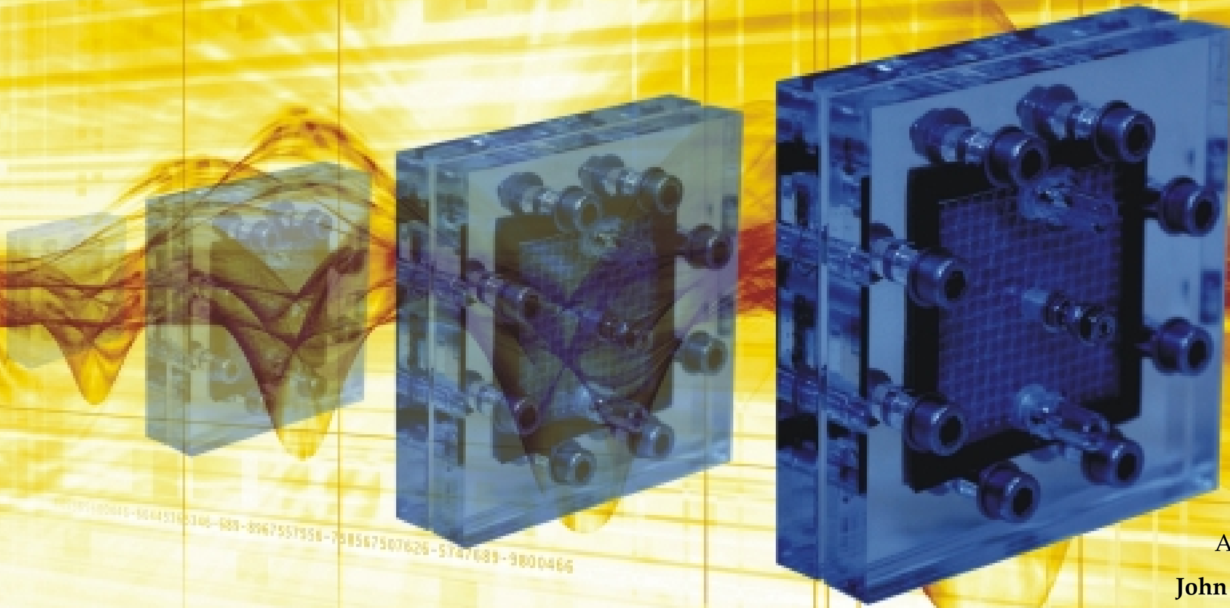
Fuel Cells
A Technology Forecast

Implications for Community & Technical Colleges
in the State of Texas



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Texas State Technical College

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Preface

On November 14, 2002, Technology Futures, Inc. (TFI), was contracted by the Texas State Technical College (TSTC) System to conduct a technology forecast on fuel cell technologies. The plans for the conduct of the technology forecast were submitted to TSTC on November 20, 2002. This report presents the results of this technology forecast and its implications for the state's community and technical colleges. Although this report targets these colleges, the information and insights presented in the report may be of interest and value to other individuals and groups.

The research presented in this report is designed to provide Texas community and technical college instructional officers and curriculum development coordinators/directors with timely analysis and actionable insights into emerging technologies and their potential impacts on existing and new technical education curricula. A highly-skilled workforce is essential to the success of Texas companies and the overall economic competitiveness of the state. Therefore, by anticipating and proactively responding to future Texas workforce demands, community and technical college curriculum offerings can be a constructive force in attracting high-tech companies to the state and ensuring existing high-tech companies continue to have an appropriately skilled source of employees. Through this research, TSTC hopes to drive the development and support of emerging technology curricula and facilitate informed and accurate future curriculum development efforts for all Texas community and technical colleges.

Acknowledgments

Any reasonably comprehensive technology forecast is founded on the efforts of not one or two people, but rather on a number of recognized experts. Because of the many aspects of fuel cell technology and the fact that the technology is in a period of transition, this is especially true for a technology forecast such as this one.

For this forecast, the authors owe particular thanks to Michael Bettersworth, Associate Vice Chancellor for Technology Advancement, *Texas State Technical College System* and Program Director of Programs for Emerging Technologies www.forecasting.tstc.edu. Michael not only provided many useful suggestions for the forecast and arranged interactions with experts in the fuel cell and related fields, but he also reviewed several versions of the forecast report and suggested major revisions and reorganizations that added significantly to its value. Dr. Lawrence Grulick, Associate Vice Chancellor for Instructional Support and Research, *Texas State Technical College System*, also reviewed portions of the report and made suggestions that assisted in targeting the report to its primary audience, the Deans and other instructional leaders of the State's community and technical colleges.

One of the most important people in promoting fuel cell programs in the State's two-year colleges is Sidney G. Bolfing, a Senior Instructor at *Texas State Technical College Waco* and Project Director of the Texas Fuel Cell Technology Consortium. Sid was extremely helpful, both in providing information and in facilitating contacts with various experts in the field. Special thanks also goes to Malcolm Jacobson and Christine Herbert, President and Executive Director, respectively, of *Fuel Cell Texas*. Malcolm reviewed preliminary versions of this report and provided useful comment not once, but three times. Christine not only provided important insights into the Texas fuel cell industry, but also provided liaison with other experts in the field.

Dr. Arumugan Manthiram of the Material Engineering and Science Department of *The University of Texas at Austin* patiently provided information on the technical aspects of fuel cell technology and Dr. Ross Baldick of the University's Department of Electrical and Computer Science provided the authors with special insights on the potential role of fuel cells in electric power grids. In similar manner, William Muston, Director of research and development at the *Texas Utilities Company* provided insights from within the electric power industry.

An event of particular importance to the development of this forecast was the meeting of the Fuel Cell DACUM (Develop a Curriculum) committee in April 2003. The authors would truly like to thank the participants of that meeting (who are listed in Appendix C) for agreeing to our attendance at that meeting and for responding to our questions during breaks in the meeting.

This research was made possible by a Carl D. Perkins grant through the Texas Higher Education Coordinating Board. Texas State Technical College would like to thank the Texas Leadership Consortium for Curriculum Development and its Steering Committee members for their guidance and support for this and future technology forecast reports.

Finally, the authors would like to thank Charlene Canaris, Administrative Assistant, *Texas State Technical College System*, Debra Robison, Administrative Director, *Technology Futures, Inc.*, Eliska Beaty, Associate Vice Chancellor for Marketing and Communications, *Texas State Technical College System*, Jan Osburn, Director of Marketing and Communications, *Texas State Technical College Waco*, Mark Burdine, Coordinator of Photography, *Texas State Technical College Waco*, Bill Evridge, Director of Printing Production, *Texas State Technical College Waco*, and Debbie Moore, Prepress Technician I, Printing Production, *Texas State Technical College Waco* for their outstanding efforts with the layout, graphics, editing, formatting, and printing involved in this report. A special thanks is extended to Dr. Barbara Selke-Kern, Executive Vice Chancellor, *Texas State Technical College System*, for her guidance and final copy editing.

The primary foundation of this technology forecast is the input that we have received from the listed experts and a number of other people with whom we interacted during the conduct of this forecast. The forecast reflects the authors' interpretations of these inputs. Any misinterpretations of these inputs are the fault of the authors, and we apologize for these to the people who have so obligingly contributed to our efforts.

Dr. John H. Vanston and **Henry Elliott**

Fuel Cell Forecast: General Observations

Growing Interest

Over the last several years, there has been an ever-growing interest in fuel cells, in both government and commercial sectors throughout the world. This interest has expressed itself in increased funding for research and development activities and for the initiation and evaluation of demonstration projects. The newly created Texas Energy Center has also identified hydrogen as one of several key energy sources of interest. Given this special interest, continued growth of the industry appears to be almost certain.

> *"Our heavy reliance on fossil fuels leaves us increasingly dependent on foreign nations for oil and gas, with serious national security implications. To achieve our vision of cleaner, smaller, and more efficient sources of energy, we will expand our exploration of the role of fuel cells and hybrid engines. Fuel cells, which can run on hydrogen, or traditional fuels that convert to hydrogen, offer the opportunity to address two different challenges…. First, they may serve as the backbone of the distributed energy network. Second, as the auto manufacturers are already discovering, they offer the opportunity to dramatically change the debate about fuel efficiency."*
>
> ***–Energy Secretary Spencer Abraham,*** *Keynote Address, Alliance to Save Energy in Washington Development Initiative*

Potential Obstacles

There are a number of obstacles—technical, economic, and institutional—to the rapid growth of the fuel cell industry. However, there appear to be no fundamental reasons why these obstacles cannot be overcome in the reasonably near future.

Types Of Markets

The fuel cell market can be divided into three general categories:

- Stationary: primarily for electric power production.
- Mobile: primarily for powering various types of motor vehicles.
- Portable: primarily as replacements for batteries in items such as laptop computers and cell phones.

Fuel cells offer a number of distinct advantages in each of these areas, including: efficient fuel use, essentially zero emissions, and quiet, continuous operation.

Electric Power Production

In many regards, the use of fuel cells for electric power production is very attractive. Fuel cell systems are versatile, quiet, and virtually non-polluting. The single major factor limiting the widespread use of fuel cells in electric power production is their cost. However, if projected price reductions are realized, fuel cells will become cost competitive with other power generation technologies in a growing number of areas.

Fuel Cell Vehicles

In the long run, the most important market for fuel cells will probably be in motor vehicles. However, it is unlikely that the number of fuel cell vehicles in use will be great enough to provide meaningful employment opportunities for graduates of Texas community and technical colleges (CTCs) in the near future.

Portable Fuel Cells

There have been some announcements that portable methanol-powered fuel cells will be offered commercially, primarily by Japanese firms, within the next two or three years. Even if such products are introduced, it does not appear that they will be very important to the Texas economy.

Fuel Cell Costs

A key reason for the current high cost of fuel cells is that they are now manufactured on a single unit basis. As the number of units produced increases, the cost per unit will go down. Because of this fact, it is important that key players such as the federal government, various state governments, electric utilities, and education groups continue to subsidize the production, installation, and operation of fuel cell systems to encourage development and to gain experience in the field. One interesting development in this area is the extensive funding of fuel cell systems by the Department of Defense (DoD) to learn more about their operation in real-world situations, and the increasing number of fuel cell demonstration projects throughout the nation.

> *The U.S. Department of Energy states that the most widely marketed fuel cells cost about $4,500 per kilowatt. More conventional forms of power, such as a diesel generator, costs $800 to $1,500 per kilowatt, and a natural gas turbine costs even less.*
>
> ***— U.S. Department of Energy***

Need For Commitment

Because the fuel cell industry is only now beginning to achieve its promise, it is possible for Texas to establish itself as an "early adopter" state. Such a position will make the state attractive to manufacturing and service companies as commercialization accelerates. Given its strong long-term position in the energy sector, Texas could easily become a leader in the fuel cell field, if the state government, industry, and academic institutions are willing to make the necessary commitments. The resulting opportunities could be very significant in terms of capital infusion and job creation. The recent announcement that Dow Chemical Company and General Motors Corp. plan to jointly test fuel cell technology in Dow's largest manufacturing facility in Freeport, Texas indicates that these opportunities may be realized in the relatively near future.[1] The availability of trained fuel cell system technicians will be a major asset in attracting fuel cell investments in Texas.

Government Support

In his January 2003 State of the Union Address, President George W. Bush announced that $1.2 billion will be invested over the coming decade in the development of fuel cell automobiles. As part of the President's Hydrogen Fuel Initiative, Secretary of Energy Spencer Abraham announced the release of two hydrogen technology solicitations on July 31. The solicitations will provide up to $200 million in funds over four to five years (subject to congressional appropriations) for research and development in hydrogen production and delivery technologies and also hydrogen storage technologies. This commitment by the federal government should accelerate fuel cell development.

> *"In this century, the greatest environmental progress will come about not through endless lawsuits or command-and-control regulations, but through technology and innovation. Tonight, I'm proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles…. A single chemical reaction between hydrogen and oxygen generates energy, which can be used to power a car—producing only water, not exhaust fumes. With a new national commitment, our scientists and engineers will overcome obstacles to taking these cars from laboratory to showroom, so that the first car driven by a child born today could be powered by hydrogen, and be pollution-free…. Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy."*
>
> ***—President George W. Bush,*** *State of the Union Address (2003)*

[1] Brooks, Bob. "GM, Dow to Begin Fuel-Cell Power-Generation Project." July 8, 2003 http://wardsauto.com/ar/auto_gm_dow_begin/

Initial Employment Opportunities

It appears that initial fuel cell employment opportunities for Texas community and technical college graduates will be in the electric utilities industry. These graduates will probably be employed to service groups of cells that act as backup power sources to prime generation technologies (gas and coal turbines, etc).

Needed Skills

In the near future, employment opportunities will be most promising in the areas of installation, calibration, operation, maintenance, systems design, and support. The training and skills required for fuel cell installation (i.e., licensed plumbers and electricians) are quite different from those required for maintenance (i.e., fuel cell specific technicians).

> *The National Energy Policy Report directed the Secretary of Energy "to develop next generation technology—including hydrogen…" and to "focus research and development efforts on integrating current programs regarding hydrogen, fuel cells, and distributed energy."*
>
> *—Issued in May 2001*

Manufacturing Opportunities

Additional employment opportunities may emerge if fuel cell manufacturing facilities are established in Texas. At present, there are no such facilities in the state, nor are there any announced plans for building such facilities. On the other hand, there are indications that such facilities will probably be built in "early adopter" markets. In fact, a representative of one manufacturer indicated that his company would consider building a plant in Texas if installations reached 50 MW (megawatts) per year. It should be noted that hydrogen production at the Dow plant in Freeport (see Planned Fuel Cell Activities section) is a natural by-product of an existing production process. This "production" would take place even if Dow had no interest in fuel cells.

Skill Areas

Employment opportunities in the electric power production area will require three general areas of skill sets: heating, ventilation, and air conditioning (HVAC); electrical systems; and systems control. In the longer run, there will be a need for people who have skills in all of these areas, as well as fuel cell specific training. Graduates with these multiple skills should be appropriately compensated, particularly those who enter the field at an early stage.

Expanding Opportunities

As the number of power-producing fuel cells increases, a need for trained technicians in each of these areas will develop. The Texas Department of Economic Development has estimated that 453 jobs, with an average wage of $33,275, will be created for every 20 megawatts of installed base. Approximately 200 of these jobs will be “direct” employees. The extent of employment opportunities will, thus, be directly proportional to the number of units installed. (Direct employees are those that work directly on fuel cells; indirect employees are those that work in related industries and businesses in local economies where fuel cell companies and employees spend their earnings.)[2]

> *The current $40 million stationary fuel cell market will grow to more than $10 billion by 2010, and the overall fuel cell energy generating capacity will increase by a factor of 250, with global stationary fuel cell electricity generating capacity jumping to over 15,000 megawatts by 2011 from just 75 MW in 2001.*
>
> —As reported by ***Allied Business Intelligence, Inc.***

Requirements In Differing Areas

Because of emission control requirements and new power line restrictions in the state’s larger cities, there will be greater motivation for fuel cell use in urban areas than in more rural areas. This concentration of fuel cells in specific urban areas will allow for more efficient utilization of fuel cell maintenance and repair technicians by utility companies.

2 Texas Department of Economic Development. *Potential Impact of a Fuel Cell Industry* (July 2002).

Vehicle Markets

Several automobile companies including, most prominently, GM, DaimlerChrysler, and Honda, have invested hundreds of millions of dollars in fuel cell research, development, and commercialization. Each of these companies has a fuel cell prototype car currently being tested in a demonstration program. However, due to their high cost and other technical problems, it is unlikely that there will be any major market for mobile fuel cells within the next 10 to 15 years.

Portable Fuel Cells

There have recently been some indications, particularly from Japan, that portable fuel cells for use in laptop computers, cell phones, and other small devices may appear on the market in the near future. However, even if such fuel cells become available, the area does not appear to offer many employment opportunities for Texas community and technical college graduates. Since these fuel cells will undoubtedly be discarded after use, there will be no jobs related to their installation, maintenance, or operation, and it does not appear that any manufacturing facilities will be located in Texas.

> *Motorola wants to put fuel cells on chips that could power cell phones that take fountain-pen cartridge-like hydrogen refills.*
>
> *—"A Fuel Cell in Your Phone," **Technology Review** (November 2001)*

The potential growth of the fuel cell industry presents the academic and administrative leaders of the community and technical colleges (CTC) of Texas with a challenging dilemma. On the one hand, it is incumbent on these colleges to assist in the development of emerging industries in the state, as well as provide their graduates with the promising employment opportunities that typically characterize the adoption of new technologies. On the other hand, leaders must use discretion to assure that graduates can be gainfully employed and that scarce resources are not wasted if development of a vibrant fuel cell industry in the state is delayed or deferred. To address this dilemma, the following approaches are suggested.

Potential Expansion Of Need

CTC leaders should evaluate the most appropriate role they can play in the fuel cell arena. Those colleges that determine they should be involved in this technology should plan a limited involvement for the near future, but prepare themselves to expand their programs quickly if there is rapid growth in the fuel cell industry. The Potential Impacting Factors section of this report lists a number of possible trends, events, or decisions that might significantly accelerate fuel cell adoption.

> *The Ohio Department of Development will also set aside a total of $3 million to assist Ohio's fuel cell companies upgrade the skills of its workers over the next three years. As companies upgrade equipment with new investments, training remains critical for the investment to pay off. The ODOD will work closely with Ohio's fuel cell industry to provide quality training to ensure the industry's success.*
>
> ***—Ohio Fuel Cell Development Initiative***

Options For Expansion

A number of actions can be taken to provide a foundation for rapidly expanding fuel cell training. Developing an appropriate fuel cell system curriculum is an obvious step. The Texas Fuel Cell Consortium http://eps.nhmccd.edu/txcon/Projects02/FuelCell.htm is currently developing such a curriculum, based in part on the DACUM meeting in Houston on April 2-3, 2003. (Appendix A presents an overview of that meeting, Appendix B is the resulting DACUM chart, and Appendix C lists meeting participants.) Interested CTCs should review the resulting curriculum to evaluate its application to their specific situations and consult with consortium member institutions for instructor training and coordinated curriculum offerings. In addition, CTC decision makers should closely monitor fuel cell development progress, particularly those fuel cell opportunities arising in their geographical areas.

Need For Cooperation

There are many different types of fuel cells under development today, and fuel cell equipment is expensive. Therefore, it is important that CTCs choose the right technology for their training applications. CTCs should promote coordination between colleges, as well as with manufacturers who conduct training at their own facilities. Consideration should also be given to coordinating fuel cell programs with nearby four-year colleges and universities to facilitate further training, education, and research in the area.

> *"The introduction of fuel cells in mobile and stationary applications could possibly revolutionize the world's energy picture."*
>
> ***—Jan Smeele,*** *Chief Executive Officer, Shell Hydrogen*

Equipment Needs

Texas State Technical College (TSTC) Waco purchased a five kilowatt PEM (proton exchange membrane) fuel cell from Plug Power, Inc., and will use it to train the first fuel cell technicians in the state. At present, TSTC Waco is the only Texas CTC to have a fully operational commercial-grade fuel cell on-site, and the college has recently acquired a second smaller PEM fuel cell. Both will be utilized for hands-on training. Strategies for gaining access to needed equipment such as this include developing programs to share the equipment at TSTC Waco, negotiating with local fuel cell owners and operators, or acquiring equipment from manufacturers at an affordable price or through donation.

Training Requirements

Fuel cells, together with their ancillary equipment, are very complicated systems. Therefore, fuel cell service technicians will be expected to perform a variety of tasks in areas such as electrical, thermal, water, ventilation, fuel, magnetic, fuel stack, and process air systems. People who have an acceptable level of skill in all of the listed areas will be in high demand. Therefore, colleges might want to consider programs that include training in all of these technical areas.

Special Employment Opportunities

Fuel cell service technicians would be particularly attractive to employers in the fuel cell industry, as well as other industries, such as electric utilities, industrial facilities managers, and government agencies. Discussions with fuel cell industry representatives indicate that such specialists can expect pay premiums of 20 to 50 percent over other technicians. Moreover, graduates with this type of training will almost certainly be able to find suitable employment in related areas (i.e., electronic control systems, HVAC, etc.) if the fuel cell industry does not develop as rapidly as projected.

Potential Employers

CTC graduates will typically find themselves employed by one of the three fuel cell groups listed below. To enhance employment opportunities, CTC graduates should be trained to effectively serve any of these groups:

- Manufacturers
- Fuel cell owners
- Service providers (technician services)

Expanded Programs

Considering the wide range of skill requirements for fuel cell service technicians, it may be difficult to provide the needed skills in a two-year program. Thus, CTCs should be prepared to conduct third-year programs leading to Level II Certificates or Advanced Training Certificates.

Post Graduation Training

Since previous CTC graduates will have many of the skills required by the fuel cell industry, the availability of Level II and Advanced Training Certificate programs will make it possible for these graduates to gain the additional skills necessary to become fuel cell service technicians.

Expanding Current Programs

Rather than establishing stand-alone fuel cell programs at the present time, many colleges may be better served by adding fuel cell courses to current HVAC, electricity generation, and systems control programs. If colleges have prepared programs on hand, they will be able to deal with an unexpected rapid expansion of the fuel cell industry. For example, students with one year of participation in a related program could switch to a final year in a fuel cell program, if significant new employment opportunities developed.

Industry Standards

As the number of installed fuel cells increases and as they are added to the electric power grid, there will be a growing need and demand for standards involving health and safety, compatibility with other grid components, requirements for certification, and a host of other items. The CTC community should stay informed with the development of these standards. Moreover, they should ensure that graduates of fuel cell programs are qualified for certification in the appropriate areas.

Coordination

In considering the initiation of fuel cell programs, college Deans and other decision makers should maintain close liaison with the Texas Fuel Cell Consortium. A review of the results of the recent fuel cell DACUM conducted in Houston on April 2-3, 2003 is available at www.eps.nhmccd.edu/txcon/Projects02/Fuel_Cell/PressRelease.htm (see Appendix A).

As indicated in the following paragraphs, there is considerable interest in the state in establishing Texas as a premier fuel cell player. However, a great deal more must be done before a vibrant fuel cell industry is developed. To a large extent, fuel cell growth in Texas will be highly dependent on its growth in other regions of the country. Increases in fuel cell production that will reduce unit costs to an acceptable level will require large-scale adoption in many different regions, not only in the United States, but also throughout the world.

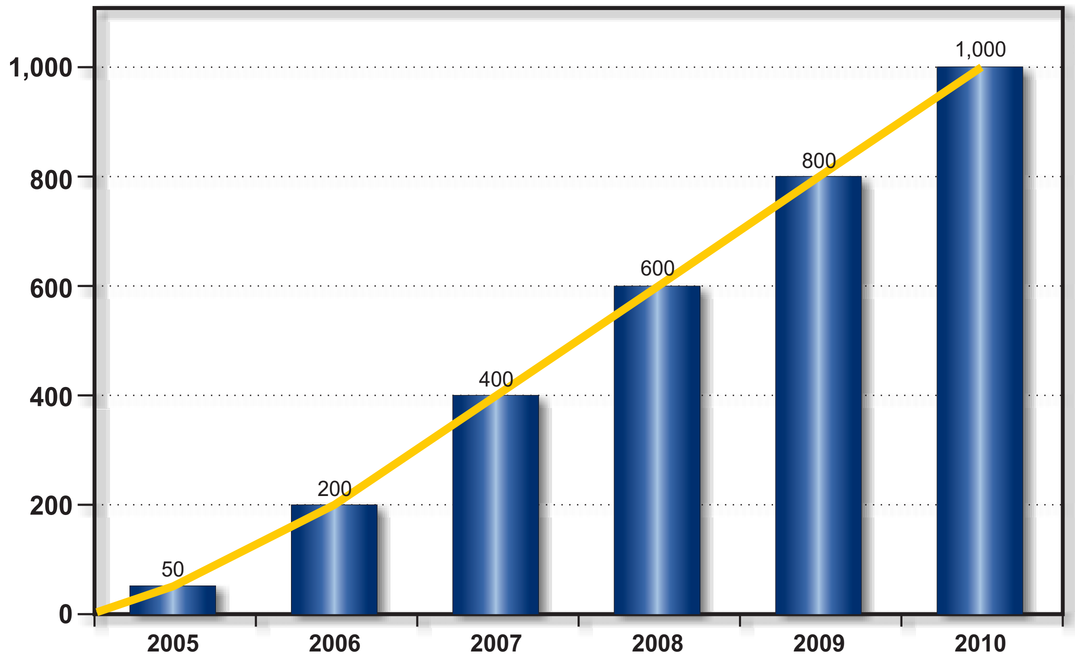
> *The CCEF recently issued the 2002 Fuel Cell Request for Proposal (RFP) to promote clean, reliable distributed generation in Connecticut and the commercialization of fuel cells. The funding level for the 2002 Fuel Cell RFP could reach almost $9 million.*
>
> ***—Connecticut Clean Energy Fund***

State Government Activities

Public Utility Commission White Paper

On May 6, 2002 the Public Utility Commission of Texas published for public comment a Staff White Paper on Stationary Fuel Cells for Power Generation www.seco.cpa.state.tx.us/fciac_pucpaper.pdf. This paper presented a discussion on the attractiveness of fuel cell systems for the state, described the obstacles to state development of a fuel cell program, presented a roadmap for the establishment of a vibrant fuel cell industry in Texas, and offered an outline of legislation that would provide incentives for fuel cell development. This report envisions an installed fuel cell capacity of 1,000 MW in Texas by the year 2010.

Figure 1
Projected Texas Fuel Cell MW Targets



Source: Army Engineer Research and Development Center

In September 2002, the Texas State Energy Conservation Office (SECO) www.seco.cpa.state.tx.us submitted to the House of Representatives Energy Resources and Senate Business and Commerce Committees a plan for accelerating the commercialization of fuel cells in Texas www.seco.cpa.state.tx.us/fciacfinalreport.pdf. Included in this plan were 15 recommendations, as follows:

1) Texas should create a public/private partnership, overseen by the Texas Council on Environmental Technology, to encourage the commercialization of fuel cell technology and the growth of a fuel cell industry in Texas.

2) Texas should adopt concrete goals for fuel cell development.

3) Texas should encourage and assist in the formation of a Texas Consortium for Advanced Fuel Cell Research.

4) The state of Texas should become an "early adopter" of fuel cell technology.

5) Texas should purchase fuel cell power through off-take utility contracts.

6) Texas should develop and fund fuel cell demonstration projects.

7) The legislature should reserve a percentage of current state research funding to serve as matching funds for federal grants related to fuel cell systems.

8) The public/private partnership should assist the development of a wide variety of fuel cell training and education.

9) The legislature should provide financial incentives to support its goals for fuel cell development.

10) The legislature should allow power transmission and distribution companies to own fuel cells.

11) The legislature should amend or create other state laws, regulations, and permits, as needed, to accommodate the use of fuel cells.

12) The Texas Commission on Environmental Quality should continue its efforts to ensure that fuel cells can generate both direct and indirect emission reduction credits.

13) Texas should support and pursue the adaptation of national codes and standards to accommodate the use of fuel cells.

14) Texas should participate in regional and national consortia and partnerships related to fuel cells.

15) When they become available, Texas should seek federal permission to allow fuel cell-powered vehicles to use high-occupancy vehicle lanes on Texas highways, regardless of the number of passengers.

> *"If new fuel cell technology were to replace all of the current installed capacity of electric generators in the United States, emissions of greenhouse gases could be reduced by about 50 percent and emissions of nitrogen oxides, sulfur oxides, carbon monoxide, and hydrocarbons could be reduced by about 80 percent to 90 percent."*
>
> —***Jack Brouwer,*** *Associate Director, National Fuel Cell Research Center*

Texas Emissions Reduction Program (TERP) Changes

HB 1365, passed during the 2003 legislative session, included measures to improve the state's major clean air plan, including providing new funding to reduce emissions from Texas' diesel engines, conduct more clean air research and development, and develop more fuel cells. The main sponsors include Sen. Chris Harris, R-Arlington and Rep. Dennis Bonnen, R-Angleton.

Texas Energy Center

The recently created Texas Energy Center (TxEC) in Sugar Land appropriated $31.1 million in state matching funds as part of the governor's economic development package. TxEC will focus on the following four energy areas:

- Deepwater
- Advanced Natural Gas
- Hydrogen Infrastructure
- Clean Energy

These funds will enable TxEC to gain access to "$3.6 million to match local start-up funds, $2.5 million to put toward Texas' bid for management of an anticipated $2 billion in federal funds, earmarked for an ultra-deepwater research program, $10 million to develop zero-emissions power plant technology, and $15 million to develop a statewide fuel cell industry."[3]

Proposed Fuel Cell Legislation

A number of legislative bills intended to accelerate the commercialization of fuel cell technology in the state were submitted in the 2003 legislative session. The bills called for statewide fuel cell demonstration incentive programs, temporary sales tax exemptions, leveraged federal funds, and coordination of efforts at the state and federal levels. The introduction of these bills and passage of HB 1365 demonstrate the increasing interest in this technology by the state's political leaders.

[3] Perin, Monica. "Proposed Energy Center gets Major Boost with State Funds." *Houston Business Journal*. August 8, 2003.

> *"Joint federal/private programs are critical to advancing the commercialization of fuel cell products throughout the nation. Federal investment is vital for research in materials, low-cost manufacturing processes, testing, and evaluation, and is achievable with the active support of government at all levels. Additionally, the federal government has a crucial role in ensuring the seamless adoption of new technologies such as fuel cells. This includes market entry support, such as tax incentives and removing barriers. We believe a comprehensive national strategy, such as this, is essential to advance the cause of a clean independent energy solution for our nation."*
>
> *—**Greg Silvestri,** Chief Operating Officer, Plug Power, Inc., Latham, New York)*

Demonstration Projects

An increasing number of fuel cell demonstration projects are taking place throughout Texas, the nation, and the world. These projects can be an effective method of advancing the development, commercialization, and general awareness of an emerging technology like fuel cells. This section provides an overview of the various fuel cell demonstration projects taking place in Texas, pertinent contact information, and relevant descriptions of each project. This information and the company listings found in Appendix F should be particularly useful for those interested in expanding or forging new partnerships in the Texas fuel cell arena.

Project Name	**Brooks City Base Fuel Cell Projects**
Contact 1	**Greg Brady, St. Phillip's College**
Phone	**(210) 921-4829**
Contact 2	**Joe B. Redfield, Southwest Research Institute**
Phone	**(210) 522-3729**
Website	**www.swri.edu/fuelcell**

Description. Brooks City Base is home to two fuel cell demonstration projects. One project is officially the first residential application of fuel cells in south Texas, and the other generates electricity and heats water for an aerospace education center, the Challenger Learning Center http://home.satx.rr.com/clcsa/general.htm, which provides hands-on simulated space missions for middle school students. "Both year-long fuel cell projects, which became operational in early 2003, will help 11 partner organizations gain experience in distributed generation and determine how this technology may benefit consumers.

> *"One percent of U.S. homes will have residential fuel cells between 2006 and 2010. When cell prices fall more a few years later, the units will be in half of all homes. And, by 2031, we'll all be off the grid."*
>
> ***—Peter Bos,** a Pacific Palisades fuel-cell analyst*

Figure 2
Brooks City Base Project

Source: Army Engineer Research and Development Center

"Both demonstration projects are using 5 kW fuel cell systems, manufactured by Plug Power, Inc. www.plugpower.com. Project objectives include gaining experience in the installation, operation, and maintenance of fuel cells; documenting costs of operating the equipment; quantifying environmental benefits; recording the interaction with the electric grid; and verifying the operational stability and reliability of equipment in San Antonio's climate.

"The U. S. Army Construction Engineering Research Laboratory (CERL) www.cecer.army.mil/td/tips/index.cfm, a part of the U.S. Army Corps of Engineers' Engineer Research and Development Center, was the primary funding agency responsible for the residential base housing project. The residential project is part of the CERL fuel cell program that encompasses

"40 similar projects at several U.S. military bases. The Challenger Learning Center fuel cell project was funded through a mutual fund for research managed by the Gas Technology Institute (GTI) www.gri.org. City Public Services (CPS), the utility company that serves San Antonio, supplied additional funding for both projects.

"The Brooks City Base's housing area pictured in Figure 2 provides electrical output from three fuel cells for three housing units of about 1,600 square feet each.

"Southwest Research Institute (SWRI) was commissioned by CERL to lead the effort. CPS was responsible for permitting and installing the three 5 kW fuel cells in base housing, and now CPS will be in charge of operating and maintaining the units. In essence, CPS configured a fuel cell "mini-substation" where electricity is produced and metered, and any excess power flows into the electric grid—a first for CPS. The 12-month project seeks to demonstrate the viability of using fuel cell technology to power homes.

"St. Philip's College plans to utilize the project as an educational opportunity to teach students the basics of fuel cell systems. St. Philip's offers tours of both fuel cell sites at Brooks City Base."[4]

Organization	**Houston Advanced Research Center (HARC)**
Contact	**George R. King, Energy Director**
Phone	**(281) 364-6050**
Website	**www.harc.edu/harc/Projects/Fuelcell**

Description. "HARC's Fuel Cell Research and Applications Center was created in July 1998 in response to a growing demand for clean power generation products. The HARC consortium, comprised of Southern Company, Texaco Energy Systems, Inc., and Walt Disney Imagineering Research & Development, Inc., was created in 2000 to demonstrate and analyze promising fuel cell technologies. The group is testing a number of fuel cells to determine how they work both in large (250 kW) and small-scale (5 kW) stationary applications. The consortium is considering issues such as power quality and reliability, as well as how fuel cells might be applied to incentive programs that promote emission reductions."[5]

[4] San Antonio - City Public Service Press Release. http://www.citypublicservice.com/press_room/factsheets/fuelcell_021803.asp
[5] Houston Advanced Research Center Press Release. http://www.harc.edu/harc/Content/NewsEvents/ShowNews.aspx/98

"One such application involved the successful installation of a 5 kW proton exchange membrane (PEM) fuel cell system designed and manufactured by Plug Power in May 2002. The system is being tested as part of a project to demonstrate the viability of fuel cells as a source of safe, clean, and efficient electric power. "The Plug Power system is the first in the HARC study to be located outdoors," said Bruce Rauhe, project director of the HARC consortium at the time. "We are reproducing real-world conditions by installing it outside the laboratory on a concrete pad and fueling it with pipeline natural gas."[5] Additionally, HARC is "working with the Port of Galveston to develop and install a 250 kW molten carbonate fuel cell that will operate on natural gas and provide docked marine vessels with electrical power for auxiliary systems (lights, HVAC, etc.) while in port. By utilizing electricity from the stationary fuel cell, ships will be able to shutdown their nosier and more pollution prone diesel generators. The Texas Alternative Fuels Council (TAFC) awarded HARC a $200,000 grant to manage the project."[6]

Project	**Laughlin Air Force Base Hospital (Del Rio, Texas)**
Contact	**Cmdr. Garland Scott**
Phone	**(210) 652-4601**
Website	**www.dodfuelcell.com/pafc/laughlin.php3**

Description. Phosphoric acid fuel cells (PAFCs) were installed at 30 U.S. Department of Defense (DoD) bases between 1994 and 1997. The stated objectives of the PAFC demonstration program were to:

- Demonstrate fuel cell capabilities in real-world situations.
- Stimulate growth and economies of scale in the fuel cell industry.
- Determine the role of fuel cells in DoD's long-term energy strategy. (see http://www.dodfuelcell.com/SiteEvals/SE_Laughlin_TR.pdf)

One such cell, which is no longer operational, was located at an outpatient super clinic at Laughlin Air Force Base, located near Del Rio, Texas (see Figure 3). The base is home to the 47th Flying Training Wing, and its primary mission is the undergraduate training of pilots. "The fuel cell sat outside of a wall surrounding the electrical yard, and its electrical interface tied directly into the site's existing electrical transformer. Two hospital thermal loops were served by the fuel cell, domestic hot water and the space heat/cool re-heat loops. The fuel cell was a PC25™ system manufactured by United Technologies Corporation (UTC)."[7]

[6] Auliff, Lily. "Powering the Future." *CEC Environmental Exchange* June 2001 http://cechouston.org/newsletter/2001/nl_06-01/power.html
[7] US Army Corps of Engineers. "Site Evaluation for Application of Fuel Cell Technology." *ERDC/CERL TR-01-41*. April 2001

Figure 3

Laughlin Air Force Base, Building Application: Hospital

Source: Army Engineer Research and Development Center

Organization	**Rebekah Baines Johnson Health Center (City Health Clinic), operated by Austin Energy**
Contact	**Larry Alford, Manager of Distributed Energy, Austin Energy**
Phone:	**(512) 322-6228**
Website	**www.austinenergy.com/press/2002/fuelcell.html**

Description. In July 2002, Austin Energy installed a 200 kW fuel cell system at the Rebekah Baines Johnson (RBJ) Health Center. Pictured in Figure 4 (next page), the system also produces 900,000 BTUs of usable heat per hour.

Figure 4
Rebekah Baines Johnson Health Center

Courtesy of Larry Alford, Austin Energy

"Electricity produced by the unit is fed into the Austin Energy electric grid. It was the first fuel cell in Texas to feed power to a local utility grid. Additionally, the health center is using the heat produced by the unit to heat water for the health center, helping it avoid the cost and the emissions associated with operating a natural gas-fired boiler.

"The RBJ Health Center is headquarters for the public health and community care components of the Austin/Travis County Health and Human Services Department. Austin Energy, which is Austin's community-owned utility, plans to open the installation to the public as a demonstration facility and provide tours and educational programs. The fuel cell is a PC25™ system manufactured by UTC Fuel Cells, a unit of United Technologies Corporation."[8]

[8] UTC Press Release July 25, 2002. http://www.utcfuelcells.com/news/archive/2002-07-25.shtm

Fuel Cell Education and Advocacy Groups

Organization	**Fuel Cell Initiative Advisory Committee**
Contact	**Joe B. Redfield, Committee Member**
Phone	**(210) 522-3729**
Website	**www.seco.cpa.state.tx.us/fciac_info.htm**

Description. House Bill 2845, passed by the 77th Legislature, directed the Texas State Energy Conservation Office (SECO) "to develop a plan for the acceleration of the commercialization of fuel cells in Texas. The bill also called on SECO to appoint an advisory committee to help with this task. The duty of the Fuel Cell Initiative Advisory Committee (FCIAC) was to help develop the plan that offers policy options to the legislature to ensure the viability of a fuel cell industry in Texas now and in the future."[9] The FCIAC has a number of their published reports online at www.seco.cpa.state.tx.us/fciachome.htm.

Organization	**Fuel Cells Texas**
Contact	**Christine Herbert, Executive Director**
Phone	**(512) 480-2226**
Website	**www.fuelcellstexas.org**

Description. Incorporated in September 2001, Fuel Cells Texas is a non-profit trade association representing the fuel cell industry in Texas. The mission of Fuel Cells Texas is to "accelerate the broad commercialization and deployment of fuel cells in the state of Texas through public education, policy alignment, and development of state-sponsored initiatives."[10] The members of Fuel Cells Texas include FuelCell Energy, Hunt Power, Methanex Corporation, Siemens Westinghouse Power Corporation, DuPont Fuel Cells, IdaTech, Plug Power, Air Liquide, UTC Fuel Cells, Ballard Power Systems, and Shell Hydrogen.

Organization	**Good Company Associates**
Contact	**Christine Herbert, Vice President**
Phone	**(512) 480-2226**
Website	**www.goodcompanyassociates.com**

Description. "Good Company Associates is a business development, advocacy, and consulting company focused largely on helping its clients create a positive government policy and regulatory environment for new environmental

9 State Energy Conservation Office. "Texas Fuel Cell Initiative." http://www.seco.cpa.state.tx.us/fciachome.htm
10 "The Mission of Fuel Cells Texas." http://www.fuelcellstexas.org

technologies in Texas. The company has helped pass legislation under which Texas utilities have spent over $100 million annually on efficiency incentives, and a renewable energy portfolio standard that will generate a $2 billion investment in renewable energy in Texas over the next 10 years. In the spring of 2003 they submitted a bill to the legislature asking for an incentive program that would accelerate the adoption of fuel cells as a power generation technology."[11]

Organization	**Southwest Research Institute (SWRI)**
Contact	**Joe B. Redfield, Group Leader, Fuel Cell System**
Phone	**(210) 522-3729**
Website	**www.swri.edu/3pubs/brochure/d03/FuelCell/fuelcell.htm**

Description. SWRI is an independent, nonprofit, applied engineering and research development organization. In addition to its work in other areas, SWRI "promotes innovative approaches to fuel cell construction, fueling infrastructure, waste heat utilization, and power control and storage. SWRI engineers also develop ancillary fuel cell processes such as fuel processors and fuel storage, delivery, and cleanup systems."[12] SWRI engineers are heavily involved in the fuel cell demonstration project at Brooks City Base.

Organization	**Texas Fuel Cell Technology Consortium**
Contact	**Sid Bolfing, Instructor, Texas State Technical College Waco**
Email	**sidney.bolfing@tstc.edu**
Phone	**(254) 867-3206**
Website	**http://eps.nhmccd.edu/txcon/Projects02/FuelCell.htm**

Description. The goal of the Texas Fuel Cell Technology Consortium is to "assemble a partnering college panel, research fuel cell technology, perform a DACUM, and assemble an advisory committee composed of industrial and academic partners to develop a structure for a two-year associates degree in fuel cell technology. Partnering colleges will share grant funds and information to lay the foundation for curriculum development. The research will include reviewing curriculum presently being taught in other colleges, visiting sites utilizing fuel cells, working with research and development companies, attending manufacturers' schools, and collecting any other data pertinent to the development of a fuel cell curriculum."

The Consortium's DACUM panel is comprised of administrators and

11 "Good Company Associates." http://www.goodcompanyassociates.com/comp/
12 Southwest Research Institute. "Fuel Cell Technology." http://www.swri.edu/3pubs/brochure/d03/FuelCell/fuelcell.htm

technicians from companies that are designing, testing, manufacturing, and utilizing fuel cells. They have started the process of actual curriculum development (see Appendices A, B, and C) and, in cooperation with the Texas Higher Education Coordinating Board and TSTC Waco, are assessing which currently-approved GIPWE/WECM courses will be included in the associate degree and what new courses will need to be developed to address technical issues specific to fuel cell technology. Sid Bolfing will work closely with members of the consortium to disseminate project deliverables and accelerate duplication of the fuel cell associate degree curriculum statewide.

Project partners include Texas State Technical College Waco, Texas State Technical College Harlingen, Lamar Institute of Technology, Southwest Texas Junior College, Dallas County Community College District, North Harris Montgomery Community College District, St. Philip's College, Del Mar College, Alamo Community College District, Houston Community College District, Houston Community College System, Midland Community College District, Tarrant County Community College District, Wharton County Junior College, Texas State Leadership Consortium for Curriculum Development, Houston Advanced Research Center, Good Company Associates, Bay Area Houston Economic Partnership, Space Alliance Technology Outreach Program, and Southwest Research Institute.

Figure 5
Texas State Technical College Waco Fuel Cell

Source: Texas State Technical College Waco

Planned Fuel Cell Activities

On May 7, 2003, the Dow Chemical Company and General Motors announced that they are teaming to test a fuel cell system at Dow's largest manufacturing facility in Freeport, Texas.[13] The project should be completed in two years at a cost of about $50 million. The fuel cells will produce as much as 35 MW of power. A representative for General Motors stated that its participation in the project is to "reduce the cost of fuel cells and improve their durability so that we may put them in cars by the end of the decade."

Additionally, in the near future, SECO will execute its first fuel cell project, the Texas LPG Fuel Processor Development and Fuel Cell Demonstration Program. The SECO led program, which was funded under a competitive U.S. Department of Energy grant process, is a partnership of private and public entities including the Alternative Fuels Research and Education Division of the Railroad Commission of Texas; Plug Power, Inc.; UOP/HyRadix, Des Plaines, Illinois; Southwest Research Institute; the Texas Commission on Environmental Quality; and the Texas Department of Transportation.

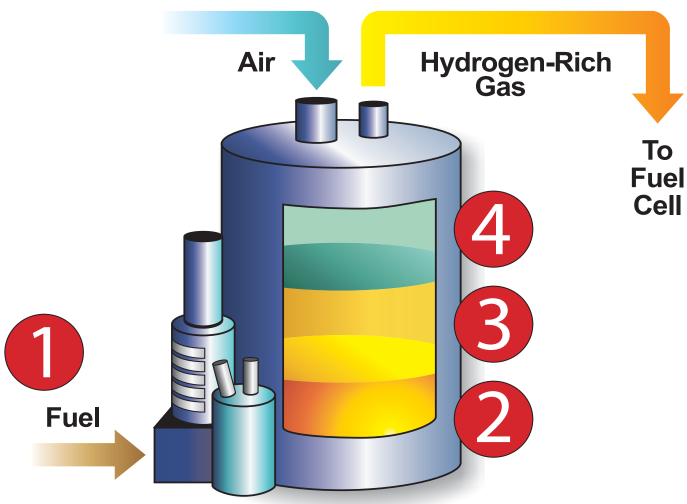
"The program's primary goal is to develop, test, and install a prototype propane-fueled residential fuel cell power system in a variety of building types and conditions of service. The system integrates HyRadix's Liquid Propane Gas fuel processor system (reformer) into Plug Power's residential-scale Gen Sysa 5C (5 kW) PEM fuel cell system. Following integration and independent verification of performance by Southwest Research Institute, Plug Power and HyRadix will produce a production-ready unit for use in a field demonstration at the Texas Department of Transportation's TransGuide headquarters in San Antonio. Concurrently, the partnership will perform market analysis to identify early-entry customers, technical and regulatory requirements, and other challenges and opportunities that need to be addressed if the units are to be commercialized."[14]

[13] Dow Press Release. May 7, 2003 http://www.dow.com/dow_news/corporate/2003/20030507c.htm
[14] "Fuel Cells." http://www.platinum.matthey.com/applications/fuelcells.html

How Fuel Cells Work

"A fuel cell is a device that uses hydrogen, or a hydrogen-rich fuel such as methane (CH_4), and oxygen to create electricity by an electrochemical process. Fuel cells could have several benefits over conventional combustion-based technologies currently used in many power plants and passenger vehicles. They produce much smaller quantities of the greenhouse gases that contribute to global warming and none of the air pollutants that create smog and cause health problems. In fact, if pure hydrogen is used as a fuel, only heat and water are emitted as byproducts."[15] If a hydrogen-rich fuel is supplied to the cell, some sort of "reforming process" must be employed to separate the hydrogen from the other elements in the fuel. In the case of methane, reforming "strips" carbon from the four atoms of hydrogen, leaving pure hydrogen (see Figure 6).

Figure 6
Fuel Cell Reformer



This reformer, produced by Argonne National Labs, is "an inexpensive, easy-to-manufacture device that reforms conventional fuels into hydrogen using a process similar to that used in today's automotive catalytic converters. Vaporized fuel (1) is mixed with steam and air and sent through a catalyst packed cylinder. The first stage catalyst (2) releases hydrogen to feed the fuel cell. Carbon monoxide created by this reforming process is used to make additional hydrogen as it passes through a second stage catalyst (3) and a cartridge absorbs the sulfur (4)."[16]

Courtesy of U.S. Department of Energy, Argonne National Laboratory

Additionally, fuel cells can be more efficient than combustion-based technologies, converting up to 80 percent of the fuel's chemical energy into electricity (compared to 40 percent efficiency for conventional power plants).[17] Hydrogen used to power a fuel cell can be obtained from a variety of sources, including fossil fuels, renewable sources, and nuclear energy. Moreover, "since the fuel can be produced from domestically available resources, fuel cells have the potential to improve national energy security by reducing our dependence on oil from foreign countries."[18]

[15] Department of Energy. "Fuel Cell Basics." http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html
[16] Argonne National Laboratory. "Argonne's Fuel-Flexible Reformer." http://www.cmt.anl.gov/science-technology/fuelreformer.shtml
[17,18] Department of Energy. "Fuel Cell Basics.

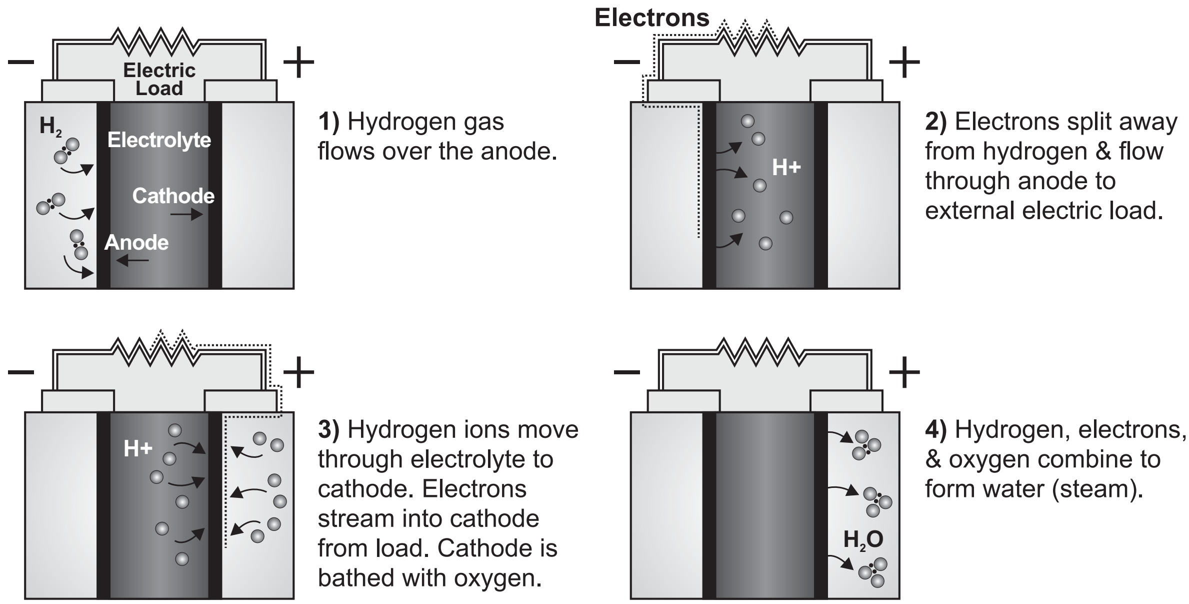
> *"Not only is the conversion of stored energy in fuels such as coal and gas an inherently low-efficiency process, but also running electricity long distances over the grid is extremely wasteful, with substantial transmission losses. Fuel cells can offer about twice that overall efficiency."*
>
> ***—Jim Seymour,*** *TheStreet.com*

"Although their structure is somewhat like that of a battery, fuel cells never need recharging or replacing."[19] There are certain components of the cell, such as the stacks and filters, that have limited life spans and need to be replaced periodically. Thus, fuel cells can continuously produce electricity if a constant supply of hydrogen and oxygen exists.[20]

Figure 7 is a schematic representation of a simple acid-electrolyte fuel cell, which is representative of the basic operation of all the various types of fuel cells. In this figure, it is easy to see that "fuel cells have a similar structure to a battery, with two porous electrodes separated by an electrolyte. Electricity is produced by a chemical reaction between a hydrogen-based fuel and oxygen inside the fuel cell."[21] In Figure 7, it is also possible to "see the electrochemical reaction that takes place inside a fuel cell. Hydrogen (H_2) flows over the anode and splits into positively charged hydrogen ions and electrons that carry a negative charge. The electrons flow through the anode to the external circuit, performing useful work (the electric current generated), while the hydrogen ions pass through the anode into the electrolyte, moving toward the cathode (the positive electrode). The electrons eventually return to the cathode, which is supplied with oxygen (O_2)."[22]

[19,20,21,22] Energy Educators of Ontario Energy Fact Sheet. "Fuel Cells." http://www.iclei.org/EFACTS/FUELCELL.HTM

Figure 7
Schematic of an Acid-Electrolyte Fuel Cell



Source: Energy Educators of Ontario

"At this point, the electrons, hydrogen ions, and oxygen react to form water (H_2O) and heat. In stationary fuel cell power plants, this heat can be captured and used for process heat in industries or space heating (cogeneration). As long as the fuel cell is supplied with hydrogen and oxygen, this electrical production can continue indefinitely."[23]

Fuel Cell Technologies

The next section is an excerpt of the Department of Energy's description of the various fuel cell technologies:

"Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. This section includes a discussion of the five most promising types and their applications."[24]

[23] Energy Educators of Ontario Energy Fact Sheet. "Fuel Cells." http://www.iclei.org/EFACTS/FUELCELL.HTM
[24] Department of Energy. "Types of Fuel Cells." http://www.eere.energy.gov/hydrogenandfuelcells/fuelcells/types.html

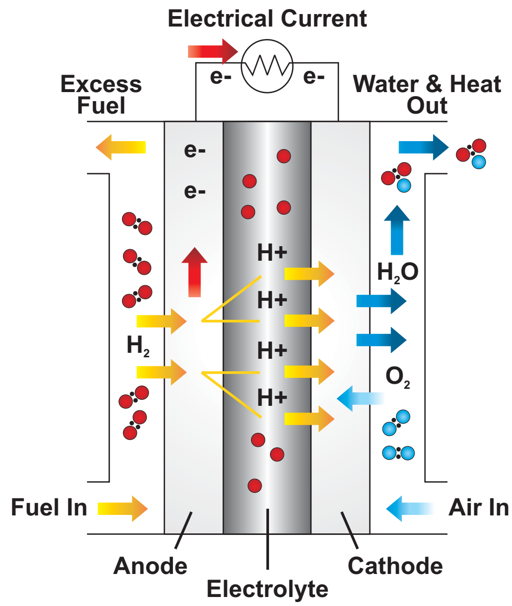
Table 1
The Five Most Promising Fuel Cell Types

Fuel Cell Technology	*Operating Temperature*	*Efficiency (Overall)*
Proton Exchange Membrane (PEMFC)	80° C	25-35% (40-60%)
Phosphoric Acid (PAFC)	200° C	37-42% (85%)
Direct Methanol (DMFC)	Room Temp to 90° C	40%
Molten Carbonate (MCFC)	650° C	60% (85%)
Solid Oxide (SOFC)	1,000° C	50-60% (80-85%)

Proton Exchange Membrane Fuel Cells (PEMFC)

"PEM fuel cells, also called polymer electrolyte fuel cells, deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst (see Figure 8). They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers.

Figure 8
PEM Fuel Cell



Source: U.S. Department of Energy, *Energy Efficiency and Renewable Energy*

"PEM fuel cells operate at relatively low temperatures, around 80°C (176°F). Low-temperature operation allows them to start quickly (less warm-up time) with less wear on system components, resulting in better durability. However, it requires a noble-metal catalyst (typically platinum) to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to carbon monoxide (CO) poisoning, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO.

"PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses. However, they currently have efficiencies of about 25 to 35 percent, which is lower than the grid and conventional combustion technologies.

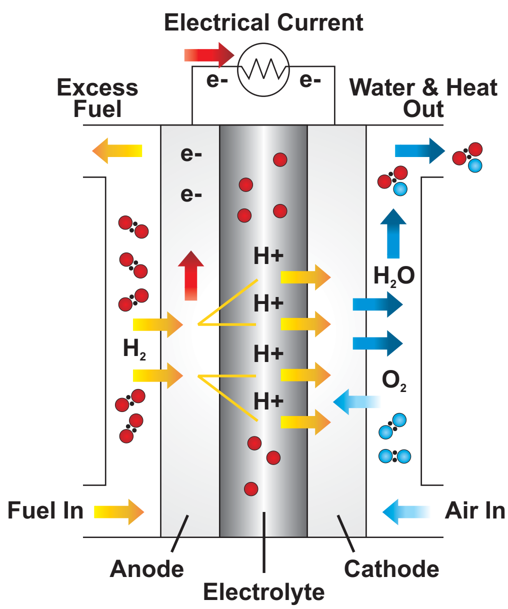
"A significant barrier to using these fuel cells in vehicles is hydrogen storage. Most fuel cell vehicles (FCVs) powered by pure hydrogen must store the hydrogen onboard as a compressed gas in pressurized tanks. Due to the low energy density of hydrogen, it is difficult to store enough hydrogen to allow vehicles to travel the same distance as gasoline-powered vehicles before refueling, which can typically travel 300 to 400 miles without refueling.

Higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline can be used for fuel, but the vehicles must have an onboard fuel processor to reform the methanol to hydrogen. This increases costs and maintenance requirements. The reformer also releases carbon dioxide (a greenhouse gas), though about 95 percent less than that emitted from current gasoline-powered engines."

Phosphoric Acid Fuel Cells (PAFC)

"PAFCs use liquid phosphoric acid as an electrolyte. The acid is contained in a Teflon-bonded silicon carbide matrix and porous carbon electrodes containing a platinum catalyst. The chemical reactions that take place in the cell are shown in Figure 9. The PAFC is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use.

Figure 9
PAFC Fuel Cell



Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy

"PAFCs are more tolerant of impurities in the reformate than PEM cells, which are easily "poisoned" by carbon monoxide (CO binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency). They are 85 percent efficient when used for the cogeneration of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell. A typical phosphoric acid fuel cell costs between $4,000 and $4,500 per kilowatt to operate. According to Dr. Michael Binder, Fuel Cell Program Manager at the U.S. Army's Engineer Research and Development Center/Construction Engineering Research Laboratory (ERDC/CERL), this technology has been developed as far as possible and will probably be phased-out due to its technical limitations."

Direct Methanol Fuel Cells (DMFC)

"Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. Direct methanol fuel cells (DMFCs), however, are powered by pure methanol, which is mixed with steam and fed directly to the fuel cell anode.

"Direct methanol fuel cells do not have many of the fuel storage problems typical of some fuel cells, since methanol has a higher energy density than hydrogen, though less than gasoline or diesel fuel. Methanol is also easier to transport and supply to the public using current infrastructure since it is a liquid, like gasoline."

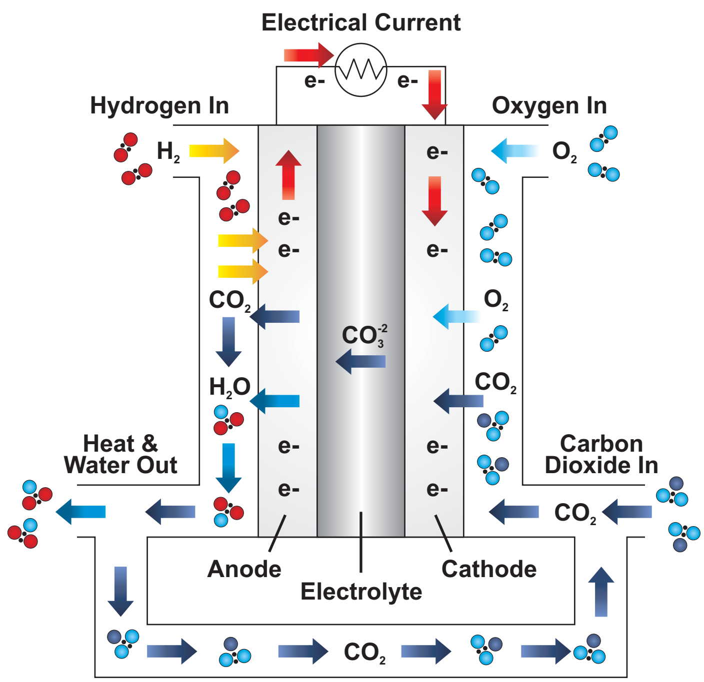
Molten Carbonate Fuel Cells (MCFC)

"MCFCs are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide (LiA_1O_2) matrix. Since they operate at extremely high temperatures of 650ºC (roughly 1,200ºF) and above, non-precious metals can be used as catalysts at the anode and cathode, reducing costs (see Figure 10).

"Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric acid fuel cells. MCFCs can reach efficiencies approaching 60 percent, considerably higher than the 37 to 42 percent efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be as high as 85 percent.

"Unlike alkaline, phosphoric acid, and polymer electrolyte membrane fuel cells, MCFCs do not require an external reformer to convert more energy-dense fuels to hydrogen. Due to the high temperatures at which they operate, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost.

Figure 10
Molten Carbonate Fuel Cells



Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy

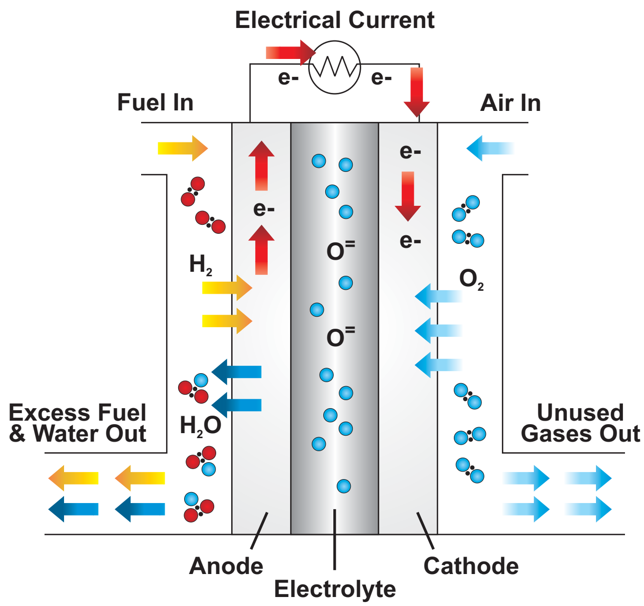
"Molten carbonate fuel cells are not prone to carbon monoxide or carbon dioxide "poisoning"—they can even use carbon oxides as fuel—making them more attractive for fueling with gases made from coal. Although they are more resistant to impurities than other fuel cell types, scientists are looking for ways to make MCFCs resistant enough to impurities from coal, such as sulfur and particulates.

"The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components, as well as fuel cell designs that increase cell life without decreasing performance."

Solid Oxide Fuel Cells (SOFC)

"SOFCs, as shown in Figure 11, use a hard, non-porous ceramic compound as the electrolyte. Since the electrolyte is a solid, the cells do not have to be constructed in the plate-like configuration typical of other fuel cell types. SOFCs are expected to be around 50 to 60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (cogeneration), overall fuel use efficiencies could top 80 to 85 percent.

Figure 11
Solid Oxide Fuel Cells



Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy

"Solid oxide fuel cells operate at very high temperatures, around 1,000ºC (1,830ºF). High-temperature operation removes the need for a precious metal catalyst, thereby, reducing cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system. SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types. In addition, they are not poisoned by carbon monoxide, which can even be used as fuel. This allows SOFCs to use gases made from coal.

"High-temperature operation results in slow startup and requires significant thermal shielding to retain heat and protect personnel. These operating constraints may be acceptable for utility applications but not for transportation and small portable applications. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology.

"Scientists are currently exploring the potential for developing lower-temperature SOFCs operating at or below 800ºC (~1,500ºF) that have fewer durability problems and cost less. Lower-temperature SOFCs produce less electrical power, however, and stack materials that will function in this lower temperature range have not been identified."[25]

[25] Department of Energy. "Types of Fuel Cells."

Forecast Underpinnings

The fuel cell industry (as opposed to fuel cell theory) is still very young, and there are few quantitative tools with which to measure its size and scope. Federal employment and earnings statistics currently lack the level of detail necessary to accurately capture business activity in this young industry, and there are no reliable means of extrapolating trends or analogous relationships with other energy sources due to the unique nature a "hydrogen economy." In the absence of data on business activity, literature searches and interviews were seen as appropriate tools to gain information about the development of the technology. Thus, the forecasts presented below were based on:

- A number of published reports and studies (a listing of reports and studies used in this forecast is presented in Appendix D).
- Articles and announcements in public publications and company-provided information.
- Interviews with knowledgeable experts (a listing of experts interviewed for this forecast is presented in Appendix E).

Applications

Several fuel cell types are under development, and they have a variety of potential applications. Fuel cells are being developed to power passenger vehicles, commercial buildings, homes, and even small devices such as laptop computers. The type of fuel cell technology utilized is often dictated by the constraints of its operating environment. Thus, we have chosen the following application classification scheme: stationary, portable, and mobile applications.

Stationary Applications

Fuel cells can be used to generate power centrally for use throughout existing electrical grids, but they are also well suited for "distributed power generation." Both provide lower pollutant and greenhouse gas emissions than conventional methods of power generation. Fuel cells will probably find their first wide-scale adoption providing on-site, grid-independent power for homes and offices and as a backup power source for critical electronic systems such as those used in data centers, hospitals, and emergency response headquarters. Besides clean and reliable energy, the heat produced as a byproduct of cell operation can be circulated to heat offices and provide hot water, similar to a conventional boiler. In fact, using the combined heat and power in this way considerably raises the efficiency of the system. A number of such units are already in use in the United States, Europe, and Japan.

> *The market for stationary fuel cells is very large, and these systems benefit from the following characteristics:*
> - *Large systems (>100 kW) obtain scale economies.·*
> - *Natural gas is widely available as a feedstock fuel to power the units.·*
> - *Installation and operation are performed by skilled technicians.*
>
> *As a result, stationary fuel cells are likely to be the initial applications driving commercialization and certain applications within the market since stationary fuel cells have features that lend themselves to early adopters.*
>
> ***—Fuel Cell Initiative Advisory Committee**, Texas Energy Conservation Office*

Portable Applications

"Fuel cells can compete with batteries and generators for portable use, from a few kilowatts to power an emergency home generator down to a few watts to power a laptop computer."[26] NEC Corporation and Toshiba have publicly demonstrated prototypes of this sort, and the first few products should enter the market in 2004. (See Figure 18 on page 50)

> *A fuel cell analyst and former Motorola executive recently told the Grove Fuel Cell Symposium in London that fuel cells could replace batteries in most applications by 2006.*
>
> ***—Chris Dyer***

Mobile Applications

"The advantages of fuel cells for transport are primarily environmental. The only emissions from a fuel cell vehicle come from the generation of hydrogen. These emissions are hardly measurable, making fuel cell vehicles virtually equivalent to zero-emission vehicles."[27]

Fuel cell cars, which use higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline, will have similar range and performance to cars with internal combustion engines. Even though the use of such fuels requires the use of reformers, a significant reduction in carbon dioxide will be achieved for every mile traveled, as compared to traditional internal combustion engines. Run on hydrogen, the cells produce zero carbon dioxide emissions. However, the use of hydrogen as a fuel will result in reduced engine efficiency because of the large tanks that must be used to store the low energy density gas.

[26,27] Matthey. "Fuel Cells." http://www.platinum.matthey.com/applications/fuelcells.html

Forecast of Commercialization

The following forecasts of how the various types of fuel cells will be employed over the coming two decades, together with projections of evolving costs, are offered here. These are based on analysis provided in the following sections.

> *On December 3, 2002, Coleman Powermate announced the launch of Airgen™, the first hydrogen fuel cell generator available to the public.*
> *The Airgen™ is powered by a Ballard Nexa™ Power Module (1.2 kW DC fuel cell system).*
>
> ***—Coleman Powermate***

Table 2
Forecast of Fuel Cell Use

Short Term (0-5 Years)		
Application	***Customer***	***Projected Fuel Cell Cost***
Stationary	Hospitals, Data Center Backup Power Generation	$1,500/kW
Portable	Laptops, PDAs, Cellular Phones	$5,000/kW

Mid Term (5-10 Years)		
Application	***Customer***	***Projected Fuel Cell Cost***
Stationary	Power Generation Remote Supply (Grid Backup)	$1,000/kW
Stationary	Cogeneration	$750/kW
Mobile	Fleet Vehicles	$500/kW

Long Term (10 or more Years)		
Application	***Customer***	***Projected Fuel Cell Cost***
Mobile	Passenger Vehicles, Delivery	$400/kW
Stationary	Distributed Power Generation (Primary)	$400/kW

Background Information

Stationary Applications

In many respects, the use of fuel cells for electric power production is very attractive. Fuel cell systems are versatile, quiet, and essentially non-polluting. Because of these attractive characteristics, a number of companies are investing a great deal of time and money to develop practical and cost-efficient fuel cell systems. (A list of companies currently engaged in the development of stationary fuel cell systems is presented in Appendix F.)

Without a doubt, the single major factor limiting the widespread use of fuel cells in power production is their cost. Although estimates vary, quoted costs range from about $3,000 to $4,000 per kilowatt. At this cost level, the majority of commercial installations will require some form of subsidy or market incentive to yield attractive economics. The magic number for cost is often quoted as about $1,500/kW. At this price, fuel cell systems become attractive for a broad spectrum of uses, such as: in facilities requiring guaranteed power, such as hospitals, semiconductor chip manufacturers, and data centers; in areas where toxic fumes are unacceptable, such as mines; in areas where pollution reduction is necessary; and in areas with growing electric power needs where new power transmission lines are prohibited, especially expensive, or difficult to install.

> *"Over the past 10 years, cost-shared fuel cell research and development funded primarily by the U.S. Department of Energy at U.S. national laboratories, universities, and private companies has improved several fuel cell technologies through significant size and cost reductions (each by a factor of 10). However, the cost of fuel cells still remains high and has made them unaffordable for most consumers, and very few products are available with full commercial warranties and a track record for reliable operation."*
>
> ***—U.S. Department of Energy,*** *Fuel Cell Report to Congress*

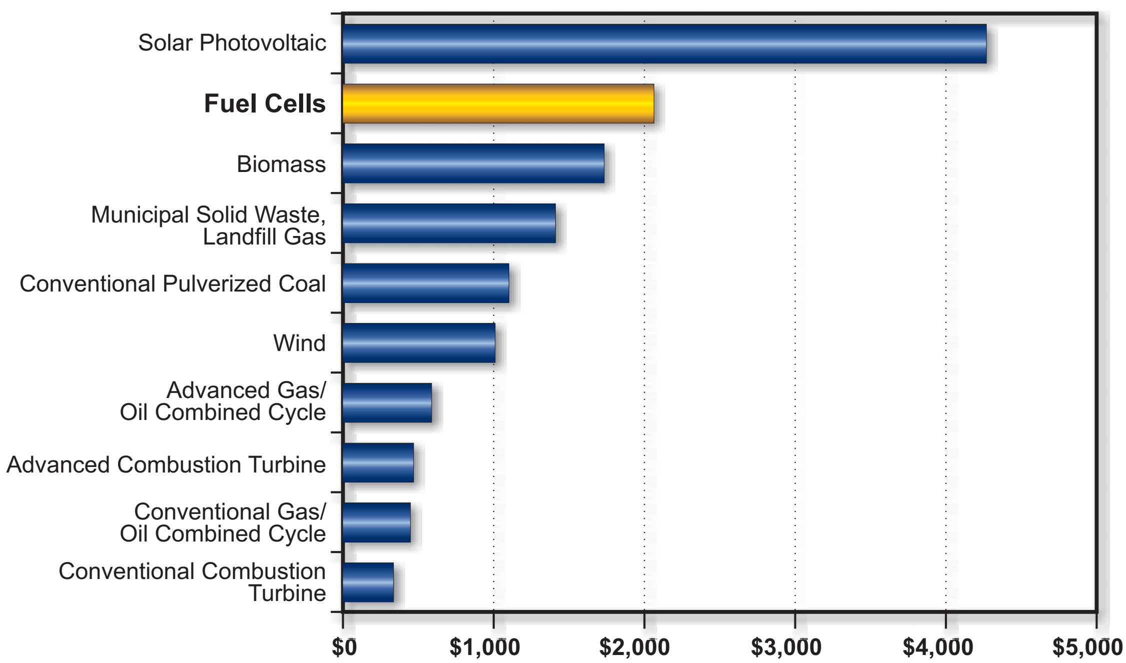
A small number of such units are already in commercial use in the United States, Europe, and Japan.

A key reason for the current high cost of fuel cells is that they are now manufactured on a single unit basis. It has been estimated by the U.S. Department of Energy (DOE) and industry sources that the price of high-temperature stationary fuel cells urrently on the market could be reduced to the $1,200 to $1,500/kW range, using current technology, if the number of units produced was raised significantly. At this price, fuel cell systems would be an attractive power source alternative. The current cost for conventional gas/oil combined cycle generators is about $400/kW, and conventional combustion turbine generators are a bit less. (Figure 12 shows the capital cost of various generating options.)

> *"There's a lot of discussion about what the right size fuel cell is for the typical home. When you do the math and consider that most consumers pay about 8 to 12 cents per kilowatt, you've really got to get the capital costs of a fuel cell down to about $500 a kilowatt before you sell to individuals."*
>
> —***Mark Sperry,*** *Chief Marketing Officer, Plug Power*

However, these costs for central station generators do not take into account the not insignificant transmission and distribution costs associated with such systems. For example, recent combined cycle projects proposed for areas where emissions are a concern have installed costs of $1,000 to $1,200 per kW.

Figure 12
Capital Cost per kW of Capacity



Source: U.S. Energy Information Adminstration, *Assumptions to the Annual Energy Outlook 2002* (U.S. Department of Energy, EIA 0554, 2002), p. 68.

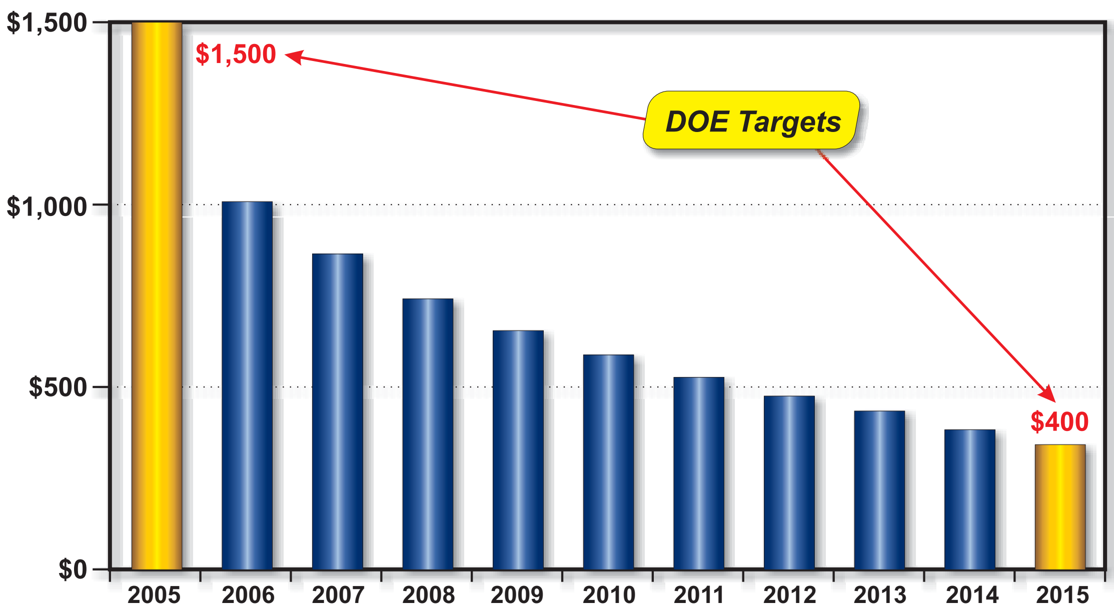
Recently, UTC Fuel Cells announced a new proton exchange membrane demonstration fuel cell that will sell for about $2,000/kW. This, of course, is approaching the "magic number."

Basically, adoption of fuel cell systems is facing a chicken/egg quandary, i.e., costs will not come down until production is increased, and production will not go up until costs come down. Because of this situation, key players—the federal government, various state governments, electric utilities, and education groups—are currently subsidizing the production, installation, and operation of fuel cell systems to encourage development and to gain experience in the field. One interesting development in this area is the sponsorship of fuel cell systems by the U.S. Department of Defense. DoD is funding the installation of fuel cell systems in a number of defense and other government sites to learn more about their operation in "real world" situations; to date, about 150 are installed or planned.

To achieve the goal of lower fuel cell costs, in August 2001, the DOE announced a $500 million initiative to drastically reduce the cost of fuel cells to $1,500/kW by 2005 and $400/kW by 2015. The first, $1,500/kW, is the price at which the DOE feels fuel cells will gain wider acceptance in applications such as stationary power generation, and $400/kW is the price at which the technology will achieve wide acceptance (automobiles, etc.). The DOE is funding research projects that show promise in achieving this goal. DOE's projection of future fuel cell costs is shown in Figure 13.

Figure 13

Projected Cost Curve (per kW of Installed Capacity)



Source: U.S. Department of Energy

The Texas State Energy Conservation Office's Fuel Cell Initiative Advisory Committee (FCIAC) www.seco.cpa.state.tx.us/fciachome.htm concurs with the DOE's assessment and believes that fuel cell manufacturers must be able to produce and sell 1,000 megawatts of generation capacity in Texas to achieve competitive pricing and industry self-sufficiency at the $1,500/kW level. To that end, the FCIAC is proposing tax credit initiatives that would encourage the installation of 35 MW of fuel cell capacity by January 2005 and 1,000 MW by January 2010. The SECO paper, "Accelerating the Commercialization of Fuel Cells in Texas," states that currently about 50 MW of fuel cell capacity is installed in the entire world; therefore, FCIAC is proposing a very aggressive adoption schedule that will require significant incentives. Currently, according to SECO, 87,000 MW of electricity is generated by electric utilities in the state.

Each of the various types of fuel cell systems provides challenges that must be addressed if the systems are to be successful. For example, PEM fuel cells require the use of platinum catalysts. Platinum is both expensive and scarce. (Rubidium can be used in place of platinum, but this metal is at least as expensive and scarce as platinum.) With regard to price, one fuel cell manufacturer stated that the cost of platinum in a medium-sized fuel cell sold by his company was less than $100. This cost would not appear to be a very significant factor in fuel cell cost. However, if the number of fuel cells manufactured increased materially, significant rises in the price of this precious metal could well occur. Research is currently underway both to find ways to replace the platinum with a more abundant catalyst or to use platinum more efficiently.

A number of fuels have been proposed for fuel cell operation, e.g., methane, methanol, propane, and hydrogen gas. In reality, all of these fuels must be converted into hydrogen ions for the fuel cell to operate. Although many mobile applications envision the use of hydrogen gas as a fuel, most current stationary fuel cell systems use "reformers" to convert the base fuel. Given the existing methane infrastructure, fuel supply does not appear to be a significant problem.

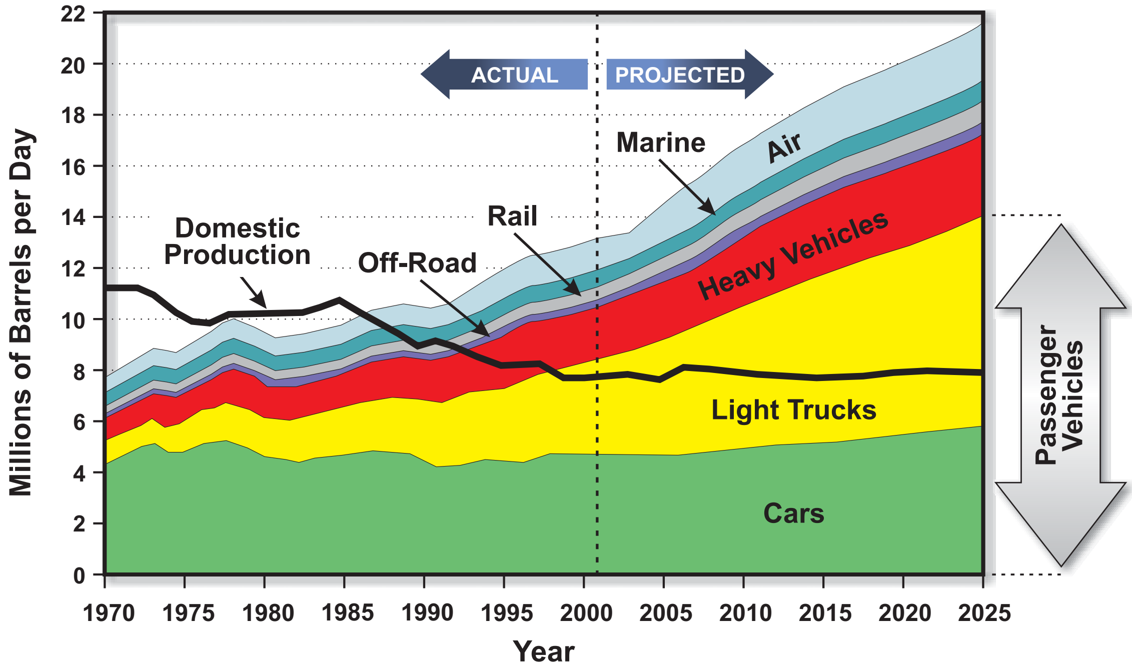
Mobile Applications

Fuel cells can be used to provide propulsion or auxiliary power for many transportation applications. PEM fuel cells are most applicable to transportation due to their low operating temperature, fast startup time, and increasingly high energy density.

> *According to a recent study, "10,000 fuel cell vehicles running on non-petroleum fuel would reduce oil consumption by 6.98 million gallons per year."*
>
> ***—Arthur D. Little** Consulting Company*

Highway vehicles. According to the Environmental Protection Agency (EPA), highway vehicles account for about 65 percent of the nation's petroleum use (an estimated 13 million barrels per day) and 78 percent of carbon dioxide (greenhouse gas) emissions. As Figure 14 indicates, U.S. oil consumption is projected to increase dramatically over the next 25 years, not to mention significantly higher consumption rates in developing nations around the world. At the same time, a projected decline in U.S. domestic oil production will result in increased dependencies on foreign oil supplies.

Figure 14
US Oil Use for Transportation



Source: U.S. Department of Energy

> *"I believe fuel cell vehicles will finally end the hundred-year reign of the internal combustion engine as the dominant source of power for personal transportation. It's going to be a winning situation all the way around—consumers will get an efficient power source, communities will get zero emissions, and automakers will get another major business opportunity—a growth opportunity."*
>
> ***—William C. Ford, Jr., Chairman,*** *Ford Motor Company International Auto Show (January 2000)*

Advances in fuel cell power systems for stationary power production and eventually transportation could substantially improve energy security and air quality. While fuel-cell-powered cars are not yet commercially available, almost every major auto manufacturer has a fuel cell vehicle program underway, with various targets for demonstration between 2003 and 2006 www.eere.energy.gov/hydrogenandfuelcells/pdfs/fc_report_congress_feb2003.pdf. (An overview of current highway vehicle fuel cell projects is presented in Appendix G.)

> *"Successful application of fuel cell technologies in automobiles will improve energy security and provide significant environmental benefits. A 10 percent market penetration could reduce U.S. oil imports by 130 million barrels per year. Fuel cell vehicles will reduce urban air pollution and mitigate climate change. They will be 70 percent to 90 percent cleaner than conventional gasoline-powered vehicles on a fuel cycle basis, and will produce 70 percent less carbon dioxide emissions."*
>
> ***—The President's Committee of Advisors*** *on Science and Technology Federal Energy Research and Development for the Challenges of the Twenty-First Century*

For example, in 1997, "DaimlerChrysler, Ford, and Ballard Power Systems joined together in a consortium to build fuel cell engines and drivetrains for cars. Recently, DaimlerChrysler, Ford, Honda, and Toyota confirmed that they expect to build tens of cars each by 2004, with the numbers increasing for every following year."[28] In October 2001, Ballard announced that its ZEbus (zero emission bus) successfully completed its fuel cell demonstration program with SunLine Transit Agency in Thousand Palms, California (Figure 15). Additional units were successfully demonstrated in Chicago, Orlando, and at Georgetown University. Over the next few years, "a total of 30 fuel cell buses built by DaimlerChrysler and Ballard will go into service in Europe. This project will demonstrate fuel cell technology to a wide audience and increase public awareness of fuel cells."[29]

DOE defines other fuel cell applications: "Other highway-based applications include large passenger buses and long-haul trucks. Fuel cell auxiliary power units (APUs) for commercial trucks could also reduce energy use and emissions, since these vehicles must often run while idle to provide electricity for refrigeration, heaters and air conditioners, and sleeper compartment accessories."[30]

[28,29] Matthey. "Fuel Cells." http://www.platinum.matthey.com/applications/fuelcells.html
[30] Department of Energy. "Fuel Cells: Transportation Potential Applications"

Figure 15
ZEbus (Zero Emission Bus)

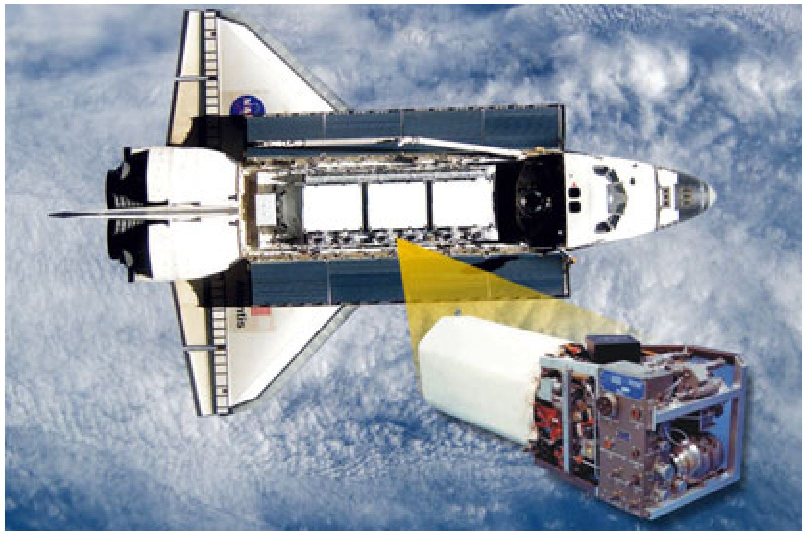
Courtesy of SunLine Transit

Other land transportation. "Other potential surface transportation applications include rail locomotives, mining locomotives, scooters, and personal mobility vehicles for the disabled."[30]

Aerospace. "Fuel cells have been used to provide power in spacecraft since the 1960s. Fuel cells were used in all 18 Apollo missions and over 100 space shuttle missions. In fact, all electrical power for NASA's space shuttle orbiter is provided by fuel cell power plants. In the orbiter, a complement of three 12 kW fuel cells produces all onboard electrical power; there are no backup batteries, and a single fuel cell is sufficient to ensure safe vehicle return. In addition, the water produced by the electrochemical reaction is used for drinking water and spacecraft cooling. Other similar applications include powering near-earth-orbit (NEO) satellites."[31]

[30,31] Department of Energy. "Fuel Cells: Transportation Potential Applications"

Figure 16
Fuel Cell Power Plant for the Space Shuttle



Courtesy of NASA

Marine vessels. "Ships and submarines can use fuel cells for auxiliary power. In fact, a new submarine developed by German company Howaldtswerke-Deutsche Werft AG (HDW) uses a fuel cell system that allows the submarine to loiter at low speeds for extended periods of time without surfacing. During such operations, the fuel cell produces limited amounts of noise and exhaust heat, which assists making the submarine undetectable.

"At some point in the future, recreational and personal watercraft may also be powered by fuel cells."[32]

Demonstration Projects and Programs for Mobile Applications

The Department of Energy supports fuel cell demonstration programs all over the United States. "Fuel cell vehicle demonstrations are currently underway in the United States, with federal, state, and local government entities partnering with industry. Most of these demonstration projects are evaluating the performance of cars, light-duty trucks, and transit buses."[33]

California Fuel Cell Partnership. "In the United States, the majority of fuel cell vehicle demonstrations for passenger cars and trucks are being conducted in cooperation with the California Fuel Cell Partnership (CaFCP) www.fuelcellpartnership.org. CaFCP is a collaboration of auto companies, fuel providers, fuel cell technology companies, and government agencies (including DOE and EPA)

[32,33] Department of Energy. "Fuel Cells: Transportation Potential Applications"

demonstrating fuel cell electric vehicles in California under day-to-day driving conditions. The goals of the partnership are to test and demonstrate the viability of fuel cell vehicles (FCVs) and related technology under real-world conditions, move them toward commercialization, and increase public awareness. The partnership expects to place about 60 FCVs and fuel cell buses on the road by 2003."

Toyota Fuel Cell Vehicle Demonstration with California Universities. "Toyota is conducting a fuel cell vehicle demonstration study with two California universities: the University of California-Davis and the University of California-Irvine www.toyota.com/about/environment/technology/fueltech.html. Currently, Toyota is leasing to these universities a total of six "market-ready" hydrogen hybrid FCVs based on its Highlander sport utility vehicle platform, so they can be evaluated under real-world driving conditions (see Figure 17). The demonstration program will span three years, with each vehicle being driven for 30 months. The demonstration will allow Toyota to get feedback from drivers, as well as increase public awareness of fuel cell technology."[34]

Figure 17
Fuel Cell Powered Toyota Highlander

Courtesy of U.S. Department of Energy

Honda Fuel Cell Vehicle Demonstration with City of Los Angeles. "Honda is conducting a fuel cell vehicle demonstration with the City of Los Angeles. The city leased five Honda FCX hydrogen fuel cell vehicles beginning in December 2002 with other vehicles to follow in 2003 http://world.honda.com/news/2002/ 4021202.html. Los Angeles City Hall employees will use the vehicles as pool cars and for commuting. The demonstration will allow Honda to evaluate the vehicles under real-world driving conditions and obtain feedback from customers. It may also accelerate public acceptance of these vehicles and help in the development of a refueling infrastructure for fuel cell vehicles."

[34] Department of Energy. "Fuel Cells: Transportation Potential Applications"

California Transit Agencies to Put Fuel Cell Buses into Regular Service. "Two California transit agencies are initiating an internationally-recognized fuel cell demonstration. AC Transit in Richmond and SunLine Transit Agency in Thousand Palms will be adding state-of-the-art hydrogen fuel cell buses to their fleets and setting up infrastructure facilities for fueling and maintenance.

"The demonstration, which will run from 2004 to 2008, will include an extensive, multi-year evaluation program, developed in conjunction with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) www.nrel.gov and the University of California-Davis Institute of Transportation Studies www.its.ucdavis.edu. Data will be collected, analyzed, and compared to that of other fuel cell bus programs internationally. NREL will maintain a central repository for this information, which will be made available via the NREL and AC Transit websites."[35]

Portable Applications

Today's portable electronic devices perform an ever increasing number of complex tasks. The increased functionality of these devices is a major challenge to manufacturers who must supply them with batteries capable of meeting their power demands.[36]

"The inherently higher energy density of small fuel cells, in comparison to batteries, would lead to longer operational times and serve the power demands of next-generation portable electronics. As a result, many device manufacturers are seriously examining the technology potential of fuel cells."[23] Casio, HP, NEC, and Motorola all have ambitious fuel cell programs and are developing miniature fuel cell solutions to power portable electronics. Figure 18 shows NEC's experimental direct methanol micro fuel cell for portables that uses nanocarbon material for its electrodes. NEC expects that the device, which measures 40mm by 50mm and 5mm thick, will be more powerful by an order of magnitude than lithium ion batteries, currently the best available power sources for portable devices such as laptop computers.[37]

> *"The energy capacity of the current Li-ion batteries is around 130 Wh/kg. We estimate about 1,300 Wh/kg or more for a well-designed portable direct methanol fuel cell based on carbon nanotube technology."*
>
> ***—Dr. Yoshimo Kubo,*** *Director, Portable Fuel Cell Project, NEC Fundamental Research Laboratories (Tsukuba,* Japan)

35 Department of Energy. "Fuel Cells: Transportation Potential Applications"
36 Eye for Fuel Cells. "Fuel Cells for Portable Applications: Conference Announcement." Boston September 2002
37 "NEC Researchers Employ Carbon Nanotubes to Design Micro DMFC for Portables." *Hydrogen Fuel Cell Letter* October 2001

Figure 18
Portable Direct Methanol Fuel Cell

Source: Hydrogen Fuel Cell Letter (October 2001)

"While consumer applications such as cell phones, notebook computers, camcorders, and cordless tools will be the obvious mass market application for direct methanol fuel cells at a power level up to 100 W, there should be an earlier market for PEM fuel cells in a niche sub-1 kW market. The type of device that fits this class includes weather stations, signal units, APUs, gas sensors, and security cameras. Companies involved in this area include Plug Power www.plugpower.com and Ballard Power Systems www.ballard.com."[38]

Nevertheless, portable fuel cells are in their infancy. Investment costs to generate 1 kilowatt are still very high, around $10,000 to $100,000 per produced kilowatt. However, portable fuel cells should become cost competitive (~$5,000/kW) with lithium-ion batteries, commonly used in laptop computers, within the next five years.

The forecasts presented in the previous section are based on projections that the authors believed to be the most likely or, as such forecasts are often referred to, a "surprise free" scenario. However, in a technology as dynamic as fuel cells, various unexpected breakthroughs, events, or decisions could materially change the nature, rate, and implications of technical advances and market developments. Shown below are some of the factors that might accelerate or deter the fuel cell developments projected above.

> *Global demand for fuel cells is forecast to reach $46 billion by 2011.*
>
> ***—PricewaterhouseCoopers***

[38] Eye for Fuel Cells. "Fuel Cells for Portable Applications: Conference Announcement."

Accelerators

It is generally agreed that market forces alone are unlikely to result in large-scale use of fuel cells in the next few decades. Increasing efforts by state and federal governments to establish joint programs with private industry should result in accelerated development of a vibrant fuel cell industry. President George W. Bush's January 2003 announcement that $1.2 billion will be invested in the development of fuel cell automobiles over the next decade is an indication that the federal government is committed to fuel cell advancement. More aggressive and effective public/private partnering and support should accelerate fuel cell progress.

There is currently a considerable amount of research going on in industries, universities, and government to solve basic problems limiting the expanded use of fuel cells. Projects include work on methods for reducing requirements for platinum catalysts in fuel cells, increasing the active life of fuel cells, reducing operating temperatures, decreasing component costs, and reducing health and safety concerns. There is also research being conducted in "balance of plant" subsystems, such as fuel processors, hydrogen production, storage and distribution, power electronics, and heat exchangers. The forecasts assume progress in each of these areas. However, technical breakthroughs in one or more of these areas could materially enhance the market attractiveness of the technology.

> *During August 2001, the DOE announced a $500 million effort to produce breakthrough fuel cells that will overcome current cost barriers. DOE believes that developing an all-solid-state fuel cell "building block" that can be mass manufactured is one of the best ways to dramatically lower costs, much like advances in solid-state technology that have cut the costs of computers and other electronic devices.*
>
> ***—U.S. Department of Energy***

Because of the dramatic promise of fuel cells, there is a great deal of interest in their development throughout the world. International commitment to fuel cell technology enhances the probability of key breakthroughs.

An important element in the development of a vibrant fuel cell industry will be the relationship between the owners and operators of individual fuel cells and the local electric utilities. Most contemplated fuel cell systems envision an interconnection between the fuel cells and the electric power grid. Typically, electricity transmission and distribution companies are very concerned about connecting distributed power sources to their grids. (In Texas, transmission and distribution companies are forbidden by law from owning generation facilities.) The adoption of uniform national standards that address the interconnection of fuel cells to utility grids will increase their economic feasibility and accelerate their utilization. These standards would regulate both the physical (equipment) connection of the cell to the grid and economic issues related to the "buy back" of fuel cell generated power by utility companies. The Institute of Electrical and Electronics Engineers IEEE SCC21 P1547 Working Group http://grouper.ieee.org/groups/scc21/1547/ is currently working to produce a standard document for interconnection of all types of distributed generation resources with electric power systems by the end of 2003. Moreover, a new technology, the isolated gate bipolar transistor (IGBT), is currently being developed that will decrease the cost of interconnecting fuel cells with the power grid.

> *The American Gas Association forecasts that, by 2020, on-site power at industrial facilities or distributed generation in commercial or even residential locations will account for 20 percent of all new capacity, or 5 percent of all electricity generated in the United States.*
>
> ***—American Gas Association***

By nature, fuel cells produce direct current (DC) electricity. Since power grids and most electric equipment currently utilize alternating current (AC) electricity, the output of fuel cells normally must be converted into AC before it is used. However, there are important exceptions to the AC norm, including computers and related equipment that use DC power. If organizations that rely on the use of large numbers of computers were to install DC wiring systems throughout their operations, this would provide an important incentive for fuel cell adoption.

The forecasts presented above assume no dramatic, long-term change in the international petroleum market. Major disruptions in petroleum supply will result in increased gasoline and fuel oil prices and will, thus, increase the relative attractiveness of fuels that are in greater supply in the United States, e.g., natural gas. This should accelerate efforts to develop fuel-cell-powered automobiles.

Decelerators

The forecasts assume that current interest of government agencies and commercial organizations will continue to grow over the next two decades. If this interest does not occur, there will undoubtedly be an impact on continuing progress in the fuel cell area. For example, a prolonged period of economic sluggishness, as the United States is currently experiencing, could reduce government spending on fuel cell research and its “will” to offer tax incentives. The continuation of both of these forms of supports is essential to lowering the cost of cells to the point that they gain widespread acceptance. Such economic doldrums could also impact commercial support of fuel cells.

The forecasts also assume that technical progress in the fuel cell area will continue at a rate comparable to recent advances. Failure to maintain this progress or the discovery of significant, unanticipated technical problems could deter industry development.

Currently, production, transportation, storage, and distribution systems for hydrogen gas are limited in Texas. However, establishing such systems does not appear particularly difficult, providing funding is available. On the other hand, there is a solid infrastructure in Texas for handling methane. However, the process of reforming methane and methanol involves the release of carbon atoms, which are “stripped” from the fuel, into the environment. These carbon atoms react with oxygen in the air to form carbon dioxide, a greenhouse gas. Nitric oxide, an undesirable air pollutant, is also produced in the reformation process. This is obviously a problem because emission concerns are a major factor driving the development of fuel cells in the first place.

Fuel Cell Forecast: Final Comments

Over the last decade, interest in fuel cell technology has grown steadily and projections of future progress have been increasingly optimistic. Deans and other instructional officers of Texas community and technical colleges (CTCs) must be aware of the realities underlying this technology and determine the implications of these realities to their decisions about adding fuel cell programs to their curricula.

The practical applications for fuel cells fall into two general categories—power for vehicles (primarily automobiles) and production of electric power. A number of major automobile manufactures have developed prototype fuel cell models, and some tests are being run on fuel-cell-powered automobiles and buses. In addition, President George W. Bush has promised additional funding for mobile fuel cell development. It should be noted, however, that similar prototype programs for electric cars have been in progress for at least two decades with little electric car production resulting.

The development of a significant fuel cell automobile industry will require extensive retooling of current production lines; the development of hydrogen production, storage, and distribution systems; advances in technology sufficient to compete with a mature internal combustion system; and acceptance of the public of an unfamiliar technology. Even the strongest fuel cell proponents doubt that these events could occur in less than a decade. The prospects of a viable fuel cell automotive market is further diminished by increasing interest of automotive companies in hybrid electric/internal combustion vehicles. A retooling of current production lines to produce this type of car would make a later retooling for fuel call cars even less likely.

Given these factors, it does not appear that there will be many employment opportunities for automotive fuel cell specialists in a time frame of interest to CTCs, i.e., three to eight years. It is also significant that the knowledge, skills, and abilities (KSAs) related to the maintenance and repair of fuel cell automobiles are very different from those required for current automobiles, so that there will be very few crossover opportunities.

The situation for electric power fuel cells as it applies to CTCs is quite different. There are driving forces in place that could result in a viable fuel cell power industry in the relatively near future. Typically, when a revolutionary new technology arises, it faces severe structural disadvantages. The old technology has an established physical and intellectual infrastructure; people understand the old technology and are loyal to it; systems are in place to operate, maintain, and repair the old technology; and companies are making money producing and utilizing the old technology. In addition to these structural disadvantages, the new technology typically faces an important technical obstacle—the new technology is inferior to the old technology in regard to most of the parameters that people use to compare the two. Successful new technologies tend to follow a similar path to success. Although the new technology is inferior to the old technology in most traditional measures, there are some characteristics of the new technology that makes it particularly attractive to some specific part of the overall market. Typically, this special market is small, but it is not very cost sensitive. Service to this market provides funding for additional development that in time opens up larger, but more cost sensitive market areas. This "bootstrap" operation continues until the new technology becomes commercially viable.

Currently, it appears that fuel cell technology is in the first phase of this process. In general, fuel cell systems are more expensive, have shorter operating lives, and are less well understood than traditional generating sources. However, there are certain situations, such as in mines and other restricted working areas, where fuel cells provide special, almost essential characteristics. There are other situations, such as areas with particularly difficult environmental problems or where cheap hydrogen is available, in which fuel cells offer distinct advantages. There are indications that fuel cell costs are nearing the point where they will be cost effective in these situations. Thus, it appears that fuel cells may well be following the path to wide spread commercial acceptance typical of other new technologies. The question for CTCs is how rapidly the process will proceed and what will be the total size of the industry when it reaches maturity.

The answers to these questions depend, in large measure, on developing near term demand and research and development success. There is no doubt that the recent power outage in the Eastern United States and Canada will instigate a review of the current power supply and distributions systems. It is probable that this review will increase interest in distributed power networks, both within the traditional power industry and among individual power users. The most common current electric backup systems are diesel generators. However, these generators present serious pollution problems. There are, of course, other distributed power options available, such as microturbines, but it is quite possible that many power companies and individual power users will investigate the use of fuel cells. Moreover, the traditional power companies will undoubtedly be motivated to accommodate the connection of separate generators to the power grid.

In projecting the employment opportunities for CTC graduates in the fuel cell power area, it is obvious that requirements for fuel cell specialists within a given area will depend on the density of fuel cell generators in that area. Unless there is a very rapid increase in the number of fuel cells installed, there will be few areas that will justify full-time fuel cell specialists for installation, maintenance, and repair. On the other hand, many of the KSAs of the fuel cell specialists are very similar to those required in related areas. For example, those required to service the electrical controls of a fuel cell are essentially the same as those required to service any electric control system. Thus, a student trained in fuel cell systems will be able to gain employment in the electronic controls field, with the additional advantage of having special abilities in the fuel cell area. Students who complete the program being developed by the Fuel Cell Curriculum Consortia can expect to have many attractive employment opportunities upon graduation.

In summary, because of the favorable characteristics of fuel cells, there is widespread interest in their development and application in government and commercial sectors throughout the world. It is highly probable that this interest will be reflected in continuing growth of the fuel cell industry over the next two decades. However, there are serious obstacles—technical, economic, and institutional—to the rapid growth of the industry. Such obstacles have deterred fuel cell adoption for decades. However, there are no fundamental reasons why these obstacles cannot be overcome in the reasonably near future.

Therefore, it is probable that developments in fuel cells in terms of core research, practical applications, and economic attractiveness will be characterized by steady but measured progress.

Appendix: Overview of Develop a Curriculum (DACUM) Meeting

Overview

In order to identify the skills graduates of the state's community and technical colleges will have to possess for employment in the fuel cell industry, the authors attended a Fuel Cell Technologist DACUM workshop in Houston at the Marriott Intercontinental Hotel on April 2-3, 2003.

In summary, DACUM is a method of analyzing occupations by using input from expert workers to list the specific tasks essential for successful job performance. This approach to occupational analysis has proven to be a very effective, low-cost method of quickly determining the tasks that must be performed by persons employed in a given job or occupational area. Information resulting from the DACUM task analysis is ultimately incorporated into curriculum and instructional materials for students and instructors.

The Fuel Cell Technologist DACUM, which was facilitated by Michael Jones of TSTC Waco and Larrie Barkley of the Lamar Institute of Technology, involved individuals with proven qualifications in a number of different fuel-cell-related areas. This group included 12 people from fuel cell manufacturers, fuel cell installers, and fuel cell users/researchers. TSTC and the Texas Fuel Cell Technology Consortium will use data from the DACUM to establish a relevant, up-to-date fuel cell curriculum for two-year colleges in the state.

Title and Job Description

The first order of business for DACUM participants was to develop an occupation title and job description. The occupation title of *fuel cell service technician* was chosen. DACUM participants emphasized that this title would apply only to those who operated and maintained the cells, *not* installers. DACUM participants agreed that this distinction was important, because the skills and qualifications of fuel cell installers are different than the ones required of operators and maintainers; state licensed plumbers and electricians will be required for fuel cell installation.

Additionally, although participants agreed that there needed to be a formal interface structure between fuel cell installers and fuel cell maintainers/ operators at the commissioning (start up) of a system, they agreed that the DACUM would focus on the skills and tasks required of maintainers and operators.

Duties

The group next discussed the duties of a fuel cell service technician. These duties included:

Public relations/marketing. Fuel cells are a new technology with which most people in the state are unfamiliar. Graduates of the state's first fuel cell programs will be ambassadors who will educate the public about the capabilities (and limitations) of the systems. Additionally, technicians will serve as "peacekeepers" between fuel cell users and manufacturers.

System certification. Technicians will be required to commission and document (in reports) the condition of systems upon start up. Additionally, technicians will be required to check electrical/mechanical interfaces according to manufacturer site specifications and applicable state laws at start-up.

Service. Technicians will be required to repair, troubleshoot, and maintain cells. Maintenance will include both scheduled and unscheduled items. (See sub-duties noted below)

System interfaces. Technicians will be responsible for the interconnections between the fuel cells and the systems with which they are connected (utility grids and building power plant and cogeneration facilities).

Safety awareness. Technicians must be familiar with and adhere to relevant safety regulations. These regulations include OSHA guidelines (trip and accident hazards), HAZMAT regulations related to the disposal of toxic materials, local fire and National Electrical Codes, and gas leak detection procedures for both natural gas and hydrogen.[8]

Under Service, a number of specific sub-duties were identified by the group. These duties include:

Maintain records. Technicians will document system performance in standardized field reports (gas quality, operation temperatures, maintenance procedures, etc.).

Maintain air, fuel delivery, and fuel processing systems. Technicians will be responsible for ensuring the proper function of the systems that deliver and process the fuel and air delivered to the cell. This duty will include ensuring fuel and air purity and maintaining the systems that reform the fuel into hydrogen.

[8] OSHA = Occupational Safety and Health Administration. HAZMAT = hazardous materials.

Maintain electrical/electrical control systems. Technicians will have to possess a solid understanding of AC/DC motors, invertors, transformers, high-voltage interconnects, interfaces between the utility grid and cell, and electrical control systems.

Maintain thermal management systems. Technicians will be required to maintain the systems used to heat and cool the fuel cell stack (membranes) and other systems.

Knowledge and Skills

DACUM participants also identified a number of knowledge and skill sets fuel cell technicians must possess in order to work on fuel cell systems:

Algebra-level math proficiency.

Ability to read schematics, blueprints, diagrams, ladder diagrams, and physical layout drawings.

Three-phase power theory, distribution systems, transmission systems, circuit protection systems.

National Electric Code and fire codes.

Electrothermal processing.

Single-phase power.

DC power distribution.

Fundamentals of catalyst operation.

Grid protection (islanding): isolating fuel cells from the utility grid should power on the grid fail.

Grid fundamentals.

Problem solving/analytical skills.

Tools and Equipment

Participants also identified tools and equipment with which fuel cell technicians must be familiar with:

Gas analyzers.

Oscilloscopes, signal generators, bridges, voltage meters, meggers, hipotential tests, amp meters, grounding equipment, electrical wire.

Computers.

Trends and Concerns

Finally, each participant was asked to identify and discuss trends and/or concerns that might impact the training and demand for fuel cell technicians in the state. These items were identified as outlined in the following paragraphs.

Cost. There was considerable agreement among participants that the current cost of fuel cells did not make them economically viable. Demand for fuel cell technicians will increase only as manufacturers are able to reduce their cost to a point that fuel cells are competitive with other power generation technologies.

State licensing/regulatory environment. Participants felt that restrictive government regulation of the fuel cell industry might slow down the technology's adoption rate. The Texas Railroad Commission is currently discussing how it might regulate the fuel cell industry in terms of hydrogen storage and distribution. Participants agreed that it was important to influence this process so that decisions would be based on science, not fear or misinformation.

Regulatory codes and acceptance/cooperation of major utilities. Participants agreed that uniform standards that addressed the interconnection of fuel cells to utility grids would accelerate the adoption of fuel cells when they become economically viable. Such standards could be used by fuel cell operators anywhere and would address both actual physical equipment issues and economic issues (buy back of fuel-cell-produced power by utilities). The Institute of Electrical and Electronics Engineers IEEE SCC21 P1547 Working Group is currently working to produce a standard document for interconnection of all types of distributed generation resources with electric power systems by the end of 2003. The draft, entitled IEEE P1547 Standard Draft 04–Distributed Resources Interconnected with Electric Power Systems, has already been written (see http://technet.nreca.org/distribgen.html).

Insufficient supply of technicians. It was pointed out by a DACUM participant that there were only about 10 people outside of United Technologies Corporation that could service its PC25 fuel cell, which is one of the most widely-used cells in operation. He indicated that, if there were a rapid increase in demand for fuel cells in the near future, the number of qualified technicians to service the cells would be woefully inadequate.

Continued installation of combined heat/power systems. The use of fuel cells to generate both heat and power drastically increases their efficiency, which enhances their economic viability. This reality means that fuel cell technicians must be familiar with not only the operation of fuel cells but their interconnection with the systems that are used to distribute heat.

New DC homes/businesses. Many electronic systems in homes and businesses operate on DC power, which has been converted from the AC delivered from the utility grid. Fuel cells produce DC power that could deliver power directly to these systems without the need for expensive transformers and inverters. If new homes and businesses were fitted with DC distribution systems, fuel cells could become a more viable power alternative.

Continued federal/state incentives. Because of their current cost, fuel cells are not competitive with other power generation technologies. Thus, the continued support of federal and state governments in the form of incentives and R&D funding is necessary to ensure the continued development of the technology. If this support dies, the fuel cell industry's progress will be severely reduced.

DACUM Research Chart

A copy of the DACUM Occupational Research Chart for Fuel Cell Systems Technicians is provided on the next four pages (Appendix B).

Appendix: DACUM

DACUM Research Chart for Fuel Cell Systems Technician

<u>DACUM Panel</u>

Larry Alford
Austin Energy
Austin, TX

Chuck Berry
Gas Technology Institute
Merrick, NY

Mike Binder
US Army Construction Engineering
Research Laboratory
Champaign, IL

George Collard
GBC Electrical Services
Twenty-nine Palms, CA

Alan Huddleston
Toshiba International Corp.
Houston, TX

Malcolm Jacobson
FuelCell Energy, Inc.
Magnolia, TX

George King
Houston Advanced
Research Center
The Woodlands, TX

Sam Logan
Logan Energy Corp.
Roswell, GA

Richard Shaw
FuelCell Energy, Inc.
Danbury, CT

Mark Stevens
Gas Technology Institute
Des Plaines, IL

Rick Wallace
United Technologies Corp.
South Windsor, CT

Mark Welch
NASA Johnson Space Center
Houston, TX

Scott Wilshire
Plug Power, Inc.
Latham, NY

The Texas Leadership Consortium for Curriculum Development

The Texas Fuel Cell Technology Consortium

Dallas County Community College District

Del Mar College

Lamar Institute of Technology

North Harris Montgomery Community College District

Southwest Texas Junior College

St. Philips College

Texas State Technical College Harlingen
Texas State Technical College Waco

April 2 – 3, 2003
Houston, TX

Mike Jones, TSTC Waco
Larrie Barkley, LIT
Facilitators

Coordinated by
TSTC Waco
IDEAS Center
3801 Campus Drive
Waco, TX 76705
(254) 867-3300
(254) 867-3326 fax

 For information about the Consortium or the Fuel Cell Systems curriculum, contact Sid Bolfing, TSTC Waco, (254) 867-3206.

For DACUM process information, please contact Michael Jones, IDEAS Center, TSTC Waco, 3801 Campus Drive, Waco, TX 76705. E-mail: mike.jones@tstc.edu or call (254) 867-3300.

DACUM Occupational Research Chart for

Fuel Cell Systems Technician

Duties — **Tasks** →

Duty														
A Maintain Safety Practices	**A1** Attend safety training	**A2** Assist in determining safety procedures	**A3** Follow safety procedures	**A4** Determine site-specific safety training requirements	**A5** Maintain tools & equipment in safe condition	**A6** Maintain & use PPE	**A7** Ensure proper operation of safety monitoring equipment	**A8** Maintain on-site safety communication	**A9** Conduct site safety inspections	**A10** Report unsafe conditions	**A11** Verify certification & rigging procedures	**A12** Maintain clean site	**A13** Respond to emergencies	**A14** Document incidents & accidents

Duty																		
B Perform Commissioning Start-up	**B1** Take service call	**B2** Follow all approved procedures	**B3** Coordinate with site POC	**B4** Perform site inspection	**B5** Verify power plant interfaces	**B6** Verify & install shipped-loose items	**B7** Verify installation of upgrades	**B8** Contact local utilities	**B9** Verify safety devices/ placards	**B10** Check fluid levels	**B11** Verify remote data communications	**B12** Perform pre-start systems check	**B13** Start unit	**B14** Perform functional tests	**B15** Perform customer-specific acceptance tests	**B16** Provide customer training	**B17** Clean site	**B18** Close service call

Duty							
C Maintain Records	**C1** Maintain power plant configuration control	**C2** Maintain site log	**C3** Manage parts/tools inventory	**C4** Maintain technical manuals	**C5** Document service calls	**C6** Maintain MSDS book	**C7** Maintain disposal log

Duty											
D Perform Scheduled Maintenance	**D1** Determine maintenance schedule	**D2** Take service call	**D3** Follow all approved procedures	**D4** Verify test equipment calibration	**D5** Put unit into safe condition	**D6** Check for leaks	**D7** Maintain system sensors	**D8** Maintain filters & screens	**D9** Maintain cooling systems	**D10** Process waste/ parts	**D11** Close service call

NOTE:
Duties **E – H** are "sub-sets" of the **Scheduled Maintenance** activities listed in **Duty D**

Duty							
E Maintain Water Systems	**E1** Verify water quality specs	**E2** Test water quality	**E3** Change out resin bottles	**E4** Maintain reverse osmosis system	**E5** Maintain make-up water system	**E6** Maintain water system components	**E7** Clean storage tank

Duty								
F Maintain Thermal Management System	**F1** Maintain fluid levels	**F2** Verify system performance	**F3** Maintain fluid coolant system (e.g. glycol)	**F4** Maintain freeze protection systems	**F5** Maintain thermal system components	**F6** Maintain external cooling equipment	**F7** Clean condenser	**F8** Maintain heat recovery system

See insert for Duties G - J

For DACUM process information, please contact Michael Jones, IDEAS Center, TSTC Waco, 3801 Campus Drive, Waco, TX 76705.
E-mail: mike.jones@tstc.edu or call (254) 867-3300.

DACUM Occupational Research Chart for

Fuel Cell Systems Technician

Houston, TX April 2 – 3, 2003

Texas Fuel Cell Technology Consortium **Texas Leadership Consortium for Curriculum Development**

G — Maintain Air & Fuel Delivery System *

G1	G2	G3	G4	G5	G6	G7	G8	G9
Maintain humidification system	Maintain pressure regulation system	Maintain fuel components	Maintain sulfur removal system	Maintain air components	Check CO_2 quantity	Maintain insulation integrity	Perform gas analysis	Verify fuel properties

G10	G11	G12
Replace catalysts	Maintain purging systems	Maintain cabinet ventilation systems

* Fuel delivery systems include: hydrogen (electrolyzers, bottles, pipelines, reformate and others), natural gas, propane, methanol, ethanol, anaerobic digestor gas (ADG), diesel, bio-diesel, gasoline, landfill methane, and jet fuels

H — Maintain Electrical Systems

H1	H2	H3	H4	H5	H6	H7	H8
Maintain electrical connections	Verify operation of communication interface	Maintain software	Verify grounding quality	Verify inverter performance	Verify cell stack performance	Verify switching components performance	Maintain grid interface

H9	H10	H11	H12	H13	H14	H15
Maintain mechanical switchgear	Maintain electrical enclosures	Maintain/replace AC/DC motors	Maintain batteries & UPS	Clean electronics	Check/replace electrical components	Check/replace circuit boards

I — Perform Repairs

I1	I2	I3	I4	I5	I6	I7	I8	I9
Take service call	Follow all approved procedures	Make initial assessment	Put unit into safe condition	Trouble-shoot the problem	Correct the problem	Test the correction	Process removed parts	Close service call

J — Pursue Continuing Education

J1	J2	J3	J4	J5	J6	J7	J8
Maintain licenses & certificates	Participate in site-required safety training	Read service bulletins	Attend manufac-turers/vendor product training	Attend seminars & trade shows	Participate in customer rela-tions training	Maintain personal technical library	Participate in cross-training

 For information about the Consortium or the Fuel Cell Systems curriculum, contact Sid Bolfing, TSTC Waco, (254) 867-3206. For DACUM process information please contact Michael Jones, IDEAS Center, TSTC Waco, 3801 Campus Drive, Waco, TX 76705. E-mail: mike.jones@tstc.edu or call (254) 867-3300.

General Knowledge and Skills

Able to read schematics, blueprints, diagrams, ladder diagrams, physical layout drawings
Office computer application software
Advanced reading & cognitive skills
Working knowledge of:
- Electrical systems, symbols & terminology
- Three-phase power theory
- Single-phase and polyphase power distribution
- Instrumentation basics
- Power delivery
- Basic thermodynamics, basic chemistry
- Catalysts
- Math (esp. algebra)
- Mechanical systems
- Motor control circuits
- Programmable logic controllers (PLC)
- FC electrical and safety codes & standards
- Electronics
- Grid interconnectivity
- Fiber optics
- Wireless systems

Electrical backup systems
Control systems design
Basic power system coordination
Distribution systems, transmission systems
Circuit interrupting systems
Product knowledge
Quality control
Good communication skills (written and verbal)
Computer literacy
Testing and measuring procedures and tools
Power and hand tools

Worker Attitudes, Traits and Behaviors

Reliable
Critical thinking, analytical
Good personal grooming & appearance
Team worker, desire to learn
Self-reliant, self-motivated
Organizational skills
Problem solving, troubleshooting skills
Demonstrates safety awareness
Demonstrates quality awareness
Tenacious, patient
Common sense
Honesty, integrity
Communicative
Self-confident
Innovative
Positive work ethic
Customer service oriented
Detail oriented
Able to pass drug and alcohol testing
Physically fit

Tools, Equipment, Materials and Supplies

Computer (including office application and unit controller software)
Oscilloscope
Signal generator
Pressure meters
Conductivity testing equipment
Turbidity testing equipment
Refractometer
Gas chromatograph
Bridge
Voltage meter
Megger
Hipotential test set
Multimeter
Amp meter
Hand and power tools
Tubing bender
Rigging equipment
Multifunction test sets
Frequency counter
RF (radio frequency) wattmeter
db power meter
Safety equipment
Personal protective equipment (PPE)
Grounding equipment
Data wire or cable
Tensiometer
Cell phone

Future Trends and Concerns

Interstate regulations, licensing
Cost of the technology
Scarcity of trained technicians
Continued federal incentives
Combined heat and power
Acceptance and cooperation by major utilities
Deregulation of electricity industry
Widespread codes and standards proliferation
Multiple technologies, hybrids

Acronyms and Term Definitions

EPA – Environmental Protection Agency
HAZMAT Hazardous Materials
HVACR – Heating, Ventilation, Air Conditioning & Refrigeration
MSDS – Material Safety Data Sheets
NEC – National Electrical Code
NESC – National Electrical Safety Code
CO_2 – Carbon dioxide
OSHA – Occupational Safety & Health Administration
PPE – Personal Protective Equipment
POC – Point Of Contact

Appendix C: DACUM Meeting Participants

Larry Alford	Manager, Distributed Generation Austin Energy 721 Barton Springs Road Austin, TX 78704-1194	(512) 322-6228 Fax (512) 322-6016 larry.alford@austinenergy.com www.austinenergy.com
Mike Binder, Ph.D.	Fuel Cell Program Manager U.S. Army Corps of Engineers Engineer Research and Development Center Construction Engineering Research Laboratory	(217) 373-7214 m-binder@cecer.army.mil www.cecer.army.mil
George Collard	Owner GBC Electrical Services 6767 Adobe Road Twenty-Nine Palms, CA 92277	(760) 367-0024 Fax (760) 367-1223 george.gbc@prodigy.net
Alan Huddleston	Supervisor, Facilities Toshiba International Corporation 13131 West Little York Road Houston, TX 77041	(713) 466-0277 Fax (713) 896-5228 alan.huddleston@tic.toshiba.com www.tic.toshiba.com
Malcolm Jacobson	President FuelCell Energy Houston, TX	(281) 356-4043 mjacobson@fce.com www.fce.com
George R. King	Energy Director Houston Advanced Research Center 4800 Research Forest Drive The Woodlands, TX 77381	(281) 367-1348 Fax (512) 363-7914 www.harc.edu
Sam Logan	Owner Logan Energy 210 River Landing Roswell, GA 30075	(770) 650-6388 Fax (512) 491-0002 samlogan@loganenergy.com www.loganenergy.com
Mark Stevens	Mechanical Power Systems Engineer Gas Technology Institute Distributed Energy Group 1700 South Mount Prospect Road Des Plaines, IL	(847) 768-0568 Fax (847) 768-0510 mark.stevens@gri.org www.gri.org
Rick Wallace	Senior Representative, Customer Support United Technologies Corporation	
Mark Welch	NASA Johnson Space Center Houston, TX	
Scott Wilshire	Director Plug Power, Inc. 968 Albany-Shaker Latham, NY 12110	(518) 782-7700 scott_wilshire@plugpower.com www.plugpower.com

DACUM Facilitators

Larrie Barkley	DACUM Facilitator Lamar Institute of Technology Workforce Training, Continuing Education 855 East Lavaca Beaumont, TX 77710	(409) 880-8202 www.theinstitute.lamar.edu
Michael Jones	DACUM Facilitator Texas State Technical College IDEAS Center, 3801 Campus Drive Waco, TX 76705	(800) 792-8784 Mike.Jones@tstc.edu www.tstc.edu

Observers/Staff

Eliska Beaty	Associate Vice Chancellor Associate Vice President Marketing & Communications Texas State Technical College System Operations Office 3801 Campus Drive Waco, TX 76705	(254) 867-3049 Fax (254) 867-3044 Eliska.Beaty@tstc.edu www.tstc.edu
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Henry Elliott	Research Associate Technology Futures, Inc. 13740 Research Boulevard, Building C Austin, TX 78750	(512) 258-8898 Fax (512) 258-0087 helliott@tfi.com www.tfi.com
John H. Vanston, Ph.D.	Chairman Technology Futures, Inc. 13740 Research Boulevard, Building C Austin, TX 78750	(512) 258-8898 Fax (512) 258-0087 jvanston@tfi.com www.tfi.com

D Appendix: Reports and Studies Utilized

Accelerating the Commercialization of Fuel Cells in Texas, State Energy Conservation Office Report on Fuel Cells. The 2001 Texas legislature directed the State Energy Conservation Office (SECO) to develop a statewide plan for accelerating the commercialization of fuel cells in Texas and to submit a report on this plan to the House of Representative Energy Resources and Senate Business and Commerce Committees no later than September 15, 2002. This is that plan.

Staff White Paper on Stationary Fuel Cells for Power Generation. On May 6, 2002, the Public Utility Commission of Texas published this paper, which presented a discussion on the attractiveness of fuel cell systems for the state, described the obstacles to state development of a fuel cell program, presented a roadmap for the establishment of a vibrant fuel cell industry in Texas, and offered an outline of legislation that would provide incentives for fuel cell development. This report envisions an installed fuel cell capacity of 1,000 megawatts in Texas by the year 2010.

Fuel Cell Report to Congress (ESECS EE-1973). Congress asked the U. S. Department of Energy (DOE) to prepare two reports describing the status of fuel cells. The Interior and Related Agencies Appropriations Conference Report (House Report 107-234) that accompanies Public Law 107-62 (enacted in November 2001) requests that the DOE report within 12 months to the House and Senate Committees on Appropriations on the technical and economic barriers to the use of fuel cells in transportation, portable power, and stationary and distributed power generation applications. It also requests that the DOE provide, within six months after enactment, an interim assessment that describes preliminary findings about the need for public/private cooperative programs to demonstrate the use of fuel cells in commercial-scale applications by 2012. The aim of the Fuel Cell Report to Congress is to respond to these requests.

Opportunities for Creating a Fuel Cell Industry in Ohio, prepared by Gregory M. Stoup of the Center for Regional Economic Studies, Weatherhead School of Management, Case Western Reserve University. The purpose of this white paper was to "open the conversation for public investment in the Ohio fuel cell industry" by providing a profile of the fuel cell industry and establishing a framework for describing the commercialization system through which technology would be crafted into new products and new companies. The paper's deliberate focus is the state of Ohio, with an assessment of the state's current assets and identification of areas that need further support.

Energy Efficiency and Renewable Energy Report. This report prepared by the U.S. Department of Energy, describes the applications for and advantages and disadvantages of various fuel cell systems.

Assumptions to the Annual Energy Outlook 2002. This report, prepared by the U.S. Department of Energy, U.S. Energy Information Administration, presents the installation costs associated with various power generation technologies.

E Appendix: Experts Interviewed

During the conduct of this forecast the fuel cell experts listed below were interviewed in person, by telephone, or by e-mail by one or both of the forecast authors.

Note: In all cases, the listed experts provided much more information and insight than is indicated.

- Malcolm Jacobson (Vice President, Market Development, Fuel Cell Energy, Inc.) provided general information on the fuel cell industry.
- Christine Herbert (Executive Director, Fuel Cells Texas) provided information about fuel cell activities in Texas.
- Michael J. Binder, Ph.D. (Manager, Department of Defense (DoD) Fuel Cell Program) provided information on current and planned DoD fuel cell activities.
- William E. Muston (R&D Manager, TXU Services) provided insights on electric utilities' views on fuel cells.
- Dub Smothers (Private Citizen/Fuel Cell Advocate) provided information on fuel cell history in the San Antonio area.
- Larry Alford (Manager, Distributed Generation, Austin Energy) provided information on the City of Austin's fuel cell demonstration project.
- Ross Baldick (Professor, Department of Electrical Engineering, University of Texas at Austin) provided information on electric utility strategic planning.
- Samuel Logan (President, Logan Energy) provided information on fuel cell technician work requirements.
- Joe B. Redfield (Group Leader, Fuel Cell Systems, Southwest Research Institute) provided information on the institute's work on less expensive platinum coating technologies for membranes.
- Scott Wilshire (Director, Plug Power, Inc.) provided information on Plug Power's fuel cell activities and the cost/operation of various fuel cell components.
- Rick Wallace (United Technologies Corporation) provided information on the economics of fuel cells, especially those installed under DoD programs.
- George R. King (Houston Area Research Center) provided information on the Texas Railroad Commission's desire to begin regulating the fuel cell industry (hydrogen storage tank refill requirements, fuel cell installation, etc.).

Appendix: Selected Fuel Cell Companies

Company info is extracted directly from each company's website

Company Name	**Avista Labs**
Contact	**Peter Christensen, Vice President, Engineering & Technology**
Phone Number	**(509) 228-6500**
Website	**http://www.avistalabs.com/**
Application Area	**Portable and Stationary**

Description. "Avista is a leader in the development and marketing of modular, cartridge-based, proton exchange membrane fuel cell technology. Currently, the company is marketing a range of stationary fuel cells for emergency and back-up power requirements, uninterruptible power supplies, digital power needs, and a variety of off-grid power requirements. Avista's PEM fuel cells are commercially available today and have been installed in over 80 locations in the United States and abroad. One of its three-kilowatt fuel cells was installed under the U.S. Department of Defense Fuel Cell Demonstration Program and powered critical loads, including maintenance bay lighting and the local area network switch at the Washington Air National Guard facility at Geiger Field in Spokane, Washington. The program is led by the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory. This is the same program that operates the fuel cells at Brooks City Base. Avista Labs is a subsidiary of Avista Corporation, a company involved in the production, transmission, and distribution of energy. Both are headquartered in Spokane, Washington."[39]

Company Name	**Ballard Power Systems**
Contact	**Rachel Mussard, Market and Sales Analyst**
Phone Number	**(604) 453-3620**
Website	**http://www.ballard.com/**
Application Area	**Mobile, Portable, and Stationary**

Description. "Ballard (Burnaby, British Columbia) is recognized as the world leader in developing, manufacturing, and marketing zero-emission PEM fuel cells. Ballard is commercializing fuel cell engines for the transportation market, electric drives for both fuel cell and battery-powered electric vehicles, power conversion products for micro-turbines and other distributed generation technologies, and fuel cell systems for markets ranging from portable power products to larger stationary generation products. The company is currently offering a 1.2 kW DC system, called Nexa™, to educational institutions for inclusion in their fuel cell programs. The Nexa-based course will cover basic fuel cell operation, providing details on individual subsystems and components."[40]

[39] "Avista Labs." http://www.poweronsite.org/AppGuide/Manf/AvistaLabs.htm
[40] Ballard Press Release. http://www.ballard.com/pdfs/6BMPRelease.pdf

Company Name	**DaimlerChrysler**
Contact	**DaimlerChrysler Fuel Cells Division**
Phone Number	**(248) 576-5741**
Website	**http://www.daimlerchrysler.com**
Application Area	**Mobile**

Description. "DaimlerChrysler, headquartered in Auburn Hills, Michigan, has been pioneering fuel cell technology development decisively since 1994, when it began a program to develop methanol fuel cells for its own use. In fact, DaimlerChrysler and Toyota have already built prototype fuel cell vehicles that cleanly and efficiently reform liquid methanol to gaseous hydrogen on board their cars."[41]

Company Name	**Energy Conversion Devices Ovonics**
Contact	**Ghazaleh Koefod**
Phone Number	**(248) 293-0440**
Website	**http://www.ovonic.com/res/2_3_regen_fuel/ regen_fuel_cells.htm**
Application Area	**Mobile, Stationary**

Description. "Energy Conversion Devices (ECD) has developed enabling technologies based on amorphous, disordered, and related materials, with an emphasis on fuel cells, hydride batteries, and hydride storage materials capable of storing hydrogen in the solid state for use as a feedstock for fuel cells or internal combustion engines or as an enhancement or replacement for some hydrocarbon fuels. ECD's Ovonic™ fuel cell technology has many unique advantages over conventional fuel cells, including the ability to start up instantly, accept recaptured energy (such as that of regenerative braking), increased efficiency and power availability, and a dramatic improvement in the operating temperature range of -20^{o} to 120^{o}C compared with proton exchange membrane fuel cells, which operate over a narrow temperature range. Corporate headquarters are in Rochester Hill, Michigan."[42]

[41] Daimler Chrysler Press Release. "The Fuel Cell on its Way to the Customer."
[42] Ovonics Press Release http://www.ovonic.com/news_events/5_2_press_releases/20020919.htm

Company Name	**Fuel Cell Energy, Incorporated**
Contact	**Malcolm Jacobsen**
Phone Number	**(281) 356-4043**
Website	**http://www.fce.com/**
Application Area	**Stationary**

Description. "Fuel Cell Energy, Incorporated (FCE) is a developer of carbonate fuel cell technology for stationary power generation. The company has developed and manufactures a line of power plants targeted for large commercial, industrial, and utility applications. FCE's Direct FuelCell® is a state-of-the-art technology now emerging into the marketplace with significant fuel efficiency and cost advantages over competing fuel cells. FCE's product slate currently consists of units ranging in size from 250 kW to 2.0 mW. The company, which employs about 450 people in Connecticut and maintains offices in California, Texas, and Washington, DC, is publicly traded on NASDAQ under the symbol FCEL."[43]

Company Name	**IdaTech, LLC**
Contact	**Dr. David Edlund, Chief Technology Officer**
Phone Number	**(541) 383-3390**
Website	**http://www.idatech.com/**
Application Area	**Stationary**

Description. "Originally founded in 1996 as Northwest Power Systems, IdaTech is a leader in the development of fuel processors and integrated PEM fuel cell systems. IdaTech's core technology is its patented fuel processing technology, which is capable of converting fuels, including natural gas, propane, and diesel into high-purity hydrogen. The company also has extensive experience in integrating a variety of fuel cell modules with its processors for use in fuel cell systems for portable and stationary applications. IdaTech is field-testing and evaluating these solutions in North America, Europe, and Japan. At the 2002 Fuel Cell Seminar, IdaTech introduced three versions of its FCS 1200™ fuel cell system— all based on a similar platform, yet operating on different fuels. On October 15, 2002, the U.S. Army Communications-Electronics Command contracted with IdaTech to develop two-2 kW FCS 1200™ fuel cell systems. The 2 kW systems will provide on-board power for "silent watch" field exercises in which quiet operation is essential. The company is located in Bend, Oregon."[44]

43 Fuel Cell Energy. http://www.fce.com/
44 "Idatech -Advanced Fuel Cell Solutions." http://www.idatech.com/

Company Name	**Manhattan Scientifics, Inc.**
Contact	**Robert Hockaday, Chief MicroFuel Cell Scientist, ERD/MicroFuel Cell Unit Leader**
Phone Number	**(505) 662-0660**
Website	**http://www.mhtx.com**
Application Area	**Portable**

Description. "In 1998, Manhattan Scientifics (OTC: BB MHTX) became a publicly held company to provide capital for its fuel cell technology called MicroFuel Cell. This technology is the result of more than 16 years of research by physicist Robert Hockaday. The Hockaday MicroFuel Cell, which runs on a methanol and water mixture similar to common windshield washer fluid, recently achieved an energy output three times greater than standard lithium ion batteries currently used for cellular telephones. Manhattan Scientifics researchers believe this achievement is a step toward their target goal of exceeding 20 times the energy output of conventional batteries. Corporate offices are in New York City, and research headquarters is located in Los Alamos, New Mexico."[45]

Company Name	**McDermott Technology, Inc.**
Contact	**Laurie M. Wessel**
Phone Number	**(330) 829-7878**
Website	**http://www.mtiresearch.com/**
Application Area	**Portable and Stationary**

Description. "McDermott Technology (MTI) is focused on developing planar solid-oxide fuel cells (pSOFC) and on fuel processors that produce the hydrogen needed for fuel cells to operate. The U.S. Department of Energy (DOE) recognized the potential of the SOFC approach and, in 1999, awarded McDermott a contract for the first phase of a multi-year $20 million program to support its efforts. Phase 2 of this program was awarded in September 2000, following successful completion of Phase 1.

The DOE has continued its support of McDermott's program by selecting the Cummins Power Generation/McDermott team for a $74 million award under its Solid-State Energy Conversion Alliance (SECA). The team will develop a 10 kW SOFC system for auxiliary power in RVs and commercial work vehicles and for emergency power at remote telecommunications sites. MTI has offices in Alliance, Ohio and Lynchburg, Virginia."[46]

[45] Manhattan Scientifics."Quick Overview." http://www.mhtx.com/quickoverview.htm
[46] McDermott Technology. http://www.mtiresearch.com/

Company Name	**Millennium Cell, Inc.**
Contact	**Dr. Michael Kelly, Senior Lead Scientist**
Phone Number	**(732) 542-4000**
Website	**http://www.milleniumcell.com/about/index.html**
Application Area	**Mobile, Stationary, and Portable**

Description. "Millennium Cell (NASDAQ: MCEL) was founded in 1998 and is based in Eatontown, New Jersey. Currently, Millennium Cell employs approximately 60 people, primarily in technology development. The company's research and development efforts are focused primarily on the production of a variant of the PEM fuel cell with a special reformer that generates hydrogen from the reaction of borohydrides and ordinary water. Millennium Cell's patented boron-based energy technology delivers a hydrogen fuel that is safe, clean, and easily transported, without the need for compression or liquefaction. In addition, the company has a partnership with Peugeot, which is particularly interested in the transportation market."[47]

Company Name	**Plug Power**
Contact	**Scott Wilshire**
Website	**http://www.plugpower.com**
Application Area	**Stationary**

Description. "Plug Power designs, develops, and manufacturers on-site electric power generation systems utilizing proton exchange membrane fuel cells for stationary applications. Plug Power's fuel cell systems are expected to be sold globally through GE Fuel Cell Systems and DTE Energy Technologies in a four-state territory that includes Michigan, Illinois, Ohio, and Indiana. The company's headquarters are in Latham, New York, with offices in Washington, D.C. and The Netherlands. The company grew from 22 employees to more than 350 during its first four years of operation and made its initial public offering of common stock in October 1999. The company acquired another fuel cell company, H Power, in November 2002."[48]

Plug Power is concentrating on 5 kW fuel cell systems intended for the residential market. In fact, the company has installed three 5 kW PEM cells at Brooks City Base in San Antonio. The cells, supplying power to three homes in the base's housing area, are being maintained, monitored, and operated by the U. S. Air Force and City Public Services, the San Antonio utility company. The operational characteristics of the cell will be reported to the Army Corps of Engineers, which is funding the entire project through the Southwest Research Institute.

[47] Millenium Cell, Inc. http://www.milleniumcell.com/about/index.html

[48] "Plug Power - Members of Fuel Cell Texas." http://www.fuelcellstexas.org/members/

Company Name	**Siemens Westinghouse**
Phone Number	**(678) 256-1500**
Website	**http://www.pg.siemens.com/en/fuelcells/index.cfm**
Application Area	**Stationary**

Description. "This joint venture represents major manufacturer involvement in the fuel cell market. For nearly four decades, Siemens has been performing basic research and product development of solid oxide fuel cells. Siemens Westinghouse Power Generation (SWPG) has further developed this technology and created tubular SOFC technology as part of the U.S. Department of Energy's advanced fuel cell research program. In addition, SWPG has formed a new division, the Stationary Fuel Cells Division, dedicated to completing the commercialization of these solid oxide fuel cells, which they believe are ideal for providing high-quality power at small distributed sites. The company has begun demonstrating prototypes of the first commercial SOFC products. These prototypes consist of 250 kW cogeneration systems and SOFC/GT hybrid power systems of 300 kW. A new factory to produce this distributed generation technology is under construction in Pittsburgh, Pennsylvania."[49]

Company Name	**United Technologies Company Fuel Cells**
Contact	**Tom Coulbourn**
Phone Number	**(804) 353-5327 ext. 409**
Website	**http://www.utcfuelcells.com/**
Application Area	**Stationary and Mobile**

Description. "United Technologies Company Fuel Cells (UTCFC), formerly known as International Fuel Cells, is the world leader in fuel cell production and development for commercial, transportation, residential, and space applications. A unit of United Technologies Corporation (NYSE: UTX), UTCFC is the sole supplier of fuel cells for U.S. manned space missions, and has been manufacturing a commercially available fuel cell system, the PC25, since 1991. The PC25 produces 200 kilowatts of electricity and 900,000 BTUs of heat. UTCFC has delivered more than 250 PC25 systems to customers in 19 countries on five continents. The PC25 fleet of fuel cells has accumulated over five million hours of operational experience in a range of operating environments. UTCFC is also developing a next-generation commercial power plant based on PEM fuel cell technology. In the Texas market, UTCFC has installed fuel cells in Houston, Austin, El Paso, and Del Rio. The company is located in South Windsor, Connecticut."[50]

[49] "Siemens Power Generation Fuel Cells." http://www.powergeneration.siemens.com/en/fuelcells/index.cfm
[50] UTC Press Release. http://www.utcfuelcells.com/news/archive/2001-12-19.shtm

Appendix: Current Highway Vehicle Fuel Cell Projects

Company	Examples of Activities
General Motors	Set a new world record for power density in a PEMFC stack which generates 1.75 kW per liter. Teamed up with Hydrogenics Corporation and unveiled a demonstration stationary power unit to provide backup power to cellular towers during power outages.
DaimlerChrysler	Unveiled a fuel-cell/battery hybrid concept vehicle based on the Jeep Commanders with near-zero tailpipe emissions and twice the fuel efficiency of a standard SUV.
Ford Motor Corporation	Developed several sedan and SUV-sized fuel cell vehicles based on methanol reformers and stored hydrogen. Uses Ballard FC electric powertrain. Also is collaborating with Mobil on a fuel processor to extract hydrogen from hydrocarbon fuel cell vehicles.
BMW	Developed, along with Delphi Automotive, a vehicle using a solid oxide fuel cell auxiliary power unit to power subsystems. Also developing 7 series sedans with hydrogen combustion engines and fuel cells from International Fuel Cells.
Fiat	Presented its first fuel cell car, Seicento Elettra H2 Fuel Cell in June 2001.
Volkswagen/Volvo	Produced a zero-emission vehicle called the Bora HyMotion, based on the Jetta, using hydrogen fuel cells. Also planning a methanol-fuel PEM hybrid "Golf"-type car.
Daewoo Motors	Establishing a fuel cell research and development program with a state-run laboratory.
Honda	Developed a four-seat fuel cell car, the FCX-V3. Plans to build 300 fuel cell powered vehicles a year starting in 2003, for sale in Japan and the United States.
Hyundai	Developed a fuel cell concept car powered by methanol, with its affiliate Kia Motor Corporation.
Mazda	Testing its "Premacy FC-EV" car powered by a methanol reformer fuel cell. Will begin marketing around 2005.
Mitsubishi	Plans to have a running prototype FCV with a production model ready in 2005.

Source: The Fuel Cells 2000 Organization

Company	Examples of Activities
Nissan	Along with Renault SA of France, will spend $714 million on a fuel cell vehicle project and will market the vehicles as early as 2005. Showcased the new fuel cell powered electric Xterra SUV. Says that they will have a commercial model fuel cell vehicle within two years.
Toyota	Unveiled methanol and hydrogen fueled versions of its FCEV, based on the RAV4 sport utility vehicle. Both use Toyota's own PEM engines in hybrid configuration. Plans to launch a commercial FCV in 2003.
Ballard Power Systems	Its leading supplier of PEM fuel cells for transportation. Has received orders from auto manufacturers around the world. Unveiled its latest fuel cell stack, the Mark 900.
Energy Partners	Its one of four fuel cell "engine" companies participating in the DOE-funded program. Claims the first fuel cell passenger car, a demonstration sports car called the "Green Car." Developed a demonstration fuel cell utility vehicle.
H Power	Makes PEM fuel cells for a variety of specialty mobile applications.
International Fuel Cells	A subsidiary has shown an unpressurized 50 kW fuel cell engine. Is working with Toshiba to develop a prototype fuel cell system that extracts hydrogen from gasoline.
Plug Power LLC	Along with Arthur D. Little and Los Alamos National Lab, demonstrated a fuel cell operating on hydrogen derived from gasoline and is focusing on integrating the system into a vehicle. Developing a 50 kW engine for DOE.

Source: The Fuel Cells 2000 Organization

Programs for Emerging Technologies

Programs for Emerging Technologies (PET) identifies and forecasts selected new and emerging technologies and respective future curriculum development opportunities for Texas community and technical colleges. This program fulfills a legislative mandate enacted by the 76th Regular Session, which charges Texas State Technical College with developing and administering a program to identify, evaluate, and forecast potential emerging technology programs that are likely to have a positive impact on the State's economy (SB1819).

Programs for Emerging Technologies Goals:

- Identify promising emerging high-technology program areas.
- Conduct meaningful technology forecasts for the identified technologies.
- Disseminate findings and technology forecasts to the State's community and technical colleges and other curriculum development stakeholders to promote informed and proactive decision-making.

This technology forecast is specifically designed to provide Texas community and technical colleges with insights and data useful in identifying and initiating new technology-related programs in the field of fuel cells. This forecast looks at the state of fuel cell development, training strategies for community and technical colleges, current fuel cell activities in Texas, the nature and rate of technical advances, and potential employment demands, and it provides forecasts and insights into the future of fuel cell development and commercialization.

By increasing awareness of specific emerging technical programs and pro-actively advancing the development of applicable high-technology curriculum, Texas community and technical colleges enhance the economic competitiveness of Texas and ensure a competitively skilled workforce for future Texas employers.

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