



New Class of Flow Batteries for Terrestrial and Aerospace Energy Storage Applications

Applications include energy storage in conjunction with renewable energy generation technologies such as solar, wind power, and automotive.

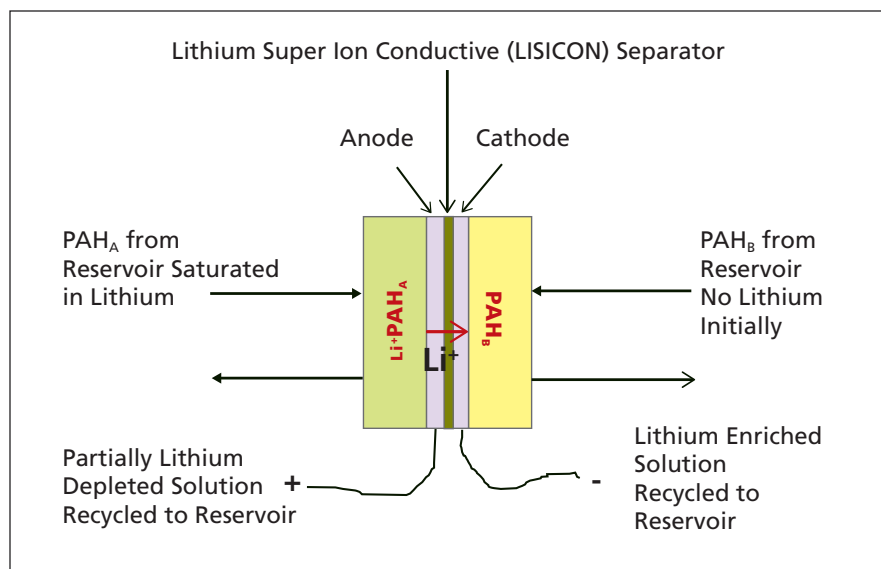
NASA's Jet Propulsion Laboratory, Pasadena, California

Future sustainable energy generation technologies such as photovoltaic and wind farms require advanced energy storage systems on a massive scale to make the alternate (green) energy options practical. The daunting requirements of such large-scale energy systems — such as long operating and cycle life, safety, and low cost — are not adequately met by state-of-the-art energy storage technologies such as vanadium flow cells, lead-acid, and zinc-bromine batteries. Much attention is being paid to redox batteries — specifically to the vanadium redox battery (VRB) — due to their simplicity, low cost, and good life characteristics compared to other related battery technologies.

NASA is currently seeking high-specific-energy and long-cycle-life rechargeable batteries in the 10-to-100-kW range to support future human exploration missions, such as planetary habitats, human rovers, etc. The flow batteries described above are excellent candidates for these applications, as well as other applications that propose to use regenerative fuel cells.

A new flow cell technology is proposed based on coupling two novel electrodes in the form of solvated electron systems (SES) between an alkali (or alkaline earth) metal and poly aromatic hydrocarbons (PAH), separated by an ionically conducting separator. The cell reaction involves the formation of such SES with a PAH of high voltage in the cathode, while the alkali (or alkaline earth metal) is reduced from such an M-PAH complex in the anode half-cell. During recharge, the reactions are reversed in both electrodes. In other words, the alkali (alkaline earth) metal ion simply shuttles from one M-PAH complex (SES) to another, which are separated by a metal-ion conducting solid or polymer electrolyte separator.

As an example, the concept was demonstrated with Li-naphthalene//Li



The **Flow Cell Technology** is based on coupling two novel electrodes in the form of Solvated Electron Systems between an alkali metal and poly aromatic hydrocarbons, separated by an ionically conducting separator.

-DDQ (DDQ is 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone) separated by lithium super ion conductor, either ceramic or polymer (solid polymer or gel polymer) electrolytes. The reactants are Li-naphthalene dissolved in tetrahydrofuran (THF) with a lithium salt of 1M LiBF₄ (lithium tetra fluoroborate) in the anode compartment, and DDQ again dissolved in THF and also containing 1M LiBF₄ salt in the cathode half-cell. The solid electrolyte separator used in the first set of experiments is a ceramic solid electrolyte, available from a commercial source. The open circuit voltage of the cells is close to 3.0 V, as expected from the individual half-cell voltages of Li-naphthalene and Li-DDQ.

Upon discharge, the cell shows steady discharge voltage of -2.7 V, which confirms that the electrochemical processes do involve lithium ion shuttling from the anodic compartment to the cathode half-cell. The reversibility or rechargeability is demonstrated by charging the

partially discharged cells (i.e., with lithium present in the DDQ half). Once again, a steady voltage close to 3.0 V was observed during charge, indicating that the system is quite reversible. In the subsequent concept-demonstration studies, the ceramic electrolyte has been replaced with a gel polymer electrolyte, e.g., PVDF-HFP (poly vinylene difluoride-hexafluoropropene) gel, which has several advantages such as high ionic conductivity (almost comparable to liquid electrolyte and about 2 orders of magnitude better than the ceramic equivalent), lower cost, and possibly higher chemical stability at the anode. In addition, it can be bonded to the electrode by thermal fusion to form membrane electrode assemblies (MEAs), as is done in fuel cells.

Though the initial experiments were performed with Pt electrodes, subsequent tests with porous carbon electrodes showed better kinetics, yielding higher discharge currents. Combining

the polymer electrolytes with carbon substrates, flow-cell stacks with membrane electrode assemblies (MEAs) may be configured much like with fuel cells with suitable flow-fields in bipolar plates for an all-liquid rechargeable flow-battery.

There are several unique attributes of this flow cell, which is amongst the highest voltage flow batteries, with cell voltages higher than the prior non-aqueous 1.7 V vanadium acetylacetonate redox flow battery. (1) The reaction involves the shuttling of lithium ions from the anolyte to catholyte, much like with traditional Li-ion cells; (2) The reactions involved at both electrodes are mostly

chemical, with the oxidized or reduced lithium reacting with the liquid active materials; (3) Both the anolyte and catholyte are electronically conducting with some lithium, thus negating the need for ionic conduction through a lithium salt solution; and (4) The electrodes are only for current collection purposes, which precludes any morphological or interfacial changes at the electrode. All these features will, in principle, contribute to a long cycle life, calendar life, safety, and low self-discharge rates.

This work was done by Ratnakumar V. Bugga, William C. West, Andrew Kindler,

and Marshall C. Smart of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

*Innovative Technology Assets Management
JPL*

Mail Stop 321-123

4800 Oak Grove Drive

Pasadena, CA 91109-8099

E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-48555, volume and number of this NASA Tech Briefs issue, and the page number.

Reliability of CCGA 1152 and CCGA 1272 Interconnect Packages for Extreme Thermal Environments

CCGA packages are used in logics and microprocessor functions, telecommunications, flight avionics, and payload electronics.

NASA's Jet Propulsion Laboratory, Pasadena, California

Ceramic column grid array (CCGA) packages have been increasing in use based on their advantages of high interconnect density, very good thermal and electrical performance, and compatibility with standard surface-mount packaging assembly processes. CCGA packages are used in space applications such as in logics and microprocessor functions, telecommunications, flight avionics, and payload electronics. As these packages tend to have less solder joint strain relief than leaded packages, the reliability of CCGA packages is very important for short- and long-term space missions.

Certain planetary satellites require operations of thermally uncontrolled hardware under extremely cold and hot temperatures with large diurnal temperature change from day to night. The planetary

protection requires the hardware to be baked at +125 °C for 72 hours to kill microbugs to avoid any biological contamination, especially for sample return missions. Therefore, the present CCGA package reliability research study has encompassed the temperature range of -185 to +125 °C to cover various NASA deep space missions.

Advanced 1152 and 1272 CCGA packaging interconnects technology test hardware objects have been subjected to extreme temperature thermal cycles from -185 to +125 °C. X-ray inspections of CCGA packages have been made before thermal cycling. No anomalous behavior and process problems were observed in the x-ray images. The change in resistance of the daisy-chained CCGA interconnects was measured as a func-

tion of increasing number of thermal cycles. Electrical continuity measurements of daisy chains have shown no anomalies, even until 596 thermal cycles. Optical inspections of hardware have shown a significant fatigue for CCGA 1152 packages over CCGA 1272 packages.

No catastrophic failures have been observed yet in the results. Process qualification and assembly are required to optimize the CCGA assembly processes. Optical inspections of CCGA boards have been made after 258 and 596 thermal cycles. Corner columns have started showing significant fatigue per optical inspection results.

This work was done by Rajeshuni Ramesh of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48505

Using a Blender to Assess the Microbial Density of Encapsulated Organisms

This technology has applications in medical device manufacturing to ensure device sterility.

NASA's Jet Propulsion Laboratory, Pasadena, California

There are specific NASA requirements for source-specific encapsulated microbial density for encapsulated organisms in non-metallic materials. Projects such as the Mars Science Laboratory (MSL)

that use large volumes of non-metallic materials of planetary protection concern pose a challenge to their bioburden budget. An optimized and adapted destructive hardware technology employ-

ing a commercial blender was developed to assess the embedded bioburden of thermal paint for the MSL project.

The main objective of this optimization was to blend the painted foil pieces