Rare-earth Information Center INSIGHT

Ames Laboratory
Institute for Physical Research and Technology
Iowa State University / Ames, Iowa 50011-3020 / U.S.A.

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FUEL CELLS COMING OF AGE

A fuel cell is a device which converts the chemical energy of a fuel, such as H_2 and/or CO, to usable energy (electricity or heat) by oxidation without combustion. The operating principle of fuel cells is similar to batteries, but instead of recharging periodically, the fuel and oxidant are supplied continuously to the electrodes of a fuel cell producing the direct current. The key components are an *anode*, to which the fuel is supplied, a *cathode*, to which the oxidant is supplied, an *electrolyte*, which allows the ions to flow between the anode and cathode, and an *interconnect*, which electrically connects the individual fuel cells to produce the required voltage. A series of cells, which can be connected in series, or parallel or both, are referred to as a stack.

A fuel cell has a high energy conversion efficiency because it converts the chemical energy of the fuel directly to electrical energy without the intermediate stage of thermal energy conversion as in the direct combustion process used in a typical electrical power plant. Fuel cells have several advantages of conventional methods of power generation: (1) a higher conversion efficiency, (2) a much lower emission of pollutants (e.g. NO_x emissions from fuel cells are 10% that of turbines and 1% that of combustion engines), (3) modular construction, (4) minimal siting restrictions, and (5) a high efficiency at a partial load. There are four major types of fuel cells: (1) polymer electrolyte fuel cell (PEFC), which operates between 80 and 110°C; (2) phosphoric acid fuel cells (PAFC), which operate in a temperature range of 150 to 210°C; (3) molten carbonate fuel cell (MCFC), which operates at 600 ± 50°C; and (4) solid oxide fuel cell (SOFC), which operates between 1000 and 1100°C. One of the advantages of the last two (MCFC and SOFC) is that both can supply high grade waste heat which can be used to cogenerate steam and improve the efficiency of the fuel cell by as much as 25%.

Practically all developed countries have fuel cell development research projects in progress. The leading developers are the USA and Japan. Currently there are about 250 PAFC, 35 MCFC, and 23 SOFC power installations in development around the world, with a total output of 45 MW. The largest operational unit today is a 250 kW MCFC unit, with a planned 1 MW plant demonstration unit planned for 1997.

You may be wondering what does PEFC, PAFC, MCFC and SOFC have to do with rare earths? For the first three nothing, except that they are competitors of the last, SOFC, which is essentially almost entirely made up of rare earth containing materials. The make-up of the various components are as follows: (1) the anode is generally a nickel-yttria stabilized zirconia (YSZ) cermet. Because the anode needs to be porous, it consists of nickel metal dispersed on the surface of the YSZ support. In addition at the fuel inlet, the cell operates in a reducing atmosphere of H_2 and/or CO and at the outlet end it is exposed to a more oxidizing atmosphere. (2) The cathode is made of a strontium-doped lanthanum manganite $(La_{1-x}Sr_x)MnO_3$. The strontium doping increases the electrical conductivity of $LaMnO_3$ by increasing the Mn^{4+} content, but at the

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Telephone: (515) 294-2272
Facsimile: (515) 294-3709

Telex: 269266
Internet: RIC@AMESLAB.GOV

same time it increases the thermal expansion coefficient, which could be a problem since the $(La_{1-x}Sr_x)MnO_3$ is bonded to the YSZ electrolyte, which has a lower thermal expansion coefficient. (3) The electrolyte is generally yttria-stabilized zirconia with about an 8% Y_2O_3 content. Other rare earth oxides as a zirconia stabilizer will also work, but Y_2O_3 is preferred because it is readily available in sufficient purity and at a lower cost, and because it is one of the better dopants with respect to ionic conductivity. The solid electrolyte serves to conduct the O^{2-} ions from the cathode to the anode. At the anode surface, the O^{2-} ions react with the H_2 to form H_2O (i.e. equivalent of the combustion in a normal electrical generating plant) on the nickel metal surface generating electrons which flow to an external circuit (i.e. generating the electricity). The electrons from the outer circuit are returned to the cathode where the O_2 is converted to O^{2-} ions completing the circuit. If the fuel contains CO, the CO reacts with the H_2O formed at the anode surface to give CO_2 and H_2, which is then oxidized by the anode to form more H_2O. (4) The final component is the interconnect, which is a doped lanthanum chromite, $LaCrO_3$. $LaCrO_3$ is the preferred interconnect material because of its excellent conductivity at the 1000°C operating temperature, and its refractory nature (i.e. a melting point greater than 2400°C). It suffers, however, because it undergoes a phase transition from orthorhombic to rhombodedral at ~260°C and then remains in the stable form up to 1650°C. But since the cell operates at 1000°C, the upper transition presents no problem. The major problem is that $LaCrO_3$ is difficult to sinter to high densities. This is important since the interconnect needs to prevent cross leakage of the fuel and oxidant gases.

Fuel cells are expected to make an impact on the electrical power generation in the next five years. Initially, they will be used for maximum peak shaving and isolated power stations, but in time they will become part of the main power generation facilities of an electrical utility. Already the PAFCs are producing (or shortly will produce) a few percent of the electrical power in Japan, and by the year 2000, MCFCs are predicted to generate 10% of the electric utility market in Japan. In the beginning of the 21st century, about 7% of the total worldwide electric power supply will be generated by fuel cells, including SOFC. By 2015, the electric generating facilities will be much different from today's centrally located mega watt generator power plants. The power generation plants of the future will be much smaller and decentralized within a utility's service area. Clearly this will be an important and expanding the rare earth market beginning in two or three years from now and it will continue to grow for the next twenty years. The rate of growth depends upon how quickly some of the material problems associated with SOFC are solved.

The solid oxide fuel cells have several advantages over the other types of fuel cells. These include the use of non-precious materials, no liquids involved in the fuel cell, high operating temperatures, and an invariant electrolyte. The first means that, in principle, SOFC will be inexpensive relative to other fuel cells, however, there are special fabrication problems that need to be solved. Since no liquids are involved the cells can be fabricated in thin layers, and the components can be configured in unique shapes which are unachieveable in PAFC and MCFC units. This allows cell designs with additional performance improvements. The use of a solid electrolyte eliminates material corrosion and electrolyte management problems. Finally the high operating temperature promotes rapid reaction kinetics, allows reforming of hydrocarbon fuels within the fuel cell itself, and the by product heat is suitable for cogeneration or bottoming cycle.

All-in-all SOFCs offer a promising future for the rare earth oxide markets, especially for yttria and lanthania products.

Karl A. Gschneidner, Jr.

K. A. Gschneidner, Jr.
Director, RIC