TECHNICAL WORKSHOPS AT THE 1989 SPACE ELECTROCHEMICAL RESEARCH AND TECHNOLOGY CONFERENCE: A COMPENDIUM OF OUTLOOKS AND OPINIONS

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Introduction

Long range planning of research and technology programs in space power is essential to ensure that the appropriate technologies will be available when needed, and the inputs and collective views of experts in the field are vital to this planning process. At the 1989 Space Electrochemical Research and Technology Conference, workshop sessions were held in the four technical theme areas to discuss in depth the critical issues related to the technologies which will enable, or enhance, our nation's future space missions.

The workshop sessions, which were attended by a proper mix of research scientists, mission planners, technology advocates, and power system engineers, provided a forum for general discussions to coalesce views and findings into conclusions on progress in the field, prospects for future advances, areas overlooked, and the directions of future efforts. Advanced technologies, concepts, systems, and components were examined with respect to such factors as mission applicability, projected potential, critical technology barriers, research and development needs, and approaches for addressing the critical problem areas which affect the advancement of electrochemical energy storage systems for space applications. The following sections summarize each of the four technical workshop sessions with regard to the collective inputs and opinions of the participants; these summaries do not necessarily reflect the views or positions of NASA.

Advanced concepts workshop

At the time of the conference, the initial claims by Pons and Fleischmann of their observations of electrochemically-induced cold fusion had just been announced. Although there was no verification of the experimental results to the satisfaction of the scientific community at this time, interest of, and discussions among, the attendees were predominantly focused on this subject.

If the concept of cold fusion is confirmed and found to be viable, it was felt that it would radically change our way of thinking about future space

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power sources. If high-quality heat could be generated, the coupling of a cold fusion reactor with classical heat cycles could be envisioned as a technological breakthrough for future baseload power, and possibly for propulsion, especially if the need for heavy radiation shielding was minimal. While exciting, if true, this concept would take a long time to implement and the risk level would be very high.

Other advanced concepts being considered for future space power applications, which are presently in various stages of development, can be grouped into three main categories: high-temperature batteries, high-temperature fuel cells, and low-temperature systems. Specific mission requirements (*e.g.*, specific energy, power density, cycle life, and reliability) will determine which advanced system is best suited for a particular application.

High-temperature batteries

Considerable progress has been made to improve the performance of sodium/sulfur, sodium/transition metal chloride, and other systems which utilize solid electrolytes. Improving the reliability of the ceramic electrolyte and seals still remains as a technical challenge, and new electrolyte configurations need to be explored. Sodium/metal chloride systems may offer better life as a result of their lower operating temperatures, and these systems should be relatively safe due to the insolubility of the metal chlorides in the sodium tetrachloroaluminate secondary electrolyte. New insulating or conducting high-temperature materials with improved corrosion resistance are also being developed.

Results from recent work on $Li-Al/FeS_2$ cells in a bipolar configuration have indicated the possibility of achieving high specific energy (210 W h kg^{-1}). Materials compatibility, corrosion resistance, and hermetic seals are technical issues which are being addressed for this molten salt system.

High-temperature fuel cells

Solid oxide fuel cells with monolithic or pseudomonolithic structural designs have shown significant performance improvements during the course of their development, and these system concepts could be attractive for stationary power or for space-based pulse-power applications. The possibility of coupling a monolithic electrolyzer with a low-temperature fuel cell can also be envisioned. New solid ionic conductors for fuel cell operation in a lower temperature regime are a developmental need.

Low-temperature systems

Ultracapacitors with significantly higher energy densities than conventional capacitors could be useful for applications requiring periods of pulsed or peaking power. Higher effective electrode surface areas, higher faradaic pseudocapacitances, and higher voltage levels are developmental needs for practical devices.

Ambient-temperature secondary lithium systems may be suitable for low power, limited cycle life applications. Current research efforts include the assessment of transition metal oxides and chalcogenides as cathode materials, the development of new polymer electrolyte structures, and the development of autonomous lithium conductors.

Other advanced concepts and approaches for low-temperature power sources include investigations of new aqueous couples (*e.g.*, Bi-doped MnO_2/H_2), development of new designs with old couples (*e.g.*, bipolar Ni/H_2), and the development of a reliable self-contained regenerative fuel cell/electrolyzer.

In general, high system capability (low weight, low volume, etc.) must be consistent with system reliability. New systems need a reliability analysis before funds are committed for pilot production on inappropriate designs for a particular mission. Also, in order to reduce the level of risk associated with a specific approach, alternative options need to be considered and explored.

Hydrogen–oxygen fuel cells and electrolyzers workshop

Hydrogen–oxygen regenerative fuel cell energy storage systems are considered to be the enabling technology with regard to power requirements for several projected future space missions. Future near-Earth missions would benefit from the successful development of an integrated system which employs a single electrochemical module operating in both the fuel cell and water electrolysis modes. For extraterrestrial surface power applications, long-life, reliable, efficient Proton-Exchange Membrane (PEM) and alkaline fuel cells and electrolyzers need to be developed and performance needs to be validated. It is felt that the level of risk for successful development is not exceedingly high, but there are key technology issues which need to be addressed. Provisions for long-term research must also be present in mission-driven programs.

It was the consensus of the workshop participants that the most important technology issues currently confronting fuel cell development are centered around component life tests in full planar area hardware. Failure mechanisms need to be examined and understood, and predictive models of long-term failure modes, which are based upon shorter, accelerated testing timespans, need to be developed and validated. Parasitic losses due to reactant crossover and performance degradation due to corrosion and materials incompatibility are two critical areas which need to be understood.

The most important developmental need was felt to be the achievement of truly passive fuel cell/electrolyzer operation. Quite often the ancillaries are the source of failure, and passive systems will be needed for high reliability.

Nickel electrode workshop

Cells containing nickel electrodes currently represent the only established long-cycle-life technology. Advanced nickel electrode technology development is presently focused in two directions: (i) the development of lightweight nickel electrodes (sintered or fiber structures) which are optimized for high energy density, and (ii) the optimization of nickel electrode structures for long cycle life. Battery systems based on lightweight nickel electrodes, which are characterized by high energy density (~100 W h kg^{-1}) and moderate cycle life (~1000 cycles, >50% DOD), could be useful for planetary rover applications. Systems based on long-life nickel electrodes (>30 000 cycles, 50% DOD) could be viable for space station power or for long-term Global Change Technology missions.

The critical technology needs which were identified for advanced nickel electrode development are summarized in the following list:

(i) Structural instability
  (a) Swelling
  (b) Extrusion
  (c) Loss of ohmic contact with current collector
(ii) Improved mechanical properties of active material
  (a) Additives
  (b) Electrolyte
(iii) Improved test procedures (technology support)
  (a) Accelerated/real time correlation
  (b) Lot confirmation testing
  (c) Routine destructive physical analyses of cells on a lot basis
(iv) Modeling
  (a) Inputs — impedance, pore distributions, etc.
  (b) Analytical methods for the correlation of electrochemical and structural characteristics

A compilation of the critical research needs for advanced nickel electrode development is as follows:

(i) Causes of structural instability
  (a) Active material movement/shedding
  (b) Sinter fracturing
  (c) Detection and causes of shorting
(ii) Corrosion rates
  (a) Accelerating factors
  (b) Inhibition
(iii) Additives
  (a) Improved charge efficiency
  (b) Improved capacity (nickel utilization)
(iv) Effects of electrolyte concentration on performance
(v) Interactions with gaseous hydrogen
  (a) Storage
  (b) Self-discharge
  (c) Effect on capacity/second plateau effects
(vi) Testing
  (a) Charge control methods

(vii) Scale-up
  (a) Evaluate present assumptions of linear scaling
  (b) Examine life test data and failure modes
(viii) Fundamental electrochemistry of nickel electrode processes
  (a) Application of novel analytical techniques (calorimetry, neutron scattering, acoustic emission spectroscopy, noise spectrum analysis, EXAFS)

Technology maintenance is an important area that needs to be addressed. The institution of a technology maintenance program would assure high reliability for evolving technology and would afford a smooth transition of advanced technology into practice.

Advanced rechargeable batteries workshop

Following a review of various mission applications and their associated energy storage requirements, specific advanced rechargeable battery technologies were selected and assessed with respect to their potential for meeting the mission requirements. Assuming that there would be no cost constraints for development and that bipolar technology would not be a limitation, potential candidates for applications requiring large power systems (*i.e.*, >2.5 kW h of energy storage required) and/or small power systems were examined in greater depth. Based on anticipated improvements over present day technology, a consensus was reached in regard to estimates of the projected specific energy for each system, the time frame for projected technology demonstration to verify capability, and the likelihood of success. Key technology issues were also identified for each potential candidate. In general, the advanced rechargeable systems which show the most progress to date are those which have received substantial levels of financial support for their development programs.

Sodium/sulfur system

Being considered as a viable candidate for future large power systems applications, high-temperature sodium/sulfur batteries with a projected specific energy of 200 W h kg^{-1} appear highly possible within the next 25 years. For low cycle life applications (*e.g.*, planetary rover or lunar base), a technology demonstration should be feasible by the year 2010. For meeting GEO and LEO requirements, five additional years may be required before operational capability can be verified. Technology issues include a cell/battery redesign for high specific energy, materials problems and corrosion at high temperatures, freeze/thaw, electrolyte sealing, and control of the failure mode. Significant progress has been made in sodium/sulfur technology as a result of active and well-funded development programs.

Lithium alloy/iron disulfide system

Based upon expectations of high reliability and high energy density capability, the "Upper Plateau" Li–Al/FeS_2 system will be a strong future contender with sodium/sulfur for GEO and for low cycle life applications. Capability for GEO applications of a 175 W h kg^{-1} system is felt to be verifiable by the year 2010. Technology issues include cell redesign, electrolyte and separator modification, cell equalization, and overcoming corrosion and hermetic seal problems.

Sodium/metal chloride systems

Sodium/metal chloride systems with projected specific energies of 160 W h kg^{-1} would be potentially viable candidates for missions requiring a large power system. Technology demonstrations for planetary rover or for lunar base applications were felt to be possible by the year 2000, and by the year 2010 for GEO and LEO applications. For high cycle life applications, the lower operating temperature of these systems enhances their attractiveness. Technology issues to be addressed include cell redesign, seal development, the identification of time-dependent failure mechanisms, clarifications of the cell chemistries, and the need for a stronger development effort within the United States.

Advanced nickel/hydrogen battery

Although specific energy characteristics are relatively low, advanced nickel/hydrogen technology is expected to be a potential candidate for most mission applications which will require a large power system. The technology is especially attractive for meeting the strenuous cycle life requirements for LEO missions. Considered to be a near-term technology as a result of its advanced stage of development, a technology demonstration to verify LEO mission applicability of an advanced Ni/H_2 system with a specific energy of 70 W h kg^{-1} should be feasible within the next decade. The modification of component, cell, and battery support structures is considered to be the major technology issue.

Lithium/solid cathode systems

In general, the class of ambient-temperature rechargeable lithium systems employing metal oxide or intercalation cathodes should be capable of offering specific energies in the 100 - 200 W h kg^{-1} range. These systems are considered as potential candidates for GEO and for planetary orbiter missions requiring small power systems.

A high specific energy (200 W h kg^{-1}) lithium/solid cathode battery will require a highly energetic long-life cathode, such as CoO_2, and a suitable electrolyte which is stable and conductive. Lithium rechargeability, scale-up, and safety are other technology issues which need to be addressed. A technology demonstration of this system would be envisioned by the year 2005.

Within the same time frame, lithium/solid cathode technology could be enhanced by employing a solid polymer electrolyte. Technology issues associated with a lithium/polymer electrolyte/solid cathode system would include the composition and conductivity of the polymeric electrolyte and the ability to maintain interfacial contact.