The Federal Role in Fuel-cell Research and Development

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Fuel cells have the potential to provide environmentally-friendly sources of energy for transportation, portable, and stationary applications. Because fuel cells convert chemical energy directly to electrical energy, high efficiencies can be realized. Production of electrical power from fuel cells has several other advantages. There are no moving parts. Fuel cells operate noiselessly with no frictional wear. Because electrical energy is generated by an electrochemical process rather than by combustion, atmospheric pollutants produced are minimal.

For near-term applications low-temperature (<200^{o}C) devices are being developed. The proton-exchange membrane (PEM) and direct methanol fuel cells (DMFC) are being considered as transportation and portable power sources. The PEM fuel cell typically consists of a polymer electrolyte sandwiched between carbon electrodes with noble-metal catalysts. With hydrogen and oxygen feeds the sole product is water. A similar configuration is used for the DMFC but the ability to store a liquid fuel offers significant advantages for portable applications.

In the longer term, high-temperature fuel cells have the potential to be more efficient, but materials problems are a particular challenge. Solid-oxide fuel cells (SOFC) operate at temperatures around 1000^{o}C, where electrode kinetics are facilitated. The electrolyte is typically fabricated from an yttria-zirconia ceramic material.

Since the early 1990s the federal government has recognized the potential of fuel cells for widespread applications and has sponsored an increasing amount of research and development. In addition, the major automotive companies have invested in fuel cells to develop a clean vehicle engine comparable to conventional ones. A market for stationary distributed generation (DG) has also been a driver for fuel-cell development. There is increasing concern regarding the reliability of electric energy, and this has created increased demand for emergency power for hospitals and major computational and computer data storage resources. During the past several years, the demand for high energy density portable power has grown. This demand is driven by the proliferation of portable electronic and computer devices and the desire for longer operation times. High energy density power sources imply greater capability in military applications. These factors are the cause for a resurgence of interest in fuel cells and their development.

Despite this increased interest, formidable technical challenges remain. Although low-temperature systems are capable of high efficiency, the catalyst and transport processes limit actual performance. Engineering challenges of integrating and controlling the fuel-cell system (fuel processor, fuel cell, power conditioner) must be met. In the case of portable power, miniaturization requires the implementation of novel fluid and transport processes since these devices need to be passive without mechanical pumps, compressors, humidifiers or complex flow systems. In addition, fuel cells overall are material intensive and the cost of materials and fabrication is significant. Significant market penetration by fuel cells will require advances in materials and designs. Fundamental research that provides the technical basis for fuel-cell advances will be essential.

The hydrogen economy will require advances in fuel processors and/or new sources of hydrogen. In the future hydrogen may be derived from biomass or solar or nuclear driven processes, but near term hydrogen will be derived from fossil fuels. The fuel processing area is a complex and challenging part of the fuel-cell system. It must be customized depending on the fuel, which can range from natural gas to diesel with widely varying levels of sulfur. The challenges are greatest for PEMs due to their intolerance of impurities. The typical fuel-processing section will have an initial autothermal reactor, which converts the fuel and water in the presence of catalyst t to hydrogen, carbon dioxide, carbon monoxide, and impurities. A water-gas shift reactor increases the conversion to hydrogen.

A primary objective of fuel-processor improvement is to simplify the system. Elimination of reactors and reducing or eliminating precious metal catalysts are major targets. The control and removal of impurities is also important with sulfur and carbon monoxide being key for PEMs. Rapid start-up, operation at different temperatures and the transient temperature behavior make operational control a challenge. Better algorithms and sensors are needed for this complex system.

For PEM fuel cells the membrane has several shortcomings. Perfluorosulfonate ionomer materials (e.g., Nafion^{TM}) have dominated the commercial market. These materials have unacceptable methanol crossover and water transport rates. They also do not perform well at temperatures above 100^{o}C. In an attempt to fill these gaps, several new materials have emerged. Membranes prepared from other polymer groups, including polybenzimidazole (PBI), polyetheretherketones (PEEK), and polyethersulfone, are being investigated. The development of a satisfactory membrane system will require a coordinated research effort encompassing polymer synthesis, fundamental research on proton conduction in polymers, development of functioning catalyst-coated membranes, and assessment of their performance in fuel cells.

The current generation of low-temperature fuel cells requires noble-metal catalysts that are expensive and are poisoned by a range of impurities. The presence of sulfur and nitrogen oxides as well as carbon monoxide, and aromatic species in the gas feeds of cathodes and anodes can impair the performance of fuel cells by blocking active sites for electron transfer. A mechanistic understanding of these processes should be helpful in offsetting such undesirable effects. Several recently developed approaches are being employed in the development of new catalysts. Combinatorial approaches are being used in catalyst discovery. A theoretical rationale for the selection of components in the mixtures will be helpful in accelerating discovery. Fundamental studies of the sluggish oxygen reduction reaction should be useful in improving the electrode kinetics.

High-temperature fuel cells offer the possibility of improved electrode kinetics and efficiency without noble-metal catalysts. The higher temperature promotes the reaction kinetics and transport processes. High quality exhaust heat has the potential to be used in cogeneration. The fuel source is flexible with the potential for internal fuel reforming. The main disadvantage is that materials requirements are severe. There is interest in reducing operating temperatures so that degradation of components would be less severe. Simplified thermal management and a reduction of expensive interconnects and balance-of-plant materials could be realized.

Total federal support for fuel-cell development is currently on the order of $200 million per year. Much of this support is centered on PEM fuel cells with lesser amounts being devoted to DMFCs, SOFCs and other systems. The amount of funding allocated to hydrogen technology, which encompasses areas such as storage, production, and safety, is significantly higher. For FY05 the DOE budget request for hydrogen technology is $227 million. The NSF, NIST, and DoD also support a significant amount of fuel-cell activity. Estimates of support from federal sources and some examples of research activities will be presented.