonstrated. Rapid start-up and load-following requirements are being addressed by development of:

- Improved PEM fuel cell technology, with quick start-up capabilities from a cold condition.
- Fuel processors with inherent load-following capability.
- System designs which incorporate batteries, ultracapacitors, or hydrogen storage to improve dynamic response and handle load surges and regenerative braking.

***Durability and Reliability.*** Fuel cell power systems will be required to achieve the same level of durability and reliability, and to function over the full range of operating conditions (-40° C to 80° C), as do current automotive engines.

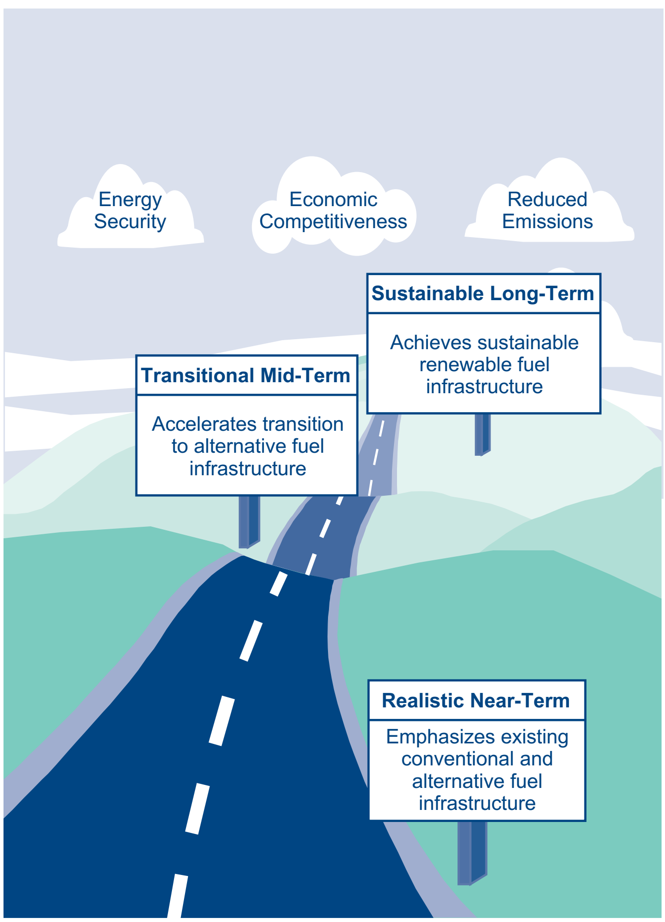
***Fuel Storage, Conditioning, and Delivery.*** Significant advances in fuel processing and delivery are necessary for fuel cells to make a substantial market penetration. In the long-term, hydrogen will be the preferred fuel, but the fueling infrastructure does not exist to service a large number of cars. In order to use the existing fueling infrastructure, compact, low-cost fuel processors capable of reforming common (petroleum-based and alternative) transportation fuels are required. New and/or improved catalysts that can operate effectively over a broad range of conditions are necessary to produce hydrogen from other transportation fuels. Fuel infrastructure issues are being addressed by:

- Developing fuel processor capability which provides fuel flexibility.
- Defining fuel supply and distribution strategies and integrating ongoing research with DOE Hydrogen and Alternative Fuels Programs.
- Coordinating activities with alternative fuels providers and developers in government and industry.

## Fuel-Flexible Fuel Strategy

The Program is pursuing a fuel-flexible fuel strategy which utilizes the existing conventional fuel infrastructure as well as the alternative fuel infrastructures currently being developed. Use of conventional fuels encourages the initial market introduction and consumer acceptance of fuel cell vehicles by allowing refueling to be virtually identical to that of a conventional vehicle. Use of alternative and renewable fuels leads to greater energy security. Several DOE alternative fuels programs support development of the infrastructure needed for production and distribution of ethanol. The potential use of methanol, ethanol, or hydrogen (supported by the DOE Hydrogen Program) from renewable energy sources affords an opportunity for a gradual transition to sustainable alternative fuels as the supply and distribution infrastructures are made available.

Therefore, DOE is developing a fuel-flexible fuel processor which will enable gasoline, methanol, ethanol, and natural gas to be utilized in fuel cell vehicles. This technology will have virtually the same design and operating parameters for all of these fuels. When fully developed, a fuel-flexible fuel processor will be capable of reforming several hydrocarbon fuels. Preliminary analyses show that fuel cell power systems operating on conventional and alternative fuels can be competitive, in terms of efficiency, with other electric and hybrid power system technologies being developed for automotive applications. At the same time, fuel cell vehicles with on-board fuel reformers are expected to maintain tailpipe emissions well below Federal Tier II standards.




SOURCE: Abacus Techology Corporation

**The DOE fuel cell program is currently developing fuel cell technology which utilizes conventional, alternative, and renewable fuels.**

Because demonstrations of direct-hydrogen fuel cell systems have less technical risk than on-board fuel processors, the Program is developing hydrogen storage technologies in an important collaboration with the DOE Hydrogen Program. The potential of fuel cell technology can, therefore, be more easily realized through near term demonstrations of direct hydrogen fuel cell vehicles using a centrally located and controlled fueling infrastructure. Early demonstrations could accelerate hydrogen infrastructure development and user acceptance.

## Research and Development Strategy

In order for PEM fuel cell technology to be suitable for automotive applications, key technical challenges must be addressed in each of three development areas: the fuel cell stack system, fuel processing and storage system, and integrated power system. Each development area faces common overall challenges related to the automotive application (i.e., size, weight, durability, and cost) as well as those challenges which are specific to the development area. The Fuel Cells for Transportation Program R&D strategy will focus effort on the key barriers and activities as described below.

### THE FUEL CELL STACK SYSTEM IS THE HEART OF A FUEL CELL POWER SYSTEM

Fuel cell stack issues include performance improvement, weight and size reduction, and material selection for high volume manufacturing. Research priorities include:

- ***Bipolar Plate*** - Present graphite bipolar plates are expensive, heavy, and large. Research is focusing on lightweight, low-cost plates that will not require machining and can tolerate the highly corrosive operating conditions.
- ***Membrane*** - Polymer membranes will require higher ionic conductivity, improved humidification properties, higher operating temperature, and lower gas permeability, at lower cost than state-of-the-art membranes.
- ***Membrane Electrode Assembly (MEA)*** - Lower cost methods are required for high volume manufacturing of MEA's.
- ***Catalyst*** - Current platinum catalysts are expensive and are easily poisoned by carbon monoxide in the fuel stream. Improved, lower-loading or non-precious metal catalysts are needed that are efficient and carbon monoxide tolerant.
- ***Compressor/Expanders*** - Compressor/Expanders and other *balance-of-plant* components are needed for the unique fuel cell requirements of flow rate, pressure, efficiency, turn-down characteristics, automotive durability, and cost.

### FUEL FOR THE STACK MUST BE PROCESSED OR STORED ON THE VEHICLE

Advanced fuel-flexible fuel processors capable of rapid start-up and full load-following capability will be developed demonstrating the low cost and high efficiency required for automotive application. Research priorities include:

- ***Catalysts*** - Improved reactor catalysts are needed to maximize hydrogen production and reduce the production of carbon monoxide.
- ***Carbon Monoxide Clean-Up*** - Highly selective, efficient, and inexpensive preferential oxidation catalysts and improved, compact reactor designs are needed for elimination of carbon monoxide in the fuel stream. Alternative clean-up methods are also being investigated (i.e., filters, adsorption/desorption).

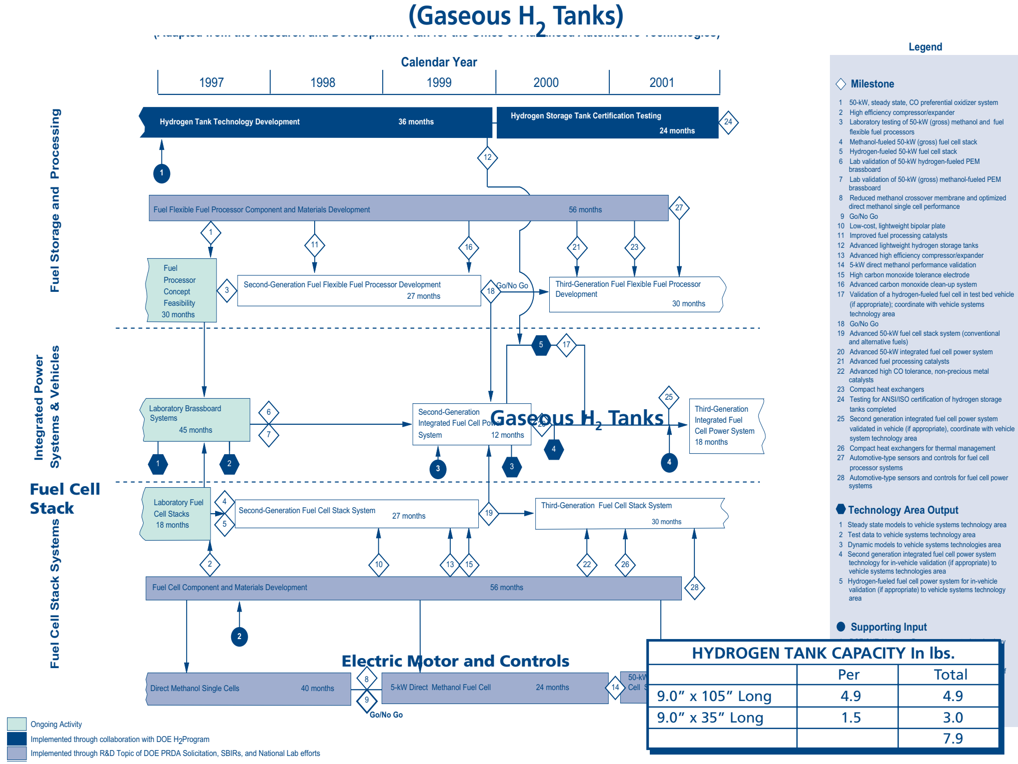
- ***Integrated Fuel Processor*** - Fuel processor components need to be integrated into the fuel processor system (i.e., sensors, controls, heat exchangers).
- ***Direct Methanol Fuel Cell*** - An improved performance direct-methanol fuel cell with a reduced-methanol crossover membrane requires development.
- ***Compressed Gas Storage*** - Improved high pressure, lightweight tanks need to be developed and certified (in collaboration with the DOE Hydrogen Program).

## INTEGRATED FUEL CELL POWER SYSTEMS ARE NEEDED FOR AUTOMOTIVE APPLICATIONS

Fuel cell stack systems combined with fuel processors or on-board hydrogen storage systems require validation in an integrated power system that optimizes packaging, response, and efficiency. Research priorities include:

- ***Modeling*** - Total fuel cell power system modeling is required to support advanced vehicle modeling efforts and to guide vehicle design.
- ***Thermal Management*** - Existing systems need to be thermally integrated to achieve maximum efficiency. Thermal management processes include waste heat utilization (heat exchangers), cooling, and humidification.
- ***Sensors and Controls*** - Individual subsystem sensors and controls need to be consolidated into a single overall automated control system.
- ***Test-Bed Vehicle*** - Integrated systems require validation in a test-bed vehicle, demonstrating system packaging, operation, and durability.

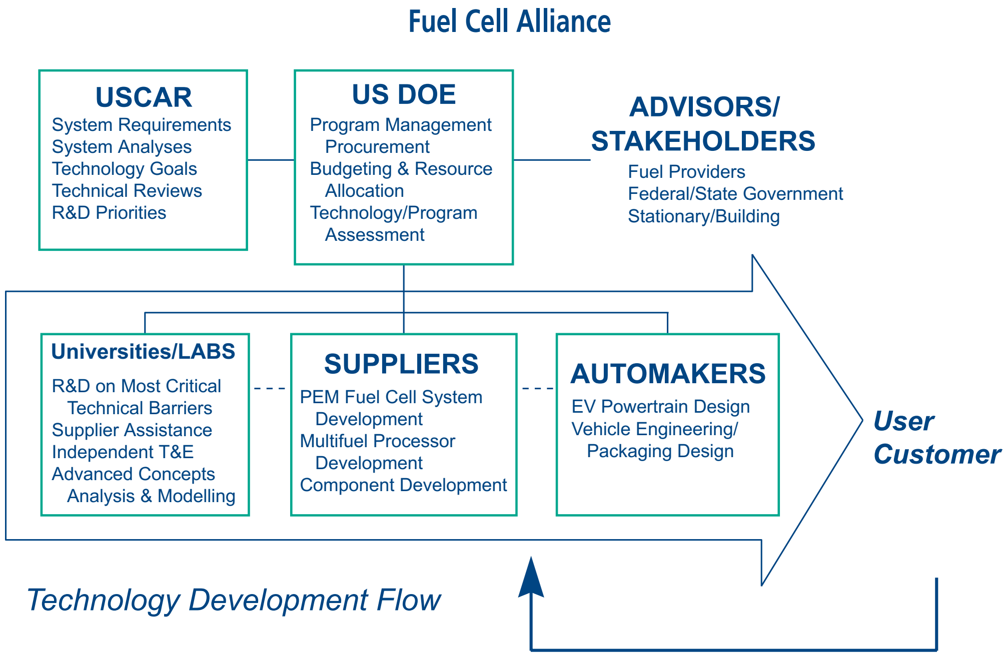
### Ford Fuel Cell Concept Vehicle
### (Gaseous $H_2$ Tanks)




| HYDROGEN TANK CAPACITY In lbs. | Per | Total |
|---|---|---|
| 9.0″ x 105″ Long | 4.9 | 4.9 |
| 9.0″ x 35″ Long | 1.5 | 3.0 |
| | | 7.9 |

## Management Strategy

Management of the Fuel Cells for Transportation Program is designed to effectively implement the research and development of highly efficient, low or zero emission fuel cell power systems as a viable alternative to the ICE. The management strategy will be implemented through the Fuel Cell Alliance to fully utilize the excellent technical capabilities and resources that exist within industry and government: the automakers, fuel cell and fuel processor developers, component suppliers, national laboratories and universities, fuel providers, and other government agencies.




***The Fuel Cell Alliance***. In cooperation with the U.S. Council for Automotive Research (USCAR), DOE formed the Fuel Cell Alliance to provide a mechanism for obtaining industry consensus and recommendations for Program direction. In addition, the Alliance facilitates the dissemination of government-sponsored fuel cell R&D within the domestic auto industry. Other members of the Alliance include the fuel providers and other Federal and state government agencies who provide advice concerning Program direction and implementation plans. Close coordination minimizes duplication of effort and ensures rapid advancement of the technology.

***USCAR.*** The role of USCAR (in conjunction with DOE) is to establish automotive technology goals for fuel cell power systems, identify R&D priorities, and review technical progress. Under the Partnership for a New Generation of Vehicles, USCAR has established technical teams for fuel cell development, system analysis, manufacturing, and vehicle engineering to guide the program.

***The Department of Energy.*** DOE maintains overall management responsibility for the Fuel Cells for Transportation Program which includes planning, budgeting, resource allocation, and technical management. DOE establishes contracts with the fuel cell and fuel processor developers, component suppliers, universities and laboratories, and the automakers to conduct the necessary R&D. DOE also performs analyses and technical assessments which help to integrate the Program with other major Federal initiatives for improving the nation's economic productivity, international competitiveness, and environmental quality.

***Universities and National Laboratories.*** Universities and national laboratories play an important role in the Alliance by performing highly focused R&D on higher risk technical issues (e.g., direct methanol fuel cells, catalyst development, CO clean-up). The universities and national laboratories retain the intellectual property rights but the results of the government-funded development efforts are made available to all suppliers — the customers for the technology that is developed in the laboratories. The national laboratories are also engaged in helping suppliers overcome technology hurdles within specific mutual proprietary agreements. They provide this important service because many of the suppliers have limited facilities, in-house expertise, and other resources. In addition, the laboratories provide independent test facilities to verify hardware performance data for suppliers and automakers.

***Suppliers.*** Fuel cell, fuel processor, and component developers (e.g., controls, ancillaries) will carry out the majority of the R&D by means of cooperative agreements and contracts with DOE in which the developers will share approximately twenty-five percent of the contract value. By cost sharing, the developers will be eligible to retain intellectual property rights. It is envisioned that the suppliers will have the opportunity to provide technology to all three domestic automakers and that no exclusive arrangements will be made between a supplier and automaker related to government-funded research efforts. This arrangement will eliminate the duplication of effort that would occur if each automaker established separate supplier teams undertaking virtually the same development. Where appropriate, hardware from suppliers will be delivered to the automakers for testing and integration.

***Automakers.*** The automakers will develop specific powertrain designs and perform the vehicle engineering and packaging studies necessary to integrate a fuel cell power system into a vehicle. The three domestic automakers will incorporate the knowledge, expertise, and experience gained in the DOE Hybrid Vehicle Program into their fuel cell vehicle development efforts. Involvement of the automakers will assure that emphasis is placed on advanced, low cost manufacturing techniques. The automakers will also assure that safety, performance, and reliability of fuel cell vehicles meets the expectations of the driving public.

***Coordination with Related Programs.*** The DOE Fuel Cells for Transportation Program coordinates with related R&D programs at both the national and international levels to leverage program funding, keep up-to-date on pertinent activities and international developments, and avoid duplicative efforts. The relationship of the Program to other coordinated areas is summarized in the following table:

| **Coordinated Areas:** | **Organizations:** |
|---|---|
| Stationary Fuel Cells | DOE Office of BuildingTechnologies<br>DOE Office of Fossil Energy, FETC |
| Alternative Fuels R&D | DOE Hydrogen Program, Office of Utility Technology<br>DOE Office of Fuels Development |
| Fundamental Fuel Cell R&D | DOE Office of Basic Energy Sciences |
| Powertrain and Vehicle Development and Integration | DOE Electric and Hybrid Vehicle Program |
| Other Federal Government Fuel Cell Development | Department of Transportation<br>National Aeronautics and Space Administration<br>Department of Defense<br>Defense Advanced Research Projects Agency<br>National Institute of Standards and Technology<br>National Science Foundation<br>Interagency Power Group |
| State Agency Fuel Cell Activities | Illinois Department of Commerce and Community Affairs<br>South Coast (California) Air Quality Management District |
| International Fuel Cell Activities | International Energy Agency<br>Russian American Fuel Cell Consortium |

***Periodic Solicitations.*** The majority of the research in the Program will be acquired through periodic solicitations such as Program Research and Development Announcements. It is anticipated that these solicitations will contain several topic areas for proposals. One topic area is intended for larger integrated fuel cell power systems development efforts geared to delivery of a complete fuel cell power system. Another topic area is intended for smaller, highly focused research efforts for critical components or subsystems that have the potential for meeting cost and performance goals when integrated into a complete fuel cell power system.

***Identification of Research Priorities.*** Research topics pertinent to the development of fuel cell power systems will continue to be defined and prioritized by means of workshops at which fuel cell researchers, stakeholders, and customers discuss the status of the technology, identify research needs, and recommend approaches to address those needs. Participants in these workshops will discuss:

- Analysis conducted to determine research and development priorities;
- Modeling performed to evaluate design tradeoffs;
- Evaluations conducted to measure Program milestones against predetermined performance measures and guide future programmatic direction; and
- Test Data.

Outcomes of these workshops will strongly influence new procurement activities. Systems analysis and modeling will be used to help define R&D needs and priorities. Advances in PEM fuel cell technology and in fuel reforming and hydrogen storage will be directly incorporated into the power system development activities. In addition, each program element will contain significant go/no-go decision points that provide the opportunity to assess progress.

## SUMMARY

Fuel cell development for transportation applications includes component and subsystem development, and technology integration and validation for fuel cell stack systems, fuel processors, on-board hydrogen storage systems, and integrated power systems. The fuel strategy includes the development of a fuel-flexible fuel processor (e.g., gasoline, ethanol, methanol, natural gas) technology for on-board the vehicle and development of hydrogen storage technology (in collaboration with the DOE Hydrogen Program) for direct hydrogen vehicles. Test-bed vehicles and concept vehicles utilizing these technologies will be demonstrated in the future, as appropriate.

# Fuel Cell Information Sources

Additional sources of information on fuel cells, other advanced power and vehicle technologies, and alternative fuels include the following:

- **U.S. Department of Energy, Energy Efficiency and Renewable Energy NETWORK**
  http://www.eren.doe.gov/transportation

- **U.S. Department of Energy, Office of Transportation Technologies Home Page**
  http://www.ott.doe.gov

- **The National Alternative Fuels Hotline (of the Alternative Fuels Data Center)**
  1-(800) 423-1DOE
  Fax: (202) 554-5049
  P.O. Box 70879
  Washington, DC 20024
  E-mail: hotline@afdc.nrel.gov
  http://www.afdc.nrel.gov

- **Office of Transportation Technologies Strategic Plan**

- **Research and Development Plan for the Office of Advanced Automotive Technologies (available December 1997)**

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