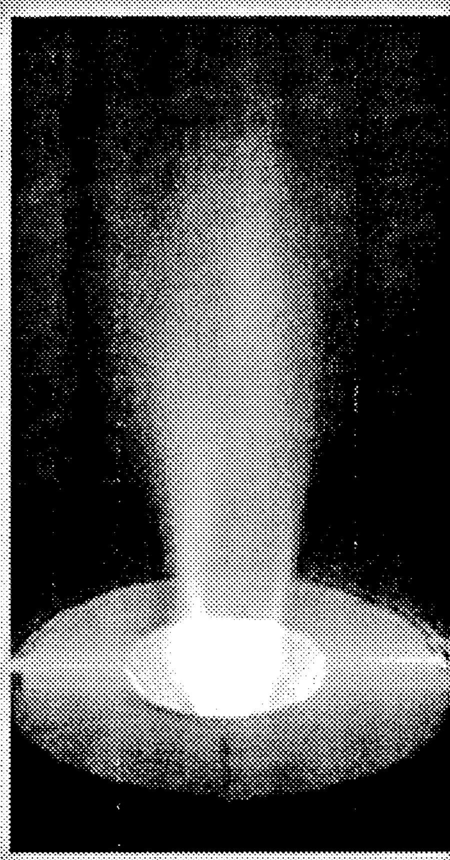
OFFICE OF TECHNOLOGY POLICY

Fuel Cell Vehicles:

Race to a New Automotive Future



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RACE TO A NEW AUTOMOTIVE FUTURE

Office of Technology Policy
Technology Administration
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FUEL CELL VEHICLES: RACE TO A NEW AUTOMOTIVE FUTURE

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FOREWORD

Hydrogen fuel cells represent one of the most promising emerging technologies in the innovation age. The ability to efficiently and cost-effectively harness hydrogen for energy will reshape industries, improve lives, and even impact many nations' wealth and strategies for success.

Recognizing the importance of fuel cells to future American competitiveness and innovation leadership, President George W. Bush is significantly increasing U.S. research and development in fuel cell technologies through such efforts as the FreedomCAR initiative. FreedomCAR focuses on the high-risk research needed to develop the necessary technologies, such as fuel cells and hydrogen from domestic renewable sources, to provide a full range of affordable cars and light trucks that are free of foreign oil and harmful emissions, without sacrificing freedom of mobility and freedom of vehicle choice. The President understands that fuel cell leadership means a cleaner environment, improved national security, continued job creation and sustained economic growth, and he's making the investments we need.

Many challenges remain to the widespread adoption of fuel cells, both technological and infrastructure-related. This report identifies some of these challenges in one of the most complex, demanding and lucrative applications for fuel cells: vehicles. It provides a snapshot of current policies and activities around the world that seek to address these challenges.

We hope this information will help policymakers in the United States and around the world better understand the challenges ahead and the global ramifications of a hydrogen economy. So armed, we can tailor policies and programs to best foster the environment for innovation and commercialization and help charter a cleaner, safer and more prosperous future for all.

Donald L. Evans
Secretary of Commerce

ACKNOWLEDGMENTS

The Office of Technology Policy appreciates the cooperation, assistance and resources provided by the Department of Energy's Office of Energy Efficiency and Renewal Energy in the preparation of this report. In particular, Dr. Robert Kirk, Program Manager of the FreedomCAR and Vehicle Technologies Office, Mr. Steve Chalk, Program Manager of the Hydrogen, Fuel Cells and Infrastructure Technologies Office, Mr. Edward Wall, FreedomCAR Partnership Director, and Dr. Phil Patterson, Industry Economist in the Office of Planning, Budget Formulation and Analysis provided resources, information and valuable insights.

This report was drafted by Dr. Phyllis Genther Yoshida, Senior Technology Policy Analyst, Office of Technology Policy, Technology Administration, Department of Commerce.

CHAPTER 1: INTRODUCTION

> "Fuel cells will power cars with little or no waste at all. We happen to believe that fuel cells are the wave of the future, that fuel cells offer incredible opportunity."
>
> *President George W. Bush,* February 25, 2002

A new future in automotive transportation is steadily approaching. This future will be one in which light and heavy vehicles are powered by new clean and efficient energy sources. While many technologies will contribute to this future, many see the fuel cell as the leading long-term candidate for becoming the power source for petroleum- and emissions-free, mass-produced light vehicles, as well as some types of heavy vehicles.

This assessment discusses the status of global efforts to address the technical and economic barriers—including cost and infrastructure—to the widespread adoption of fuel cell vehicles and thereby usher in a new transportation future. While the successful resolution of remaining technical and economic barriers to fuel cell vehicles is not a foregone conclusion, success is closer than ever before. Automotive Engineering International expressed it well: "[T]he fuel-cell-powered car—the long awaited 'clean personal transportation of the future'—is moving from laboratory vision to technical reality, if not yet market actuality."[1]

The Promise

At this point in time, fuel cell vehicles promise the best opportunity to achieve a net-zero carbon energy and emissions future for the automotive mass market. They would deliver high-energy efficiency possibly up to twice that of gasoline-powered internal combustion engines (ICEs), since hydrogen possesses the highest energy content per unit weight of any known fuel (120.7 kJ/g). Fuel cell vehicles could eventually be powered by hydrogen derived from distributed domestic sources of energy, such as wind, solar, biomass, and hydro. They would offer near-zero levels of air pollution and greenhouse gas emissions. They could be made small enough to fit compactly in vehicles, yet strong enough to produce power equivalent to that of gasoline-powered ICE vehicles. And, unlike pure

1 Steve Ashley, "Fuel Cells Start to Look Real." *Automotive Engineering International Online.* Society of Automotive Engineers, 2001. http://www.sae.org/automag/features/fuelcells, July 2002.

electric vehicles, they could provide a sufficient driving range without needing downtime for recharging.

Most important, the use of fuel cells for an application as complex and demanding as vehicles would portend a major paradigm shift in global energy consumption and supply. The potential would exist to create new industries and allow people throughout the global community to enjoy the benefits of access to an efficient, cost-effective, and reliable energy source. Thus, the new hydrogen automotive future could have a global economic impact far beyond the automotive sector itself, both in terms of the automotive industry's effect on overall economic world growth and as the driver of an enabling technology applicable to many sectors and industries.

The first fuel cell vehicles became available for commercial lease in late 2002 in Japan and the United States.[2] It is highly unlikely, however, that fuel cell vehicles will be truly affordable, durable, and available to average consumers until the 2010–2020 time frame. Significant technical and infrastructure barriers must be overcome. And it will be many more years after those barriers fall before the world's automotive fleets can turn over and accommodate substantial numbers of fuel cell vehicles. In the interim and in parallel, companies and governments are investing in other technologies for highly efficient, clean vehicles, including clean diesels and electric hybrids. They are doing so to maintain medium-term market share and profits, lower harmful emissions, and decrease petroleum use in the transportation sector. Many of these technologies will also be applicable to future fuel cell vehicles.

The major automotive manufacturers have been pouring resources into their own fuel cell laboratories since the early 1990s. GM chief executive officer Rick Wagoner stated, "Fuel cells are very important to GM's future. We've spent hundreds of millions already, and we're going to spend a lot more than that until we get into production vehicles."[3] In 2000, DaimlerChrysler invested approximately $900 million in hybrid and fuel cell research and development (R&D)[4] and, in June 2002, successfully drove its latest fuel cell-powered vehicle, the NECAR 5, across the United States. Every major vehicle company has joined forces in

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2 Toyota Motor Company, "Toyota Advances Marketing of Fuel Cell-Electric Hybrid SUV," press release, July 1, 2002; and American Honda Motor Co., Inc., "Honda Fuel Cell Vehicle First to Receive Certification," press release, July 24, 2002.

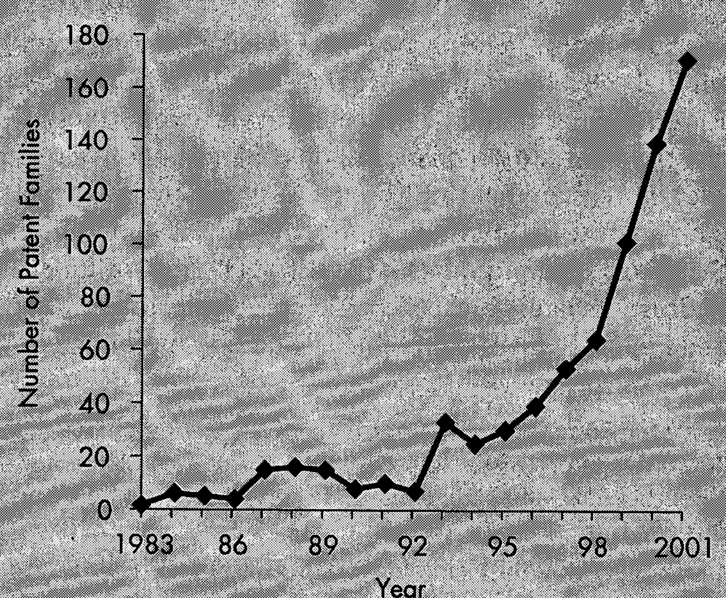
3 Stuart F. Brown, "A Wild Vision for Fuel Cell Vehicles," *Fortune,* April 1, 2002.

4 Canadian Driver Communications, Inc., www.CanadianDrive.com, March 19, 2002.

some manner with other companies and with governments to push the technology further and faster.

The larger vehicle companies have all displayed fuel cell concept cars. Toyota and Honda have announced plans for limited, controlled leases of first-generation fuel cell vehicles using hydrogen in high-pressure insulated tanks in late 2002. They will be followed closely by other companies planning initial sales within the 2003–2004 time frame. Companies are busy preparing for more demonstrations of test vehicles at the California Fuel Cell Partnership, with more demonstrations being planned throughout the world—including in Europe, China, and Australia. Other companies are planning to use fuel cells first on city buses that can use a central refueling facility and have less stringent technical and size requirements. DaimlerChrysler, for example, delivered its first city buses with fuel cells in 2002. Still other vehicle companies and suppliers have announced plans to build fuel cell stationary power sources, which will give them experience in fuel cell technology, earlier return on investment, and manufacturing expertise in a product area with less stringent operational requirements than automobiles. For example, Larry Burns, GM's vice president for research, unveiled a stationary fuel cell-powered generator in early 2002. A final indicator of the growing interest in and expectations for fuel cell technology, patenting activity, has skyrocketed over the past few years, as shown in chart 1.

Chart 1: Automotive Fuel Cell Patent Family Activity (1983–2001)



Source: CHI Research, Inc.

The Public Policy Dimension

An accepted role of national public policy is assisting the development of new enabling and emerging technologies that promise large economic and social benefits. This role is critical for technologies such as the hydrogen storage needed for fuel cell vehicles because of the magnitude of the technological challenges that individual companies may be unable to overcome and invest in sufficiently to cover their high cost, high risk, need for specialized scientific expertise, and delayed returns on investment.[5] Government participation and investment in basic and precompetitive research can help alleviate these issues and, at the same time, shape goals and provide an incentive to private companies to make the necessary investments to bring the technology to market.

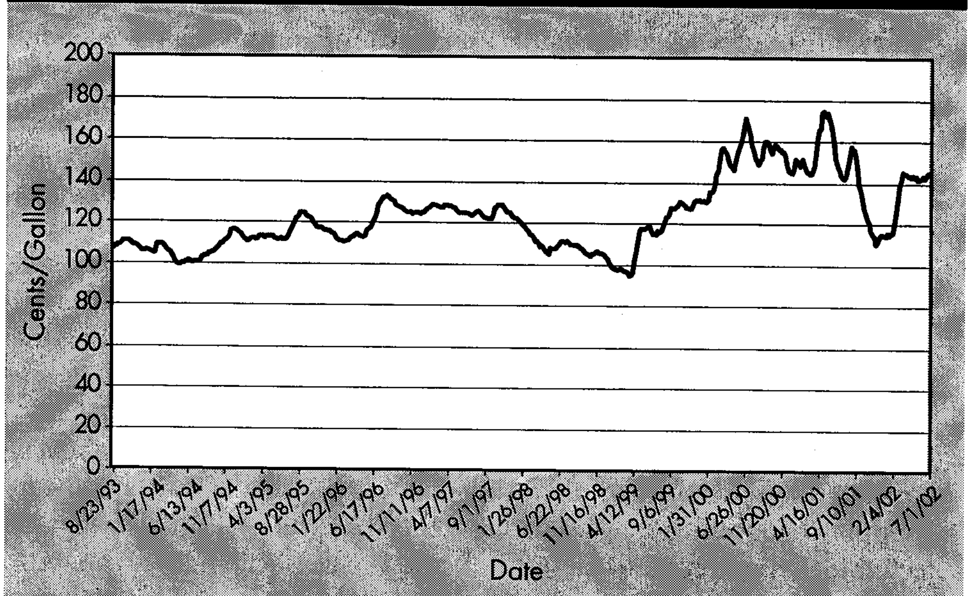
Despite their great technological promise, fuel cell vehicles face market barriers that have little to do with technology. Technical success is not enough to guarantee market success. It is also true that in order for the technology's potential to be fulfilled and the public benefits realized, public policy actions and public-private partnerships will be necessary to support and encourage technology development. The market by itself will not provide sufficient incentives for vehicle manufacturers or energy companies to fully develop fuel cell vehicles or the necessary infrastructure, nor will it be enough to motivate consumers to select fuel cell vehicles over conventional gasoline-powered ICE vehicles. In fact, the biggest barrier to the widespread adoption of fuel cell vehicles and the development of the necessary hydrogen infrastructure might be that the market drivers for consumers to switch to fuel cell vehicles are weak.

In fact, the biggest barrier to the widespread adoption of fuel cell vehicles and the development of the necessary hydrogen infrastructure might be that the market drivers for consumers to switch to fuel cell vehicles are weak.

A major market driver is the price of gasoline. As long as gasoline is affordable and plentiful, there is little incentive to switch to a new fuel (hydrogen) and a new powertrain (a fuel cell system). As seen in chart 2, the average retail price of gasoline has fluctuated from a low of 94.9 cents per gallon in February 1999 to a high of $1.75 in May 2001. Even with these fluctuations, the price has not been high enough to produce a long-term change in consumer buying habits. While prices have been higher in Europe and Asia, creating more of an incentive to switch, even

[5] The technological challenges are addressed in detail in chapter 2.

Chart 2: U.S. All Grades All Formulations Retail Gasoline Price



Source: U.S. Department of Energy, Energy Information Administration

in those regions prices have not caused consumers to make the shift to alternative (nonpetroleum) fuel vehicles.[6]

Another major market driver is fuel supply. First, petroleum in the form of gasoline and diesel is still easily available. Second, it is uncertain how the proposed alternative, hydrogen, will be delivered to vehicles. Delivering the hydrogen (or other fuels such as natural gas, from which hydrogen will be reformed on board vehicles in the shorter term) will involve creating a large and expensive infrastructure. Many have termed this issue a classic "chicken and egg" problem. Vehicle companies will not want to invest large amounts to mass produce the vehicles because consumers will not want to buy automobiles for which no easily accessible refueling structure exists.[7] Energy companies do not want to build a

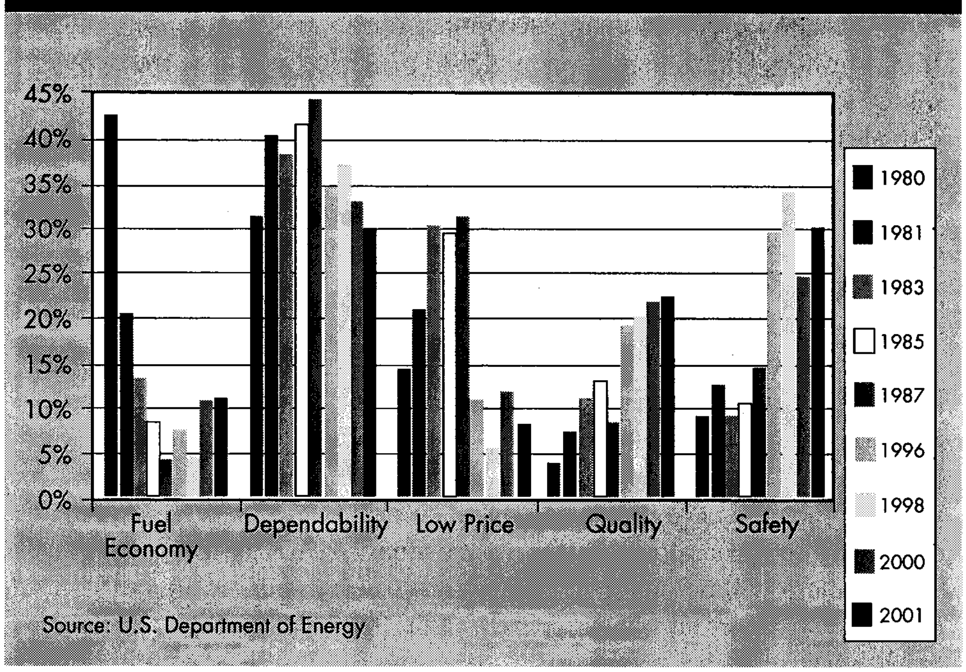
[6] The rise in the market share of diesel light vehicles in Europe in the past few years is partly due to rising gasoline prices, but is also a reaction to concern about CO_2 levels. Many European countries also provide an incentive to purchase diesel vehicles by maintaining lower taxes on automotive diesel fuel and by establishing vehicle CO_2 taxes or standards.

[7] For example, some experts point to the lack of a convenient refueling structure as a major factor inhibiting the widespread adoption of compressed natural gas (CNG) vehicles.

costly infrastructure until there are fleets of vehicles to use it. According to the results of the National Hydrogen Vision Meeting in November 2001, some automakers estimate that hydrogen would have to be available in at least 30 percent of the nation's fueling stations for a viable hydrogen-based transportation sector to emerge.[8] While estimates of the cost to build a hydrogen infrastructure for vehicles vary enormously, one detailed analysis suggests that with current technologies, a hydrogen delivery infrastructure to serve 40 percent of the light vehicle fleet is likely to cost more than $500 billion.[9]

A final major market driver is consumer preference, which reflects fuel supply and fuel prices, as well as differing transportation needs, in various world markets. Will the public want to buy the vehicles? According to a 2001 survey by Opinion Research Corporation International for the U.S. Department of Energy, consumers most value safety and dependability (30 percent), followed by quality (22 percent), fuel economy (11 percent), and low vehicle price (8 percent). Chart 3 shows how these preferences have changed over time, with dependability remaining

Chart 3: Consumer Automotive Buying Preferences



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[8] U.S. Department of Energy, *A National Vision of America's Transition to a Hydrogen Economy—To 2030 and Beyond* (Washington, D.C., February 2002), 14.

[9] Argonne National Laboratory, Transportation Technology R&D Center.

number one. The increasing popularity of light trucks (vans, pickups, sport-utility vehicles, crossovers), which rose from 19 percent of the light vehicle market in 1981 to 51 percent in 2001, reveals that consumers increasingly prefer larger, more powerful vehicles. There are some indications that this preference is increasing elsewhere in the world.

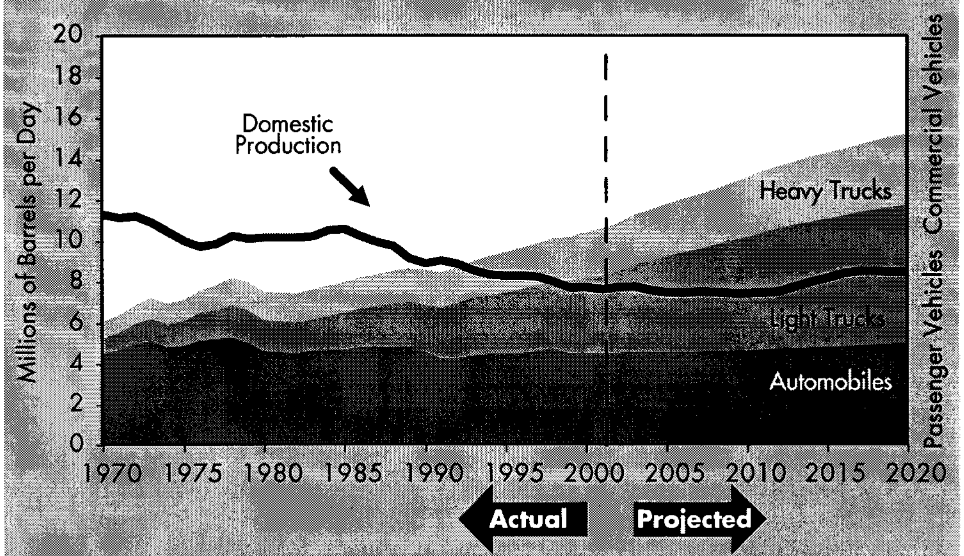
While fuel economy does appear as a preference in this survey, it is low compared with other attributes. A low-emission vehicle does not appear among the top desired attributes. Most consumers are not yet willing to sacrifice other attributes for efficiency and cleanliness. Therefore, many in government and industry around the world foresee a need for increased public education and outreach if consumers are to understand and switch to fuel cell vehicles. These experts also anticipate a need to provide vehicles that do not require sacrifices in current levels of dependability, mobility, and affordability.

In addition to public policy drivers related to technology and economic growth, there are equally strong drivers for fuel cell technology related to national security and environmental protection. In terms of national security, in 1975 the United States imported 36 percent of the oil it used. By 2000, net oil imports at 10.4 thousand barrels were slightly over 50 percent of U.S. consumption. In 2000, transportation oil use was over 147 percent of U.S. oil production and accounted for about 67 percent of U.S. oil consumption. Chart 4 shows actual and projected petroleum use by motor vehicles in the United States, and chart 5 shows the increasing oil gap and how the introduction of hybrid and fuel cell vehicles might help close it. When all these public policy drivers are viewed together—technology development, economic growth, national security, and a healthy, clean environment—there is a clear role for public policies that accelerate the adoption of fuel cell technology.

Government and corporate fuel cell R&D funding is growing swiftly around the globe, and industry alliances are rapidly emerging.

The race to the new automotive future is indeed heating up. It is clear that fuel cell technology presents the potential to create such unprecedented change in the transportation market that no major automobile-producing nation or company wants to risk being left behind. As a result, government and corporate fuel cell R&D funding is growing swiftly around the globe, and industry alliances are rapidly emerging. The winners will be determined by who is best at generating and deploying new technologies, creating long-term competitive advantage by successfully marketing vehicles that use advanced technologies such as fuel cells, and forming successful global alliances.

Chart 4: Actual and Projected Motor Vehicle Petroleum Use



Source: U.S. Department of Energy, *Transportation Energy Data Book: Edition 21* (DOE/ORNL-6966, September 2001), and *EIA Annual Energy Outlook 2002* (DOE/EIA-0383 [2002], December 2001)

CHAPTER 2: STATUS AND PROSPECTS

"Hydrogen fuel cells are the powertrains of the future."

GM Vice Chairman Harry J. Pierce

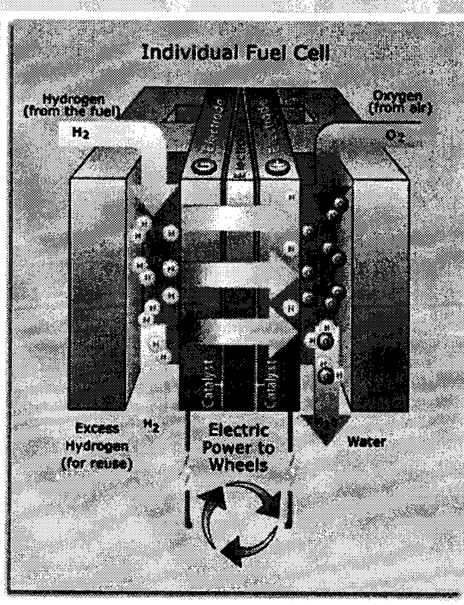
Fuel cell technology has garnered great support and interest around the world in the past decade because of its large market potential, positive impact on air quality, and radically different nature than currently available power sources. It also has the potential to strengthen national energy security by reducing dependence on imported petroleum. The transition to a hydrogen fuel cell-powered energy system, however, requires an enormous investment in research and infrastructure to realize this potential.

Just the Basics: Fuel Cells

Fuel cells can power cars, trucks, and buses without emitting harmful tailpipe emissions. Such vehicles will be cleaner and more energy-efficient than those powered by an internal combustion engine. Fuel cells also may provide energy to factories and homes without creating smokestack pollution.

A fuel cell produces electricity directly from the electrochemical reaction between hydrogen and oxygen. The electrochemical reaction is the reverse of what occurs when electricity is used to produce hydrogen and oxygen. A conventional car engine combusts fuel so it burns in tiny explosions that push the pistons up and down. In a fuel cell, the fuel is oxidized, but the resulting energy takes the form of electricity (plus a little heat).

Fuel cells are very efficient. They can capture 40 to 60 percent or more of a fuel's energy to power a car with low or zero emissions. A fuel cell vehicle running on pure hydrogen emits only water vapor.



Source: U.S. Department of Energy.

Governments and companies are investing at record levels in fuel cell R&D for stationary and transport products. They are paying particular attention to solid oxide fuel cells (SOFCs) and polymer electrolyte fuel cells (PEMFCs). For fuel cell vehicles, the emphasis is on PEMFCs, with some interest in SOFCs for automotive auxiliary power systems (e.g., as a power source for air conditioning) and heavy vehicles (e.g., in transit buses or large recreational vehicles).

Before delving into the policies of foreign governments and the incentives to accelerate development and deployment discussed in chapter three, it is important to comprehend the economic and technical context in which these activities are occurring. What is the "hydrogen economy"? What are the present characteristics of the light vehicle industry? What is the projected size of the fuel cell vehicle market, and what are that market's major business drivers for the vehicle companies? And what are the major component technology barriers that must be overcome?

The Hydrogen Economy

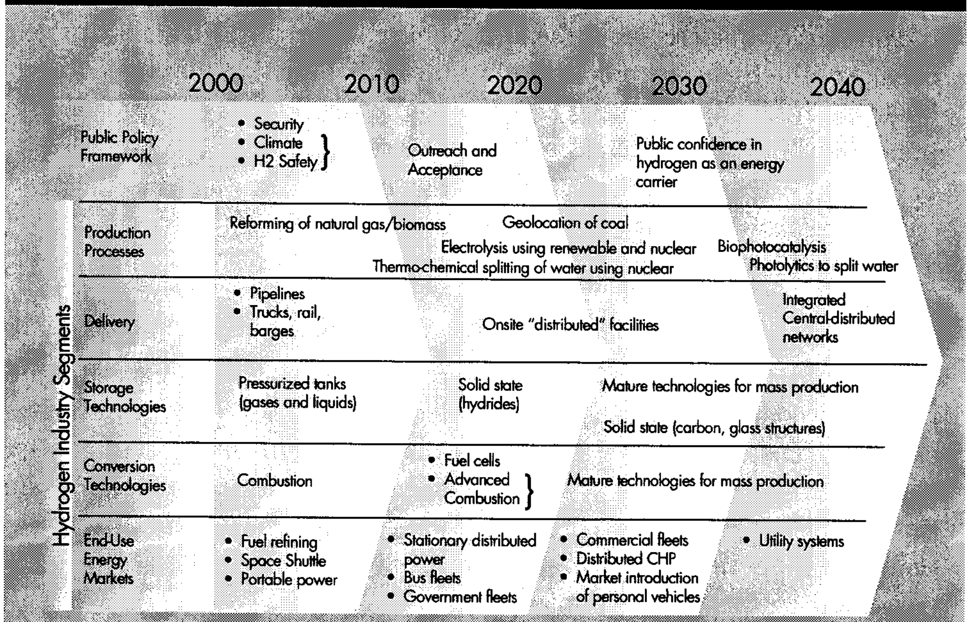
The hydrogen economy is simply an economy whose energy infrastructure uses hydrogen as the primary energy carrier. Its energy infrastructure pairs hydrogen with electricity, using hydrogen as the fuel that, through chemical reactions, is converted into electricity. This method of energy conversion is potentially two or three times more energy-efficient than the method used in internal combustion engines or existing power plants. *A National Vision for America's Transition to a Hydrogen Economy* provides a further description:

> Today we have a hydrocarbon economy. Tomorrow we will have weaned ourselves from carbon and will live in a "hydrogen economy." In the hydrogen economy... America will enjoy a secure, clean, and prosperous energy sector that will continue for generations to come. American consumers will have access to hydrogen energy to the same extent that they have access to gasoline, natural gas, and electricity today. It will be produced cleanly, with near-zero net carbon emissions, and it will be transported and used safely. It will be the 'fuel of choice' for American businesses and consumers. America's hydrogen energy industries will be the world's leaders in hydrogen-related equipment, products, and services.[10]

[10] U.S. Department of Energy, *A National Vision for America's Transition to a Hydrogen Economy* (Washington, D.C., 2002), 17.

The transition to a hydrogen economy will be arduous. It is not certain to happen, nor is it obvious how soon it could happen. The first steps in the hoped-for transition have already begun, but could take many decades to complete. The transition will involve many changes over time in how hydrogen is produced, delivered, stored, and converted into electricity. The transition will also affect different industries at different stages of the transition. Chart 6 shows what these changes could be and when they might occur by looking at the major processes involved.

Chart 6: Overview of the Transition to the Hydrogen Economy



Source: U.S. Department of Energy, *A National Vision for America's Transition to a Hydrogen Economy*, iv

A major issue in the transition is hydrogen production. Because hydrogen does not exist on Earth in its elemental form, it has to be produced by separating it from compounds in which it is found abundantly (e.g., fossil fuels, water, biomass). Most hydrogen currently is produced from fossil fuels such as natural gas, from which it can be derived in a more cost- and energy-effective manner than from water or other renewable sources. Therefore, many companies and governments are conducting research into how to produce hydrogen more cost-effectively in ways that do not require large amounts of energy for the production process itself and that would be offset by the energy saved in the end-use applications such as fuel cell vehicles.

In addition, the process of converting hydrogen to heat or electricity is a major issue in the creation of a hydrogen economy. Conversion can be done either through combustion or fuel cells. Both methods are applicable to vehicles—combustion through an ICE that burns hydrogen[11] and fuel cells through an electrochemical reaction that creates electricity. Many prefer PEMFC technology to combustion for vehicle applications because it potentially provides (1) zero emissions, while combustion would produce significant nitrogen oxides (NOx) emissions, and (2) an energy efficiency level of close to 55 to 60 percent, versus 35 percent for a hydrogen ICE vehicle. Furthermore, in terms of the overall global industrial base, fuel cell technologies are likely to have broader industrial applicability than combustion technologies, and thus to play a stronger role in stimulating economic development. Therefore, fuel cell technology is envisioned as one of the primary enabling technologies that can ensure that the promises of the hydrogen economy come to fruition.

A Global Industry With Global Economic Impact

The new automotive future will have an economic impact far broader than the automotive sector, extending far beyond the United States. The automotive industry is one of the most multinational of all industries. It is a key driver of economic growth and contributor to gross domestic product (GDP). Most future growth in the vehicle market will occur not in already heavily industrialized countries such as Japan, Germany, and the United States, but in industrializing countries such as China and India.

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As a percentage of the top 50 multinational enterprises, the assets of the top 10 multinational automotive enterprises represent 28.1 percent of total assets, 29.1 percent of total employment, and 30.3 percent of total sales.[12] Automotive R&D today is as global as sales and manufacturing, with vehicle companies among the world's largest private-sector sources of R&D. Automotive research centers of excellence are located around the world, with many technology breakthroughs flowing quickly among

[11] BMW and Ford have done extensive work with hydrogen-powered internal combustion engines. Some analysts feel that if a hydrogen-powered internal combustion engine were designed from the ground up to burn hydrogen, it could be as efficient a conversion process as fuel cells.

[12] United Nations Conference on Trade and Development (UNCTAD), *World Investment Report 2001* (Geneva, Switzerland, 2001).

Hydrogen Basics

What are some characteristics of hydrogen?

- Hydrogen is a nontoxic, colorless, odorless, and tasteless gas.
- Bound in organic matter and water, hydrogen makes up 70 percent of the Earth's surface. It is the most common element in the universe.
- Hydrogen usually exists in combination with other elements, such as oxygen in water and carbon in methane, and in trace elements such as organic compounds.
- When cooled to a liquid state, hydrogen takes up 1/700 as much space as it does in its gaseous state.
- Hydrogen is about one-fourth as dense as air.
- The temperature needed to cool hydrogen to a liquid state is -423°F (-253°C).

Why is hydrogen used as a fuel?

- Hydrogen has the highest energy content per-unit-weight of any known fuel—52,000 Btu/lb (120.7 kJ/g).
- Hydrogen burns cleanly. When hydrogen is burned with oxygen, the only by-products are heat and water. When it is burned with air, which is about 68 percent nitrogen, some oxides of nitrogen are formed.

How is hydrogen produced?

- Most of the hydrogen produced in the United States is made by steam reforming, which is currently the most cost-effective way to produce hydrogen. There are many other ways to produce hydrogen, including electrolysis.
- In fuel cells, electrolysis is reversed by combining hydrogen and oxygen through an electrochemical process that produces electricity, heat, and water.

Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy Network, Consumer Energy Information: EERC Reference Briefs, *Hydrogen Fuel*, February 2001

the world's major automakers. For example, in 1999, foreign automotive companies had approximately 54 R&D facilities in the United States.[13] In the same year, U.S. automotive companies had approximately 35 R&D facilities overseas, the most of any U.S. industrial sector.[14]

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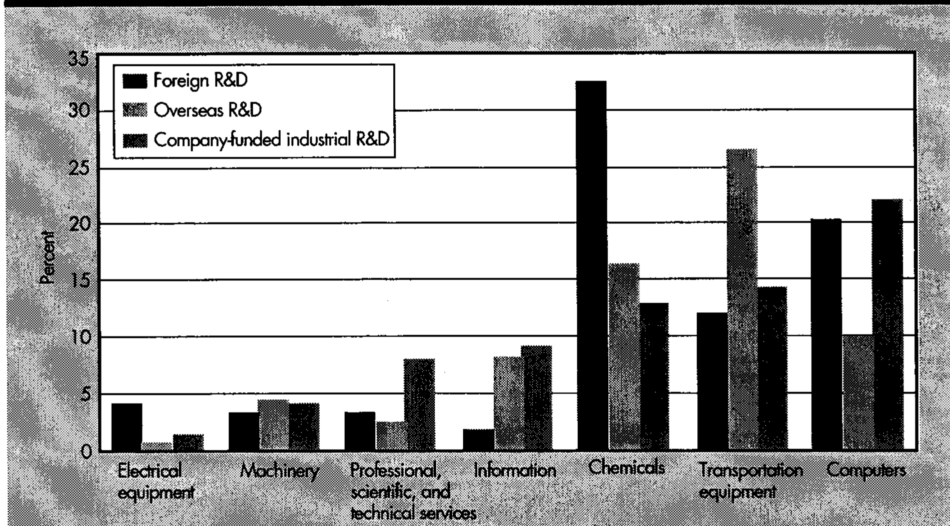
[13] Donald Dalton, Manuel Serapio, and Phyllis Yoshida, *Globalizing Industrial Research and Development,* U.S. Department of Commerce (Washington, D.C., September 1999). These figures do not include R&D functions that are part of manufacturing plants.

[14] Ibid.

According to the National Science Foundation's Industrial Globalization R&D index, the transportation equipment industry ranks second only to chemicals in terms of the highest degree of internationalization. This high degree of internationalization or globalization is shown clearly in chart 7.

Chart 7: Share of Selected Industries in Foreign, Overseas, and Company-Funded Industrial R&D in the United States, 1998



Notes: Foreign R&D refers to R&D performed in the United States by U.S. affiliates of foreign parent companies. Overseas R&D refers to R&D performed abroad by foreign affiliates of U.S. parent companies. The seven industries in this figure account for 77 percent, 69 percent, and 72 percent of foreign, overseas, and domestic company-funded R&D, respectively.

Source: National Science Foundation, *Science and Engineering Indicators*, 2002

The automotive industry's contribution to the world economy is significant. In the United States, transportation-related goods and services accounted for $1,050 billion (10.8 percent) of the $9.87 trillion GDP in 2000. A study released in March 2001 by the University of Michigan for the Alliance of Automobile Manufacturers and Center for Automotive Research found that "No other single industry is linked to so much of U.S. manufacturing or generates so much retail business and employment, as these facts show:

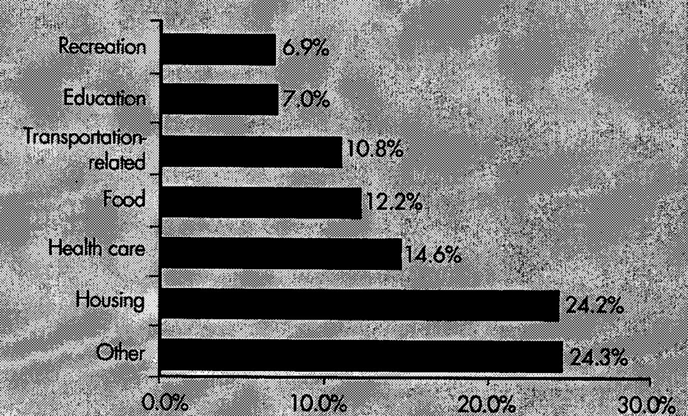
- Employment: America's automobile industry is one of the largest industries in the country. When jobs dependent on the industry are included, the auto industry is responsible for 6.6 million jobs nationwide, or about 5 percent of private sector jobs.

- Compensation: The contribution of automotive manufacturing to compensation in the private sector is estimated at $243 billion, or 5.6 percent of U.S. private sector compensation.

- Job Creation: For every worker directly employed by an automaker, nearly seven spin-off jobs are created. America's automakers are among the largest purchasers of aluminum, copper, iron, lead, plastics, rubber, textiles, vinyl, steel, and computer chips.

- GDP: More than 3.7 percent of America's total gross domestic product is generated by the sale and production of new light vehicles (see chart 8).

Chart 8: U.S. Gross Domestic Product by Major Function, 2000



Note: "Transportation-related" includes all consumer and government purchase of goods (e.g., vehicles and fuel) and services (e.g., auto insurance) and exports related to transportation. "Other" includes entertainment, personal care products and services, and payments to pension plans.

Source: U.S. Department of Transportation, Bureau of Transportation Statistics, *Pocket Guide to Transportation*, BTS002-02, February 2002, 22.

- Output: The U.S. automotive industry produces a higher level of output than any other single industry. When measured in constant 1996 dollars, automotive economic output increased by 47 percent during 1987–1999.

- R&D: The auto industry invested $18.4 billion in research and development in 1997, higher than any other manufacturing industry.

- Exports: Automotive exports rose from $33.4 billion in 1988 to a record $74 billion in 1997, an increase of 122 percent."[15]

There are similar economic impacts in other major vehicle-producing countries. In the European Union, the transport sector accounts for just over 7 percent of GDP. In Japan, the total domestic output of automotive-related industries represents more than 13 percent of total annual manufacturing output and approximately 5 percent of GDP. The transport sector (overwhelmingly automotive-related goods) also accounted for close to 23 percent of Japan's exports in 2001. In the major automobile manufacturing countries, the automotive industry and industries dependent upon it account for 5 to 10 percent of jobs.

General Motors and Ford Motor Company remain the two largest vehicle manufacturers in the world. Combined, they generated net income totaling $23.6 billion between 1997 and 2001 from their automotive operations and revenues, which reached an aggregate of $1.4 trillion.[16] General Motors and Ford, respectively, sold about 8 million and 7 million units worldwide in 2001. The Chrysler Group, part of DaimlerChrysler AG and the third-largest participant in the U.S. market, sold 2.3 million units in 2001 in the United States and 500,000 units overseas. Chart 9 lists vehicle manufacturers in terms of total assets, total sales, total employment, and rank among the top 100 global companies in terms of assets.

Another trend in the automotive market that will affect the deployment of fuel cell vehicles is the continuing consolidation of vehicle producers and increasingly, major automotive suppliers, through purchase and alliances. The consolidation is a result of the excess capacity created over the past 20 years and the increasing globalization of the world economy. Some of the biggest consolidations so far include (1) Daimler-Benz, Chrysler, and Mitsubishi; (2) Ford, Volvo, Mazda, and Rover; (3) Nissan and Renault; and (4) General Motors, Fiat, and Saab. As a result, as few as eight manufacturing families could remain from the more than 100 that existed in the middle of the twentieth century.[17] For example, chart 10 shows the Japanese vehicle companies' current investment relationships—the strongest form of alliance.

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[15] Alliance of Automobile Manufacturers, http://www.autoalliance.org/ecofacts.htm, July 2002.

[16] U.S. Department of Commerce, *The Road Ahead for the U.S. Auto Industry* (Washington, D.C., April 2002), 4.

[17] Ibid., 10.

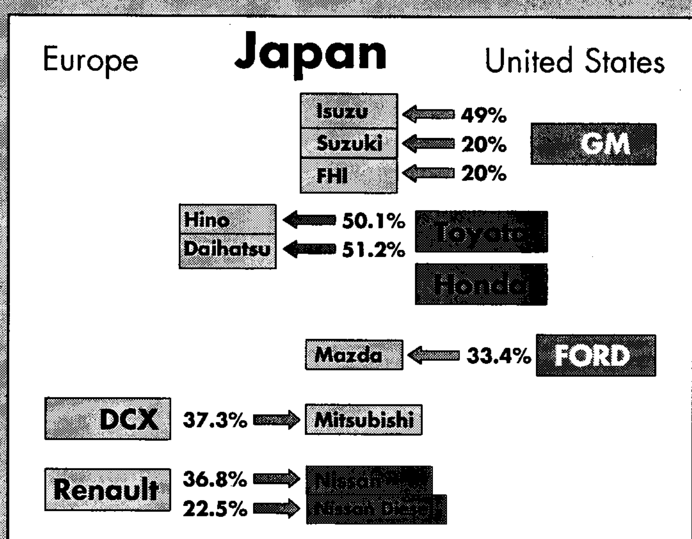
Chart 9: World's Largest Multinational Motor Vehicle Companies, 1999

(billions of U.S. dollars and number of employees)

Name	Rank	Assets	Sales	Employment
General Motors Corporation	4	274.7	176.6	396,000
Ford Motor Company	5	273.4	162.6	364,550
Toyota Motor Corporation	6	154.9	119.7	214,631
DaimlerChrysler AG	7	175.9	151.0	466,938
Volkswagen Group	12	64.3	70.6	306,275
BMW AG	20	39.2	36.7	114,952
Renault SA	28	46.1	37.6	159,608
Honda Motor Co., Ltd.	29	41.8	51.7	112,200
Nissan Motor Co., Ltd.	34	59.7	58.1	136,397
Peugeot SA	49	39.8	37.8	165,800
Fiat SpA	51	60.4	45.2	221,319
Volvo AB	88	17.7	51.1	53,600
Mitsubishi Motors Corporation	98	25.4	29.1	26,749

Source: United Nations Conference on Trade and Development (UNCTAD), *World Investment Report 2001*, Geneva, Switzerland, 2001

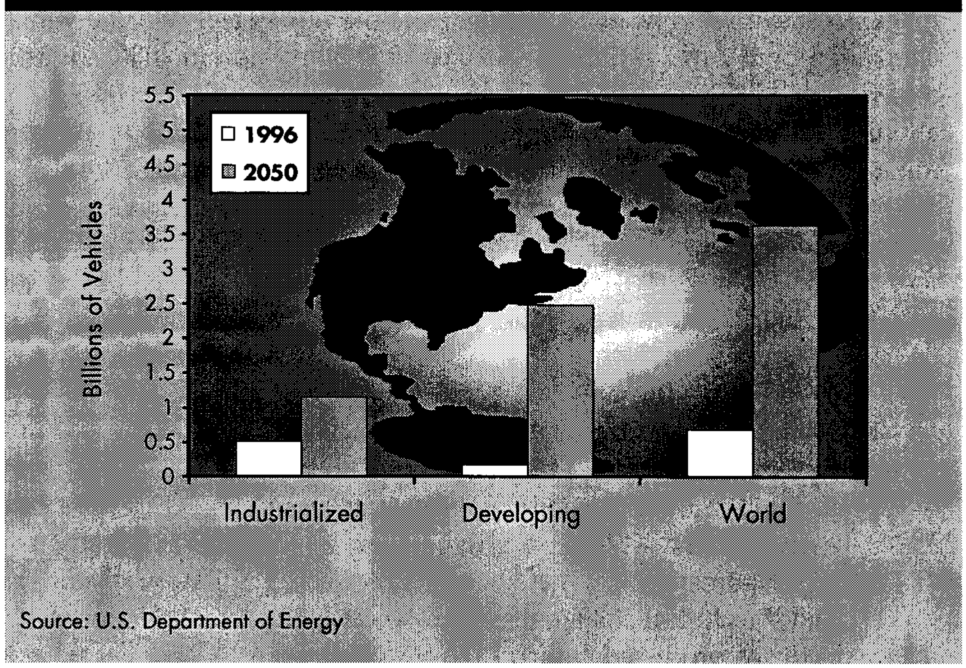
Chart 10: Japanese Vehicle Company Investment Relationships



Source: Japanese Ministry of Economy, Trade, and Industry

Despite current overcapacity, the number of worldwide automobile and truck registrations is expected to grow tremendously in future years, with the number of vehicles worldwide projected to grow from 670 million in 1996 to 3.5 billion in 2050. Industrialized countries could see a doubling in registrations between now and 2050 (see chart 11). More important, developing nations like China and India are expected to experience an explosion in the number of vehicles; hence the recent moves by the major vehicle companies to enter into partnerships with Chinese vehicle makers or establish new production facilities in countries such as Thailand to serve as a hub for regional operations.

Chart 11: World Vehicle Registrations



This explosion in the developing regions of the world has major implications not just for the automobile industry's global economic impact, but also for its impact on energy use and emissions. Rapid economic growth generates demand for personal mobility and transport of goods. While mobility and transportation infrastructure are essential to continued economic growth, the potential growth could be negatively affected by the cost of increased energy use and harmful environmental effects. Therefore, while the introduction of fuel cell technology certainly will occur significantly later than in the industrialized countries because of cost and infrastructure issues, its deployment in developing regions could result in even greater potential benefits in terms of both lifestyle and economic growth.

Market Projections

While it is difficult to project what future market value and share of the transportation market will be accounted for by fuel cell technology, the potential exists for large impacts across the economy. Again, a significant market for fuel cell vehicles will not occur until major technical, policy-related, and infrastructure challenges are resolved. Fuel cell technology must be competitive with both gasoline and diesel ICE vehicles, which themselves continue to improve technologically.

Estimates of potential market size for fuel cells in the transportation market vary enormously in terms of both value and number. In terms of value, market estimates range from around $10 billion in 2010, growing to $60 to $600 billion by 2020. Estimates of the number of fuel cell vehicles range from 1 to 2 million in 2010 to 10 to 30 million in 2030. All estimates come with a multitude of caveats, as well as great uncertainty about the future policy environment and the ability to overcome remaining technical and infrastructural barriers cost competitively. To some degree, each estimate reflects the source's particular perspective. Two recent market estimates, for example, vary considerably:

- Arthur D. Little projects annual fuel cell vehicle production in 2010 of about 8 million, and in 2020 in the range of 10 to 30 million.[18]

- Allied Business Intelligence (ABI) predicts a $608,000 to $1.2 million market for fuel cell vehicles in the United States by 2010 and $1.5 million globally by 2011, accounting for 2.7 percent of market share. ABI sees a possible larger number—$2.4 million, or 4.3 percent of market share—if there are regulatory incentives and if technical challenges decrease. ABI suggests the number of vehicles produced could reach 800,000 by 2012.[19]

Market penetration of fuel cells likely will begin in markets where cost sensitivity is not as large an issue as it is for passenger vehicles.

Market penetration of fuel cells likely will begin in markets where cost sensitivity is not as large an issue as it is for passenger vehicles. These new markets will include stationary distributed power units for commercial and residential electricity and micro-fuel cells for portable electronic equipment (e.g., laptop computers and mobile phones). Fuel cell technology has the potential not only to transform the automotive industry

[18] Arthur D. Little and DRI-WEFA, *Future Powertrain Technologies—The Next Generation* (September 2001).

[19] Allied Business Intelligence, *U.S. and Global Automotive Fuel Cell Markets: Markets, Technologies and Applications* (July 10, 2001) and *Automotive Fuel Cells: Global Market Issues, Technology Dynamics, and Major Players* (December 2002).

but to help meet the increasing electricity demands of the twenty-first century. According to the Electric Power Research Institute, electricity as a percentage of total U.S. energy consumption has increased from 25 percent in 1970 to nearly 40 percent today and is forecast to exceed 50 percent in the near future. Driving this expanding demand is the explosive growth of the Internet, advanced telecommunications, and computers.

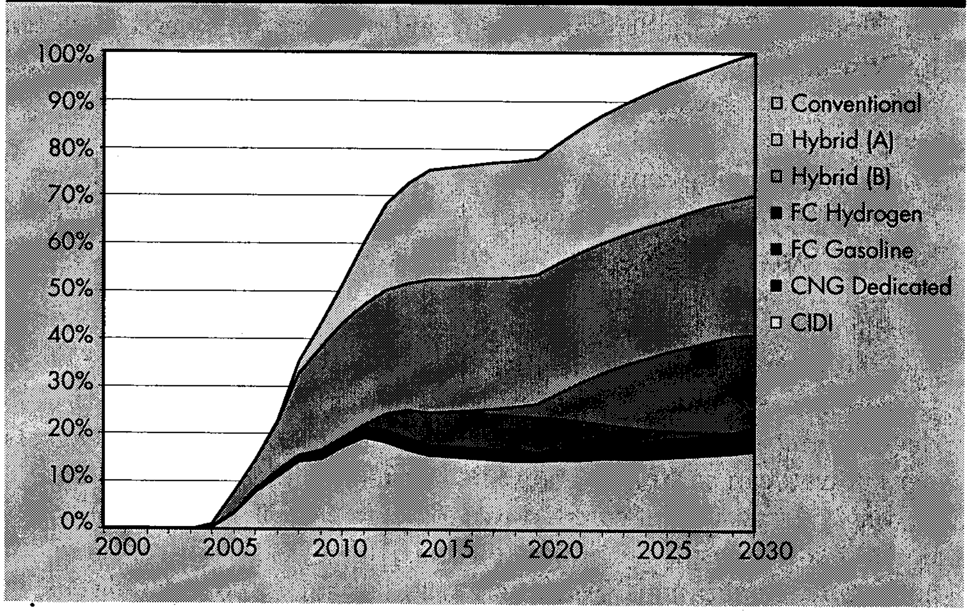
With power-quality-sensitive microprocessors becoming pervasive in U.S. businesses, manufacturing lines, and homes, stand-alone distributed fuel cell power units, with capacity of 5 to 100 kW, offer the promise of providing blackout-free electricity on site with greater than 99 percent reliability. Nearer term applications are expected for miniature, 1-Watt fuel cell micro-power systems that will be able to power a cellular phone for a month without recharge.[20] Significant markets are expected to develop in the next 10 years, first for micro-fuel cells where higher costs per kilowatt can be supported by the market and then for distributed power as the cost point comes down to below $1,000/kW. It should be noted that this cost is more than ten times that of very cost-sensitive automotive applications. Thus, stationary and micro-power fuel cells will serve to catalyze the building of a fuel cell manufacturing industry infrastructure important to automotive uses, where far more stringent cost points and robust technology targets will need to be met.

This pattern also will hold in the transportation sector, where fuel cells are first appearing in niche markets. For example, bus and taxi fleets are much easier to fuel at central facilities, just as alternative fuel vehicles (AFVs) in fleets using compressed natural gas (CNG) and liquefied natural gas (LNG) are currently. In addition, incentives and mandates are more easily applied at the fleet level through grants to state and local governments and through regulatory programs such as the U.S. Department of Energy's State and Alternative Fuel Provider Fleets Program, which requires covered state and alternative fuel-provider fleets to purchase AFVs as a portion of their annual light-duty vehicle acquisitions.

Chart 12 shows another preliminary—and quite optimistic—scenario developed by the U.S. Department of Energy of how the light vehicle market might develop up to 2030 in terms of total vehicles in use. Conventional gasoline ICE vehicles are phased out. Hybrid vehicles

[20] Stationary distributed power and portable applications of fuel cells have been recurrent themes in the $87 million of new fuel cell R&D awarded by the National Institute of Standards and Technology Advanced Technology Program of the Department of Commerce over the past five years in 18 industry proposed projects.

Chart 12: Preliminary Market Penetrations for Light Vehicles



dominate, with over half the market. With the hydrogen-fueling infrastructure complete, fuel cell vehicles account for nearly 20 percent of the market. Fuel cell vehicles using hydrogen created by onboard gasoline reformers are no longer necessary. It will take another 15 to 20 years for the vehicle market to turn over and fuel cell vehicles to dominate.

Excess capacity and the resulting industry consolidation are also contributing to the interest in creating new market segments through styling, function (e.g., crossover vehicles), and environmentally friendly attributes. For example, some companies are betting that in a few years, environmentally friendly vehicles, including fuel cell vehicles, will be a new strategic market segment in which these companies must be able to compete. *Reuters* reported that Toyota plans to double the number of its hybrid models to six by the end of 2003 in order to cement its lead in the growing field of low-emission (environmentally friendly) vehicles and triple its production to 300,000 units by 2005.[21] The need to exploit new market segments to remain viable in a consolidating industry is also one reason for moves by companies such as Honda to increase production capacity for light trucks in the U.S. market. These companies want to be players in what they perceive as a growing emerging market segment worldwide.

[21] *Reuters,* Toyota Plans to Double Hybrid Vehicle Lineup, July 29, 2002.

The speed at which the market for fuel cell vehicles actually grows will depend on whether the remaining technical, cost-related, and infrastructural challenges are overcome. The availability of incentives to enable fuel cell vehicles to compete successfully with advanced internal combustion engines will also be a major factor.

Component Technology Barriers

While there has been stunning progress in PEM fuel cells and related components in the past decade, major technology barriers remain at the component level. Laboratory tests have proven that a PEM fuel cell system can operate, but these advances are not enough to prove that fuel cells can be commercially viable in mass-produced vehicles. The U.S. Department of Energy has estimated that light-duty fuel cell vehicles will be commercially viable in the 2015 to 2020 time frame if research advances enable high-volume production (500,000 units per year), a fuel cell cost of $45/kW based on a 50 kW power plant with full vehicle performance over 5,000 hours of life, and a hydrogen cost of $1.50 to $2.10 per gallon gasoline equivalent. The Fuel Cell Commercialization Conference of Japan (FCCJ) arrived at a similar cost estimate, below ¥5,000 ($42)/kW including auxiliary equipment.

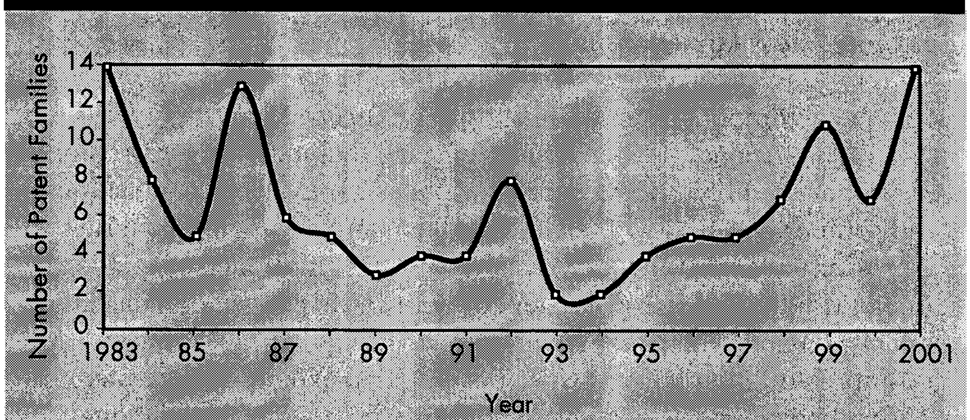
The major components of a transportation fuel cell powertrain are (1) a high-efficiency, low-cost fuel cell stack that includes a membrane electrode assembly (MEA), separator plates, and various connections and components to flow the air, hydrogen, and electricity; (2) a fuel processor to convert fuel to hydrogen (if direct hydrogen or methanol are not used); (3) a storage system to hold the hydrogen on board the vehicle; (4) an air management system to supply air to the stack through a compressor and remove exhaust through an expander; (5) water and thermal management systems to humidify the membrane, remove exhaust, and control the flow of heat; and (6) power electronics and controllers. The technology status of the various components is not uniform. The following major overall technical problems remain in achieving a commercially viable vehicle with the characteristics listed above:

1. Reducing fuel cell system start-up time when utilizing a fuel processor
2. Reducing cost for components and the fuel cell system
3. Demonstrating component and system durability
4. Developing high-efficiency thermal, water, and air management subsystems

5. Developing a suitable fuel infrastructure
6. Solving the hydrogen storage problem

The biggest remaining research problem is energy storage. Hydrogen's low energy-density makes it difficult to store enough on board a vehicle to achieve sufficient vehicle range without the storage container being too large or too heavy. Currently, hydrogen must be intensely pressurized to several hundred atmospheres and stored in a high-pressure container such as those used on CNG vehicles.[22] In liquid form, hydrogen must be stored at very low temperatures. Neither of these options is suitable for normal vehicle use. Therefore, there is much research into new hydrogen storage technologies, such as carbon nanotubes and metal hydrides, both of which theoretically can absorb and hold large amounts of hydrogen safely in a relatively small space. The lack of maturity and the technical challenges remaining in the vehicle hydrogen storage market can be seen by the extremely low level of patenting in this area, as shown in chart 13.

Chart 13: Hydrogen Storage Patent Family Activity (1983–2001)



Source: CHI Research, Inc.

[22] The Toyota and Honda vehicles available for lease in late 2002 use hydrogen stored in high-pressure containers. However, their range will be less than optimal because hydrogen's low density does not permit a sufficient amount to be stored (unlike CNG, which has a higher energy density for the same volume).

Chart 14 takes these technical issues one step further, depicting the primary deployment barriers faced at the fuel cell vehicle component technology level.

Chart 14: Deployment Barriers Faced by Fuel Cell Vehicle Technologies

	Types of Barriers				
Technology Areas	**Fundamental**	**Developmental**	**Maturity**	**Experience**	**Infrastructure**
Hydrogen PEM stack			■	■	
Ancillary devices		■	■	■	
Fuel processors (methanol, gasoline)	■	■	■	■	
Fuel storage (hydrogen)	■	■	■	■	■
Fuel supply (hydrogen, methanol)				■	■
Electric drive components			■	■	

Types of Barriers: ***Fundamental*** barriers mean that basic laboratory research work is still needed. ***Developmental*** barriers require additional engineering R&D to develop practical designs. ***Maturity*** barriers remain if suitable designs exist, but the likelihood of further improvement renders mass-production commitments premature. ***Experience*** barriers exist if costs are still higher than the long-run potential because of a lack of production learning. ***Infrastructural*** barriers limit deployment because of a lack of appropriate fuel or service facilities.

Source: John M. Decicco, *Fuel Cell Vehicles: Technology, Market, and Policy Issues*, SAE Research Report, 2001, x

Summary

As the technology develops and matures further over the next decade, governments will put more emphasis on demonstrating the technology in real-world situations. There also will be a need for public education to prepare stakeholders (e.g., consumers, automotive technicians, auto suppliers) for the hydrogen economy and the new hydrogen-powered vehicles.

The fuel cell vehicle market is developing as part of the broader effort to fulfill the promises of a hydrogen economy—an emission-free, net-zero-carbon energy future. It is also occurring in a consolidating industry that is intensively competitive and that is seeking new markets and new market segments. The true state of the technology necessitates an intense transition period filled with ongoing R&D and real-world demonstrations to ensure the technology's long-term commercial viability. And all of this must be done while building and maintaining the public's interest and enthusiasm.

Chapter 3: Accelerating Adoption and Deployment

"The automobile business is about to experience the most profound and revolutionary changes it's seen since the Model T first hit the streets."

William Clay Ford, Jr., Chairman, Ford Motor Company

Countries and regions with major automotive manufacturing capacity have adopted strategies and incentives to accelerate the adoption and deployment of fuel cell technology into their vehicle fleets. Because of the industry's potential economic and technological importance, they perceive a clear public policy need to accelerate deployment of this technology by investing in research and demonstrations, adopting incentives, and conducting educational activities.

The public policy drivers behind these measures are essentially the same throughout the world. They do differ in terms of priority rank among the major players because of differing situations. The United States and Japan are at the forefront of this effort, but increasingly, they are not alone. Others are moving quickly to jump-start and expand their own transportation fuel cell vehicle and component industries. Europe stresses the benefits of carbon dioxide reduction on global climate change, while the United States stresses energy efficiency and petroleum savings. Canada stresses the importance of fuel cells as an area in which it can provide world-leading technology, while China sees fuel cell vehicles as a visible way to demonstrate its commitment to a clean environment at the Beijing Olympics in 2008.

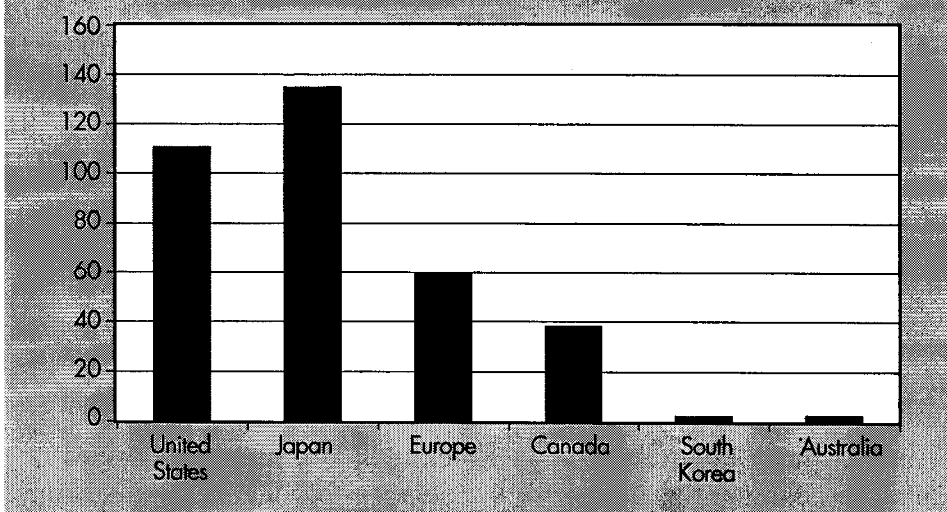
Investment Trends and Patterns

Government R&D Investment

U.S. companies and the U.S. government, long the leaders in funding fuel cell technology, are investing only about 50 percent as much as Japan in 2002. Canada is expected to spend 50 percent as much as the United States. European spending is increasing and could pass that of the United States with the advent of the European Union's Sixth Framework R&D Program. Korea and Australia are significantly increasing their investment, and smaller technology-led countries like Singapore are establishing fuel cell centers. Chart 15 shows that in 2001, Japan surpassed the United States in government fuel cell R&D funding, while Europe and

Canada invested increasingly significant amounts.[23] It is important to note that U.S. industry and government are not investing less. Rather, the others are significantly increasing their investments in what they believe is a major enabling technology with high potential environmental, economic, and energy benefits.

Chart 15: National Government Fuel Cell R&D in 2001 (in millions of dollars)

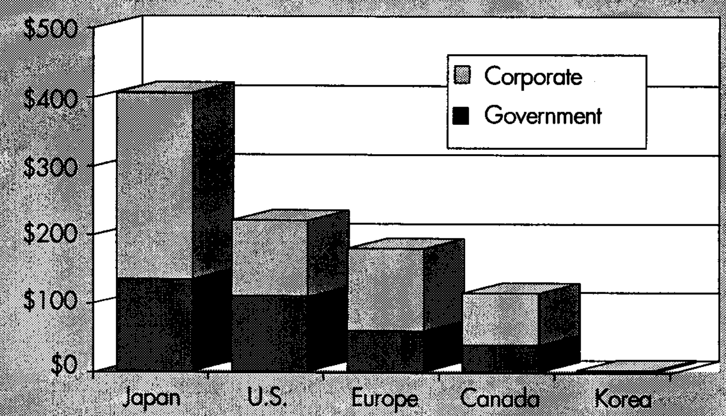


Source: U.S. Department of Energy

Chart 16 reveals a similar investment pattern in joint government/industry fuel cell R&D programs in 2001. It shows Japan's leading investment in this technology and Europe and Canada's major positions in it. It also reveals that public-private partnerships are a popular public policy tool among all the leaders in this technology as they seek to ensure that public investments will translate into commercial products and economic growth. Increasingly, these R&D partnerships are expanding to include demonstration projects, as well as public outreach and education.

[23] Government R&D programs rarely specify a specific end-use for their fuel cell R&D. Therefore, these figures include work with both stationary and vehicle applications. The recent increases, however, have been primarily in PEMFC research and can be overwhelmingly attributed to an increasing interest in vehicle applications.

Chart 16: Civilian Joint Fuel Cell R&D Programs in 2001 (vehicle and stationary uses in millions of dollars)



Source: U.S. Department of Energy

Alliances and Partnerships

Another major investment trend is the number of partnerships and alliances. Automotive industry R&D alliances in the fuel cell area appear to be growing. The alliances are helping the vehicle manufacturers combine their R&D resources and set *de facto* industry standards. Ford, for example, has had an important strategic alliance with Ballard Power Systems and DaimlerChrysler for the development of fuel cell technology. Ford also has an alliance with ExxonMobil to explore the on-board generation of hydrogen from fuels such as methanol or gasoline. In an example of *de facto* standard setting, the Japanese government and some competing companies lowered their investment in methanol-powered fuel cells after Toyota and General Motors made announcements timed closely together that favored gasoline-powered over methanol-powered fuel cells for on-board reformers. General Motors continues to cooperate closely with the companies in its own group, agreeing to merge fuel cell development with Opel and working with Suzuki on the integration of fuel cell systems in compact and small cars. Major automotive fuel cell alliances include the following:

Automotive industry R&D alliances in the fuel cell area appear to be growing.

- Ballard/DaimlerChrysler/Ford/Mazda/Volvo
- DaimlerChrysler/Mitsubishi

- General Motors/Toyota
- General Motors/Opel/Suzuki
- Nissan/PSA Peugeot Citroën/Renault
- BMW/Renault/Delphi
- United Technologies/Hyundai

As research advances are made and large-scale commercialization approaches, these alliances will understandably change or end. For example, Ballard, headquartered in Vancouver, Canada, acquired 50.1 percent of Excellsis from its partners, Ford and DaimlerChrysler, on November 30, 2001, in exchange for common shares in itself. It agreed to acquire the remaining 49.9 percent before November 15, 2004. Excellsis began as a joint venture of Ballard, Ford, and DaimlerChrysler, headquartered in Nabern, Germany. Ford and DaimlerChrysler both continue to work with Ballard. At the same time, Ballard acquired 100 percent of Ecostar Electric Drive Systems (now Ballard Power Systems Corp.), which had also been partly owned by Ford and DaimlerChrysler.

The alliances and partnerships are occurring not just within industry, but also between governments and industry. The FreedomCAR Partnership announced by U.S. Energy Secretary Spencer Abraham and senior executives from General Motors, Ford, and DaimlerChrysler in January 2002 is the most visible example of this trend. The FreedomCAR Partnership reflects major objectives in President Bush's National Energy Policy to improve energy efficiency and propose R&D programs that are performance based and modeled as public-private partnerships. Announcing the FreedomCAR Partnership, Secretary Abraham stated,

> In keeping with the President's National Energy Plan, I am pleased to announce a new public-private partnership between my department and the nation's automobile manufacturers to promote the development of hydrogen as a primary fuel for cars and trucks, as part of our effort to reduce American dependence on foreign oil....The long-term results of this cooperative effort will be cars and trucks that are more efficient, cheaper to operate, pollution-free, and competitive in the showroom.[24]

24 U.S. Department of Energy, "Energy Secretary Abraham Launches FreedomCAR, Replaces PNGV," press release, January 9, 2002.

The FreedomCAR Partnership is a cooperative research effort between the U.S. Department of Energy and the U.S. Council for Automotive Research (USCAR). USCAR comprises Ford, General Motors, and DaimlerChrysler. FreedomCAR is a public-private partnership to fund high-risk, high-payoff research in advanced automotive technologies. It builds on the advanced automotive research that took place under the U.S. Partnership for a New Generation of Vehicles (PNGV). In FY 2002, the U.S. Department of Energy spent approximately $150 million on FreedomCAR-related research, about $60 million of which supports transportation fuel cell R&D and hydrogen infrastructure.[25] FreedomCAR seeks to provide Americans with

- Freedom from petroleum dependence
- Freedom from pollutant emissions
- Freedom to choose the vehicles they want
- Freedom to drive where they want, when they want
- Freedom to obtain fuel more affordably and conveniently

The FreedomCAR Partnership sees efficient fuel cell technology as the most promising long-term pathway to achieving these goals. It is driven by the facts that America's transportation sector depends on petroleum for 95 percent of its fuel, and that transportation accounts for 67 percent of U.S. petroleum use. The steady growth of imported oil to meet these requirements is not seen as sustainable in the long term.

The FreedomCAR Partnership's approach is (1) development of technologies needed to mass-produce affordable hydrogen-powered fuel cell vehicles and ensure the infrastructure to support them; (2) support for technologies that dramatically reduce oil consumption and environmental impacts; and (3) investment in technologies that can be applied across a wide range of vehicles, not just single classes of vehicles. The FreedomCAR Partnership's 2010 technology development goals, shown in chart 17, reflect the technology component barriers discussed in chapter two.

[25] The U.S. government spent approximately $110 million on all types of fuel cell research in 2002.

Chart 17: 2010 FreedomCAR Technical Goals

	Efficiency	Power	Energy	Cost**	Life	Weight
Fuel Cell System	60% (hydrogen) 45% (w/reformer)	325 W/kg 220 W/L		$45/kW (2010) $30/kW		
Hydrogen Fuel Storage/ Infrastructure	70% well to pump		2 kW-h/kg 1.1 kW-h/L	$5/kW-h $1.25/gal (gas equiv.)		
Electric Propulsion		≥55/kW 18 s 30 kW cont.		$12/kW peak	15 years	
Electric Energy Storage		25/kW 18 s	300 W-h	$20/kW	15 years	
Materials						50% less
Engine Powertrain System*	45% peak			$30/kW	15 years	

* Meets or exceeds emissions standards.
** Cost references based on CY2001 dollar values.

In addition to supporting research in the U.S. market, the FreedomCAR Partnership is stimulating research and investment in advanced automotive technologies around the world. Japan, in particular, accelerated its efforts related to fuel cell vehicles in response to the announcement of the FreedomCAR Partnership in the United States.

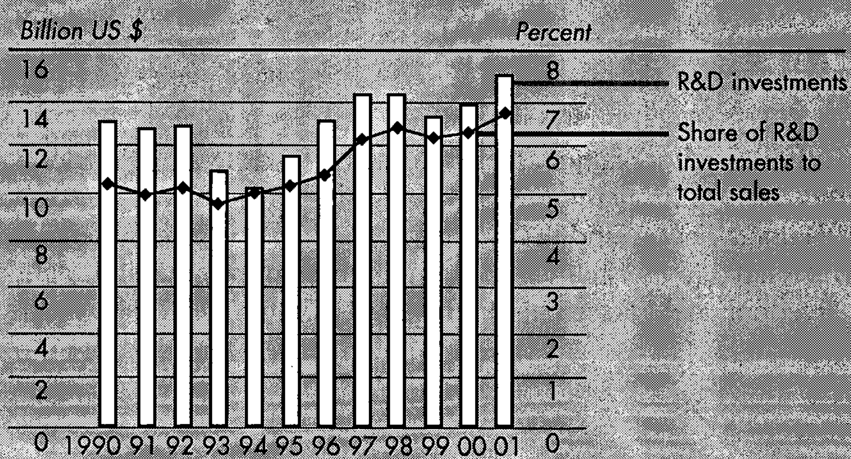
Japan

> "The fuel cell vehicle has great potential for the next millennium."
>
> *Ben Knight, Vice President, Research and Development, Honda America*

Japan is clear in its vision to remain one of the world's most competitive nations. Even in the wake of its financial downturn, the Japanese government and its multinational companies are strongly committed to science and technology and to improved domestic innovation capacity. Japan continues to account for close to 20 percent of the world's R&D, about 54 percent the amount spent by the United States and 2.5 times more than third-place Germany. It is also restructuring its science establishment and making other investments critical to improving and maintaining its relative standing as a global innovator.[26] The automotive industry remains a critical component of this strong foundation for economic growth—a role it has played since the early 1960s.

The business sector is responsible for about 72 percent of Japanese R&D expenditures. Japanese industry is well known for creating new markets by providing products and services that incorporate leading-edge technology. In terms of business expenditure on R&D per capita, Japan outspends every nation except Switzerland and Sweden, at close to $700. Chart 18 reveals that the large Japanese vehicle companies fit this pattern and continue to invest. After a dip in the early 1990s caused by the bursting of Japan's financial bubble, expenditures recovered and reached about $15 billion in Japan's fiscal year (JFY) ending March 2002. This amount

Chart 18: Japanese Vehicle Makers' R&D Investment



Source: Centra Technologies

[26] Michael E. Porter and Scott Stern, "Innovation: Location Matters," *MIT Sloan Management Review* (summer 2001).

is equal to about 6.8 percent of sales, the highest R&D investment ever for the industry as a whole. Japanese automotive suppliers spend about another $555.8 million on R&D. The automotive industry is also investing and driving new business in hot sectors such as fuel cells and nanotechnology.

Because of the large number of vehicle companies in Japan and the diversity among them, there is an understandable difference in any given year or set of years in individual company R&D budgets. As chart 19 shows, Toyota Motor Company has consistently been the largest Japanese vehicle company in terms of R&D expenditures in recent years, followed by Honda Motor Company and Nissan Motor Corporation. The smaller vehicle companies also spend significant amounts on research, with significant impacts in specific technologies (e.g., Isuzu's diesel technology and Mazda's manufacturing technology). This pattern persisted in the fiscal year ending March 2002, as shown in chart 20.

The long-term forecast for Japan's economy is still cloudy. Stagnation continues in economic growth and industrial production. Consumer confidence is extremely low. Public debt has reached a crisis level that will make it increasingly difficult for the government to enact large stimulus packages and fund major infrastructure projects. The domestic automo-

Chart 19: Japanese Vehicle Company R&D Expenditures (billions of yen)

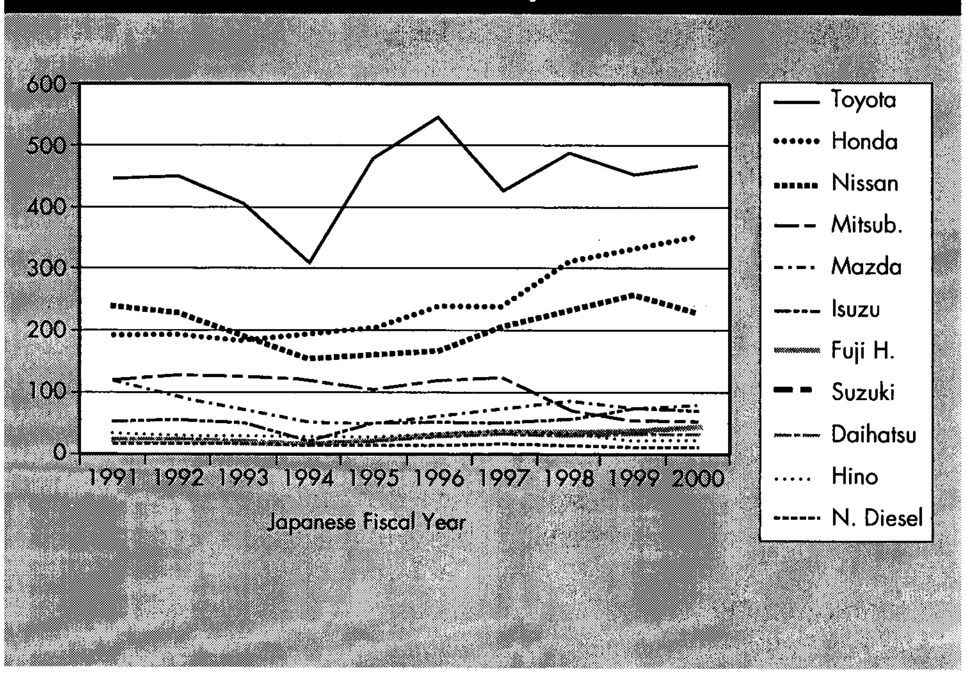
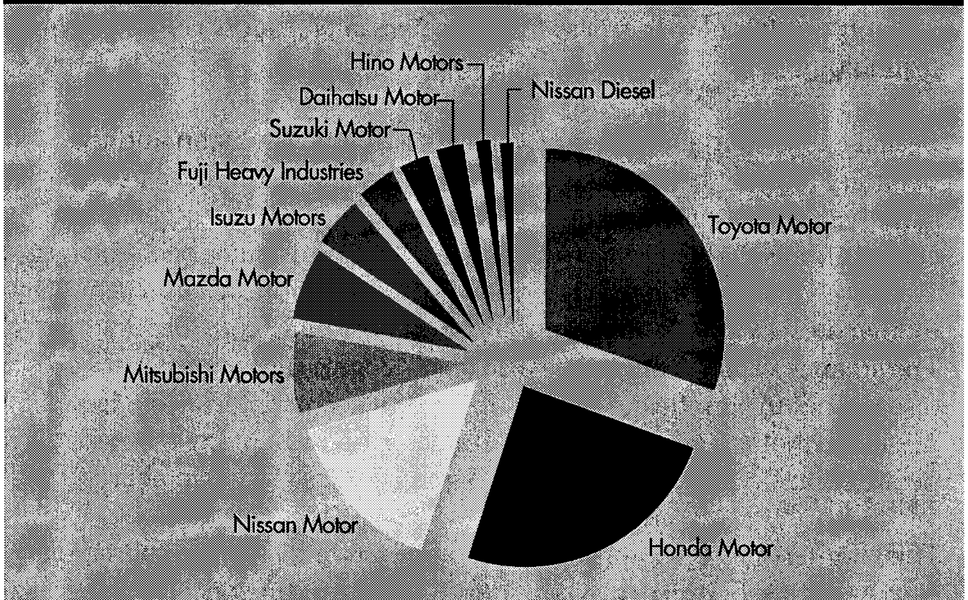


Chart 20: FY 2000 R&D Expenditures by Company (percent)



Source: Centra Technologies

tive market has also been stagnant. Light and heavy vehicle production in 2001 stood at 9.78 million units—down from a peak of 13.49 million units in 1990, but comparable to the past five years. Domestic sales in 2001 fell to 5.6 million units—their lowest level since 1985—with heavy vehicles taking the hit. Passenger car sales, in fact, actually increased slightly from 2000. Overseas demand for Japanese vehicles is likely to continue to be somewhat sluggish in the near term, given the slowdown in the U.S. and worldwide economies. Within the auto industry itself, Toyota and Honda continue to lead Japanese companies in terms of pretax profits. The prospects for Nissan and Mitsubishi have improved because of structural and other changes associated with their tie-ups with Renault and DaimlerChrysler, respectively.

Japanese Government Support

The Japanese automotive industry experienced banner years in 2001 and 2002 in terms of government support for advanced fuel cell vehicle research and related policies. The government substantially boosted support for fuel cell vehicles, revealing a determination to establish and maintain a world leadership position in fuel cell technology.

The Japanese automotive industry experienced banner years in 2001 and 2002 in terms of government support for advanced fuel cell vehicle research and related policies.

The Ministry of Economy, Trade and Industry (METI) released the *Report of the Fuel Cell Commercialization Policy Study Group* on the future of fuel

Highlights of Report of Japan's Fuel Cell Commercialization Policy Study Group

Major Barriers and Issues Facing Fuel Cell Commercialization

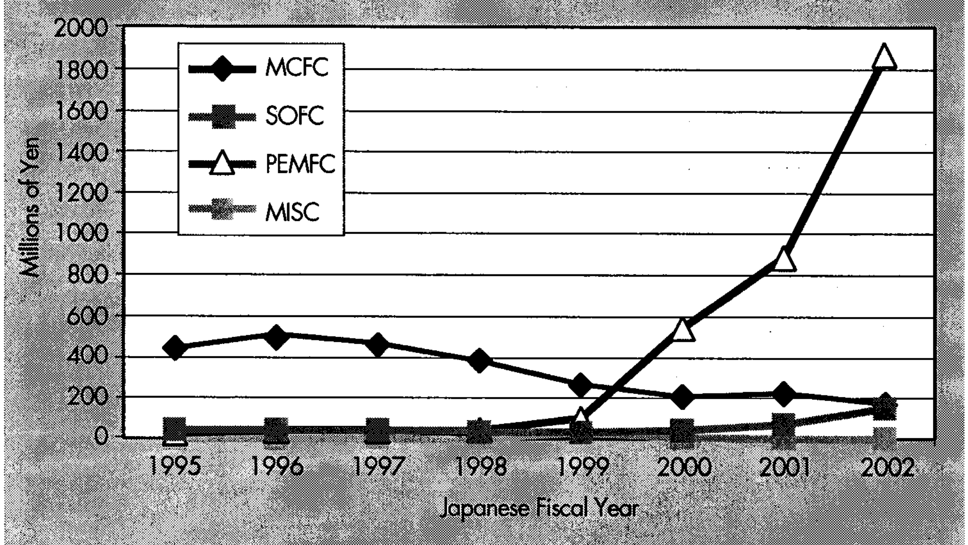
- Improved performance
- Lower cost
- Fuel and supply systems (infrastructure)
- Recycling, limitations on resources
- Standardization and regulation
- Social acceptance
- Education of fuel cell engineers

Proposed Three-Stage R&D Strategy to Overcome Barriers

1. Base preparation and technology verification (until 2005)
   - Establishment of test and evaluation methods
   - Standardization of fuels
   - Evaluation of environmental impacts/well-to-wheel efficiencies of fuel paths
   - Fleet tests/demonstration projects (including hydrogen fueling stations)
   - Government funding of basic research
2. Initial introduction of fuel cell vehicles (2005–2010)
   - Introduce fuel cell vehicles, create initial demand
   - Improve performance, cut costs
   - Install a fuel supply system
   - Continue government funding of basic research
   - Promote procurement of fuel cell vehicles for public transit and the government
3. Market penetration (after 2010)
   - Market penetration by fuel cell vehicles, mass production
   - Complete establishment of infrastructure
   - Government measures to promote use by the private sector
   - Companies to improve performance, cut cost, improve technology

Source: Ministry of Economy, Trade and Industry cell vehicles in January 2001. The report provided justification for expanded fuel cell R&D in the next decade. As shown in chart 21, government fuel cell R&D had already expanded to approximately $135 million in JFY 2001—20 percent more than in the United States ($110 million in 2001), and up from $104 million in JFY 2000. Funding rose to about $184 million in JFY 2002 and might rise as high as $268 million in JFY 2003. The funding composition has also changed to heavily favor PEMFCs. The Japanese government has rapidly increased its R&D on fuel cells, up from two-thirds that of the United States in 1995.

Chart 21: Japanese Government Fuel Cell R&D Expenditures



Source: U.S. Department of Energy

The METI report envisioned limited production of fuel cell vehicles debuting within the 2003-2005 time frame and initial mass production of fuel cell vehicles occurring after 2010. Five million vehicles are envisioned during the 2010-2020 time frame, along with 4,000 hydrogen fueling stations by 2020. The report called for gasoline as the standard fuel—immediately following and influenced by announcements from Toyota and General Motors that they had decided on gasoline.

The METI report foreshadowed the announcement of a new nine-year action plan called the Prime Minister's Action Plan to develop high-fuel-economy low-emission (LEV) vehicles (including fuel cell, hybrid, *The Japanese government uses five major mechanisms relevant to fuel cell vehicles to support automotive R&D and expand the market for advanced vehicles.*

and alternative fuel vehicles). Prime Minister Koizumi announced the Prime Minister's Action Plan on July 11, 2001, calling for at least $615 million in government funding in JFY 2002 and 10 million LEV vehicles (including 50,000 fuel cell vehicles) by 2011. The action plan pulled together and expanded existing efforts (described later in this section), including calling for about $95 million in fuel cell vehicle funding. The budget for the action plan is split four ways: $220 million for tax incentives, $155 million for R&D, $22 million for low-interest loans, and $218 million for subsidies. The budget does not include government procurement expenditures.

In January 2002, partly in reaction to the announcement of the U.S. FreedomCAR Partnership, five senior vice ministers from the Ministry of Economy, Trade and Industry; the Ministry of Land, Infrastructure and Transport; and the Ministry of Environment formed a joint team to focus on how to further accelerate fuel cell development and deployment. In late May 2002, they finalized a report titled *Project X Japan: Develop Engines for Earth's Renewal,* in which they recommended that Japan undertake the following actions to achieve global fuel cell leadership by 2005:

1. A substantial increase in fuel cell R&D as early as 2003
2. A greater exploitation of synergies across academia, government, and industry
3. An earlier introduction of the 5 million fuel cell vehicles and 10 million kW in stationary power generation capacity previously proposed to be achieved by 2020 in the 2001 Prime Minister's Action Plan
4. The inclusion of buses and other fleet vehicles in the large-scale three-year fuel cell vehicle demonstration projected scheduled to begin in late 2002
5. The completion of more hydrogen refueling stations than currently planned
6. The development of safety regulations and deregulation needed to facilitate demonstrations
7. A comprehensive review of laws and regulations 2005
8. Sponsorship of fuel cell vehicle races to raise public awareness and promote innovation

These plans will be implemented primarily through an expansion of existing programs. The Japanese government uses five major mechanisms relevant to fuel cell vehicles to support automotive R&D and expand the market for advanced vehicles: producer and consumer tax incentives; collaborative government/industry R&D programs; government procurement; direct subsidies and low-interest loans; and public education and outreach.

Producer and Consumer Tax Incentives

Japanese producers derive major benefits from tax incentives. The effective corporate income tax rate across Japanese sectors is remarkably uniform. During the 1950s and 1960s, the Japanese government widely used tax-free reserves, expanded accelerated depreciation, and foreign exchange controls to promote industrial development in specific industries, including vehicles and automotive parts. By the 1980s, these targeted tools were unavailable to large companies because Japan had signed various multilateral trade and investment agreements (e.g., Organization for Economic Cooperation and Development, General Agreement on Tariffs and Trade, International Monetary Fund).

New and high-tech sectors still benefit from a variety of universal tax credits and special depreciation allowances in the Japanese tax code. In common with the rest of Japanese industry, automotive companies can receive a 15 percent tax credit for R&D expenditures over and above the average of a company's previous three years of R&D expenditures. Prior to JFY 1999, the tax credit stood at 20 percent. There are voices urging that it return to 20 percent.

It is impossible to derive the amount of R&D tax credits actually taken by Japanese or U.S. vehicle companies without access to proprietary data. A rough estimate is that Japanese vehicle companies (excluding parts producers) were entitled to take ¥22 billion ($190 million) and ¥14 billion ($122 million) in R&D tax credits in JFY 1999 and JFY 2000, respectively. It is unlikely that this amount was actually taken. In comparison, in the latest years for which information is available, the U.S. motor vehicle industry (including parts producers) had $542 million available in R&D tax incentives in 1997 and $617 million in 1998, although it is unknown how much of this amount the industry actually used.[27]

Another way Japanese automotive companies accrue tax advantages is through participation in a government-sponsored cooperative R&D program. Any investment made or paid for by Japanese companies as part of cooperative R&D programs sponsored by the government or an independent administrative agency can be depreciated by 100 percent in the year in which the investment is made. This provision also applies to investments made within the company to support the project (e.g., equipment purchases). It also governs investments made in connection with joint projects run by certain nonprofits formally affiliated with a government agency.

[27] U.S. Internal Revenue Service. Due to a slight definitional change, 1997 data are based on 101 tax returns and 1998 data on 123 tax returns.

Companies and individuals can lower corporate and personal income taxes by 7 percent for the first year when they purchase a vehicle that meets 2010 fuel economy targets and generates at least 25 percent fewer emissions than current standards. The same tax cut is applicable to companies and individuals installing CNG or methanol fueling facilities.

Japan also maintains supply-side incentives for buyers. Vehicle taxes comprise about 10 percent of the national government's revenue. Japan has several incentives for consumers and businesses buying environmentally friendly cars.

One incentive is a reduction in the 5 percent sales tax. For electric, natural gas, or methanol vehicles, and for hybrid buses and trucks, the sales tax is reduced by 2.7 percent. The sales tax is reduced to 2.2 percent for environmentally friendly hybrid cars, such as the Toyota Prius or Honda Insight. For example, a Toyota Prius costs approximately ¥2,150,000 ($18,700).[28] At 5 percent, the sales tax is ¥107,500 ($935). At 2.2 percent, the sales tax is ¥47,300 ($411)—a savings of ¥60,200 ($524). These tax incentives are currently in place through JFY 2002, with plans to extend them. Starting in April 2001 and continuing through September 20, 2002, there was an additional 1 percent reduction in the sales tax for vehicles complying with Japan's 2002 emission requirements. This reduction was increased to 2.2 percent for the period between October 1, 2002, and February 28, 2003.

There is a break for the annual tax on cars that varies by model and year, but that ranges from 13 percent to 50 percent. The amount of reduction is based on whether the vehicle has better fuel economy than the 2010 fuel economy targets and how much lower its emissions are than current emission standards. For a Toyota Prius-size car, the annual tax is about ¥34,500 ($300). This amount is reduced by 50 percent for the first two years of ownership of a car deemed environmentally friendly by the government (e.g., the Toyota Prius would be assessed $150).

There also are disincentives for owners of older, less energy-efficient vehicles. Starting on April 1, 2001 (JFY 2001), the annual tax for vehicles over 11 years old with diesel engines and for vehicles over 13 years old with gasoline engines was increased by 10 percent as an incentive to buy newer, more energy-efficient vehicles. In addition, the government reduces the acquisition tax when an old vehicle with a diesel engine is scrapped and a new vehicle that complies with the latest emission

[28] $1.00 = ¥115.

regulations is purchased. As Japan's vehicle fleet is replaced, the amount of this reduction declines (2.3 percent from October 1, 2001, to March 31, 2003; 1.9 percent from April 1, 2003, to March 31, 2007; and 1.2 percent from April 1, 2007, to March 31, 2009).

The Prime Minister's Action Plan expands the current sales tax deduction and annual vehicle tax reduction by adding a deduction in the acquisition tax levied at the time of purchase. Under the action plan, the acquisition tax will be reduced by up to 90 percent for electric vehicles, methanol vehicles, CNG vehicles, and hybrid buses and trucks. It will be reduced by up to 73 percent for hybrid passenger cars. There is a 76 percent reduction when a LEV is purchased to replace an older diesel and up to a 33 percent reduction for light gasoline trucks, diesel passenger cars, and light diesel trucks that meet 2002 emission standards.

Collaborative Government/Industry R&D Projects

Two major government/industry R&D projects—the Advanced Clean Energy Vehicle (ACE) Project and the Dispersed Battery Energy Storage Technology Development Project (both of which just ended)—were directly supportive of the automotive industry and aided the development of Japan's fuel cell vehicles. There also were fuel cell projects. These projects have been replaced with new projects focusing even more strongly on the needs of fuel cell vehicles, described later in this section.

METI's New Energy Development Organization (NEDO) ran the ACE Project. The ACE Project's objective was to develop vehicles utilizing alternative or "clean" fuels that achieve twice the energy efficiency of conventional models rated as ultra-low emission vehicles (ULEVs). The Japan Automotive Research Institute (JARI) managed the ACE Project for NEDO. NEDO provided 20 percent of the funding (approximately $5 million per year), and the participating companies provided the other 80 percent. Over the life of the program, funding totaled about $175 million. The ACE Project supported the development of six hybrid vehicles:

- Passenger Cars—Two series hybrid vehicles equipped with the reformed methanol fuel cell and lithium-ion batteries. Nissan Motor Company developed a methanol reformer and a reformed gas carbon monoxide processing unit to be installed in hybrid cars using PEFCs. [The Nissan methanol-fuel-cell hybrid passenger car has been replaced by a Toyota gasoline reformer approach.] Honda R&D Co. pursued a CNG Otto engine (an absorbed natural gas system for hybrid cars) in series with a motor-flywheel and a flywheel battery.

- Two-Ton Cargo Trucks—Two series hybrid vehicles equipped with a compressed natural gas self-ignition turbo compound ceramic engine and an ultra-capacitor/battery combination. Isuzu Ceramics Research Institute Company mated a CNG ceramic turbo-compounded engine in series with an ultra-capacitor. Mitsubishi Motors Corporation developed a two-ton truck in which the drive system can be efficiently switched in accordance with different running conditions, with a lean-burn natural gas-fueled CNG engine and motor generator-charging lithium batteries.

- Two City Buses—Nissan Diesel Motor Co., Ltd., developed a system with a combined LNG Miller-cycle gas engine and ultra-capacitor to be installed in a large, non-step route bus. Hino Motors Co., Ltd., developed a bus with an on-board hybrid system that automatically selects the more efficient power source according to running conditions, and that also has a combined dimethyl ether (DME) engine and ultra-capacitor.

- The ACE Project kept open a broad range of drive train alternatives, retaining a diverse mix of prime movers, fuels, energy storage devices, and control systems. In addition, the ACE Project covered truck and bus platforms along with personal transportation. The project involved a diverse group of vehicle manufacturers and emphasized the selection, scaling, and optimization of component technology according to vehicle size and application.

Technical evaluations of the technologies developed within the ACE Project are not fully available, so it is difficult to assess its impact. Like other collaborative Japanese government/industry R&D projects, the ACE Project created a structure in which young engineers from different companies could come together to learn and share ideas and findings. Some have criticized the ACE Project's emphasis on methanol fuel cells—an emphasis that has been dropped in the new programs. In addition, Toyota Motor Corporation, one of the most advanced Japanese automakers in terms of fuel cell development, did not participate. Yet the project did give some companies—including some of the smaller vehicle companies—much-needed experience in fuel cell development and application.

NEDO also ran the project on Dispersed Battery Energy Storage Technology Development. The project had two major objectives: (1) to contribute to load leveling by using compact, large-capacity batteries and (2) to help develop power devices for electric cars and vehicles, including R&D on lithium secondary batteries that operate at normal temperatures. The five-year program began in JFY 1992 and ended in JFY 2001. METI/NEDO spent $18.8 million on the program in 1997 and $26.6 million annually in its last years.

The Lithium Battery Energy Storage Research Association (LIBES) is similar to the U.S. Advanced Battery Consortium (USABC) in that both seek to promote advanced battery research. Both groups work on the standardization of test methods, particularly on abuse testing methods of advanced batteries. There are differences in approach, however. No Japanese vehicle companies participate in LIBES (only battery companies), while the U.S. vehicle companies are all active in USABC. LIBES is researching advanced batteries for both stationary utility and electric propulsion applications. USABC is involved much more heavily in advanced power applications.

Japanese vehicle and automotive supplier companies continue to be involved in smaller projects. These smaller projects are under way for specific components (e.g., flywheels, electric energy storage systems with high-temperature superconducting magnetic bearings), industry-wide infrastructure technologies (e.g., energy-efficient manufacturing technology), and programs with important implications for the automotive industry. Other projects include the work of METI's Fine Carbon Technology Program on carbon nanotubes. National laboratory researchers also do work directly relevant to the vehicle industry, but it is not labeled as such and is difficult to quantify (e.g., membranes, catalysts, advanced materials, electronics).

The Prime Minister's Action Plan expands the Japanese government's fuel cell programs. These programs include work under (1) the New Sunshine Program for stationary applications, (2) the World Energy Network (WE-NET) to develop hydrogen fuel cell vehicles and infrastructure, (3) the Millennium Project, which covers hydrogen storage, fuel cell safety and durability, fuel cell evaluation, and standards development (and of which fuel cells accounted for ¥3.5 billion of ¥120 billion spent in JFY 2000), and (4) NEDO. These programs are not tied to specific industrial sectors, but perform work that can be used in fuel cells for stationary and mobile applications. However, as chart 21 shows, fuel cell funding has increased dramatically and shifted strongly into work on PEM fuel cells, rather than on other types. PEM fuel cells are particularly applicable to the automotive industry, which is one reason cited by government officials for this shift. Two specific projects relevant to fuel cells are the Polymer Electrolyte Membrane Fuel Cell and Hydrogen Technology R&D Program, which will receive about $187 million in JFY 2002, and a continuation of the Millennium Project's work on fuel cells, funded at about $32.8 million.

Another new project under the Prime Minister's Action Plan is METI/ NEDO's five-year, $5-million-per-year effort to develop lithium-ion batteries specifically for hybrid fuel cell vehicles. This effort is an area in which many in Japan perceive themselves to be behind their competitors, but which will be essential to a commercially viable fuel cell vehicle. The project's planners foresee a 75 kW lithium-ion battery combining with a 25 kW fuel cell as the nearer-term powertrain for fuel cell vehicles. Finally, METI's 2002 R&D budget also supports a development effort for advanced ICE LEV vehicles powered by CNG, DME, diesel, liquid petroleum gas (LPG), and hybrid systems.

Along with the broader issue of what technologies will be needed for the coming hydrogen economy and the low-emission, high-efficiency vehicles needed in the interim, fuel cells are increasingly an area of strong interest and commitment within the Japanese government. More funding and initiatives can be expected for this area in future years.

By creating initial market demand through government procurement, the Japanese government often encourages the development of domestic sources of technology-based products.

Government Procurement

By creating initial market demand through government procurement, the Japanese government often encourages the development of domestic sources of technology-based products. It undertakes such activities for various economic, security, or social reasons, as do many other countries. As in the United States, government procurement is also used as a tool to expose the public to new technologies.

Individual Japanese government agencies, including the Ministry of Land, Infrastructure and Transport (MLIT) and the Environmental Ministry, have procured alternative-fuel vehicles in the past, especially those powered by compressed natural gas. The national government has also encouraged taxi fleets (controlled by MLIT) and local government authorities to buy these vehicles. Recently, however, with the pending arrival of larger numbers of easier-to-maintain electric hybrids, government procurement measures are becoming more numerous, both at the national and local levels.

In March 2001, Prime Minister Koizumi took initial steps to mandate government procurement of "green vehicles." His statement, made during a policy speech before the Diet, defined green vehicles as those with alternative powertrains (e.g., hybrids, fuel cells, pure electrics, CNGs, and others). He ordered the national government's ministries and agencies to switch over immediately to purchasing green vehicles and to replace the current fleet with such vehicles within three years. The only exceptions to the order were police vehicles and limousines for VIPs. The Japanese national government operates about 7,000 vehicles worth an estimated ¥15 billion. Initially, the government budgeted ¥1.4 billion a year for the purchases (enough to replace about 10 percent of the fleet annually), but the prime minister requested, and the Project X Report reiterates, a call for this amount to be increased so that the fleet will be replaced within three years of April 2002. The prime minister also requested in April 2002 that the Japanese government provide sufficient funds in the JFY 2003 budget to buy fuel cell vehicles.

Several prefectural and municipal governments are following suit, partly to stay in compliance with the Law Concerning the Promotion of Procurement of Eco-Friendly Goods and Services that took effect in January 2001. There are plans to provide about $35 million in subsidies to local and municipal governments to purchase LEV vehicles and build fuel supply infrastructure.

Low-Interest Loans and Direct Subsidies

Initial market demand is also stimulated through direct subsidies and low-interest loans. Japan is using such measures to lower the risk—especially to small businesses—of buying advanced energy-efficient vehicles.

As of 1999, three Japanese government banks, the Japan Development Bank and the Hokkaido and Tohoku Development Public Loan Corporations, made low-interest loans available to purchasers of designated environmentally friendly vehicles and builders of refueling stations for alternative fuels (electricity, natural gas, or methanol). These banks also have a deferred repayment period available for these loans, if deemed appropriate. The loan periods range from 5 to 10 years or the length of a lease. Information on how many loans have actually been made is unavailable.

In terms of direct subsidies, METI pays half the price difference between standard vehicles and those designated as having low-pollution alternative powertrains for both purchases and leases. The amount of these subsidies varies substantially by vehicle type. The subsidies are available to both individuals and businesses. While these subsidies now are used primarily for alternative-fuel vehicles and hybrids, they could be significant for fuel cell vehicles as these automobiles become available. MLIT funds truck and bus operators who want to convert from diesel to CNG, and could extend the subsidy to fuel cell vehicles. MLIT also subsidizes companies that switch from using trucks to using other types of transportation.

There are METI subsidies for local public bodies that purchase environmentally friendly vehicles—especially public authorities in localities designated by Japan's Environmental Agency as Class 1 areas of the Pollution-Related Health Damage Compensation Law. In addition, there are subsidies and tax breaks for public bodies building refueling stations for electricity, natural gas, and methanol.

Three nonprofit associations—the METI-affiliated Organization for the Promotion of Low Emission Vehicles (LEVO), the METI-affiliated Japan Electric Vehicle Association (JEVA), and the Japan Eco-Service Stations Association (JESA)—administer the subsidy programs. In August 2001, METI and MLIT asked for additional funds to subsidize environmentally friendly vehicles. In order to reach a goal of 1 million such vehicles on the road by 2010, METI asked for an appropriation of ¥16 billion ($133 million) to subsidize the annual purchase of 20,000 natural gas, electric, methanol, and hybrid vehicles.

METI and MLIT also subsidize demonstration projects and fleet tests of alternative fuel vehicles. Over the past several years, they have funded several such programs for CNG and electric vehicles. A major three-year demonstration test program for fuel cell vehicles, the Japan Hydrogen and Fuel Cell Demonstration Project (JHFC), started in fall 2002. Participants include both vehicle and energy companies. The goal of the project is to better understand fuel cell technology and ways of creating a hydrogen infrastructure. The project will also educate the public about fuel cells and hydrogen. METI also hopes information from the project will be useful in setting standards and regulations in this technology area.

The work is organized under three organizations: the New Energy Foundation (NEF), JEVA, and the Engineering Advancement Association of Japan (ENNA). NEF is responsible for the demonstration and testing of stationary fuel cells. JEVA will demonstrate and test fuel cell vehicles, including vehicles from Toyota, Nissan, Honda, General Motors Japan, and DaimlerChrysler Japan Holding. The Japan Automotive Research Institute will evaluate the fuel cell vehicle demonstration. ENNA is working with energy companies and the Tokyo Metropolitan Government on hydrogen supply equipment, demonstration, and testing.

An integral part of the demonstration project is building hydrogen refueling stations in different cities using different methods of deriving hydrogen. WE-NET funds and oversees the stations in collaboration with vehicle manufacturers and natural gas suppliers. The first two stations opened in Osaka and Takamatsu at the Shikoku Research Institute in February 2001. The Takamatsu station uses hydrogen created by electrolysis, and the Osaka station, natural gas. The third station, in Yokohama, was completed in July 2002. Located at the headquarters of Tsurami Soda Company, it uses hydrogen created as a by-product of sodium hydroxide production. At least five additional stations are planned for 2003, with most in the Kanto (greater Tokyo) area.

Public Education and Outreach

The Japanese government undertakes campaigns—often in conjunction with nonprofit associations—to educate Japanese consumers and small businesses and expose them to new technologies. The government funds these associations' efforts, but they also receive some funding from industry members.

The nonprofit associations active with the Japanese government in public education and outreach are the same ones that administer the subsidy programs: LEVO, JEVA, and JESA. In fact, the direct subsidies are seen as the primary method for educating and promoting environmentally friendly and fuel-efficient vehicles to small businesses (e.g., trucking companies). In addition, the Japan Clean Air Program (JCAP), sponsored by the Japanese petroleum industry, the Japan Automobile Manufacturers Association, and METI, as well as other associations, such as the Japan Gas Association, receive government funds for education. These other associations often work with LEVO, JEVA, and JESA to promote environmentally friendly vehicles and the construction of alternative-fuel refueling stations.

All these organizations undertake extensive information dissemination activities, publishing brochures and other papers, holding conferences and lectures, hosting exhibitions and fairs, and collecting and disseminating research analyses and statistical information. The organizations also act as consultants to small companies, local governments, and individual consumers, providing technological and maintenance information.

With METI funding, JEVA has been running one recent public education effort directed toward consumers. Starting in fall 2001, JEVA began to operate seven electric-vehicle rental sites in Kyoto, primarily for tourists. Kyoto hosted 40.5 million tourists in 2000. About 35 vehicles are available. It is hoped that sightseers all around Japan will rent the vehicles, thus gaining exposure to new technologies and lowering the automotive pollution level in Kyoto. If the experiment succeeds, JEVA plans to expand it to other locations in Japan.

Western Europe

> "Work on the fuel cell is no longer motivated exclusively by technological and environmental considerations, but has become a genuine competitive factor."
>
> *Dr. Ferdinand Panik, Fuel Cell Project Director, DaimlerChrysler*

The European Union (EU) and its constituent governments are committed to strengthening European competitiveness and hope to make Europe the most dynamic economy in the world by 2010. The current economic slowdown will make it more difficult to achieve these goals. In 2000 and 2001, Europe saw its average economic growth halved to 1.6 percent. In 2002, average unemployment rose to 8.5 percent, and in the past decade R&D has declined relative to GDP. International trade also failed to increase in 2001 for the first time in two decades.

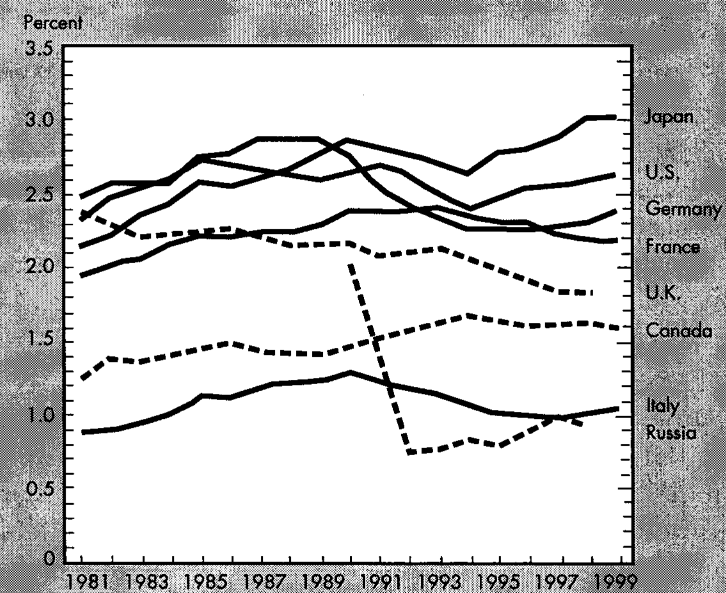
The EU hopes to help reverse these trends by supporting emerging technologies such as fuel cells, creating a network of centers of excellence, encouraging researcher mobility, and promoting technology transfer and venture capital. One of the major mechanisms is the creation of a European Research Area to better coordinate what many see as a fragmented research effort. Another important mechanism is EU joint research activity, including the Sixth Framework scheduled to begin in 2003.

While Western Europe makes significant R&D expenditures, its major countries trail the United States and Japan. Chart 22 shows that in 1998, the most recent year for which comparable international data are available, the United States spent 2.59 percent of its GDP on R&D and Japan 3.06 percent.[29] The major European countries spent less—France 2.18 percent, Germany 2.29 percent, United Kingdom 1.83 percent, and Italy 1.02 percent.

European automobile sales have been stagnant, with some companies, such as Fiat and Volkswagen, hit harder than others. Some countries, such as Germany, forecast a future decline in vehicle sales because of declining populations. Similar challenges to those facing other regions—overcapacity, for example—exist and are being sorted out.

[29] National Science Foundation, *National Patterns of Research and Development Investment: 2000 Update.*

Chart 22: R&D as a Percentage of GDP, G8 Countries

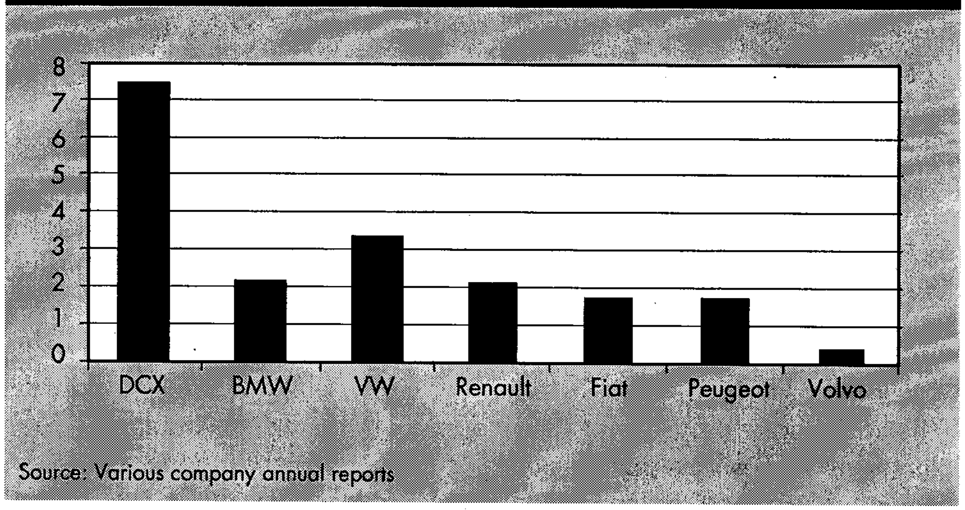


Source: National Science Foundation, Science and Technology Indicators, 2002

According to the European Council for Automotive R&D (EUCAR), the automotive sector's R&D expenditures amount to about 12 percent of the European total. Chart 23 depicts the level of R&D expenditures by major European motor vehicle companies in 2000 ($1.00 = €1.02).

EUCAR was established in May 1994 to foster strategic cooperation in research and technological development (R&TD) activities. It developed an Automotive R&TD Master Plan to define a European approach to technologies for automotive development. The members of EUCAR are the BMW Group, DaimlerChrysler, Fiat, Ford in Europe, Opel, Porsche, PSA Peugeot-Citroën, Renault, the Volkswagen Group, and Volvo. The European Union's "Car of Tomorrow" initiative, which ran from 1995 to 1998, provided substantial funding to EUCAR and others. The initiative sought to identify all needs, priorities, and actions to be addressed at the European level in terms of research, technology development, demonstration, and validation necessary for ensuring market acceptance of a new generation of competitive ultra-low and zero-emission vehicles. Starting under this initiative, EUCAR had a five-year government-funded budget of $2.3 billion, and its program plan, goals, and objectives mirrored those of PNGV in the United States.

Chart 23: R&D Expenditures in 2000 (in billions of euros)



The ratification of the Kyoto Protocol on Climate Change by the EU's 15 member states on May 31, 2002, will likely affect the social and economic backdrop in Europe for advanced vehicle development. EU Environment Commissioner Margot Wallström stated,

> Action to fight climate change is vital to achieve sustainable development. I am convinced that improving the environment through technological progress can actually enhance our competitiveness and economic growth. This is what sustainable development is about: protecting our eco-system while ensuring economic prosperity.[30]

The ratification could enhance support in Europe in the coming years for additional investment in energy-efficient, low-emission vehicle technology, including fuel cells, and relevant infrastructure.

European investment in fuel cell R&D occurs through European Commission programs, individual national efforts, and corporate research.

European Government Support

European investment in fuel cell R&D occurs through European Commission programs, individual national efforts, and corporate research. Taken together, European governments have provided less support than the United States or Japan, with funding at only about $60 million in 2001, split about evenly between national initiatives and EU R&D programs. Europe's industry invests $120 million in joint programs with government, with spending divided equally between cost sharing and infrastructure support. EU and individual European government

[30] European Union, "European Union Ratifies Kyoto Protocol on Climate Change," press release, June 3, 2002.

funding efforts are considerably more disjointed than those of Japan. Interest, however, is increasing in Europe, and along with it, EU and national government activities are expanding.

EU-Level Efforts

> "Hydrogen marks a revolution in how energy can be produced and stored....But Member States and industry cannot bring about this revolution on their own: Efforts are scattered, resources are dispersed, and costs are extremely high. We need a major effort at the EU level to streamline and make different initiatives converge in a consistent way."
>
> *Philippe Busquin, EU Research Commissioner*

Over the past decade, the EU has provided substantial R&D support to the automotive industry and development of fuel cell technology through its framework programs. EU policy objectives underlying fuel cell R&D are similar to those of the United States and Japan. Its major objectives are (1) meeting the EU's Kyoto commitment to reduce CO_2 by 8 percent by 2008–2012 compared with 1990; (2) maintaining the security of its energy supply; and (3) promoting industrial competitiveness.

In the Fourth Framework Program (1994–1998), the EU spent about $54 million on 35 fuel cell projects. PEMFC R&D received the greatest amount, around $30 million. The work was guided by a 1995 strategy for fuel cell technology up to 2005 outlined in a joint document by the then-Directorate Generals for Science, Research, and Development and for Energy. The strategy was revised in 1998.

In the Fourth Framework, much of the PEMFC R&D was directed toward the vehicle industry through three major projects: FEVER (Fuel Cell Electric Vehicle of Extended Range), HYDRO-GEN (Second Generation PEM Fuel Cell Working with Hydrogen Stored at High Pressure for the Electric Vehicle), and CAPRI (Car Autothermal Process Reactor Initiative). Renault led the FEVER project, which designed and tested the liquid-hydrogen-fueled Laguna Break vehicle. Peugeot led the HYDRO-GEN project, which was an effort to develop a hydrogen-fueled PEMFC vehicle. Volkswagen led CAPRI, which incorporated a methanol reformer and a PEMFC stack into a Golf station wagon.

The EU also spent about €700 million under the Fourth Framework for its Car of Tomorrow project. The Car of Tomorrow project explored areas similar to those in the U.S. PNGV, including energy storage and propulsion, especially battery technology; power electronics; lightweight materials; computer-aided systems; and hybrid technology.

The EU has chosen to stress mass transit applications in which it could be competitive earlier than in passenger vehicles.

The EU's Fifth Framework Program, running from 1999 to 2002, sponsored 10 fuel cell projects, with a total budget of just under $30 million—$12.4 million of which was for vehicle projects. As in Japan, government funding is largest for PEMFCs (about $46 million), with about $16 million for both planar-solid-oxide fuel cells (PSOFCs) and molten-carbonate fuel cells (MCFCs). Several of these projects will extend one to two years beyond the Fifth Framework. Of special interest is the Fifth Framework's FUERO (Fuel Cell Systems and Components General Research for Vehicle Applications) Project, which has sought to develop a PEMFC vehicle fueled by commercially available gasoline and bioethanol. Companies involved include PSA Peugeot Citroën, Volkswagen, Volvo, and Renault. DaimlerChrysler pursued research both on its own and in conjunction with the PNGV.

The EU is also increasingly active in fuel cell vehicle demonstration projects. Unlike the United States and Japan, which are heavily focused on passenger vehicle demonstrations, the EU has chosen to stress mass transit applications in which it could be competitive earlier than in passenger vehicles. The EU is providing a total of €18.5 million for the CUTE (Clean Urban Transport for Europe) project, which will operate 30 fuel cell buses in nine European cities (Amsterdam, Barcelona, Hamburg, London, Luxemburg, Madrid, Porto, Stockholm, and Stuttgart). The first will be delivered to Madrid in 2003. DaimlerChrysler will supply the buses. Each of the nine cities will demonstrate a different type of hydrogen-fueling infrastructure. The project seeks to show the viability of zero-emission buses for use in urban transport.

According to the European Commission, the main areas of fuel cell research funded under the EU Energy Research Program are as follows:[31]

- Fuel cell and related technologies for both stationary and transport applications
  - Cost reduction of PEMFC and DMFC components (e.g., stacks, reformers) and systems (e.g., "high" temperature PEMFC)
  - Development of cost-effective hydrogen production, storage, and distribution
- Fuel cell systems for stationary applications

[31] European Commission website on energy research, http://europa.eu.int/comm/research/energy/nn/nn_rt_fc4_prn_en.html, September 16, 2002.

  - Domestic and commercial stationary co-generation in the 10 and 100 kW range
  - High-temperature SOFCs (100 kWe to 1 MWe) for electricity production, with efficiencies up to 70 percent, which may include gas turbine hybrids. Co-generation of chemicals and power could also be considered
  - System simplification and Balance of Plant [supporting components necessary for the operation of the fuel processor and the fuel cell integrated into a fuel cell system]
  - Portable power in the range 500 W to 3 kWe
  - Low-cost components and systems, including multi-fuel capacity and fuel flexibility

- Fuel cell systems for transport
  - Developing fuel cell systems for public road, rail, and marine transport vehicles (e.g., buses, trams, delivery vans, and taxis)
  - The problem of fuel choice (e.g., hydrogen—the long-term choice—methanol, natural gas, gasoline (naphtha), and diesel) at the EU level, and aspects such as cost, emissions, safety, infrastructure, and distribution

One attention-catching EU project involves Iceland, which is planning to abolish the use of fossil fuels totally and transform itself into the world's first hydrogen economy. The project began in 1999, when an Icelandic Consortium signed a joint venture agreement with DaimlerChrysler, Norsk Hydro, and Shell. The joint venture, the Icelandic Hydrogen and Fuel Cell Company, applied for and won assistance from the EU for a project called the ECTOS (Ecological City Transport System). ECTOS began in March 2001 and will run through February 2005. ECTOS involves creating a hydrogen infrastructure and demonstrating fuel cell buses in Iceland's capital, Reykjavik, in the first large-scale, real-world trial of converting to a hydrogen infrastructure. The research will also focus on the socioeconomic implications of transforming from one fuel to another, transport model research, life-cycle analysis, environmental monitoring, and cost-benefit analysis. The EU will disseminate the results and lessons to the staff of other European projects.

Fuel cell research continues to be a high priority in EU R&D. EUCAR submitted a "Road Transport Research" framework used as input in the development of the Sixth Framework Program (see box below) that reflects the European vehicle companies' views. This framework includes research on clean conventional and renewable energy sources for vehicles. The research priorities announced for the Sixth Framework Program for sustainable energy systems include fuel cells (including their application) and new technologies for energy carriers/transport and storage, in particular for hydrogen. Objectives for fuel cell research include replacing a substantial proportion of combustion-based systems in the

Highlights of EUCAR's Proposal on the Future of Automotive and Road Transport R&D in Europe

Priorities of society require progress in three dimensions:

Research Dimension	Objectives and Research Priorities
ENVIRONMENT ENERGY RESOURCES	Sustainable transport systems based on renewable resources and in better balance with the environment ■ Development of solutions toward the use of clean conventional and renewable energy sources ■ Methods and measures to reduce traffic noise ■ Design and material for lean production and recycling
SAFETY FOR ROAD USERS	A steady trend of decreasing number of traffic accidents ■ Development of affordable vehicle, infrastructure, and road-user systems for preventative, active, and passive safety and post-crash assistance ■ Improvements and synergies through integration of preventative, active, and passive systems
MOBILITY, TRANSPORT	A sustainable and efficient traffic and transport system providing mobility and good delivery services to citizens ■ Intermodal concepts and supportive systems ■ Monitoring and management of traffic and goods for efficiency ■ Global harmonization and standards

(continued next page)

long term and contributing to the development of a hydrogen economy. Research is slated to focus on cost reductions in fuel cell production and application of the technology to buildings, transport, and decentralized electricity production, as well as on advanced materials for fuel cells.

The *Decision of the European Parliament and the Council Relating to the Sixth Framework Programme,* finalized on June 27, 2002, includes sustainable development, global change, and ecosystems as one of its seven priority thematic areas. Within this theme, two of the three subthemes—sustainable energy systems and sustainable surface transport—allow for projects relevant to fuel cell vehicles, such as EUCAR suggested. In particular, the work program for sustainable surface transport calls for "new technologies and concepts for surface transport, including novel propulsion systems and integration of fuel cells for transport purposes."[32] The EU has set aside €14.4 million for work under these two subthemes; it is still unclear how much of this amount will be devoted to fuel cells and fuel cell vehicles. One indication is how the EU divided its fuel cell funds in the past three years—58 percent for transport, 27 percent for stationary,

Highlights of EUCAR's Proposal on the Future of Automotive and Road Transport R&D in Europe, continued

Framework for "Road Transport Research" in the Sixth Framework Program

The above three research dimensions are not independent. The relevant stakeholders (industry, academia, administrations, public sector) therefore jointly have to agree and launch a fully coordinated Road Transport Research framework to embrace and guide research and to explore the possibilities of combining feasible approaches and restrictions in this "R&D space." An initial four-year phase of the Road Transport Research framework should be within FP6. The financial contribution from the EU is recommended to be on the order of €300 million annually. The Road Transport Research framework shall be open, encourage the stakeholders' active participation, and promote multidisciplinary approaches and new types of partnerships for deployment. The cross-border nature of mobility and transport requires constructive involvement of National R&D Programmes in this framework, both directly and complementarily. The automotive industry is prepared to contribute to the achievement of coherence between EU and National R&D using the Road Transport Research framework.

Source: Adapted from EUCAR, *Proposal for the Sixth Framework on the Future Automotive and Road Transport R&D in Europe*, December 18, 2000

[32] "Decision of the European Parliament and the Council Relating to the Sixth Framework Programme, June 27, 2002," *Official Journal of the European Communities* (August 2002), L 232/15.

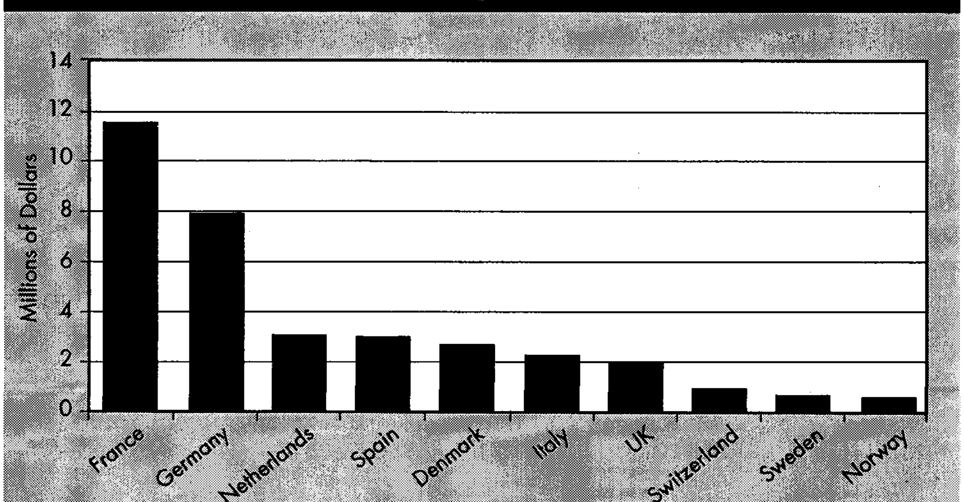
4 percent for portable applications, and 12 percent for common issues such as hydrogen research.

In September 2002, EU Energy Commissioner Philippe Busquin announced that the European Commission would establish a high-level group on hydrogen and fuel cell technologies. The group includes senior representatives from research centers, fuel cell system and component producers, energy companies and utilities, automotive companies, and public transport. The group is tasked to draw up a strategy to encourage the development and use of hydrogen and fuel cell technologies, especially for cars. This action is another indication of an increasing interest not only in fuel cells but also in the infrastructure that must support their deployment into the automotive market.

National-Level Efforts

The European Commission states that public funding for fuel cell R&D in Europe was approximately €60 million ($58 million) in 2002. Chart 24 provides a breakdown by country for 2000, the latest year for which comparable data are available. (It includes Switzerland, which is not a member of the EU, but which participates in EU research programs.) Fuel cell R&D funding at the national level in Europe in 2000 was approximately equal to the amount that the EU funded through its framework program. France spent the most, at $11.5 million, with Germany coming in second at $8 million.

Chart 24: Approximate European Fuel Cell R&D Funding in 2000



Source: European Commission

A major objective of the European Commission is to coordinate research at a European level, because it believes that energy and its associated environmental impacts must be considered in a global context in order to maximize the productivity and efficiency of research in this technology, which has such enormous economic potential. Reasons include identifying the impacts on global climate change, ensuring the security and diversity of Europe's energy supply, improving industrial competitiveness, and promoting economic and social cohesion. Therefore, the European Commission will likely try to increase linkages among the large national efforts described below, as well as among smaller efforts in other member states, such as the Netherlands, Italy, Finland, Spain, Norway, and Austria—all of which have expressed interest in fuel cell technology and have funded some projects. The three national European governments funding fuel cell technology at the highest levels are profiled below as examples. Interesting and significant activities are taking place elsewhere in Europe as well.

France

France is the world's fourth-largest vehicle manufacturer, producing just over 3.1 million automobiles in 2001. The automotive industry employs about 7.2 percent of the working population. Its largest automotive companies, Renault and PSA (Peugeot-Citroën), are among the largest groups in the automobile sector worldwide.

The French government spends more on fuel cell research than any other European national government.

The French government spends more on fuel cell research than any other European national government. It has supported work since at least the early 1990s and is gearing up to do more.

PSA and Renault gained initial experience with fuel cell vehicles by working with other European partners to design a fuel cell car in the EU's HYDRO-GEN and FEVER programs, which lasted from 1994 to 1998. The companies jointly designed a concept car based on a Renault Laguna Nevada. Through its tie-up, Renault has also drawn on Nissan's experience with fuel cell vehicles. As part of its effort to have a viable fuel cell vehicle by 2010, Renault is working with Nuvera Fuel Cells on a fuel cell processor, and with UTC Fuel Cells (PEM technology) and TotalFinaElf on fuels for fuel cells. PSA is building on its experience with electric vehicles, working with Millennium Cell and Hy Power. Other French companies heavily involved in fuel cell and hydrogen R&D include EDF-GDF, Gaz de France, Air Liquide, and Avera.

The French Ministry of Education, Research and Technology established the Fuel Cell Technology Network in June 1999. The network's objective is to foster the introduction of zero-emission cars. Initially, it set out to fund four additional years' work by PSA and Renault that had grown out of their efforts under the HYDRO-GEN and FEVER programs, which ended in 1998. The National Scientific Research Center (CNRS) and the Atomic Energy Commission (CEA) are involved in the project. CEA, in particular, has been heavily involved in hydrogen and fuel cell research, with up to 100 staff working in this area. This project looks primarily at enabling research such as reforming, hydrogen storage, membranes, and catalysis. The Ministry, through the Network, is now expanding into additional related areas of research.

PREDIT was one of the French government's main research programs directed at the transportation sector. It began in 1996 and ran until 2000. While its objective was to create an alternative to road transport through research into new solutions, part of the program contributed to research on hybrid and electric vehicles by looking at (1) the launching of new vehicles and environmentally friendly transport systems, (2) safety improvement for vehicles and systems, and (3) increased performance of companies on international markets. PREDIT's budget was approximately €1 billion over five years, with €300 million of that from the national government and the rest from research institutes, industries, and local governments. About 17 percent of the funding was devoted to basic research and 53 percent to technology, components, vehicles, and equipment. PREDIT involved about 350 experts from government ministries, public research institutes, universities, and public and private companies. It also sought to improve the connection between research and commercialization. The Ministry of Education, Research and Technology has stated that one reason for funding this type of research is that French participation in European research projects is insufficient, in part because national competition in fields like vehicle transportation makes it difficult to find a common ground for participation.

In 2001, the Ministry began a project with Renault, PSA, Air Liquide, De Nora (Italy), Delphi (United States), and other companies to further develop fuel cell vehicle technology. The first stage of the project is an evaluation study. The second stage will validate designs. The Ministry has pledged to fund 30 percent of the second stage work, which will cost about $5 million. In the third stage, Peugeot and Renault will produce prototype vehicles. The work will take place primarily at a new national fuel cell center funded by the Ministry and located in the Belfort-Montbéliard-Nancy region of France at the University of Belfort-Montbéliard. Peugeot and Renault will be partners in the new Belfort Fuel Cell Center and will help oversee it. Construction for the center began in September 2001.

Germany

> "Fuel cells have the potential to be the most attractive alternate propulsion system for the long term."
>
> *Juergen Schrempp, Chairman of the Board, DaimlerChrysler*

Germany is the world's third-largest automotive market, producing nearly 5.5 million personal and commercial vehicles annually. The industry employs about 754,000 people. Germany is also home to major multinational automotive companies such as DaimlerChrysler, BMW, Volkswagen, and Robert Bosch. It is not surprising, therefore, that German automotive companies, particularly DaimlerChrysler, are major players in the fuel cell vehicle race.

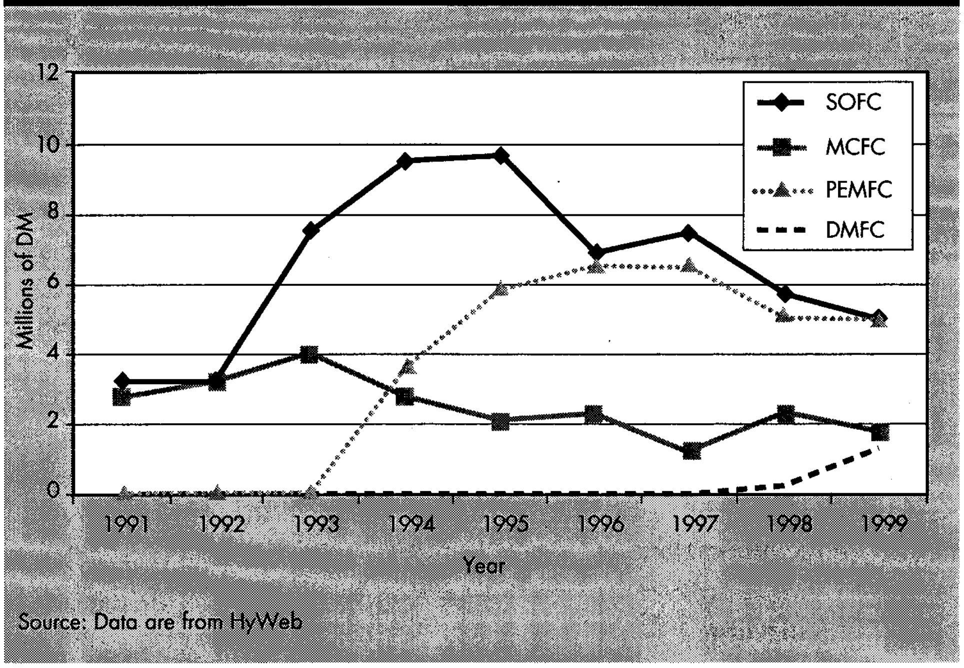
It is possible to find research somewhere in Germany on almost every aspect of hydrogen and fuel cell technology.

Other major nonautomotive German multinationals such as Siemens, BASF, and Hoechst/Celanese are also very active in various types of fuel cell and hydrogen R&D. Germany can claim one of the first private hydrogen refueling stations, which opened in Hamburg in 1999 to provide fuel for delivery trucks. It also has a hydrogen station at the Munich Airport, the Robotics Hydrogen Filling Station. It is possible to find research somewhere in Germany on almost every aspect of hydrogen and fuel cell technology, including work supported by foreign multinationals such as Ford and General Motors. There appears to be less coordination of these efforts at the national level, however, than in Japan or the United Kingdom.

Germany's two major national research institutes, the Max Planck Research Society and the Fraunhofer Society, are both active in fuel cell research. The Max Planck Institutes for Solid State Research (Stuttgart) and Polymer Research (Mainz) are looking particularly at PEMFCs for stationary uses. The Fraunhofer Institute for Environment and Energy Research in Oberhausen, with about DM 30 million in funding from the North Rhine-Westphalia government, built a new Polymer Electrolyte Membrane Fuel Cell Center that began work in 2002.

It is surprising that the German government has decreased its R&D in this sector in recent years rather than increasing it, maintaining a rather moderate stance in this technology. Most German fuel cell R&D funding is from the German Ministry of Education, Science, Research and Development (BMBF). Siemens received substantial funds from BMBF for work on SOFCs in the 1990s. BMBF also funded PSOFC work at Forshungszentrum Julich. It is not clear why German federal funding decreased at the end of the 1990s, although as chart 25 shows, it was primarily due to a decline in SOFC R&D and occurred in the context

Chart 25: German Federal Fuel Cell R&D



of overall spending cuts in renewable energy R&D. PEMFC funding also declined, though to a lesser extent.

The Office of Technology in the German Parliament, however, completed and released in late 2001 a positive assessment of fuel cells (portable, transport, and stationary) that should lead to more funding. The report stated that the automotive industry is the most likely commercial user of fuel cells, as stationary needs can conceivably be filled more cheaply through conventional energy sources.

The German government is moving ahead with a new demonstration project funded by the German Federal Ministry of Traffic. In June 2002, it formed the Clean Energy Partnership Berlin with Aral, BMW, Berlin Transport, DaimlerChrysler, Ford, GHW, Linde, MAN, and Opel. The partnership will operate a test fleet of 30 vehicles using hydrogen generated by electrolysis. At the announcement, German Minister of State Hans-Martin Bury said, "I want Germany to be the first country where the zero-emission car everyone talks so much about becomes a serial product."[33]

[33] German Hydrogen Association, "Berlin Partnership," *Hydrogen Mirror* (March 2002).

Several German states are taking active roles in fuel cell and hydrogen infrastructure development. While welcome, this fact raises coordination and redundancy issues. In addition to the new center in Oberhausen, North Rhine-Westphalia in April 2002 created the Future Technology Fuel Cell Rhineland Palatinate network to link its groups active in fuel cell technology and stimulate the development of a hydrogen economy. The network is particularly aimed at strengthening medium-size companies and helping them become suppliers for the new industry. The state of Hesse also announced a fuel cell initiative in April 2002, building upon existing expertise at Hoechst. In February 2002, the state of Mecklenburg-Western Pomerania announced the formation of a new association called Hydrogen Technology Initiative Mecklenburg-Western Pomerania. Bavaria funded a fuel cell bus project in Munich. Baden-Württemburg founded its Fuel Cell Education Center Ulm in July 2002. The state is providing €3.3 million and the federal government €1.5 million to fund it. Lower Saxony is studying beginning a similar initiative and will release the results of its study in 2003. All the groups include public education as one of their objectives.

United Kingdom

> "Meanwhile, hydrogen technologies offer the potential of zero-pollution transport. The vision of the scientists and engineers developing this technology is of clean and safe cities, without the air quality and health impacts of conventional vehicles."
>
> *Prime Minister Tony Blair*

The United Kingdom's automotive industry, after a decline in the 1970s and 1980s, is recovering, primarily because of foreign investment from companies like Nissan, BMW, General Motors, and Toyota. The industry represents about 5 percent of UK GDP and contributes 11.7 percent of UK exports. Because of its long tradition of automotive manufacturing, the United Kingdom maintains a strong design engineering and R&D capability. For example, UK firm Ricardo is a leader in diesel engine technology. Up to now, the United Kingdom has not had a strong transport fuel cell R&D infrastructure compared with its other automotive R&D capabilities.

The UK's leading government research program related to advanced automotive technologies is the Department of Trade and Industry's (DTI) Foresight Vehicle Initiative. It began in November 1997 in response to what DTI termed a worldwide crisis in transport:

> Affluent societies demand increasing personal mobility and a range of goods that depend on an extensive distribution network. Modern

> industry must operate in a global market and have an efficient transport system to provide its raw materials and distribute its products. At the same time there is serious concern about the effects of pollution, the use of energy, the increasing amounts of space that are needed for the transport infrastructure and the injuries that result from road accidents. Worldwide, the search is on for vehicle technologies that meet modern expectations for mobility, satisfy strict environmental and safety requirements, and help sustain the competitiveness of manufacturing industry. The challenge to develop technology options that can form the basis of a sustainable transport policy is a formidable one.[34]

The Foresight Vehicle Initiative has invested about $40 million so far—$18.5 million from government and the remainder from industry. It covers about 100 projects and is on its fifth call for research proposals. It has more than 250 organizations involved. It is not aimed at a particular type of automobile but at a low-carbon vehicle, and it includes research on manufacturing as well as demonstration (e.g., a taxi demonstration in London of diesel hybrids). Main areas of research include hybrid, electric, and alternatively fueled vehicles; materials and structures; advanced electronics and sensors; telematic systems; and powertrain technology. The initiative is increasingly focusing on expanding fuel cell technology research, especially for novel applications that might not be the focus of extensive research elsewhere in the world. Fuels are handled in a separate program.

DTI also runs the United Kingdom's Fuel Cell Programme. The Programme began in April 1992 with a focus on SOFCs and PEMFCs, and funded work for transport and other applications. Through November 2001, the Programme supported 147 projects, with a total DTI contribution of £11.8 million ($18.9 million) or about £2 million a year. These funds were leveraged with private sector investments. Approximately half was spent on transport applications. As of June 2000, total funding—public plus private—for the Programme was £78 million ($123 million). The PEMFC research has covered a wide range of work, including electrode design and catalyst utilization, carbon monoxide-tolerant catalysts, alternative membrane electrolytes, improved oxygen reduction electrocatalysts, development and evaluation of novel reforming and gas clean-up systems, cost reduction for PEMFC stacks, fuel processing for a range of liquid hydrocarbon fuels, car design studies, light

[34] Foresight Vehicle Initiative, http://www.foresightvehicle.org.uk/programme, September 2002.

commercial vehicles studies, stationary power design studies, positive displacement compressor-expanders, fuel quality tolerance, effects of air contaminants, and high-temperature membranes.

The UK Engineering and Physical Science Research Council (EPSRC) supports fundamental research in universities on fuel cells and hydrogen. EPSRC will have spent approximately £15.7 million on these areas between budget years 1992/1993 and 2002/2003.

The United Kingdom maintains a variety of measures to encourage the introduction of efficient vehicles.

The United Kingdom maintains a variety of measures to encourage the introduction of efficient vehicles. In 2001, it introduced a graduated vehicle excise duty for new cars based on CO_2 emissions and energy efficiency, and increased the incentive in May 2002 to range from £60 to £160 a year, with a zero emissions level for electric cars. Car taxes are also tied to CO_2 emissions, and there are tax breaks for companies purchasing vehicles with CO_2 emissions of 120 gram/km or less. There also are £1,000 grants to consumers who purchase hybrid vehicles to help defray higher purchase costs and encourage sales.

The Scottish Fuel Cell Consortium (SFCC), a partnership between two universities (Napier University and the University of Strathclyde) and six industrial partners, demonstrated the UK's first fuel cell hybrid electric car in June 2002. The SFCC seeks to introduce fuel cells for transport to Scotland first through the car and next through a fuel cell bus. It is trying to transform the island of Islay into the world's first hydrogen-powered island. It hopes ultimately to spin off the research to establish companies and organizations in Scotland, and make use of Scottish sources of alternative energy (e.g., hydro, wind) to produce the hydrogen.

On July 31, 2002, the UK's Department of Transportation and other agencies released its new "Powering Future Vehicles Strategy" developed in conjunction with DTI and others. The strategy promotes low-carbon vehicle technologies and fuels to reduce greenhouse gases and help the United Kingdom meet its targets under the Kyoto Protocol. The goal of the strategy is to have 10 percent of the passenger cars and 20 percent of the buses sold by 2012 be low-emission vehicles—similar to plans in Japan. It identifies advanced internal combustion engines, alternative fuel vehicles, and hybrid and fuel cell vehicles as ways to reduce CO_2 emissions. While most of early vehicles that will meet the standards are likely to be clean diesels and hybrid electric vehicles, they will help create an overall market for low-emission, energy-efficient vehicles that, in the long term, could be filled by fuel cell vehicles.

Canada

> "The Government of Canada has supported the Canadian fuel cell industry since day one. The continued growth of this industry will lessen our dependence on fossil fuels while creating a healthier environment and building new opportunities to diversify the Canadian economy."
>
> *Stephen Owen, Secretary of State for Western Economic Diversification*

Canada has a substantial automotive industry, ranking seventh in world vehicle production in 2001. The automotive industry accounts for 14 percent of Canada's manufacturing GDP. The vehicle assembly segment of the industry consists almost entirely of foreign direct investments, with most of the major global companies—including General Motors, Ford, DaimlerChrysler, Toyota, and Honda—maintaining manufacturing facilities.

The relatively small amount of automotive R&D conducted by companies in Canada (CDN $161 million in 1999) is cause for concern. The Canadian government has long offered R&D tax credits, R&D grants, and training support to the industry. In June 2002, Industry Canada hosted the Canadian Forum on Automotive Innovation and Investment to look at actions to remove barriers to innovation and enhance the sector's long-term global competitiveness. New actions and activities related to the automotive sector are expected in 2003 that should both complement and take advantage of the large amount of ongoing Canadian fuel cell research, while building on the Motor Vehicle Fuel Efficiency Initiative begun in 2001.

Natural Resources Canada's Motor Vehicle Fuel Efficiency Initiative, funded at CDN $16 million, is similar to efforts in Japan and the United States to enhance the efficiency of conventional internal combustion vehicles in the period before fuel cell technology is practical. It has three components: (1) public education, (2) vehicle testing and demonstration activities, and (3) negotiations with the United States and automakers to set new fuel efficiency targets.

In terms of fuel cell R&D, Canada is already the global leader in PEMFC technology. It is aggressively seeking to maintain and expand its leading position in this technology and groom additional companies to become global players in PEMFC and other fuel cell technologies. Canadian companies involved in fuel cell research include Ballard Power, Energy Visions, Global Thermoelectric, DuPont Canada, and Fuel Cell Technologies. One indication of Canada's strength in this technology is the fact that out of the 19 test vehicles in the California Fuel Cell Partnership as of summer 2002, 13 are equipped with Ballard fuel cells.

Ballard Power Systems, the dominant player in Canadian fuel cell R&D, began its PEMFC research in 1983 under a contract awarded by the Canadian Department of National Defense (DND). DND had obtained fuel cell technology originally developed by General Electric for the U.S. National Aeronautics and Space Administration's Gemini V Spacecraft project. DND's contract was to further develop this technology. Ballard continued to receive funding under this contract until 1989 and some additional funds for fuel cell research from DND throughout the 1990s. Before that time, Ballard had specialized in advanced lithium battery technology. Ballard later acquired technology licenses for direct methanol fuel cell technology from the California Institute of Technology and the University of Southern California.

Before 2001, the Canadian government spent approximately CDN $100 million (US $64 million) on fuel cell R&D. In 2001, it spent about US $38.9 million, one-third as much as the United States. Adding industry contributions, spending on Canadian joint research programs reached US $116 million in 2001, almost half as much as the United States.

Investment and activities accelerated in Canada in 2001. The Canadian government spent CDN $2.7 million to help Fuel Cells Canada (FCC), a national nonprofit association established in October 2000 to advance Canada's fuel cell industry, develop six new research laboratories in Vancouver. These laboratories included the National Research Council's new Fuel Cell Technology Centre, on the campus of the University of British Columbia. At the time of the investment, FCC President Brian T. Josling stated, "In 2001, we believe that the fuel cell industry is the greatest opportunity for Canada in terms of job creation—both knowledge-based and manufacturing. Canada can emerge as a leading manufacturer and consumer of fuel cell products."[35]

In June 2001, Canada formed the Canadian Transportation Fuel Cell Alliance. According to Natural Resources Canada, "The Canadian Transportation Fuel Cell Alliance is a $23 million federal government initiative that will demonstrate and evaluate fuelling options for fuel cell vehicles in Canada. Different combinations of fuels and fuelling systems will be demonstrated by 2005—for light, medium and heavy duty

[35] National Research Council, Canada, "Government of Canada Funds Expansion of Fuel Cells Research Laboratories in Vancouver," press release, June 8, 2001.

vehicles. The initiative will also develop standards and training and testing procedures as related to fuel cell and hydrogen technologies."[36] The Alliance seeks to address the 25 percent of Canadian CO_2 emissions attributable to the transportation sector and to position Canada at the forefront of global innovation in this technology. The Alliance includes approximately 50 members from industry, local governments, nongovernmental organizations, federal and provincial governments, and universities.

In February 2002, the Canadian Secretary of State for Science, Research and Development, Maurizio Bevilacqua, announced a CDN $19 million Technology Partnerships Canada (TPC) investment in DuPont Canada aimed at reducing the cost of manufacturing fuel cell systems, and in particular to support research in flowfield plates and unitized cells. While initially directed at portable applications (communications and electronic devices), the government investment will help build R&D capabilities in fuel cells generally. In March 2002, Canadian Minister of Industry Allan Rock announced that the National Research Council would increase funding for fuel cell research and development at its Fuel Cell Technology Centre by CDN $20 million over the next five years, more than double its existing base budget.

In June 2002, the Canadian government and the provincial government of British Columbia announced plans to invest more than CDN $5.2 million (approximately US $3.3 million) in six fuel cell-related demonstration projects. This decision reveals the recognition that demonstrations, as well as research, will be necessary to accelerate the adoption of fuel cell technology in the marketplace. FCC will coordinate the projects. The transportation-related demonstration projects include a fuel cell truck and a hydrogen fueling station.

Emerging Players

> "We believe that technology and innovation will uncover creative solutions for an efficient and sustainable energy system and open the doors to new businesses."
>
> *Raymond Lim, Minister, Singapore Ministry of Trade and Industry*

Other countries are emerging players in fuel cell technology. Most active are the Republic of Korea and the People's Republic of China. Singapore

[36] Natural Resources Canada, *Canadian Transportation Fuel Cell Alliance,* http://www.nrcan.gc.ca/es/etb/ctfca/index_e.html, July 2002.

is building its R&D role and will conduct a demonstration project. It also is worth watching Australia and India, where the governments support fuel cell research and global vehicle companies invest heavily in local manufacturing alliances.

Interesting activities are also taking place in countries not profiled, ranging from work in Taiwan to convert all its motor scooters to fuel cells, to a growing vehicle industry built on foreign investment in Thailand—a country that, like China, is hoping to position itself to absorb and manufacture the new technologies. With the globalization of technology, it is worth monitoring not just the traditional, but also the nontraditional players.

With the globalization of technology, it is worth monitoring not just the traditional, but also the nontraditional players.

Republic of Korea

Korea's support for fuel cell technology began as early as 1985 in a project on phosphoric acid fuel cells undertaken by the Korea Electric Power Corporation and the Korea Institute of Energy Research (KIER). Research accelerated in 1992, when the Korean government designated fuel cell technology a national priority research area (although research remained modest compared with that in Japan, the United States, and Europe, and did not include work on PEMFC technology). Until recently, government R&D investment was directed primarily at stationary systems for electric utility and small device applications. Government and industry fuel cell R&D investment totaled approximately W 50.8 billion ($41 million) between 1992 and 2001.

In 2001, Korea's Ministry of Commerce, Industry and Energy (MOTIE) announced a plan to spend W 938 billion ($750 million) by 2006 on six alternative energy technologies, with approximately 30 to 40 percent devoted to fuel cells. While one of MOTIE's stated objectives was to help position Korea's automotive sector, Korean government R&D related to PEMFCs is relatively recent, with most work still focused on SOFCs and Phosphoric Acid Fuel Cells (PAFCs). (In contrast, the Japanese government sponsored PEMFC research as early as 1992.) In 1999, KIER successfully tested a 5 kW PEMFC stack and the Institute of Science and Technology tested a 4 kW PEMFC stack developed with Hyundai. Partly as a result of the findings of these tests, Korea's automotive PEMFC strategy is relying heavily for now on joint development with foreign partners, rather than indigenous R&D. Some Korean experts believe it will take seven to eight years for domestic automotive fuel cell R&D to catch up with that elsewhere.

Not surprisingly, Korea's largest motor vehicle maker, Hyundai Motor Corporation, is the most active in pursuing fuel cell research. Hyundai is a founding member of the California Fuel Cell Partnership. Chung Goo Lee, president of Worldwide R&D for Hyundai, has stated,

> Hyundai Motor Company is committed to the long-term, leading-edge development of environmentally friendly vehicles. Fuel cell vehicles are as friendly to the environment as electric vehicles, have higher fuel economy than hybrid gas-electric vehicles, plus convenient fueling options at the level of conventional gasoline-powered vehicles. Representing Korea, Hyundai is actively participating in the worldwide efforts to develop and commercialize fuel cell vehicles, the importance of which can be compared to the introduction of the internal combustion engine in the early 1900s.[37]

In an effort to accelerate its fuel cell vehicle development, Hyundai has entered into several partnerships with foreign partners in the past two years. Examples of Hyundai's foreign relationships include the following:

- Hyundai unveiled the Santa Fe hydrogen-fueled fuel cell vehicle (FCV) in November 2000. The vehicle used technology from U.S.-based International Fuel Cells (IFC), Enova Systems, and Quantum.
- In spring 2001, Hyundai signed an agreement with IFC to accelerate its fuel cell vehicle research. It expanded its strategic relationship with IFC in early 2002, with the objective of having a commercial vehicle within the 2004 to 2006 time frame. Kia Motors, an affiliate of Hyundai, is participating in the relationship.
- In April 2002, Hyundai signed a Memorandum of Understanding with Quantum, a subsidiary of IMPCO Technologies, Inc., for the joint development and commercialization of advanced fuel systems for fuel cell and alternative fuel systems for the Santa Fe FCV and the CNG Elantra.
- Enova Systems, a designer and producer of drive systems and related components for electric, hybrid-electric, fuel cell, and microturbine-powered vehicles, has a business relationship with Hyundai and IFC.

[37] Statement made at the opening of the California Fuel Cell Partnership on November 1, 2000, http://www.fuelcellpartnership.org/quotes.html.

- In July 2001, Canada's Hydrogenics Corporation announced an agreement with Hankook BEP Co., Ltd., a Korean distributor of automotive testing systems, to market and sell its advanced PEM fuel cell-testing and controls technology in Korea.

People's Republic of China

It is clear that advanced vehicles have caught the imagination of senior Chinese officials. They see advanced energy-efficient vehicles, in particular fuel cell light and heavy vehicles, as an opportunity to (1) visibly demonstrate their commitment to a clean environment at the Beijing Olympics in 2008 and (2) help one of their key industries—the automotive—leapfrog to the latest technologies. The Chinese government also foresees a sharp increase in motor vehicle registrations—the annual growth rate in Beijing ranged between 10 and 15 percent during the 1990s. China produced 1.9 million cars and trucks in 2001. It is estimated that production could rise to more than 3.6 million by 2007. It is also predicted that by 2010, 64 percent of air pollution in China will come from vehicle exhaust emissions.[38]

It is clear that advanced vehicles have caught the imagination of senior Chinese officials.

In its five-year plan for the 2001–2005 period, China is seeking to accelerate the growth of its high-tech industry, including information technology, biotechnology, and new materials.

The Ministry of Science and Technology (MOST) plans to invest about Y 880 million ($106.4 million) a year over the next five years in advanced vehicle work. Most of the initial work will be focused on buses rather than light vehicles. Combined with R&D investments from its partners (First Automotive Corporation, Dongfeng Motor Corporation, Shanghai Automotive Industry Corporation, Tsinghua University, and Tongji University), the total R&D investment will be about Y 2.5 billion ($302.4 million).

The United Nations Development Fund's Global Environment Facility (GEF) is supporting China's Fuel Cell Bus Project, which will involve at least 12 buses and several hydrogen fuel stations in Beijing and Shanghai.[39] Other fuel cell projects are being planned in conjunction with the 2008 Beijing Olympics.

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[38] "China Ushers in Electric Vehicles," *People's Daily*, July 31, 2002.

[39] http://www.gefweb.org/Documents/Project_Proposals_for_Endorsem/CHINA-Fuel_Cell_Bus-full.pdf, June 2002.

MOST is also working with Chinese companies, such as Beijing LN Green Power Company, Ltd. (LN) and Beijing Fuyuan Fuel Cell Group, to commercialize indigenous fuel cell vehicle technologies and promote joint ventures with foreign companies. Beijing LN, established in 1998 as the LN Research Institute, is attempting to parlay its experience in electric vehicles to fuel cells. In 2001, the institute assembled three PEMFC conceptual vehicles. Beijing Fuyuan Fuel Cell Group consists of two companies: the Beijing Fuyuan Century Fuel Cell Power Limited Corporation and the Beijing Fuyuan Pioneer New Energy Material Limited Corporation. Beijing Fuyuan works closely with the Automobile Engineering Department of Tsinghua University. Together they have developed a fuel cell motor scooter and make PEM fuel cells for small devices like laptops.

The Chinese Academy of Sciences (CAS) announced in January 2002 that it intends to make China globally competitive in the field of hydrogen technology. It plans to invest up to Y 100 million ($12 million) in PEMFC technology over a three-year period. While vehicles are listed as the primary benefactor of the research, other products cited by CAS that could benefit are space shuttles, submarines, underwater robots, communications systems, medium-sized power plants, home appliances, and other mobile power supplies.

Dalian Institute of Chemical Physics has been working on fuel cell research, including alkaline fuel cells, for many years. There are increasingly sophisticated research efforts at Tsinghua University in vehicle and hydrogen technology. Tsinghua is in charge of the National Key Fundamental Projects: Fundamental Research for Hydrogen Production, Storage, and Transportation in Large-Scale and Relative Fuel Cells and Fuel Cell Engines Used for Buses. The university is also working on developing polymer electrolyte membranes, PEM fuel cells, and a PEM fuel cell engine and on making hydrogen from ethanol. The Beijing Institute of Aerospace Testing is doing research related to hydrogen storage, including high-pressure storage and sensors. The General Research Institute for Non-Ferrous Metals (GRINM) is developing hydrogen storage materials using rare earths, titanium, magnesium, and nano-hydrogen. GRINM also produces and sells metal hydrides and hydrogen storage containers for fuel cells for mobile phones, bicycles, and motor scooters.

With the advent of China's admission to the World Trade Organization and the accompanying prospect of increased import competition, China's domestic automotive industry is experiencing a shakeout and consolidation. Substantial vehicle price reductions began in 2002, along with almost daily announcements of new tie-ups and agreements with foreign companies. Volkswagen, General Motors, Ford, Toyota, Peugeot-Citroën, Fiat, Nissan, Honda, and Hyundai, along with a multitude of parts makers, all have plants or have announced plans for plants in China. In the long term, China will be positioned to be a player in fuel cell vehicles and their components not just because of its increased research, but also to a great degree because of these rapidly growing ties between Chinese and foreign automakers.

Australia

Australia is not a strong player in PEMFC technology. In the past, the Commonwealth Scientific and Industrial Research Organization (CSIRO), the network of national research institutes, put its substantial resources behind planar SOFC technology, which resulted in the establishment of Ceramic Fuel Cell Limited (CFCL), a corporation for commercialized CSIRO research. While CFCL is a world leader in SOFC technology, there are currently no major Australian companies with PEMFC research capabilities. Monash University is working on PEMFCs and trying to expand its capabilities.

Despite the scarcity of fuel cell R&D in Australia, the Australian government, especially at the state level, is beginning to investigate and sponsor fuel cell and hydrogen demonstrations. The State Government of Western Australia is committing AUS $4 million (US $2.5 million) to a two-year demonstration by DaimlerChrysler and BP of three fuel cell buses in the state's capital, Perth. The demonstration will start in 2003. State Minister for Public Transport Michelle Roberts stated that she hopes the trial will put Perth at the forefront of the technology and that "Fuel cell technology holds the key for the long-term future of road transport and protection of our environment—both in terms of cleaner air and combating climate change."[40] The State of Victoria is considering a proposal for a hydrogen fuel cell bus project that would build a hydrogen refueling station to service several buses going to and from the Victorian Fast Train.

Singapore

Singapore is investing in projects that will enhance its position as a world model and center for high technology and clean, environmentally friendly technologies. It wants to be a hub of innovation for alternative energy solutions. Alternative energy is part of a larger three-part energy plan.

[40] "Perth Commits $4 Million to Fuel Bus Trial," www.eyeforfuelcells.com, June 26, 2002.

According to Raymond Lim, Singapore's Minister of State for Foreign Affairs and Trade & Industry, "We believe that technology and innovation will uncover creative solutions for an efficient and sustainable energy system, and open the doors to new businesses. The Singapore government has stepped up efforts to promote more R&D and test-bedding activities in cleaner fuels and alternative energy sources. To achieve these objectives, we shall firstly build core capabilities and intellectual capital stock in fuel cell technology, and create the framework for a sustainable hydrogen economy; secondly, offer test-bedding opportunities to create first-mover's advantage; and thirdly, promote the manufacturing of fuel cell systems and materials. SINERGY, or Singapore Initiative in New Energy Technology, serves as a collaboration platform to fund R&D and test-bedding activities in clean energy technology."[41]

As the first project under SINERGY, in October 2001 the Economic Development Board of Singapore signed an agreement with BP Singapore to build a hydrogen refueling station. BP Singapore's president, Koh Kim Wah, said, "BP is taking up the challenge to develop inexpensive transport energy solutions to enable economic and social growth without damaging the natural environment. BP believes that hydrogen could become the ultimate clean transport fuel of the future and aims to have one of the world's first retail stations selling hydrogen fuel to the passenger car market."[42] Earlier, in May 2001, the Economic Development Board had signed an agreement with DaimlerChrysler to cooperate on a fuel cell vehicle demonstration project that would use the BP refueling station.

A small amount of basic fuel cell research is occurring in Singapore, particularly at the National University of Singapore, in areas such as hydrogen storage involving carbon nanotubes. ST Kinetics, Singapore Technologies Automotive, Ltd., is one of the major shareholders of H Power Corporation, a U.S. fuel cell manufacturing and development company that designs PEM fuel cells for stationary and portable applications.

India

India does not undertake a large amount of fuel cell or automotive R&D. However, it deserves monitoring, since it is likely to be one of the biggest consumers of vehicles in the coming decades. Most of its vehicles

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[41] Speech at the Singapore-British Business Council's Energy Forum, September 16, 2002.

[42] BP Singapore, "Singapore Continues Drive Towards Environmentally Friendly Cars," press release, October 22, 2001.

are concentrated in urban areas, and as the fleet grows, concerns over emissions and energy use are growing too.

As a result, the Indian government is looking at policy and technological initiatives that could lead to vehicles with more efficient engines and better fuel quality. It has decided to concentrate initially on fuel cell buses, because mass transit accounts for nearly 60 percent of total passenger-kilometers traveled and the fueling infrastructure can be established much more easily for buses than for passenger cars. Tata Energy Research Institute (TERI) in New Delhi is testing a Ballard fuel cell bus.

Along with China, India is among the countries chosen by GEF as a site for its fuel cell bus demonstration project. The other countries are Brazil, Mexico, and Egypt. GEF is deploying between 40 and 50 fuel cell buses in these five countries in 2002 and 2003, at a total cost of about $130 million. The project is part of GEF's strategy to help demonstrate to industry and these countries the viability of environmentally friendly technologies, such as fuel cell buses, in developing countries.

Along with China, India is among the countries chosen by GEF as a site for its fuel cell bus demonstration project.

In terms of R&D, India's Ministry of Non-Conventional Energy Sources (MNES) funds most Indian fuel cell public research. Work is being done at several universities and research institutes. For example, TERI is doing research jointly with the Central Electrochemical Research Institute on an MCFC stack and coal gasification. The SPIC Science Foundation is studying PEMFCs, and has demonstrated a small 10 kW PEM fuel cell vehicle. The Banaras Hindu University is doing R&D on metal hydrides for hydrogen storage. MNES is also evaluating various commercial fuel cell products.

Summary

While the United States and Japan have the best coordinated and most comprehensive fuel cell vehicle R&D programs, the other major automotive manufacturing regions and countries are in the race. Governments are supporting their efforts with funding and, in many cases, various tax and financial incentives for both manufacturers and consumers.

Most of the countries and companies are building on prior research and advances made in other types of energy-efficient, low-emission vehicles, including work in recent years on hybrid technology. In fact, most are continuing work in these areas as an interim solution that shares many synergies with fuel cell vehicles and, just as important, as a means of building up a mass market for environmentally friendly vehicles. Even countries like Australia and Singapore that have not been greatly involved in the past are getting into the game in limited ways.

Government emphasis in the late 1990s was on R&D. While this emphasis is continuing and even expanding, many national governments perceive that fuel cell technology is at the stage where demonstrations of both vehicles and the hydrogen infrastructure to refuel them are also becoming important.

Chapter 4: Conclusion

> "Governments from around the world are providing support for the development of improved technologies and are active in the regulation of alternative fuels, vehicle efficiency, and noxious pollutant and greenhouse gas emissions. However, more work can be done."
>
> *International Energy Agency, Working Group on Hybrid and Electric Vehicles*

Agreement on the Public Interest

It is apparent that most nations have accepted that support for and acceleration of the adoption of fuel cell technologies is in the public interest. The most common reasons cited for believing that fuel cell development is in the public interest are the possibilities of cutting CO_2 and other harmful emissions, reducing dependency on petroleum, and enhancing industrial competitiveness. Despite the public need for a cleaner environment, less dependency on petroleum, and the economic benefits derived from a strong automotive sector, however, the market will not be able to make the transition by itself, given current fuel prices and infrastructure requirements. Accordingly, there is also a consensus that a public policy role exists.

For the most part, public policies are geared toward helping domestic companies—vehicle manufacturers and component suppliers—be ready to (1) commercially produce mass transit vehicles (buses), niche market vehicles (scooters), and light vehicles (cars and light trucks) and (2) play a role in a globally competitive market by around 2010 to 2015. Emphasis is on PEMFCs, with some work on SOFCs for auxiliary power units. Considerably less attention has been paid to issues relating to the hydrogen infrastructure needed to supply the vehicles, although demonstrations of fueling stations are beginning and strategic planning is under way. These efforts are expanding in terms of scope, size, and the number of countries involved.

There are 12 major approaches that nations are taking or considering to position themselves and their companies to play a role in this new energy paradigm.

1. Developing codes and standards related to hydrogen storage and distribution
2. Developing codes and standards related to fuel cell vehicles

3. Funding and validating R&D to overcome final cost and performance barriers for fuel cells, hydrogen storage, and hydrogen production
4. Funding and validating R&D to accelerate the adoption of interim energy-efficient and environmentally friendly technologies
5. Running demonstration projects of fuel cell vehicles, hydrogen fueling stations, and hydrogen production facilities
6. Beginning public awareness and educational activities on fuel cells and hydrogen safety issues
7. Beginning to consider workforce training needs
8. Using targeted tax credits and other financial incentives for manufacturers and consumers
9. Creating and coordinating networks of universities, companies, and research institutes
10. Building and expanding centers of excellence
11. Increasing involvement of state and local governments
12. Increasing international and regional cooperation

The Current Global Situation

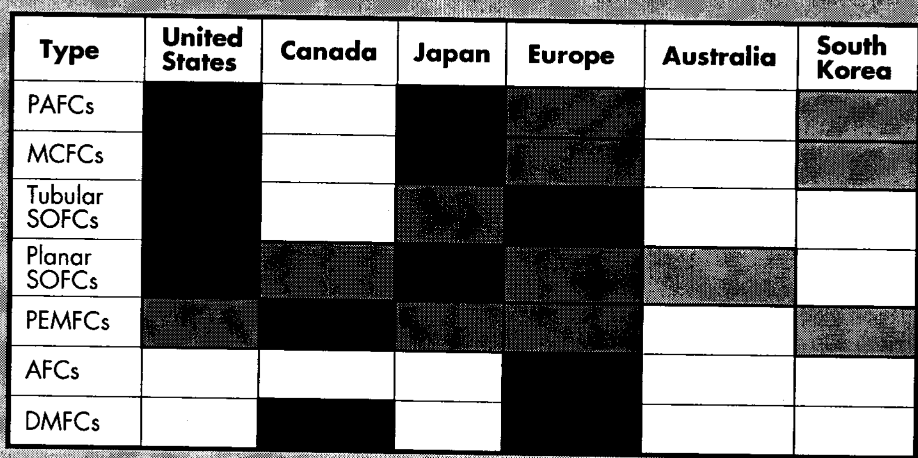
The current global situation is extremely competitive. Because of the continuing importance of the automotive industry to the economies of many countries, it is seen as a necessary large investment that, as an Austrian government strategic fuel cell proposal explains, "appears, however, to be sensible."[43] No one wants to be left out, and many perceive opportunities to gain a place in what is essentially a new competitive environment from which no one is yet excluded and in which no one is yet the winner.

Japan's well-funded and well-focused programs have helped put many of its companies on a par with those in the United States. The financial vigor of some of Japan's major vehicle manufacturers is a continuing strength, although the country's stagnant economy is an impediment. Canada's small but very focused programs have had a major impact in helping Ballard get a head start as a world leader and in getting other companies up to speed. Canada is, however, increasingly being chased. Europe has several leading companies, but has suffered from lack of coordination of its wide-ranging resources. The EU is trying to remedy this concern, to a certain extent, in the upcoming Sixth Framework

[43] Federal Ministry for Transport, Innovation, and Technology, *Austrian Strategy Proposal: Fuel Cell Research, Development and Marketing in Mobile (Transport) Applications,* May 31, 2001.

Program. Smaller countries are choosing to become focused niche players or investing just enough to remain in the race (see chart 26).

Chart 26: Relative Technical Capabilities of Global Fuel Cell Developers



Dark Blue = World Leader; Medium Blue = Second Tier; Light Blue = Third Tier
Source: U.S. Department of Energy

None of the national efforts would have been as effective, nor will they be so in the future, without the investment of hundreds of millions of dollars by the private companies involved. These corporations, in turn, can invest more because the government programs both help to lower the risks involved and leverage and network resources that the companies cannot influence by themselves. These risks are particularly large in the transportation sector: While conventional vehicles and the existing infrastructure to support them are convenient and economical, the cost of replacing the infrastructure and developing commercially viable fuel cell vehicles is enormous and long-term. The rewards, however, are particularly large in light of the size and impact of the potential global market and the potential gains in environmental preservation and energy efficiency.

None of the national efforts would have been as effective, nor will they be so in the future, without the investment of hundreds of millions of dollars by the private companies involved.

It is also apparent that national efforts to develop fuel cell technology are taking place in an increasingly globalized industry. Many multinational companies are taking part in more than one national program. For example, DaimlerChrysler participates to some degree in programs in Germany, the United States, the EU, Singapore, and Japan. Companies allied with each other, such as Renault and Nissan, are sharing expertise and coordinating R&D work. Other companies are doing research in more than one region—Ford, for example, in its German R&D center in Aachen, as well as in its U.S. facilities. Fuel cell component suppliers such as Ballard are doing joint research with, and supplying, companies all over the world.

This global context creates a dynamism and synergy impossible to achieve within a single region. But it also creates special issues related to (1) creating universal codes and standards that do not stifle technology or trade, (2) raising the amount of resources needed (e.g., sufficient resources within the companies and among countries for all the proposed demonstration projects), and (3) dealing with such challenges as reciprocity and access that are likely to increase as commercialization gets nearer.

The global context raises the question of what type of international collaboration is absolutely necessary, and what type of cooperation it makes scientific and economic sense to pursue regionally (e.g., within the EU) and globally. It also raises the question of whether a national government can or should help its companies become world leaders in all areas, or focus its efforts on select component and technology fields. The United States and Japan appear to have chosen the first approach and have sufficient resources to do so. Smaller countries such as Canada appear to have chosen the latter approach. Still others continue debating and considering their approach.

The Remaining Hurdles

Significant technical and infrastructure barriers remain. Even if those barriers fall, it will be many more years before the world's automotive fleets can turn over and accommodate substantial numbers of fuel cell vehicles. The major overall technical problems that stand in the way of achieving a commercially viable vehicle have been detailed earlier, with the biggest problems being energy storage and cost reduction.

Of great importance as well, there is not yet a hydrogen infrastructure, even in the most industrialized nations, to support even a moderate number of fuel cell vehicles. Such an infrastructure might be developed sooner in small countries like Iceland or specific regions like the Scottish island of Islay and the Japanese island of Yakushima. But everywhere else, it will take many years to develop and be cost-effective. The hydrogen infrastructure that does develop, at least initially, is likely to be diverse and distributed given regional and national differences.

The biggest hurdle, however, is the long-term sustainability of an extremely costly public-private effort over the 15 to 20 years minimum it will take to build a commercially viable industry and the infrastructure to support it. Is the public policy interest high enough to sustain investment and provide cost-lowering financial offsets in order to make fuel cell vehicles and a hydrogen infrastructure competitive with advanced internal combustion vehicles and petroleum fuels in terms of cost and performance? Can public interest be built with other types of energy-efficient, environmentally friendly vehicles that ultimately will make fuel cell vehicles easier to accept? What economic and technological dislocations will occur along the way, and what costs will be needed to ameliorate them?

Can public interest be built with other types of energy-efficient, environmentally friendly vehicles that ultimately will make fuel cell vehicles easier to accept?

What is certain is that the race to produce fuel cell vehicles is taking place in a global industry with a wide variety of players. It will cause continued shake-ups in the vehicle, fuel cell, and supplier industries. The race will have long-term global technological and economic effects on energy use and mobility. How long it will take, and whether it is a marathon or a series of sprints, is not yet certain.