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Unitized Regenerative Fuel Cell Systems

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Energy storage systems with extremely high specific energy (>400 Wh/kg) have been designed that use lightweight pressure vessels to contain the gases generated by reversible (unitized) regenerative fuel cells (URFCs).[1] URFC systems are being designed and developed for a variety of applications, including high altitude long endurance (HALE) solar rechargeable aircraft (SRA), zero emission vehicles (ZEVs), hybrid energy storage/propulsion systems for spacecraft, energy storage for remote (off-grid) power sources, and peak shaving for on-grid applications.[1-10] Energy storage for HALE SRA was the original application for this set of innovations, and a prototype solar powered aircraft (Pathfinder-Plus) recently set another altitude record for all propeller-driven aircraft on August 6, 1998, when it flew to 80,285 feet (24.47 km).[11]

Progress is reported on the development, integration, and operation of rechargeable energy storage systems with such high specific energy. A primary fuel cell test rig with a single cell (46 cm^2 active area) has been modified and operated reversibly as a URFC for thousands of cycles at LLNL.[1] This URFC uses bifunctional electrodes (oxidation and reduction electrodes reverse roles when switching from charge to discharge, as with a rechargeable battery) for cathode feed electrolysis (water is fed from the hydrogen side of the cell) or anode feed electrolysis (water is fed from the oxygen side of the cell). The results of the cycle test are shown in Figure 1, and demonstrate high cycle life with negligible degradation.[1] Improved URFC cells, with high performance and reduced catalyst loading were demonstrated at LLNL, as shown in Figure 2. Rapid cycle operation of URFC cells has been demonstrated at LLNL. These results were obtained on the URFC test rig shown in Figure 3, using the cell in Figure 4. Proton Energy Systems, Inc. has recently built a URFC test rig (Figure 5) for testing and developing URFC cells shown in Figures 6 and 7. These cells are capable of producing up to 400 psi (2.8 MPa) gas by electrochemical pressurization. Future designs may be capable of ~3000 psi (21 MPa).

LLNL recently started testing URFC cells using Nafion 105 membrane and reduced catalyst loading. Cell #9804A uses Nafion 105, Hamilton Standard's E-5 catalyst, and catalyst loading of 1 mg/cm^2 per electrode. Figure 2 shows that fuel cell operation on URFCs is feasible at current densities >2000 ASF (2.15 A/cm^2). Cathode feed electrolysis data was limited to 1200 ASF due to cell dryout. Anode feed electrolysis data was taken at current densities >2000 ASF (2.15 A/cm^2), but has not yet been approved for publication. This figure shows that reduced catalyst loading operation of PEM electrolyzers and URFCs is feasible, and shows that consumer markets that may require reduced catalyst loading to achieve inexpensive unit costs at high volume may be filled by PEM electrolyzers and URFCs. Experiments with alternate catalyst compositions and further reduced catalyst loadings are in progress.

LLNL is working with industrial partners to design lightweight pressure vessels for hydrogen powered vehicles, where the vessels are either conformable to existing rectangular packaging envelopes, or are cylindrical and incorporated into new "designed from the ground up" vehicle configurations. URFC systems coupled with lightweight pressure vessels have been designed for automobiles and are expected to be cost competitive with primary fuel cell powered vehicles that operate on hydrogen/air.[4] URFC powered vehicles can be safely and rapidly (< 5 minutes) refueled from high pressure hydrogen sources, when available, to achieve driving ranges in excess of 360 miles (600 km). URFC powered systems could save the consumer the capital cost of a home hydrogen generation unit, since the consumer would be able to electrically recharge at any available electrical source, instead of being tethered to a single home electrolysis unit. Such URFC systems would be dual-fueled vehicles that can use the existing electrical infrastructure, or a hydrogen infrastructure when available, for rapid refueling. They would enable regenerative braking by electrolysis and power peaking by oxygen supercharging.

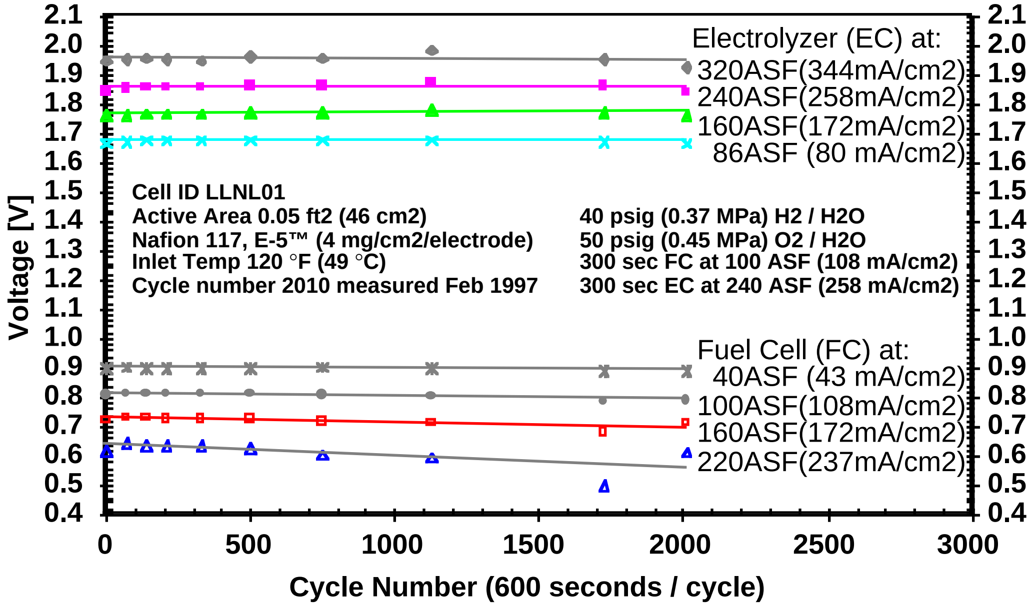

Figure 1. URFC cycle test at LLNL demonstrated negligible degradation after 2010 cycles.[1]

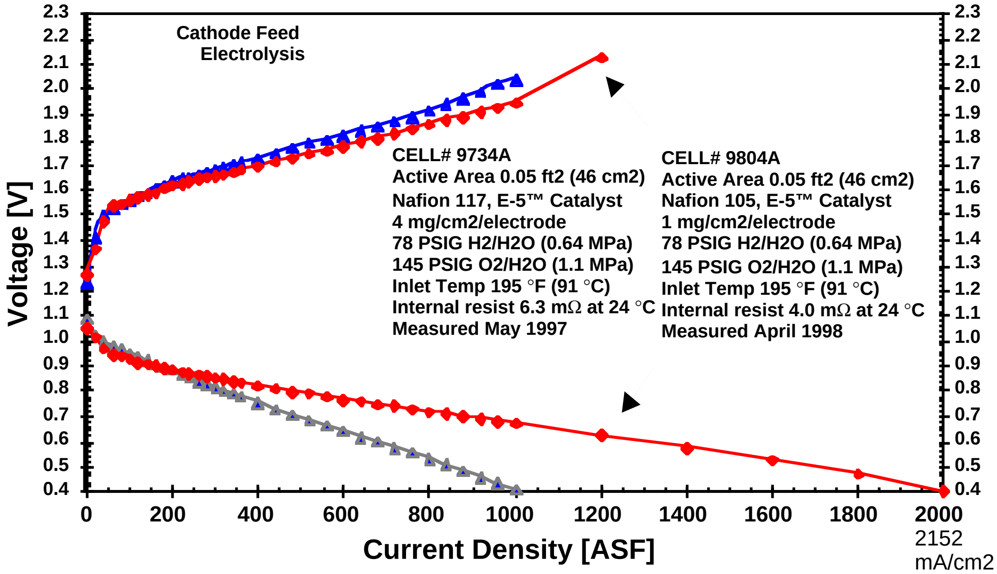

Figure 2. High performance URFCs were demonstrated at LLNL with reduced catalyst loading.

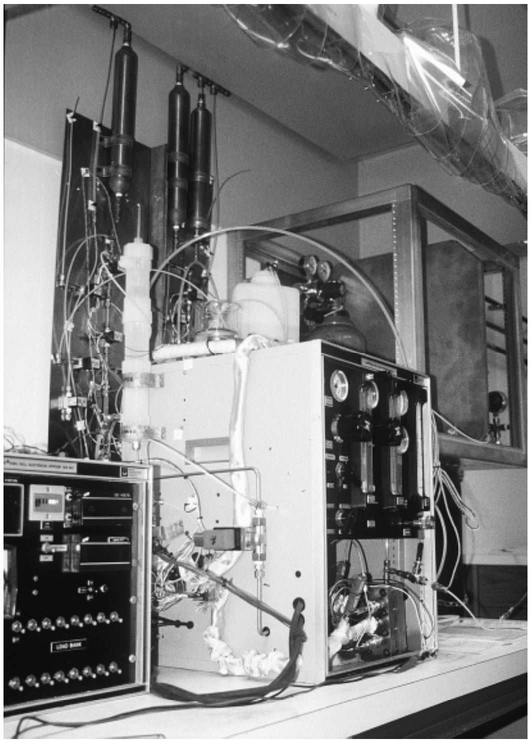

Figure 3. LLNL URFC test rig.

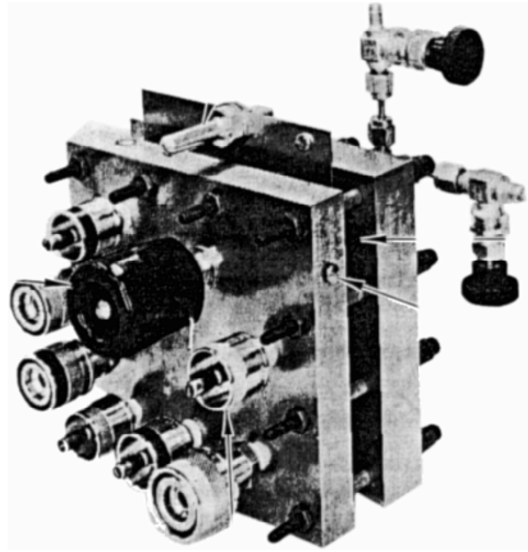

Figure 4. LLNL URFC 0.05 ft^2 (46 cm^2) cell.

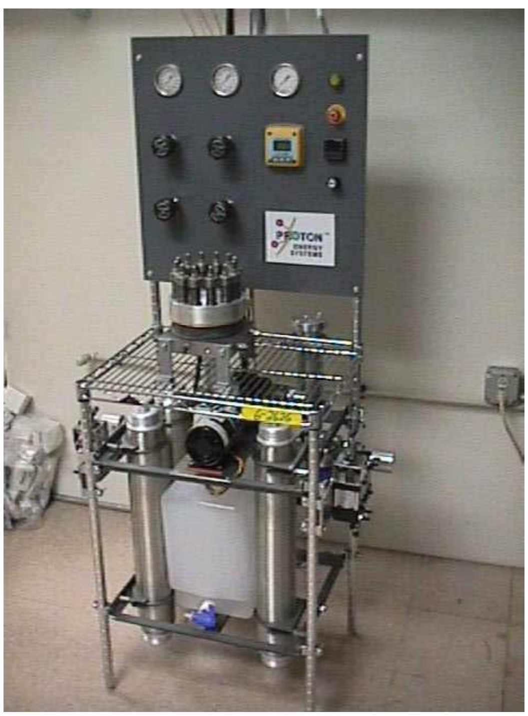

Figure 5. Proton Energy Systems URFC test rig.

Figure 6. Proton URFC 0.05 ft^2 (46 cm^2) cell.

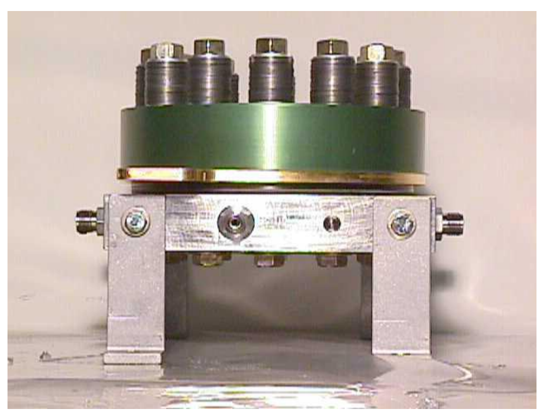

Figure 7. Proton URFC 0.1 ft^2 (93 cm^2) cell.

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