Frank DiMeo/CU

NEW MATERIALS ADVANCE FUEL CELL TECHNOLOGIES AS AN ALTERNATIVE ENERGY SOURCE

The Cornell Fuel Cell Institute (CFCI)

finiteness, pollution, and vulnerability to political instability are major concerns about the use of fossil fuels nationally and internationally.

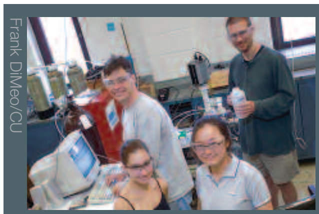
The use of fossil fuels is driving the energy debate nationally and internationally. Their finite nature, the deleterious effects associated with their use—air and water pollution and global warming—and their vulnerability to political instability cause major concerns. Long-term solutions lie with improving the efficiency of fuel use and developing alternatives even if at times they are controversial energy sources. Solar, wind, and hydrothermal, as well as oil, coal, and nuclear power sources offer alternatives. Each poses significant though different challenges. Major increases in global energy needs, however, will only be met by the appropriate utilization of most, if not all, of these options.

An especially vexing problem is fuel for transportation needs, since centralized power sources, such as electrical generation, cannot be directly tapped for many transportation uses. (It should be noted, however, that the U.S. lags behind Europe in electrically powered public transportation). In the 2003 *State of the Union* address, President Bush called for the development of "cars powered by hydrogen that would be pollution free" by the year 2020. Many reports from the national academies, professional societies, and the Department of Energy have underscored the scientific and technological barriers that must be overcome to reach the goal of national energy independence.

One promising and likely component of a higher efficiency transportation system and a central part of the so-called hydrogen economy is the fuel cell (see "*What is a fuel cell?*" page 20). Fuel cell technology has improved considerably in the last 10–20 years, mainly driven by necessary and important engineering advances. Large, stationary fuel cells with energy efficiencies in excess of 50 percent have been demonstrated. (Compare this value to the average efficiency of internal combustion engines of about 20 percent.)

The goals of low cost and, especially, durability (4000 hours of operation under typical driving conditions would give an average life of 120,000 miles) are still far from reach. The origin of these problems is the materials used in the essential components of fuel cells. Many of these materials have not changed in decades, and the time has come for scientists and engineers to make necessary breakthroughs to produce affordable and reliable fuel cells and to enable the other components of the hydrogen economy.

CFCI researchers have already found promising new catalysts for anodes.

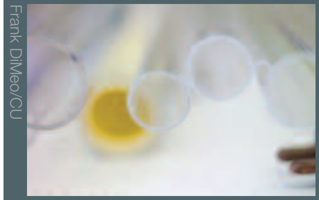


Frank DiMeo/CU

(clockwise) Jamie Cohen, Craig Downie, Mark Prochaska, and Jing Jin

Frank DiMeo/CU

Niobium tubes used for synthesis of FC catalysts using Zintl approach



Frank DiMeo/CU

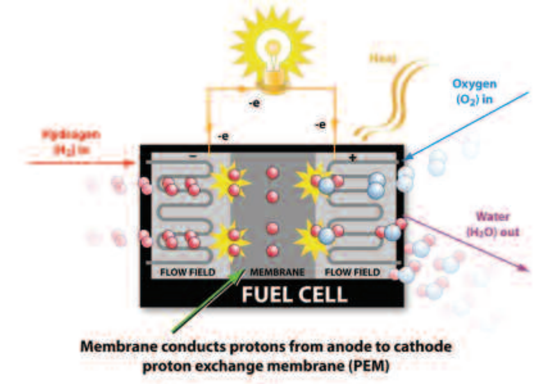
Quartz tubes used for synthesizing FC catalysts using solid-state methods fuel for transportation needs is especially vexing.

WHAT IS A FUEL CELL?
How Does It Work?

Fuel cells directly convert the energy released in certain chemical reactions, primarily combustion (oxidation) of hydrogen or a carbonaceous fuel, to electrical energy.

Interest in combustion reactions is because they release a large amount of energy per unit mass of fuel and some of these fuels are available at relatively low cost. The reaction of hydrogen (the fuel) with oxygen (the oxidizer) to produce water is such a suitable reaction. Other fuels used in fuel cells include methane, methanol, and even gasoline. More chemically complex fuels, like gasoline, require pre-processing into a hydrogen-rich gas stream before introduction to the fuel cell.

Sir William Grove invented the fuel cell in 1839. However, it was not until the 1950s that the National Aeronautics and Space Administration (NASA) constructed the first practical fuel cells to produce power for space vehicles.



Membrane conducts protons from anode to cathode proton exchange membrane (PEM).

The building block of a fuel cell is an electrochemical cell consisting of two electrodes separated by a membrane—or an ionically conducting medium. (See the diagram above.) The ionically conducting medium can be an acid, base, or salt (in liquid, they are in polymeric or molten forms), or a solid ceramic that conducts ions. The choice of electrolyte is dependent on the nature of the fuel, the temperature of operation, and the specific application of the technology. Fuel enters the cell on the left side and oxygen enters on the right side. Any reaction products, water or carbon dioxide depending on the fuel and type of cell, must also exit the cell. As fuel is oxidized, electrons are released to travel through the external load to the cathode, where oxygen consumes the electrons.*

The electrodes serve several functions. First, they must be electronically conducting. Second, they usually contain the electrocatalytic materials that facilitate the reaction of fuel at one electrode (the anode) and of oxygen at the other electrode (the cathode). Some catalytic materials are much better than others at facilitating the reactions and may themselves also be electronic conductors.

Grove used solid pieces of platinum metal for both electrodes; platinum was the conductor and the electrocatalyst. In most contemporary low-temperature fuel cells, platinum electrocatalysts are still used, but in highly dispersed form as nanoparticles. The electrocatalyst is highly dispersed in order to attain large areas that result in high electrical power output.

For the fuel cell to function properly, the electrocatalyst particles have to be easily reached by the fuel (or by oxygen on the other side of the cell), and they also must be contacted by the ionically conducting medium and the electronically conducting medium. Consequently, current low-temperature fuel cell electrodes consist of porous composites of ionic/electronic conductors with embedded nanosize particles of the electrocatalyst in order to obtain as high an electrical power from as small an amount of precious metal as possible. The electrode contains open pores for the fuel and any waste products to enter or exit the electrode. Producing electrodes that offer optimal performance is challenging.

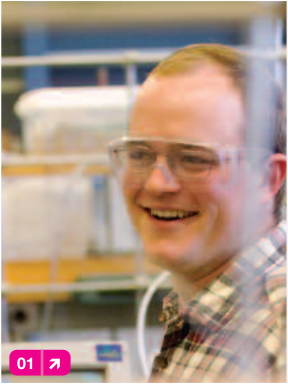
More than 150 years after Grove's discovery, fuel cells that operate near room temperature still contain the precious metal platinum. One goal of an ambitious fuel cell R&D program is to replace the expensive platinum with much cheaper materials. No one thinks this objective will be easy to attain—after all, nothing better has been found in a century and a half.

** The diagram does not show essential parts of the fuel cell, such as all the container and support materials that keep the fuel and oxygen flowing separately and direct the reaction products out of the cell, or the interconnections between a series of cells.*

For more information:

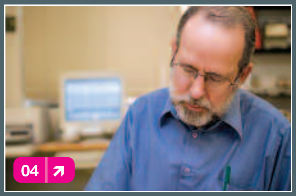
fjd3@cornell.edu
hda1@cornell.edu
http://abruna.chem.cornell.edu/fuelcell/home.html

All photos on this page: Frank DiMeo/CU


01


02

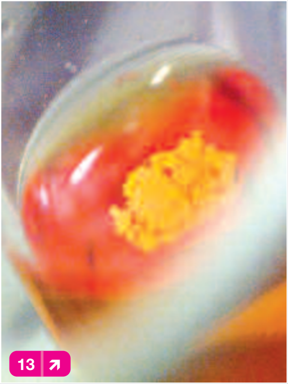

03


04


05

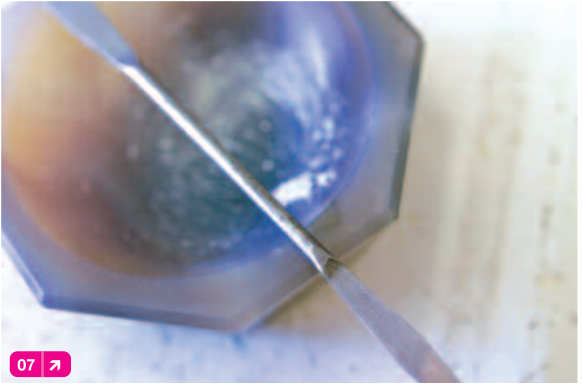

15


14


13


12

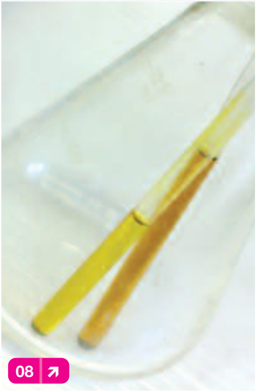

06


07


11


10


09


08

01. Laif Alden in a typical FC lab

02. Chandrani Roy Chowdhury looks at a suspension of nanoparticles; James Ledoux observes.

03. Empty sample bottles: a view through the RF coils

04. Frank DiSalvo

05. Solutions used for testing activity/stability of catalytic nanoparticles

06. Emerilis Casado Rivera (l.) and Noemí de los Santos Álvarez (r.) prepare intermetallic electrodes for characterization.

07. A sample of a ground-up reducing agent inside a mortar

08. Nanoparticle suspensions: PtPb and PtBi nanoparticles prepared from polyol processes

09. Chandrani Roy Chowdhury and James Ledoux analyze data on electrochemical leaching experiments.

10. Héctor Abruña

11. Front: Jamie Cohen (l.) and Mark Prochaska (r.) prepare the electrolyte;
back: Jing Jin operates the DEMS instrument.

12. Mark Prochaska makes a reductant solution for PtPb synthesis.

13. A solution containing Zintl-like anions in a solution; an intermediate in the synthesis of nanoparticles

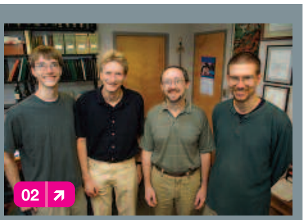
14. Emerilis Casado Rivera (l.) and Noemí de los Santos Álvarez (r.) prepare the electrolyte; Laif Alden observes.

15. Heating coils of a RF furnace

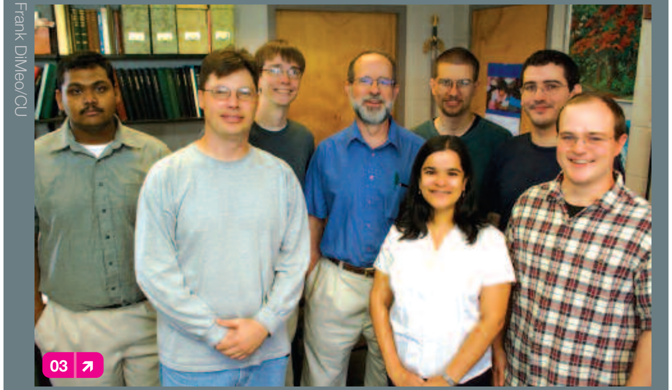
To address the materials issues, the Cornell Fuel Cell Institute (CFCI) was founded in September 2003, with support from the Department of Energy, and in the summer of 2004, support from New York State, as well as Ford and General Motors. CFCI includes six faculty at Cornell—Francis J. DiSalvo, Héctor D. Abruña, and Barry K. Carpenter, Chemistry and Chemical Biology; Emmanuel P. Giannelis, R. Bruce van Dover, and Ulrich B. Wiesner, Materials Science and Engineering; and Sossina Haile, California Institute of Technology, Materials Science and Engineering. These faculty direct the research of graduate students, postdoctorate associates, and undergraduate students aimed at identifying and developing improved performance of fuel cell materials.

CFCI includes six faculty at Cornell who direct the research of graduate students, postdoctoral associates, and undergraduate students to identify and develop improved performance of fuel cell materials. CFCI researchers concentrate on materials for low-temperature applications—transportation and consumer electronics such as laptops and cell phones.

Frank DiMeo/CU



Frank DiMeo/CU



Frank DiMeo/CU

01. (l. to r.) Jamie Cohen, Chemistry and Chemical Biology; Emerilis Casado Rivera, Chemistry and Chemical Biology; Professor Héctor Abruña, Chemistry and Chemical Biology; Noemí de los Santos Álvarez, visiting scientist, Chemistry and Chemical Biology; David Volpe, Chemistry and Chemical Biology; and Jing Jin, Chemistry and Chemical Biology

02. (l. to r.) Scott Warren, Materials Science and Engineering; Professor Ulrich Wiesner, Materials Science and Engineering; Professor Robert van Dover, Materials Science and Engineering; Mark Prochaska, Applied and Engineering Physics

03. (l. to r.) Chinmoy Ranjan, Chemistry and Chemical Biology; Craig Downie, Chemistry and Chemical Biology; Scott Warren, Materials Science and Engineering; Professor Frank DiSalvo, Chemistry and Chemical Biology; Chandrani Roy Chowdhury, Chemistry and Chemical Biology; Mark Prochaska, Applied and Engineering Physics; James Ledoux, Chemistry and Chemical Biology; and Laif Alden, Chemistry and Chemical Biology

Half a dozen fuel cell technologies have been developed to various extents. Each is characterized by factors such as the temperature of operation—up to 1000°C or the fuel used—hydrogen, methanol or methane. Every fuel cell technology is faced with serious materials problems. Most technologists believe that the bulk of transportation needs can only be met with fuel cells that operate at the lower temperatures—below 200°C. Of these, the so-called polymer electrolyte membrane fuel cell (PEMFC), typically employing hydrogen (H_2) as fuel, oxygen (O_2) as oxidant, and platinum catalysts has received the most attention. CFCI researchers are concentrating on materials for low-temperature applications including transportation and consumer electronics, such as laptops and cell phones.

as part of the "hydrogen economy," the fuel cell offers promise.

Better electrocatalysts are needed for both the anode (where hydrogen is oxidized) and the cathode (where oxygen is reduced). Current catalysts have changed little in composition since the invention of the fuel cell in 1839! Platinum metal (and sometimes a simple alloy of platinum with metals such as ruthenium) is still used, although now it is in the form of a very high surface area—nanoparticles only a few dozen atoms wide. Current membranes are not durable, often failing after 500 to 1000 hours of use.

CFCI researchers have already found promising new catalysts for anodes and are working on finding better cathode catalysts as well as improved membranes. Their work is closely coupled to several companies that are developing fuel cell technologies. Two CFCI graduate students are supported by industrial gifts from Ford and General Motors, and another is supported by a fellowship from the U.S. Environmental Protection Agency.

CFCI researchers "feel confident that materials advances at the CFCI will advance fuel cell technologies and greatly impact the energy landscape."

Francis J. DiSalvo
J.A. Newman Professor of Chemistry
and Chemical Biology
Héctor D. Abruña
E.M. Chamot Professor of Chemistry
and Chemical Biology