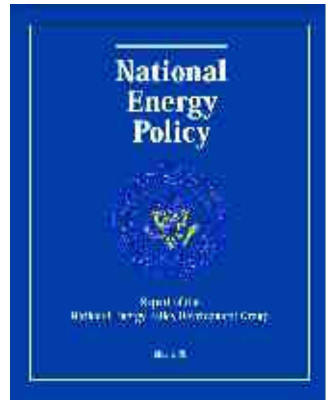
I. INTRODUCTION

Developing Advanced Hydrogen and Fuel Cell Technologies for Transportation, and Stationary Power Systems



We are pleased to present the Fiscal Year (FY) 2002 Annual Progress Report for the Hydrogen, Fuel Cells, and Infrastructure Technologies Program. This new program office integrates activities in hydrogen production, storage, and delivery with transportation and stationary fuel cell activities. Under the Assistant Secretary for Energy Efficiency and Renewable Energy (EERE), the new Office of Hydrogen, Fuel Cells, and Infrastructure Technologies is responsible for research, development and demonstration of all aspects of hydrogen and fuel cells and was formed in response to a recommendation in the National Energy Policy to "focus research and development efforts … on integrating current programs … regarding hydrogen and fuel cells…"

In January 2002, as a further step toward implementation of the National Energy Policy, Secretary of Energy Spencer Abraham announced formation of the FreedomCAR Partnership, an ambitious, cost-shared cooperative research and development partnership between the Department of Energy (DOE) and the U.S. Council for Automotive Research, the precompetitive research organization of Ford, General Motors (GM), and DaimlerChrysler. The CAR in FreedomCAR stands for Cooperative Automotive Research. And the "Freedom" principle is framed by:

Secretary Abraham announces FreedomCAR

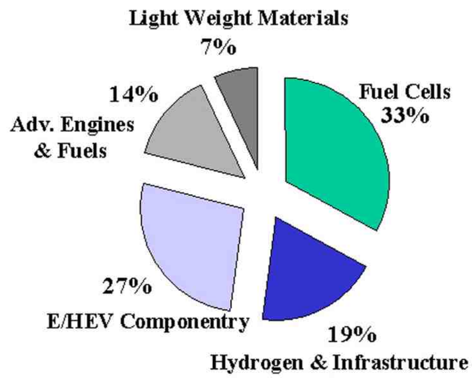
- Freedom from foreign petroleum dependence;
- Freedom from pollutant emissions;
- Freedom for Americans to drive where they want, when they want, in the vehicle of their choice; and
- Freedom to obtain fuel affordably and conveniently.

The long-term goal of the FreedomCAR Partnership is the achievement of vehicles and fuels that lead to a clean and sustainable energy future. Fuel cell vehicles running on renewable hydrogen offer a promising path toward achieving this vision. Thus, a major focus of FreedomCAR is the development of hydrogen and fuel cell technologies. The formation of FreedomCAR demonstrates the federal government's commitment to next generation transportation technologies including fuel cells and hydrogen. The FreedomCAR Partnership Plan can be downloaded from the internet at http://www.cartech.doe.gov.

President Bush and UTC Fuel Cells President William Miller discuss fuel cell technology

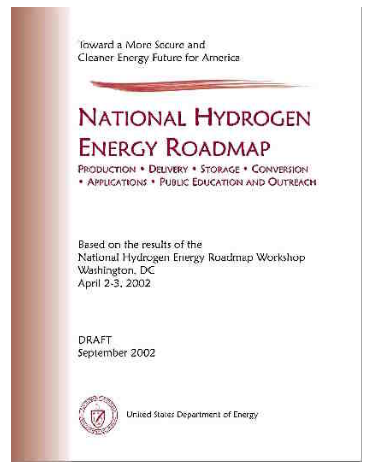
The U.S. Department of Energy has also initiated a National Hydrogen Vision and Roadmap process in response to recommendations made in the National Energy Policy. Energy Secretary Spencer Abraham stated, "The President's Plan directs us to explore the possibility of a hydrogen economy." The Vision Meeting, an important first step, took place November 15-16, 2001. The 53 business executives, Federal and State energy policy officials, and leaders of universities, environmental organizations, and National Laboratories who participated contributed to the development of the vision:

> ***Hydrogen is America's clean energy choice. It is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the country.***



Shown above is the breakdown of DOE FreedomCAR funding ($150 million) by technology area. Industry share is an additional 20-50%.

Building on the work of the Vision Meeting, more than 200 participants representing hydrogen energy industries, academia, environmental organizations, federal and state government agencies, and National Laboratories met on April 2-3, 2002 for a National Hydrogen Energy Roadmap Workshop in Washington, DC. The purpose of the workshop was to identify the key activities that will have to take place to enable the vision to become reality. The intent was to identify the most important barriers and paths forward that should be addressed in order to achieve the Vision; the time frames for the top priority research and development and other efforts; and the respective roles of industry, government, universities, and National Laboratories in dealing with these issues. In his concluding remarks to the workshop participants, David Garman, Assistant Secretary for Energy Efficiency and Renewable Energy, stated: "There are two paths we need to follow: research and development, and public outreach to capture the imagination of the American people. This will be a long journey and process, and the Department of Energy will work with you as we move forward." The National Hydrogen Energy Roadmap Report is available on http://www.eren.doe.gov/hydrogen.



This report provides an overview of the nature, objectives, and progress of the Program; examines the remaining technical barriers to commercialization of the technology; and highlights the Program's future directions. While the primary purpose of this report is to document the progress made by the DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program during FY 2002 in overcoming the R&D barriers, it also highlights some of the major advances in fuel cell technology made through other private and public initiatives throughout the year. The reader is also referred to http://www.eren.doe.gov/hydrogen for additional information.

Transportation Highlights

In October 2001, Ford set a national record for fuel cell endurance by running a P2000 car continuously for 24 hours. The vehicle traveled 1,391 miles averaging 58 mph, including stops for refueling and driver changes. Average actual on-track speed was 65 mph. The P2000 uses an advanced lightweight Ford Research vehicle platform that offers interior space for 5 passengers while weighing only ~3,300 pounds. The P2000's

Ford P2000 Fuel Cell Vehicle

fuel cell system delivers 90 hp and accelerates the car from 0 to 60 in less than 14 seconds. The polymer electrolyte membrane fuel cells and electric drive powertrain were supplied by Ballard Power Systems.

DaimlerChrysler's NECAR 5 sedan completed the first transcontinental journey of a fuel cell powered vehicle in June 2002. The NECAR 5 is powered by a fuel cell engine designed by Ballard Power Systems and fueled by methanol. The 3,262-mile trip, which took 85 hours of driving over 12 days, ended at the DOE-sponsored Future Car Congress in Washington, D.C. in June, 2002. According to DaimlerChrysler, no components of the fuel cell engine had to be repaired during the journey. An electrical short caused by moisture delayed the trip for one day, and two belts, four fuel filters, and one water compartment had to be replaced.

DaimlerChrysler NECAR 5 and Jeep Commander Fuel Cell Vehicles

In January 2002, at the North American International Auto Show in Detroit, General Motors unveiled the Autonomy fuel cell concept car. The basic component of GM's plan for a fuel cell vehicle is a so-called "skateboard" platform that would include both the fuel cells and the vehicle's electronic powertrain. The platform would allow a variety of body types to be built and assembled to the chassis.

GM Autonomy Fuel Cell Car (left) and the "Skateboard" Platform (right)

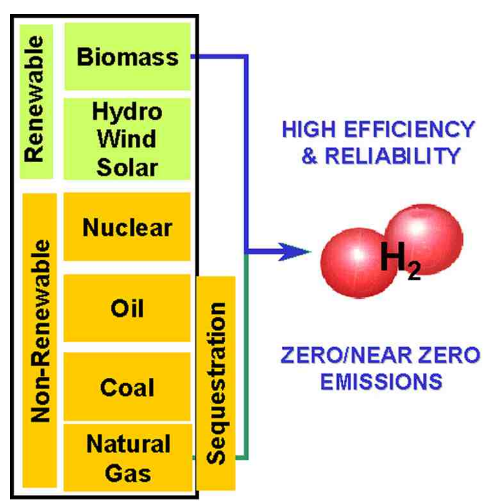
To accelerate the development of fuel cell vehicles, the California Fuel Cell Partnership (CaFCP) was established in Sacramento, CA, in November 2000 (see http://www.fuelcellpartnership.org). The CaFCP 2002 technical achievements include:

- operation of 16 CaFCP fuel cell powered vehicles,
- installation of a methanol fuel station at the West Sacramento headquarters, and
- commencement of a second joint study examining hydrogen vehicle facility construction and use issues.

Technology Status and Challenges

Hydrogen Production

Hydrogen, like electricity, can be produced from many sources, including fossil fuels, renewable resources, and nuclear energy. The Department currently supports R&D on a number of different hydrogen production technologies, including biological-, biomass-, fossil-, nuclear-, and renewable-based processes. Future R&D will also address approaches for producing hydrogen utilizing waste heat from nuclear energy sources.



The FreedomCAR target for hydrogen production via natural gas reforming is presented in Table 1. Targets for hydrogen production, separation and purification, storage, and delivery are listed in Appendix A. Remaining technical challenges for hydrogen energy systems include:

- Reducing the cost of hydrogen production from renewable resources and fossil feedstocks
- Establishing "learning" hydrogen fuel infrastructure demonstrations to address technical and economic issues that will help refocus research
- Developing standards of safe practice, codes, and product certification to enable commercial production of hydrogen-based systems for mobile and stationary applications

Technology[1]	2002 Status	2010
Natural Gas Reforming	$6.00/gge[2]	$1.50/gge[3]

1. A thorough analysis will be performed in FY 2003 to establish technical targets for biomass and other hydrogen production pathways.
2. Status based on single, 215 kg/day unit. (gge=gasoline gallon equivalent)
3. Target based on projected cost for ~900 kg/day units, produced in volume of 100 units per year.

Table 1. Hydrogen Production Status and Targets

Hydrogen Storage

The overarching technical challenge for hydrogen storage is how to store the necessary amount of hydrogen needed to fuel the vehicle for its required driving range (>300 miles), within the constraints of weight, volume, efficiency, and cost.

The Department is currently pursuing three approaches for on-board hydrogen storage: 1) physical storage, 2) reversible chemical storage, and 3) irreversible chemical storage. Physical storage involves the development of tanks for either compressed hydrogen gas or liquid hydrogen. Reversible chemical approaches store hydrogen in solid materials where the hydrogen can be released and refilled without physically removing the storage media from the vehicle. Potential reversible storage materials include metal hydrides and carbon materials such as carbon nanotubes. Irreversible chemical approaches release hydrogen via an on-board chemical reaction with the storage material. In this case, the storage media must be physically replaced with fresh material once it has become exhausted. The reaction of sodium borohydride with water is an example of this approach.

Table 2 gives the DOE hydrogen storage system goals for the year 2005 and compares these goals to the state-of-the-art hydrogen storage technology – 5,000 psi tanks, which have been certified. Development of compressed hydrogen tanks at 10,000 psi is near completion; certification activities are in progress. Materials to enable low pressure hydrogen storage are the focus of DOE hydrogen storage activities. Other hydrogen storage targets are listed in Appendix A.

Characteristic	2002 Status[2]	2005 Goal
Weight Percent	5.2	6
Specific Energy (W-h/kg)	1745	2000
Energy Density (W-h/liter)	813	1100
Cost ($/kWh)	50	5

1. 2010 targets are under review by the FreedomCAR Hydrogen Storage Technical Team
2. Status is based on certified 5,000 psi hydrogen tanks; 10,000 psi tanks have been developed – certification activities are underway

Table 2. Comparison of Current Status[1] to 2005 Hydrogen Storage System Goals

Transportation Fuel Cells

Direct hydrogen PEM fuel cell systems are more technically mature and face fewer challenges than systems requiring an on-board fuel processor. Although the demonstrated performance and efficiency of direct hydrogen systems approach the anticipated goals, several issues remain. The primary barriers are lack of a refueling infrastructure and on-board hydrogen storage, cost, durability, size, and weight.

Remaining technical challenges for automotive fuel cell power systems include:

- Reducing component and system costs (including reducing precious metal requirements)
- Developing high-volume manufacturing capability
- Demonstrating component and system durability
- Reducing system start-up time, especially for gasoline-powered systems
- Developing high-efficiency air management subsystems

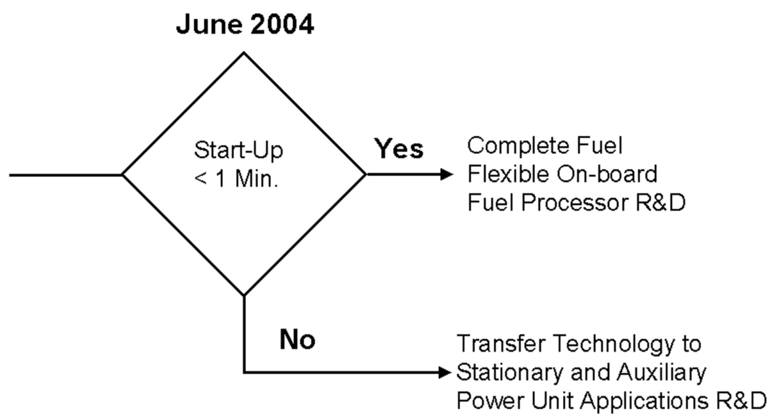
Technical and economic targets were developed for direct hydrogen transportation PEM fuel cell systems and they are indicated along with the status in Table 3, as well as in Appendix A. The targets and status of gasoline-fueled systems remain the same as in FY 2001. Note that the FreedomCAR fuel cell technical team is currently considering revisions to all technical targets.

Characteristic	2002 Status	2005	2010
Energy efficiency @ 25% of rated power (%)	59	60	60
Energy efficiency @ rated power (%)	50	50	50
Power density (W/L) excluding H_2 storage including H_2 storage	 400 140	 500 150	 650 220
Specific power (W/kg) excluding H_2 storage including H_2 storage	 400 250	 500 250	 650 325
Cost (including H_2 storage) ($/kW)	200	125	45
Transient response (time from 10% to 90% of rated power) (seconds)	3	2	1
Cold start-up time to maximum power (seconds) @ –20°C ambient temperature @+20°C ambient temperature	 120 60	 60 30	 30 15
Emissions	Zero	Zero	Zero
Durability (hours)	1000	2000	5000
Survivability (°C)	-20	- 30	-40

Table 3. Comparison of Targets for 50 kWe (net) Integrated Fuel Cell Power Systems Operating on Direct Hydrogen to Current Status

Major Go/No-Go Decision Planned

DOE is pursuing a dual pathway to evaluate fuels for fuel cell vehicles. As an alternative to the direct hydrogen approach, the Program is pursuing development of on-board fuel processors to reform gasoline and alternative fuels such as methanol, ethanol, and natural gas to produce the required hydrogen. An advanced petroleum-based fuel, which is "gasoline-like," would be an interim "transition" strategy. It would be compatible with the existing refueling infrastructure and eliminate the hydrogen storage barrier. However, on-board fuel processing has been presenting serious technical and economic challenges which may not be overcome in the required "transition" timeframe. Consequently, DOE is deciding whether to continue on-board fuel processing R&D beyond the end of FY 2004. Identification of decision criteria (such as energy required for start-up) and metrics is in the early stages.



Stationary Fuel Cells

Because the buildings sector accounts for ~36% of the U.S. primary energy consumption and between 30% and 40% of all airborne emissions, DOE is developing high efficiency polymer electrolyte membrane (PEM) fuel cell power systems as an alternative power source to grid-based electricity for buildings. A successful stationary fuel cell program will not only save energy and reduce emissions, but its inherent flexibility will help address energy shortage issues through energy diversity. Industry cost-shared projects will cross-cut several technological areas addressing research needs in stationary fuel cell systems, fuel cells for back-up power, materials for high temperature membranes, fuel cell component durability, water and thermal management, fuel processing for stationary applications, platinum recycling, and non-precious metal catalysts.

Technical and economic challenges for natural gas-based stationary fuel cell R&D include:

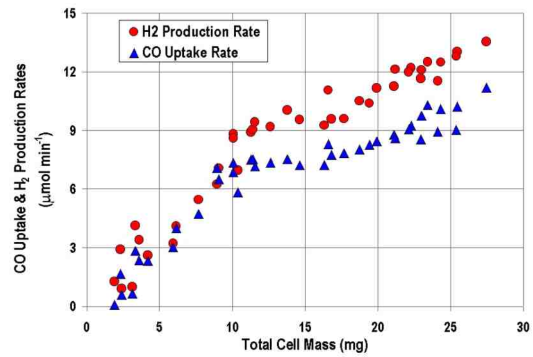
- Improving energy efficiency
- Improving integrated system durability
- Reducing component and system cost
- Resolving interconnectivity issues with grid and developing codes/standards
- Developing fuel-cell systems with potential to meet cost-effective thermal energy needs for some or all of the building's heating/cooling requirements

In FY 2003, a study is planned to establish baseline performance and outyear targets for stationary PEM fuel cells for various market segments.

Research, Development and Demonstration (R,D&D) Highlights

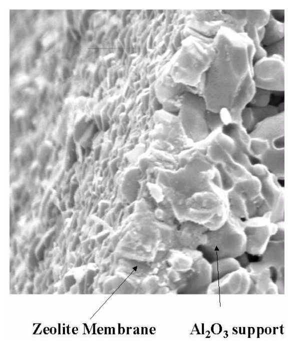
Researchers supporting the Hydrogen, Fuel Cells, and Infrastructure Technologies Program continued to make significant progress in meeting R,D&D challenges during FY 2002. The summaries that follow are selected highlights of the progress made under the program.

Biological Organisms Replace Expensive Nickel Catalysts for Hydrogen Production The National Renewable Energy Laboratory has successfully shown that a unique photosynthetic organism can replace nickel catalysts in the water-gas-shift reaction for hydrogen production from synthesis gas. These organisms are able to produce hydrogen from water while converting carbon monoxide to carbon dioxide. Industrially, this reaction is normally performed using expensive nickel catalysts and at high temperatures. To date, these organisms have been able to perform with industrial synthesis gas and with gas from a biomass gasification process development unit. The organisms are robust under a variety of conditions. Work is now progressing on improving reactor design and reaction rates.



Hydrogen Production and Carbon Monoxide Uptake Rates vs. Total Call Mass

SNL Develops Defect-Free Thin Film Membranes for Hydrogen Separation and Isolation Even small amounts of carbon monoxide or other contaminants can poison a fuel cell. Sandia National Laboratories (SNL) is working on developing gas-selective thin film membranes to improve and lower the cost for hydrogen purification. Defect-free aluminosilicate and silicalite zeolite thin films supported on commercially available alpha and gamma alumina disk substrates were developed. In tests using SNL's permeation unit, which can test both pure and mixed gases from room temperature to 250°C, excellent separation values for hydrogen were achieved.



Cross section view by SEM of the micron thick Na/Al/Si ZSM-5 membrane on gamma-alumina substrate for hydrogen purification.

University, Industry and Laboratory Team Completes Reactor Testing and Produces Hydrogen from Peanut Shells Clark Atlanta University, Georgia Institute of Technology, Scientific Carbons Inc., Enviro-Tech Enterprises Inc. and the National Renewable Energy Laboratory (NREL) have partnered to move NREL's technology for the generation of hydrogen from biomass and agricultural residue into the commercial setting. This success marks the first application of a near-term economically viable option for renewable hydrogen production. During FY 2002, the team successfully tested a 1 kg per hour shift reactor on vapors from peanut shell pyrolysis, both at NREL and at the Scientific Carbons Inc. facility in Blakely, Georgia. The unit was also used to show that the fluidizable catalyst being developed by NREL in collaboration with CoorsTek in Golden, Colorado, is able to reform the pyrolysis vapors while maintaining its physical integrity. This technology is particularly interesting because it is applicable to all forms of biomass. This project is a showcase of the hydrogen economy vision that exemplifies stakeholder involvement throughout the energy chain (farmers, food processors, industrial commodity producers, energy/fuel consumers).

QUANTUM Technologies Tanks Validated for 5,000 and 10,000 psi On-Board Hydrogen Storage

The 5,000 and 10,000 psi tanks developed by QUANTUM Technologies have been validated to meet the requirements of DOT FMVSS304, NGV2-2000 (both modified for 10,000 psi hydrogen) and draft E.I.H.P standard. The tanks were submitted to typical safety testing, including: Burst Tests (2.35 safety margin), Fatigue, Extreme Temperature, Hydrogen Cycling, Bonfire, Severe Drop Impact Test, Flaw Tolerance, Acid Environment, Gunfire Penetration, Accelerated Stress, Permeation and Material testing. These QUANTUM “TriShield” tanks achieve 6% hydrogen by weight, 1,050 W-h/L, and 2,000 W-h/kg, meeting the percent weight and specific energy goals and nearly meeting the energy density goal of 1,100 W-h/L. Significant cost reductions are possible with further optimization. QUANTUM is now working with several automotive manufacturers to incorporate these tanks into hydrogen fuel cell vehicles.

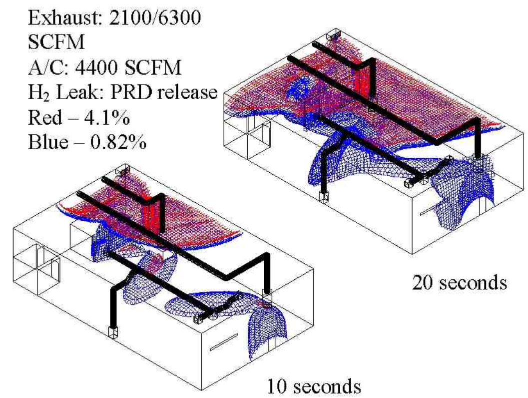
QUANTUM TriShield^{TM} Type IV Tank

World’s First Hydrogen Station Co-Produces Fuel and Electricity A facility that will serve as a “learning” demonstration of hydrogen as a safe and clean energy alternative for vehicle refueling is under construction by Air Products and Chemicals, Inc., in partnership with Plug Power Inc. and the City of Las Vegas (CLV), Nevada. The facility includes small-scale, on-site hydrogen production technologies, a hydrogen/compressed natural gas blend refueling facility, and a 50-kW PEM fuel cell system which supplies electricity to the grid. The fueling station and power plant are co-located at the existing City of Las Vegas Fleet & Transportation Western Service Center. The CLV was given easement to public lands by the Bureau of Land Management, which also conducted the appropriate environmental analyses for the facility. All permits were approved and construction is nearly complete. Other partners include NRG Technologies in Reno, Nevada, who is retrofitting the 6 buses donated by the City of Las Vegas that will be refueled at this station, and the University of Las Vegas, who is modifying a bus to burn hydrogen in an internal combustion engine and to store the hydrogen in a compressed tank.

Hydrogen Technologies for Public Transportation in California’s Coachella Valley The SunLine Services group continued to host what has been called the world’s most complex hydrogen demonstration project to date. Buses running on hydrogen and hydrogen/natural gas mixtures were used for public transport and filled at SunLine’s public access fueling island. Two different types of electrolyzers, one supplied by a photovoltaic grid and the other by a natural gas reformer, produced hydrogen on-site. A full training program, including a curriculum for the local community college, has been developed. More than 5,000 visitors a year from

Sunline Transit Clean Fuel Mall and Hydrogen Transit Bus Being Refueled around the world have toured SunLine's facilities. SunLine's experience and leadership is instrumental in establishing a knowledge base and developing codes and standards for hydrogen production and use.

University of Miami Leads Hydrogen Safety Evaluation and Simulation Studies for Codes and Standards Development Using computer simulations and real-time safety studies, Dr. Michael Swain at the University of Miami evaluated the safety protocols at the California Fuel Cell Partnership (CaFCP) building in Sacramento, California. Two different hydrogen leak scenarios were used to evaluate building ventilation and potential ignition hazards, and to establish safety procedures in the event of a hydrogen leak. Dr. Swain also developed a simple method for visualizing the motion of gases from a hydrogen leak, which will be used to determine sensor placement for hydrogen leak detection. These and other tests being done at the University of Miami are being used by the International Code Council Ad Hoc Committee to develop codes and standards for the safe use of hydrogen.



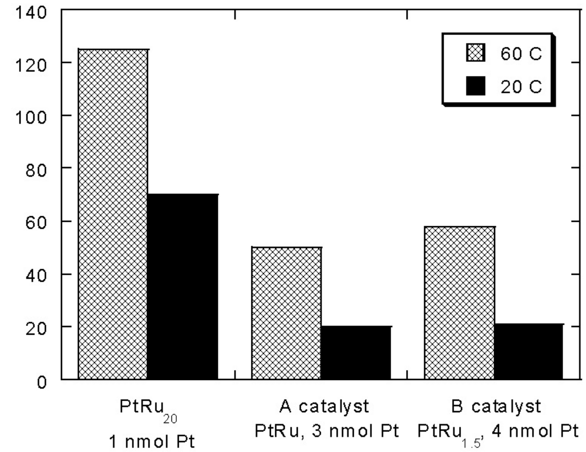
Transportation Fueling Infrastructure Analysis Completed Longitude 122 West completed its analysis of transportation fueling infrastructure costs and environmental impacts, looking at refueling alternatives (gaseous or liquid hydrogen); vehicle configuration and fuel alternatives (various hydrogen storage and power plant selections, and alternative fuels, including methanol and gasoline); cost variations for electricity, natural gas and hydrogen with economic conditions and over international boundaries; and future costs of upstream infrastructure. The analysis showed that various options for hydrogen infrastructure are possible and that the least costly option may vary with location, local pricing of gas or electricity, and technology maturity. Near-term options using hydrogen delivered from existing sources are quite feasible. The longer-term options include building new central production and distribution facilities. On-site generation requires development of commercial subsystems. The urgency of reduced local emissions can be met with hydrogen-fueled vehicles and clean hydrogen brought in by pipeline or produced by electrolysis.

Porvair Scales Up Oak Ridge Bipolar Plate Process During FY 2002, Porvair Fuel Cell Technology scaled up PEM bipolar plate fabrication technology licensed from Oak Ridge National Laboratory. The process involves fabricating porous carbon pre-forms which are subsequently impregnated with carbon by a chemical vapor impregnation or deposition process to the desired density. The plates can be embossed with the flow field pattern to eliminate machining. Porvair has scaled up production to 30 plates per day and is designing a semi-continuous process for 300 plates per day. As shown in the accompanying table, DOE material properties have been met. Plates designed by UTC Fuel Cells have been delivered to them for a 20-cell stack.

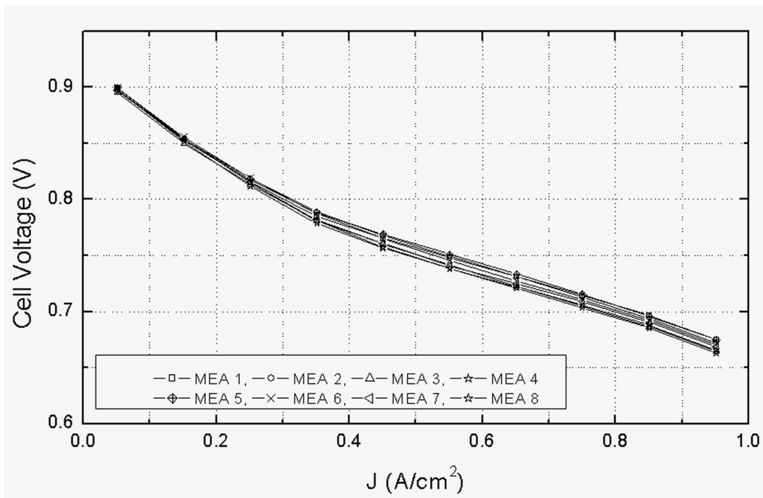
Property	Value	DOE Target
Electrical Conductivity (S/cm) (ASTM C611)	> 300	> 100
Density (g/cc)	1.00 – 1.30	-
Flexural Strength (psi)	5700	> 600 (crush)
Flexibility (%) (deflection at mid-span)	1.5 – 3.5	3-5
Nitrogen Permeability ($cc/cm^2/sec$) (ASTM D1434)	Not detected	$<2x10^{-6}$ (Hydrogen)

Porvair Carbon/Carbon BiPolar Plates

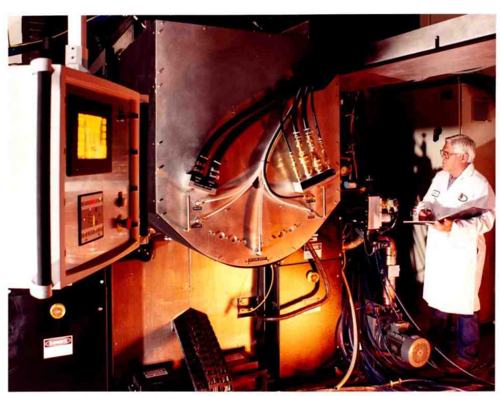
Brookhaven National Laboratory Has Developed a Process for Low-Pt Electrodes Brookhaven National Laboratory has developed and demonstrated a new electrocatalyst structure and deposition process with higher mass-specific activity (amps/mole of Pt) for hydrogen oxidation and CO tolerance than commercial electrocatalysts with several times higher platinum loadings. The concept involves synthesis of electrocatalysts by spontaneous deposition of Pt on a Ru surface, resulting in a submonolayer of Pt on the Ru nanoparticles. Based on cell testing performed at Los Alamos National Laboratory, the Pt loading and Ru loading of the new anode catalyst structure are 0.06 g/kW and 0.50 g/kW, respectively. The Pt loading is well below the DOE target of 0.2 g Pt/peak kW total for the MEA, and the Ru loading is at the level of the present state-of-the-art catalysts. Future work in this area includes replacement of the Ru with a non-precious metal such as tungsten to further reduce the precious metal loading and demonstration of the concept for oxygen reduction at the fuel cell cathode. Durability and scale-up issues will also be addressed.



<u>3M Develops High-Performance MEAs</u> This 3M project is directed toward demonstrating high-performance, matching PEM fuel cell components that can be manufactured by integrated pilot processes, using a patented nano-structured thin-film catalyst support system, and reducing precious metal loadings. Progress during FY 2002 includes: development of a new Pt ternary cathode catalyst that gives the same performance with one-half the amount of Pt, producing 0.4 A/cm^2 at 0.8 V under 30/30 psig H_2/air with 0.2 mg/cm^2 total precious metal per MEA; identification of a non-precious metal replacement for Ru on the anode for reformate tolerance, which, with air bleed, gives equivalent performances within ± 10-20 mV; integration of multiple process steps for generating the nanostructured catalyst support films into a single pass, dry web-coating, pilot plant process; and verification of the uniformity of the processed roll-goods. The accompanying figure shows the excellent uniformity of 7 statistically sampled MEAs from a 450-lineal yard roll-good.

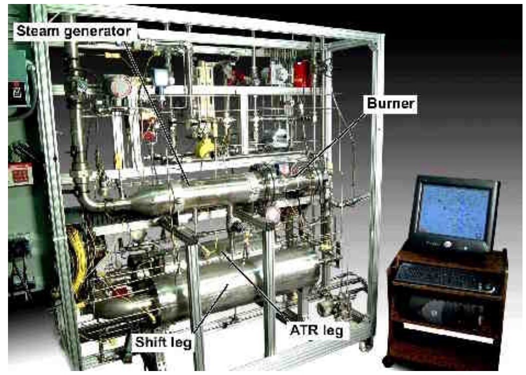


<u>SwRI Demonstrates Pilot Manufacturing of Low-Pt Electrodes</u> During FY 2002, Southwest Research Institute (SwRI), in cooperation with W.L. Gore and Associates, a leading supplier of MEAs for PEM fuel cells, completed scale-up and demonstration of a high-volume pilot manufacturing process for electrode material, a crucial (and currently costly) element in the high-volume production of fuel cell MEAs. The key component of this process is a vacuum coating unit capable of producing large quantities of high-performance, ultra-low platinum (0.1 mg/cm^2 total) per year and the potential for bringing MEA production costs below $10/kW. A pilot manufacturing facility was installed which has the capability of catalyzing more than 100,000 m^2 per year of electrode material on a 2-shift basis. Several thousand ft^2 of electrode materials at 40 linear feet per minute have been manufactured and fabricated into MEAs, which were tested on reformate and neat hydrogen in single cells. The continuously-

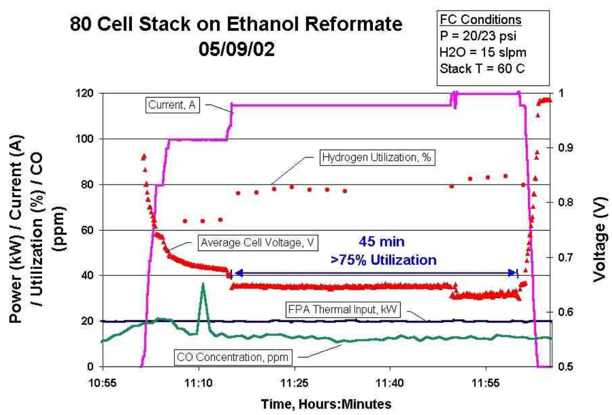


produced MEAs compare favorably with baseline MEAs with much higher Pt loadings. Future work will focus on the durability of the low-Pt MEAs.

McDermott Operates Integrated Gasoline Fuel Processor During a 100-hour test, McDermott Technology successfully demonstrated a large-scale, fully-integrated multi-fuel processor on gasoline to produce a fuel cell-quality gas containing 43% hydrogen. The fuel processor produces enough hydrogen for a 50-kW PEM fuel cell power plant, sufficient to provide propulsion power for a small vehicle or to supply hydrogen to a stationary fuel cell installation. The processor is based on a design which incorporates state-of-the-art autothermal reforming, liquid-phase desulfurization, and a medium-temperature shift reactor for CO clean-up to achieve compact size, simplified controls, and high efficiency. The system also includes a preferential oxidation (PrOx) unit supplied by Los Alamos National Laboratory and a steam generator based on microchannel heat exchanger technology developed by Pacific Northwest National Laboratory.



Caterpillar Operates PEM Fuel Cell stack on Ethanol Reformate Caterpillar, Nuvera Fuel Cells, and Williams Bio-Energy have teamed to develop and demonstrate a 15-kW ethanol-fueled PEM fuel cell system. The primary technical objectives of this project are to demonstrate performance, durability and reliability and to understand correlations and reduce gaps between stationary and transportation PEM fuel cell applications. Power module design specifications have been completed. The reformer has been tested for a short period of time (45 minutes) on ethanol at rated power, and 45- and 80-cell stacks have been successfully tested with output from the reformer.



Programmatic Highlights

Hydrogen Storage Workshop On-board hydrogen storage is a “critical path” enabling technology because current technologies offer limited driving range and demand excessive cost, volume, and weight. A Hydrogen Storage Workshop (see http://www.eren.doe.gov/hydrogen/docs/2002storageworkshop.html) was held during FY2002 to discuss approaches to increasing the capacity and reducing the cost of hydrogen storage technologies. Sessions were held on carbon technologies, chemical storage, advanced/complex hydrides, and advanced concepts. Participants included representatives of industry, academia, and DOE/national Laboratories. As a result of the Workshop, a hydrogen storage solicitation is planned for FY2003.

High-Temperature Polymer Membrane Working Group It is desirable to operate PEM fuel cells at temperatures exceeding the currently typical 80°C. Operation at higher temperature would facilitate stack and system thermal management, increase CO tolerance, and improve electrode kinetics. A High-Temperature Polymer Membrane Working Group was established to address this challenging task and to coordinate industrial, government, and academic efforts on membrane design and synthesis, thermal stability, maintaining conditions beneficial to proton conduction in the polymeric medium, implementation of new “carrier” media to replace the function of water in Nafion, study of proton transfer dynamics, and understanding the fundamentals of the proton transfer and transport processes.

The formation and processing of MEAs from any new polymers, including any critical additives, is also being addressed. The oxygen reduction reaction (ORR) activity within MEAs containing different additives or other mechanisms of proton transfer must be understood as well.

The Working Group meets biannually in conjunction with the Electrochemical Society Meetings, allowing us to assess progress and to communicate issues and needs to the High-Temperature-Membrane community at large.

Fuel Cells for Buildings and Stationary Applications A workshop was held with DOE and industry stakeholders on April 10-11, 2002 to identify the issues related to fuel cells for buildings and stationary applications (see http://www.eren.doe.gov/hydrogen/pdfs/stationary_fc_proceedings.pdf). A solicitation, “Cooperative Research, Development, and Demonstration for Fuel Cells for Stationary and Automotive Applications”, was issued (see http://www.energy.gov/HQPress/releases02/seppr/pr02193.htm) addressing the major issues raised during the workshop through DOE’s “Industry Interactive Procurement System” (IIPS) web page (http://e-center.doe.gov under the “HELP” section of the website – DE-SC02-02EE11137). The solicitation also includes topics that address cross-cutting barriers to both stationary and automotive fuel cells.

Portable and Off-Road Fuel Cell Power Applications Portable power will likely be the first high-volume market for fuel cells because of their low power requirements and less-stringent cost target (~$5,000/kW). The manufacturing capability that develops for portable power fuel cells will help accelerate commercialization of fuel cells for stationary power generation and transportation. A joint DOE/industry Portable Power Workshop was held in January 2002 (see http://www.eren.doe.gov/hydrogen/docs/2002fcportablepowerworkshop.html). The focus of the Workshop was portable fuel cells for low-power (sub-watt to 20-50W) applications such as consumer electronics and high-power (20W to 5kW) applications such as auxiliary power units (APUs) (1-10kW) for hotel and refrigeration loads for long-haul trucks and recreational vehicles. A solicitation, “Research, Development, and Integration of Energy Efficient Technologies in Portable Power and Off-Road Fuel Cell Applications” (see http://www.golden.doe.gov/business%20opportunities/solicitations.html - DE-PS36-02GO92TBD) will be issued for R,D&D in proposed consumer electronics and auxiliary power unit fuel cell systems. The solicitation will also request proposals to assess technical issues and perform R&D to evaluate and demonstrate remedies specific to off-road fuel cell applications.

Reports to Congress The United States Congress, in November of 2001, directed the DOE to submit two reports addressing the status of fuel cell technologies (see http://www.eren.doe.gov/RE/hydrogen.html. The first of these reports, to be issued in November of 2002, addressed the need for public/private partnerships to demonstrate the use of fuel cells in commercial scale applications. This report identified two public-private partnership programs, one on Stationary and Distributed Generation and one on Transportation and Infrastructure, which would be required to enable commercial-scale demonstration and to realize the benefits of fuel cell technologies.

The second report requires DOE to report on “the technical and economic barriers to the use of fuel cells in transportation, portable power, stationary and distributed generation applications.” The report is also expected to include “recommendations on program adjustments based on an assessment of the technical, economic and infrastructure requirements needed for the commercial use of fuel cells for stationary and transportation applications by 2012.” This second report is in the early draft stage.

Future Directions

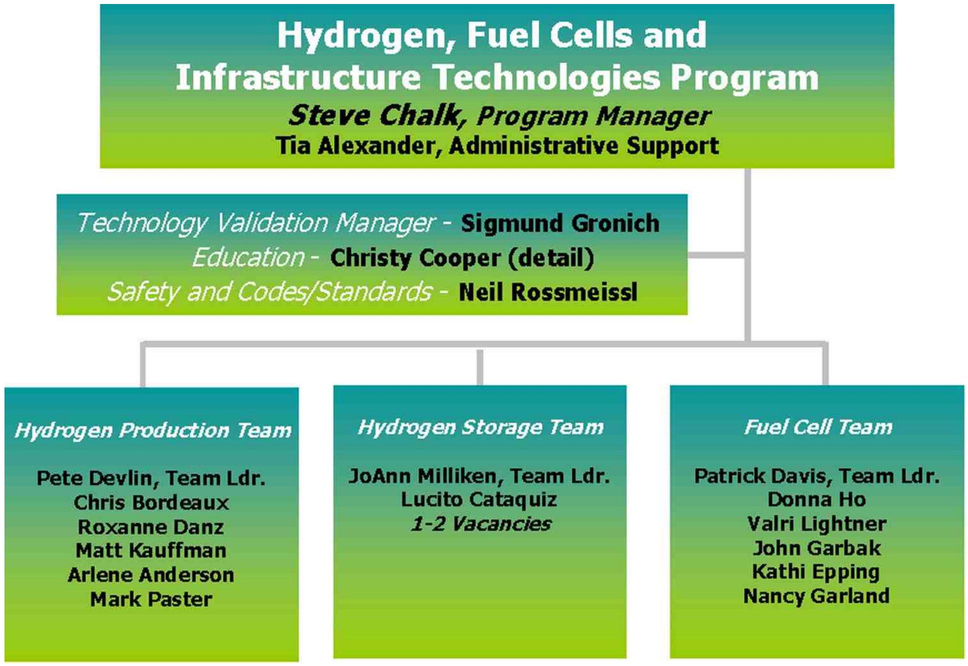
Worldwide interest in hydrogen and fuel cell technologies remains very strong for a broad range of transportation, stationary, and portable power applications. The U.S. DOE remains committed to contributing to this progress in a significant way by supporting R&D activities that address the most critical barriers to the introduction of commercially viable PEM fuel cell systems and supporting fuel infrastructure.

Recent new DOE projects de-emphasize fuel cell system integration and full-scale stack development because industry has the capability to carry these efforts forward. The DOE program will focus on addressing the most critical issues of cost, durability, and performance of materials, components, and enabling technologies. Substantial progress was made during 2002 toward meeting the technical targets for fuel cell and fueling systems for light-duty vehicles; however, significant technical and economic challenges remain before fuel cell vehicles and the supporting infrastructure will achieve significant market penetration. As we move forward, we will continue to work with our government and industry partners to address these challenges. In addition to the contracts with industry and academia, the DOE national laboratories will continue to provide valuable support to the Hydrogen, Fuel Cells, and Infrastructure Technologies Program during FY 2003 (see Table 4). Through these efforts and other related projects, researchers in the Program will continue to improve cost, durability, efficiency, and overall system performance, allowing us to move closer to the commercial availability of fuel cell vehicles.

Table 4. DOE national laboratory R&D in support of Hydrogen, Fuel Cells, and Infrastructure Technologies program.

Laboratory	R&D Focus
Argonne National Laboratory	Systems Analysis Fuel Processor Catalysis Fast-Start Fuel Processing
Brookhaven National Laboratory	Low-Pt Electrodes
Lawrence Berkeley National Laboratory	Electrocatalysts
Lawrence Livermore National	Sensors Hydrogen Storage
Los Alamos National Laboratory	Sensors Improved Cathodes High-Temperature Membranes Durability Studies Fuels Effects
National Energy Technology Laboratory	Fuel Processing
National Renewable Energy Laboratory	Vehicle and Hydrogen Infrastructure Analyses Hydrogen Production Hydrogen Storage
Oak Ridge National Laboratory	Stack Materials/Components
Pacific Northwest National Laboratory	Microchannel Fuel Processing
Sandia National Laboratory	Hydrogen Purification Hydrogen Storage

As mentioned earlier, EERE's Hydrogen Program, Fuel Cells for Buildings Program, and Fuel Cells for Transportation Program were merged to form the Hydrogen, Fuel Cells and Infrastructure Program. The Program Office is organized as follows:



Programmatic responsibilities have been assigned as follows:

Hydrogen Production Team	
Pete Devlin (202) 586-4905 Peter.Devlin@ee.doe.gov	• Overall Hydrogen Production R&D • FreedomCAR Energy Industry Expansion
Roxanne Danz (202) 586-7260 Roxanne.Danz@ee.doe.gov	• Biological, Biomass, and other Renewable Hydrogen Production
Chris Bordeaux (202) 586-3070 Christopher.Bordeaux@ee.doe.gov	• Integrated Power Parks • Uninterruptible Power Systems • H_2 Infrastructure Validation • California Fuel Cell Partnership • International Outreach (non-IEA)
Matt Kauffman (202) 586-5824 Matthew.Kauffman@ee.doe.gov	• Cross-cutting Analyses • Electrolyzers
Arlene Anderson (202) 586-3818 Arlene.Anderson@ee.doe.gov	• H_2 Production: Natural Gas, Petroleum Feedstocks • Coordinate with Fossil Energy on Coal-Based H_2 Production • 5-Year R,D&D Plan Development • Platinum Mining & Recovery
Mark Paster (202) 586-2821 Mark.Paster@ee.doe.gov	• Overall Feedstock Strategy for H_2 production • High Temperature Thermochemical and Electroysis H_2 Production • Hydrogen Delivery

Hydrogen Storage Team	
Lucito Cataquiz (202) 586-0729 Lucito.Cataquiz@ee.doe.gov	• Support Service Contractor COTR • Cost/Financial Status • Pressurized Tanks & Hydrogen Compressors
JoAnn Milliken (202) 586-2480 JoAnn.Milliken@ee.doe.gov	• Overall Hydrogen Storage • Fuel Cell International Activities • FreedomCAR Storage & Vehicle Interface Tech Team
Fuel Cell Team	
Pat Davis (202) 586-8061 Patrick.Davis@ee.doe.gov	• Overall Fuel Cell Systems • FreedomCAR Fuel Cell Tech Team • Compressors/Expanders
Donna Ho (202) 586-8000 Donna.Ho@ee.doe.gov	• Transportation Fuel Cells • CARAT Program
Valri Lightner (202) 586-0937 Valri.Lightner@ee.doe.gov	• Fuel Processing • MEA R&D
John Garbak (202) 586-1723 John.Garbak@ee.doe.gov	• Fuel Cell Vehicle Demonstration • Liaison with 21st Century Truck • Fuel Cells for APUs
Kathi Epping (202) 586-7425 Kathi.Epping@ee.doe.gov	• Stationary Fuel Cells
Nancy Garland (202) 586-5673 Nancy.Garland@ee.doe.gov	• National Lab Fuel Cell R&D • Sensors • GATE Program
Cross-Cutting Functions	
Sig Gronich (202) 586-1623 Sigmund.Gronich@ee.doe.gov	• Overall Technology Validations for Transportation and Stationary Applications
Christy Cooper (202) 586-1885 christy.cooper@ee.doe.gov	• Education on Hydrogen and Fuel Cells
Neil Rossmeissl (202) 586-8668 Neil.Rossmeissl@ee.doe.gov	• H_2 Codes and Standards • H_2 Safety • Hydrogen Technical Advisory Panel • IEA H_2 Agreement

The Office of Hydrogen, Fuel Cells and Infrastructure Technologies has established the following FY 2003 priorities:

1. Develop an integrated 5-year R,D&D Plan to address challenges identified in the National Hydrogen Energy Roadmap.
2. Implement a "national" program in hydrogen storage that focuses on low pressure, solid-state materials.
3. Develop, with assistance of the National Academy of Sciences, a feedstock strategy for hydrogen production which can be used as a basis for cost effective implementation of hydrogen infrastructure.
4. Prepare an integrated DOE Hydrogen Plan to coordinate efforts among the Offices of Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy and Science.
5. Evaluate the feasibility and conduct planning for a fuel cell vehicle and hydrogen infrastructure test and evaluation program.
6. Engage the energy industry as formal partners in FreedomCAR.
7. Establish more comprehensive PEM stationary fuel cell activities. (Initiating new activities with a solicitation for fuel cell R,D&D, see graphic.)

Solicitation for RD&D for Stationary and Automotive Fuel Cells

- **Topics include:**
  - Development of Stationary PEM Fuel Cell Power System
  - Development of Back-up Fuel Cell Power System
  - Development of Materials for High Temperature Membranes and PEM Stack Durability for Stationary & Transportation Applications
  - Fuel Processing Technology for Stationary Applications
  - Stationary Fuel Cell Demonstration
  - Platinum Recycling Technology Development
  - Non-Precious Metal Catalyst Development
  - Water and Thermal Management
  - Economic Analysis of PEM Fuel Cell Systems
- **Point of contact: Nadine Kijak (630)252-2508**

8. Publish a national plan for safety, codes and standards.
9. Develop a hydrogen education "campaign" as recommended in the President's National Energy Policy.
10. Establish closer relationships with states through EERE Regional Support Offices to execute hydrogen and fuel cell R,D&D.

The remainder of this report presents extended project abstracts that highlight progress achieved during FY 2002 under the Hydrogen, Fuel Cells, and Infrastructure Technologies Program. The extended abstracts summarize both industry and national laboratory projects, providing the major results of the work being conducted to overcome the technical barriers associated with the development of hydrogen production, storage, and delivery and fuel cell power systems.

Left to Right: Front Row: Donna Ho, Patrick Davis, Steve Chalk, Mark Paster, John Garbak
Middle Row: Christy Cooper, JoAnn Milliken, Roxanne Danz, Sigmund Gronich, Lucito Cataquiz, Arlene Anderson, Nancy Garland, Kathi Epping, Valri Lightner, Chris Bordeaux
Back Row: Neil Rossmeissl, Tia Alexander, John Petrovic (LANL), Reeshemiah Schuler (CSMI), Peter Devlin, Matt Kauffman, Bill Cleary (ANL)

We hope to see you at the next program review meeting to be held in Berkeley, California on May 19-22, 2003.

Steven G. Chalk, Program Manager
Office of Hydrogen, Fuel Cells, and Infrastructure Technologies
Energy Efficiency and Renewable Energy