Session II: Fuel Cells

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Session Summary

Six papers were presented in the second session at AUV 2002 that were grouped under the fuel cell heading. The purpose was to illuminate the range of possibilities associated with the fuel cell paradigm, which resulted in some surprising proposals and technologies discussions.

The first paper, by Swider-Lyons et al, was an excellent and concise review of current "classical" fuel cells, and included descriptions of architectures and chemistries of four of the five main types; alkaline fuel cells were omitted due to their sensitivity to hydrogen contaminants and the subsequent lack of development.

Of the remaining types, Solid Oxide (SOFCs), Molten Carbonate (MCFCs), and Phosphoric Acid (PAFCs) all require elevated temperatures. Sufficient detail was given to essentially rule them out for most direct AUV applications, though later presenters invoked indirect applications that made this discussion useful as prefacing commentary.

The bulk of the paper concentrated on low temperature Proton Exchange Membrane (PEMFC) fuel cells and their derivatives, the Direct Methanol (DMFC) fuel cells. Detailed accounts of catalysts, fueling strategies, and other "balance of plant" issues were given, with attention directed at practical systems and future ancillary technologies such as cryogenic, hydride, and carbon nanotube storage. The paper concludes with a discussion of fuel cell systems currently being developed for submarine applications both domestically and abroad, from 15-kW to 400-kW, manned and unmanned.

Next, Dr. Frano Barbir of Proton Energy Systems gave a status report on PEMFCs, from micro-power applications to prime movers. An excellent discussion of efficiency and performance calculations was presented that provided the underpinnings of an examination of issues related to system design and the choice of various details such as membranes, stack areas and cell number, system voltage, fueling options, system configuration, cooling, and power conditioning.

This paper was in some ways more realistic than the typical fuel cell literature, in that it showed the details of PEMFC installations in all their complexity. A generic block diagram of a closed-loop PEMFC system including humidifiers and heat exchangers is much more complicated than casual investigation reveals, and it was welcomed by this author as an honest portrayal of the task facing the system designers when such devices are contemplated for real-world applications. The paper concludes with the advantages PEMFCs offer, which are many, but also points out that reactant storage is problematic for vehicular use and that further development is likely to be needed before fuel cell power is an unqualified success in these applications.

To continue the theme of PEMFCs, Dave Edlund of IdaTech gave a paper in which fuel processing was used to solve some of the storage problems associated with the need for hydrogen delivery. IdaTech is a leader in hydrocarbon reforming to provide hydrogen to stationary PEM fuel cells, and his presentation of their work with compact reformers in the size range attractive for AUVs was quite interesting in that actual hardware performance was mentioned. IdaTech's 1-kW reformer is silent, small, and operates reliably on methanol. A theoretical treatment of a hypothetical AUV operating on reformate and stored oxidizer gave some attractive performance figures, though the power is likely to be in the 2-kW and under range. Rapid fueling and long mission durations for small AUVs would appear to be a solid near-term possibility.

The fourth paper was definitely a change of pace. Mr. George Hagerman took the plea to "cast a wide net" for fuel cell applications to outline a proposal for mid-ocean refueling of fuel cells via Wave Energy Systems, or docking stations based on extraction of mechanical energy from ocean surface wave action.

First glances at such notions are liable to be followed by chuckles, but in this case Hagerman has not only done his homework, he has actual projects and results to cite, at least for the energy extraction hardware. The paper is a survey of the concept filled out by global data on wind strengths and wave heights over annual cycles, and the detail is impressive. The power of moving water is not to be underestimated; the intricacies of designing mechanical devices capable of handling the spectrum of wave frequencies without suffering from impedance mismatches is not trivial, nor are they neglected in the work presented.

An impressive case is made for harnessing the power available at the sea surface, and good progress has been made for stationary power generation in numerous areas around the world. Here, the emphasis was on the possibilities for mid-ocean generation, and it is but a short leap to proposing a "feeding station" for autonomous vehicles that could benefit from such a centralized facility that could provide hydrogen and oxygen produced by electrolysis when the electrical power from a wave generator is available.

The last two papers are both problematic and highly encouraging; they are problematic in the sense that they bend the use of the term "fuel cell" slightly, though given their results one would be happy to see it bent some more. These fuel cells don't use hydrogen; they use highly purified aluminum metal and are called "semi-fuel cells" by some. Perhaps another term is justified, because they appear to be a very viable power option and deserve to be more widely appreciated, as do their designers and developers.

Both use hydrogen peroxide or bottled oxygen as the oxidizer and seawater or KOH as the electrolyte. Mike Adams of Fuel Cell Technologies Ltd. gave details of four different Aluminum Energy systems designed for various military and civilian AUV projects. All are at the hardware stage and have attained an accumulated 550 hours of underwater operation. Additional projects include a power supply for heating divers decompressing in cold water, and improvements in the electrodes may make as much as 1k-W/kg attainable. The FTC semi-fuel cell is a balanced-pressure design that does not require the components to be with a pressure hull. The execution of this technology is absolutely first-class.

Perhaps the most elegant concept presented was that of the HUGIN 3000 by Oistein Hasvold of the Norwegian Defence Research Establishment (FFI). This circulating-electrolyte, aluminum/hydrogen peroxide semi-fuel cell powered AUV has demonstrated an ability to cover 1000 miles in 50 hours at 4 kts, with rapid reactant replacement for quick turn-around in survey usage. High surface area "bottle brush" carbon electrodes allow operation at low current densities for high efficiency, and flooded architecture allows breadboard-style construction since no pressure hull is involved. These systems are elegant in the extreme, and only the relatively high cost of the purified aluminum anodes prevents adoption by a wider user base at this point.

In both the FTC and FFI semi-fuel cells avoid much of the balance-of-plant penalties associated with true fuel cells: they are flooded designs that do not require complicated cooling schemes or high pressure pumps to get waste products overboard. When the larger picture is considered, they may represent the best set of tradeoffs for fuel cells in the AUV world. One would hope something as appropriate would come along for terrestrial applications.