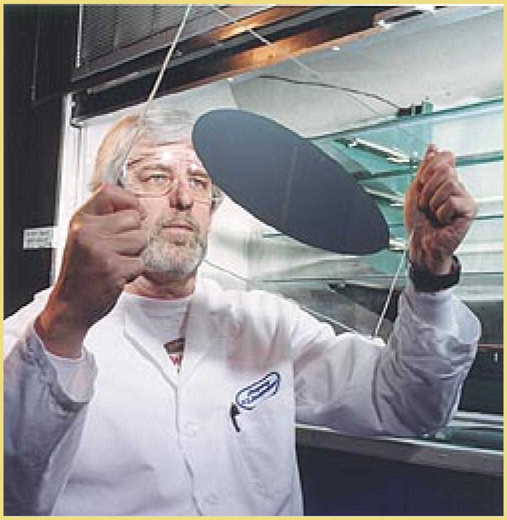
Fueling the hydrogen future with Argonne's ceramic membrane

A ceramic membrane developed at Argonne brings fuel-cell cars closer to reality by efficiently and inexpensively extracting hydrogen from fossil fuels.



CERAMIC MEMBRANE – Jack Picciolo holds a sample of the Argonne-developed ceramic membrane material for hydrogen production.

"Ceramic membranes could make possible the widespread use of hydrogen," said senior ceramist Balu Balachandran. "Hydrogen is a fuel of choice for the future. This technology provides a means to get there."

Though the membranes currently used for research are only a few millimeters across, once scaled up for industrial use, they could be installed at existing refineries or at individual refueling stations.

"Just as conventional cars need gas stations, fuel-cell cars will need an infrastructure to support them," Balachandran said. "Ceramic membranes could eliminate the need for costly, conventional hydrogen-manufacturing facilities; they could one day be small and efficient enough to have one at every gas station."

Membrane design

Industry currently uses membrane systems to filter wastewater or separate gases. Most work like a sieve, with small holes or pores that allow only smaller molecules to pass through. But these membranes are not selective enough to isolate pure hydrogen, the simplest and smallest of all elements. For this task, Argonne ceramists developed a hydrogen-filtering ceramic membrane.

Ceramic membranes, such as Argonne's new hydrogen membrane, are made of dense, conductive materials that only allow electrons and certain ions, or charged atoms, to pass through.

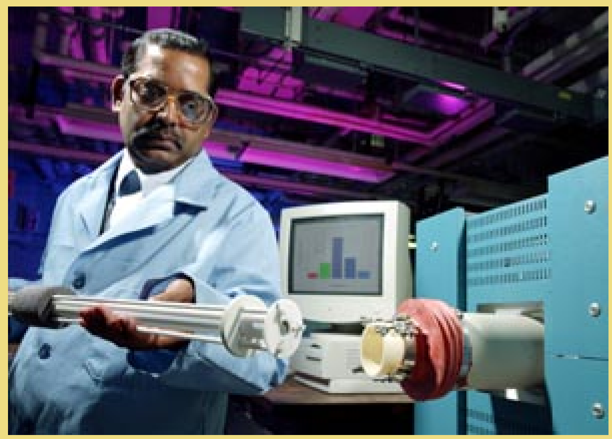
"There are no interconnected holes or pores," Balachandran said. "A molecule cannot swim through from one side to the other side."

These ceramic membranes behave differently depending on the materials used to form them. After studying the conductivity and solubility of various substances, Balachandran's team developed a composite ceramic-oxide that transports only hydrogen ions and electrons. This allows the membrane to separate pure hydrogen that is suitable for use both as a clean-burning fuel and for the production of fertilizers and other products.

In practice, a hydrogen-rich gas mixture is supplied to one side of the membrane. Charged hydrogen particles pass through the membrane, and the resulting pure hydrogen that emerges from the other side is captured for immediate use, storage or transport.

Unlike most membrane systems, Argonne's hydrogen membrane tolerates temperatures as high as 900 degrees Celsius (1,650 degrees Fahrenheit). Such elevated temperatures are an advantage for hydrogen production, since they induce the molecules to move faster, with the result that more hydrogen atoms are pushed into the membrane. These additional atoms become charged and pass through the membrane, with the result that the rate of the gaseous separation process is accelerated.

The most likely raw feedstock material for hydrogen separation with Argonne's new ceramic membrane is syngas, Balachandran explained. Syngas is commonly used to make liquid diesel and other transportation fuels as well as chemicals for the petrochemical, rubber, plastics and fertilizer industries. Short for synthesis gas, syngas is a mixture of hydrogen and carbon monoxide. It is made by reacting natural gas with oxygen. Methane, the major component of natural gas, contains hydrogen that is tightly bound to carbon, but this hydrogen is released when oxygen combines with the carbon.



FUTURE HYDROGEN SOURCE – Ceramic membranes could supply hydrogen for energy applications, according to Balu Balachandran.

More membrane help

While Argonne's ceramic membrane can extract hydrogen from syngas, this feedstock can be expensive to produce using the energy-intensive process of steam reforming or by mixing methane with air. For that reason, the economics of producing an ample and affordable supply of hydrogen for power sources through the use of Argonne's new membrane could be compromised by the cost of supplying syngas. To address this problem, the ceramics group wants to study the possibility of using a membrane they developed about 10 years ago to extract oxygen. Electrons on one side of this oxygen-transport membrane combine with oxygen to create negatively charged oxygen ions that can migrate through the membrane. Once on the other side, electrons are stripped from the transported oxygen ions, converting them back into neutral oxygen atoms and freeing the electrons to migrate back across the membrane to form more ions.

According to Balachandran, this oxygen-extraction membrane can be adapted to provide a cost-effective alternative for accomplishing the first half of the transition from natural gas to syngas to hydrogen fuel. Balachandran's team has demonstrated that the oxygen membranes successfully separate oxygen and that this separated oxygen, when reacted with methane, forms synthesis gas. This process could result in an economically efficient two-step technique to provide pure hydrogen for transportation and power applications from fossil fuels such as methane or coal gas. Because Argonne's oxygen and hydrogen membranes both function at the same high temperatures, they could work in tandem: One membrane could add oxygen to methane to create syngas, and the other could extract hydrogen from the same syngas.

Ceramic membranes such as these could be a key development in the Department of Energy's "Vision 21" program, which seeks to develop highly efficient power technologies that do not discharge pollutants.

Argonne's ceramic membranes were developed as part of a project funded by DOE's Office of Fossil Energy through the National Energy Technology Laboratory's Gasification Technologies Program. Balachandran's team also has cooperative research and development agreements with industry to address the problem of scaling up the hydrogen-separating membrane.