Materials Research Needed to Enable Automotive Fuel Cells

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In this paper, we evaluate current cost, performance, and durability issues associated with polymer electrolyte fuel cell (PEFC) membranes and catalysts, and we suggest areas where a renewed focus of R&D effort will accelerate the commercialization of PEFCs in automotive applications. Membrane, catalyst, and system constraints will dictate the optimum operating conditions of an automotive system. We will attempt to identify and prioritize these interconnected development challenges.

Electrocatalysts and Supports
With respect to beginning-of-life performance, carbon-supported Pt-based catalysts approach automotive feasibility at loadings that appear within reach. Currently available technology is sufficient to reach 0.3 mg Pt/cm^2 (05 mg Pt/cm^2 on anode and 0.25 mg Pt/cm^2 on cathode), twice the current high-volume automotive target of 0.15 mg Pt/cm^2. The most promising approach to close this gap is via development of improved Pt-alloy cathode catalysts.

Our latest understanding of catalyst and support degradation of currently available materials suggest that PEFC operating temperatures will need to be limited to 60-80°C for >95% of the drive cycle, only allowing for short-term temperature excursions up to a maximum of 100°C. To enable catalyst durability at low Pt loadings, support materials with improved corrosion resistance are desired. These may be high surface area graphitized carbon supports for maximized Pt dispersion or alternative support materials. In addition, fundamental studies are needed to understand the detailed corrosion and Pt-stability mechanisms.

Membranes/Ionomers
Perfluorsulfonic acid (PFSA) polymers (e.g. Nafion® from DuPont), the current electrolytes of choice, appear to have performance and high-volume cost potential that will be sufficient to meet automotive requirements. Price projections are shown in Figure 1 and indicate that at 1 million vehicles/yr (100 kW/vehicle at ca. 1$kg_{membrane}$/100kW), which would require approximately 1,000 MT/yr of PFSA, the membrane cost would drop to less than $100/kg. This translates to approximately $1/kW, an affordable price against the $50/kW total power system target, and demonstrates that PFSA price should not be prohibitive for automotive application. Whereas there are reasons why alternatives to PFSA membranes are of interest, the high price of PFSA membrane is at most a secondary one.

The membrane conductivity vs. RH characteristic determines the system complexity. Figure 2 shows these data for a Nafion® 1100 EW membrane at 80ºC. (Note that data are not very sensitive to temperature up to 120ºC.[2]) The conductivity drops off very quickly with RH, thereby requiring the fuel cell system to provide for humidification of the reactant streams. There would be great value in reducing system complexity, and thus cost, from a membrane that maintains good conductivity to low-RH such as those shown in the "ideal" and "desired" curves in Figure 2 even if limited to a maximum of 80-100ºC operation. Indeed developments by manufacturers have shown promising progress in this direction for PFSA membranes. An example is shown in Figure 2, a low (<800) EW PFSA that has conductivity of 0.06-0.07 S/cm at 50% RH and 80ºC.

To allow fuel cell system heat rejection using conventional vehicle thermal systems, polymer electrolyte membranes that operate at elevated temperatures (100-120ºC vs. <85ºC current) are desired. For automotive application, a membrane operating at 120ºC that needs water for conduction would require a conductivity vs. RH characteristic such as that shown by the "ideal" curve in Fig. 2. Even if such a development were successful, increasing the temperature to 120ºC also accelerates catalyst and support degradation, thus requiring substantial catalyst development prior to implementation. Therefore, the near-term membrane development goal should be to increase low-RH conductivity with materials that operate in the 60-80ºC range with occasional excursions up to 100ºC. Development of a membrane that operates up to 120ºC is a longer-term and higher risk goal.

In addition to membrane development needs, R&D efforts focused on fundamental understanding should address the following issues: 1) the physical limits of materials based on the sulfonic acid conduction mechanism in light of the development of low-RH membranes operating at 60-100°C, 2) the fundamental chemical degradation mechanisms of ionomers used both in the electrode and in the membrane, and 3) membrane morphology and its impact on mechanical properties, particularly in terms of long-term creep and structural changes under cyclic conditions (i.e., cyclic variations of temperature and RH).

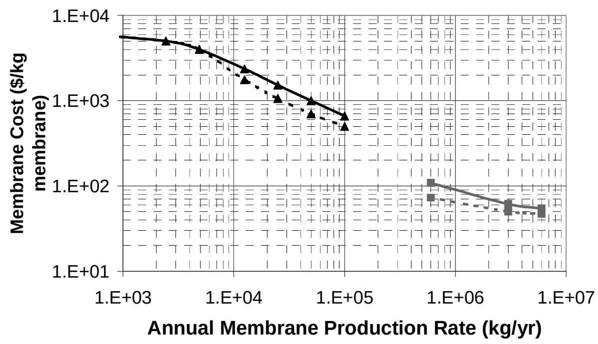

Figure 1. Price projection of PFSA membrane (25 micron thick, 0.05 kg/m^2, 1100 EW) at high volume. Low volume projections provided by DuPont.[1] High volume projections from GM-sponsored study.

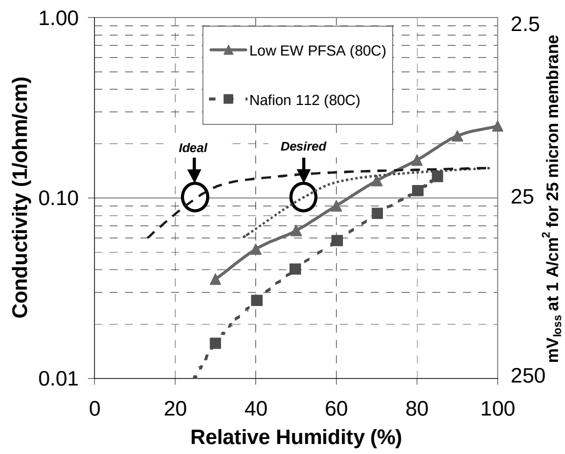

Figure 2. Conductivity vs. RH at 80ºC for Nafion® 112, and low EW (<800) PFSA. Also indicated are desired and ideal conductivity characteristics to enable system simplification and vehicle heat rejection. (Data courtesy of Cortney Mittelsteadt of Giner Electrochemical Systems, LLC)

References
1. DuPont Nafion® Fuel Cell Division, Fayetteville, NC.
2. Alberti, G.; Casciola, M.; Massinelli, L.; Bauer, B.; *J. Membrane Science*, **2001**, 185, 73.