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APPLIED SCIENCE DIVISION

Technology Base Research Project for Electrochemical Energy Storage

Executive Summary Report for 1987

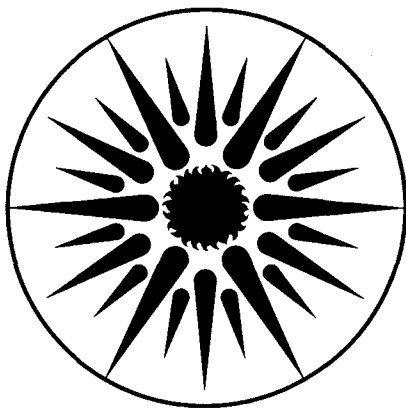
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**TECHNOLOGY BASE RESEARCH PROJECT
FOR
ELECTROCHEMICAL ENERGY STORAGE**

**EXECUTIVE SUMMARY REPORT
FOR 1987**

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Edited by Kim Kinoshita, Technical Manager

June 1988

EXECUTIVE SUMMARY

The U.S. Department of Energy's Office of Energy Storage and Distribution provides continuing support for an Energy Storage Program, which includes R&D on advanced electrochemical energy storage and conversion systems. A major goal of this program is to develop electrochemical power sources suitable for application in electric vehicles and/or electric load-leveling devices. The program centers on advanced secondary batteries and fuel cells that offer the potential for high performance and low life-cycle costs, both of which are necessary to permit significant penetration into commercial markets.

The DOE Electrochemical Energy Storage Program is divided into two projects: the Exploratory Technology Development and Testing (ETD) Project and the Technology Base Research (TBR) Project. ETD Project management responsibility has been assigned to Sandia National Laboratory (SNL), and the Lawrence Berkeley Laboratory* (LBL) is responsible for management of the TBR Project. The ETD and TBR Projects include an integrated matrix of research and development efforts designed to advance progress on several candidate electrochemical systems. The role of the TBR Project is to perform supporting research for the advanced battery systems under development by the ETD Project, and to evaluate new systems with potentially superior performance, durability and/or cost characteristics. The specific goal of the TBR Project is to identify the most promising electrochemical technologies and transfer them to industry and/or the ETD Project for further development and scale-up. This report summarizes the research, financial and management activities relevant to the TBR Project in CY 1987. This is a continuing project, and reports for prior years have been published; they are listed at the end of the Executive Summary.

* Participants in the TBR Project include the following LBL scientists: E. Cairns, K. Kinoshita and F. McLarnon of the Applied Science Division; and L. DeJonghe, J. Evans, R. Muller, J. Newman, P. Ross and C. Tobias of the Materials and Chemical Sciences Division.

General problem areas addressed by the project include identification of new electrochemical couples for advanced batteries, determination of technical feasibility of the new couples, improvements in battery components and materials, establishment of engineering principles applicable to electrochemical energy storage and conversion, and the development of air-system (fuel cell, metal/air) technology for transportation applications. Major emphasis is given to applied research which will lead to superior performance and lower life-cycle costs.

The TBR Project is divided into three major project elements: Exploratory Research, Applied Science Research, and Air Systems Research. Highlights of each project element are summarized according to the appropriate battery system or electrochemical research area.

EXPLORATORY RESEARCH

The objectives of this project element are to identify, evaluate and initiate development of new electrochemical couples with the potential to meet or exceed advanced battery and electrochemical performance goals. Research projects were conducted on **molten-salt cells** based on Li alloy negative electrodes and metal disulfide positive electrodes. These cells exhibit very high performance, ease of manufacture, and freeze-thaw capability. Two organizations are pursuing techniques to stabilize the performance of FeS_2 electrodes in these cells.

- ANL has achieved 1000 cycles (discharge at 50 mA/cm^2 for 4 h, charge at 25 mA/cm^2 to a cut-off voltage of 2.05 V) and 7000-h operation at 397°C with a small prismatic upper-plateau Li-Al/ FeS_2 cell with 25 mol% LiCl-42 mol% LiBr-37 mol% KBr electrolyte. No capacity loss was observed during the first 500 cycles, at which time equipment malfunction occurred. Then a $\leq 20\%$ capacity loss was observed to 1000 cycles. Overdischarge protection was demonstrated in an upper-plateau Li-Al/ FeS_2 cell that is Li-limited. A cell operated with discharge cutoff voltages of 1.0 to 1.3 V maintained a coulombic efficiency of 99% for over 900 cycles.

- Gould, Inc. has observed that starved-electrolyte Li-alloy/FeS₂ cells containing LiCl-LiBr-KBr electrolyte exhibited almost zero loss in upper-plateau capacity after 300 cycles (5000 h) at 400°C. The capacity utilization for these cells was 65%, which is considerably less than the 80-85% observed at ANL with flooded-electrolyte cells.

APPLIED SCIENCE RESEARCH

The objectives of this project element are to provide and establish scientific and engineering principles applicable to batteries and electrochemical systems; and to identify, characterize and improve materials and components for use in batteries and electrochemical systems. Projects in this element provide research that supports a wide range of battery systems — alkaline, metal/air, flow, solid-electrolyte, and nonaqueous. Other cross-cutting research efforts are directed at improving the understanding of electrochemical engineering principles, minimizing corrosion of battery components, analyzing the surfaces of electrodes, and electrocatalysis.

Alkaline Cells often use Zn as the negative electrode, and it is this electrode that typically limits the lifetime of these cells. Efforts are underway to identify electrode and electrolyte compositions that will improve the cycle-life performance of the Zn electrode.

- LBL has observed that an electrode of pure CaZn(OH)₄ cycled at constant current in 31 wt% KOH showed a distribution of active material, after 50 cycles, that was much more uniform than that observed with Zn electrodes containing an additive of 25-33 mol% Ca(OH)₂.
- LBL has successfully employed Zn and Cd micro-electrodes in porous Zn electrodes to study the chemical and transport processes that occur in secondary porous Zn electrodes in KOH electrolytes. The measurements indicate that during cycling, material redistribution occurs and the electrode becomes limited by transport of Zn(OH)₄²⁻, dissolution of ZnO, or precipitation of Zn(OH)₄²⁻ as ZnO.

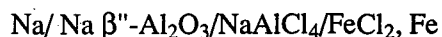
Zinc/Halogen Cells use flowing electrolytes to promote the transport of Zn ions across the cell and to remove halogen as the cell is charged. The cell performance is limited by the tendency of the electrodeposited Zn to assume unwanted shapes, and efforts are aimed at understanding the complex phenomena that control the Zn electrode morphology.

- Mathematical modeling at LBL on the effect of inhibitors on electrodeposition indicates that recirculation flow can explain the decrease in leveling action in notches (below a critical angle) compared to the leveling action in stagnant electrolyte.
- Illinois Institute of Technology (IIT) has observed that the formation of Zn dendrites is completely suppressed when Br_2 is present in the ZnBr_2 solution during electrodeposition at $\sim 20 \text{ mA/cm}^2$, up to a net Zn loading of 160 mAh/cm^2 .
- EXAFS (extended X-ray absorption fine structure) was used by Brookhaven National Laboratory (BNL) to study Zn complexes in acidic and basic electrolytes. In 1 M ZnBr_2 the data could be fitted to a $\text{ZnBr}^+ \cdot 3\text{H}_2\text{O}$ model and in 3 M ZnBr_2 to a $\text{ZnBr}_2 \cdot 2\text{H}_2\text{O}$ model.

Improved Components for Alkali/Sulfur Cells, such as superior alternatives to the $\beta''\text{-Al}_2\text{O}_3$ ceramic electrolyte and the high-temperature sulfur-polysulfide electrode used in Na/S cells, stable Li-ion conductors for Li/S cells, and a class of organosulfur electrodes for low-temperature $\beta''\text{-Al}_2\text{O}_3$ cells are under investigation.

- Investigations of novel, low-temperature ($120\text{-}150^\circ\text{C}$) secondary cell which contains a liquid sodium negative, $\beta''\text{-Al}_2\text{O}_3$ electrolyte, and a class of organosulfur (RSSR, R = aliphatic, aromatic, ethereal or fluorinated organic moiety) positives continue at LBL. Experiments indicate that the performance of these cells is enhanced by use of a CoPc electrocatalyst in the positive electrode and by varying the organic moiety attached to the S-S bond.

- Experiments are underway at LBL to confirm an advanced mathematical model of the sulfur electrode in Na/S cells. Because of the difficulties of performing wetting and wicking measurements on the sulfur/polysulfide/graphite system directly, an analogous system (water/bromobenzene/glass fiber) was investigated. This study led to the conclusion that beyond a sulfur volume fraction of 0.75, the polysulfide phase is no longer interconnected, and it does not move.
- ANL has found that the fabrication of small electrolyte tubes from ANL Glass (composition in mol%: 42 Na₂O, 8 Al₂O₃, 5 ZrO₂ and 45 SiO₂) requires careful control of the environment. Because ANL Glass is hygroscopic, moisture must be absent to fabricate a useful glass electrolyte for testing in Na/S cells. Small-scale cells (22 mAh) were successfully cycled at 400 μA for 0.5 h (discharge) and 200 μA for 1 h (charge) for 100 cycles (2-3% DOD).
- Massachusetts Institute of Technology (MIT) has observed that the addition of chlorine has little effect on K⁺-ion conduction in potassium chloroborate glasses, in contrast to the results obtained earlier for Li⁺-ion and Na⁺-ion conduction in the corresponding Li and Na glasses.
- Stanford University is exploring the development of alternative electrodes and electrolytes for the cell



Work on the following cell has been initiated to investigate alternatives to the negative electrode/ β -Al₂O₃ assembly



The NaAlEt₄ electrolyte, which can be used at about 120°C, was found to be stable at high Na activities.

Corrosion Processes in High-Temperature, High-Sulfur Activity Molten Salts are under investigation, and the aim is to develop low-cost container and current-collector materials for use in alkali/sulfur and other molten-salt cells.

- IIT observed that the cyclic voltammograms of Mo₂C- and TiN- coated samples in Na₂S_x melts were similar to that of Mo, and suggest that Mo₂C appears to resist sulfur attack.

Components for Ambient-Temperature Nonaqueous Cells, particularly metal/electrolyte combinations that improve the rechargeability of these cells, are under investigation.

- Case Western Reserve University (CWRU) has detected four major peaks at 400° (I), 500-600° (II), 770° (III) and 840°K (IV) in the thermal desorption spectra of CO₂ adsorbed on potassium-covered Ag (111) surfaces. The peaks observed at the higher temperatures may involve interactions between the adsorbed CO₂ molecules to yield oxalate-type or even larger CO₂-coupled polymeric aggregates that are formed by a radical-coupling mechanism.
- Jackson State University has observed by *in situ* Raman spectroscopy that an enhanced Raman spectrum can be obtained from 1000-Å thick layers of Li on Ag. *In situ* Raman measurements of Li in LiAsF₆/PC were not successful because of the strong Raman scattering from species in solution.
- The University of Minnesota has observed that the high-frequency charge-injection process in poly(vinylferrocene) (PVF) is the same for PVF prepared by spin coating and by solvent casting. However, charge transport is higher in the spin-coated film than that in the solvent-cast film (i.e., 10⁻⁷ cm²/s vs 10⁻⁹ cm²/s).
- Studies as the University of Pennsylvania suggest that a correlation exists between the type of complex a cation forms in poly(ethylene oxide) and its ionic mobility.

- Experiments at LBL demonstrated that Mg can be anodically dissolved with 100% current efficiency with a valence of two in PC electrolytes. However, to date, none of the attempts to electrodeposit metallic Mg from its compounds in nonaqueous electrolytes of PC, tetrahydrofuran or dimethylsulfoxide have been successful.
- Johns Hopkins University has observed that both Fe and Ni show spontaneous passivation with a wide passive range and low passive current densities in highly purified 0.5 M LiClO₄/PC. Preliminary measurements indicate that Fe undergoes passive breakdown in 0.5 M LiClO₄/PC containing both water and propylene glycol at the 500-ppm level.

Cross-Cutting Research is carried out to address fundamental problems in electrocatalysis and current density distribution, solutions of which will lead to improved electrode structures and performance in batteries and fuel cells.

- A mathematical model developed at LBL predicts that KCl precipitation can limit the utilization of the FeS₂ electrode, usually on the lower voltage plateau, of Li(Si)/FeS₂ cells.
- LBL is developing a spectroscopic ellipsometry technique for *in situ* studies of electrode/electrolyte interfaces. The formation of anodic oxide films on Cu and Ag was investigated to assess the utility of this technique. The measurements with a 20- μ m probe beam have revealed local variation of anodic film thickness and composition on a scale much smaller than the grain size.
- A mathematical model is being developed by LBL to account for the role of the morphology of the substrate on bubble size, which profoundly affects the dynamics of gas evolution on electrode surfaces. An equation was derived which relates the maximum bubble size that can form to the radius of surface protrusions.

AIR SYSTEMS RESEARCH

The objectives of this project element are to identify, characterize and improve materials for air electrodes; and to identify, evaluate and initiate development of metal/air battery systems and fuel-cell technology for transportation applications.

Metal/Air Cell Research projects address bifunctional air electrodes, which are needed for electrically rechargeable metal/air (Zn/air, Fe/air) cells; and novel alkaline Zn electrode structures, which could be used in either electrically recharged or mechanically recharged cell configurations.

- LBL has discovered one particular type of furnace black (SRF N774) that appears to be an especially good precursor for forming a highly graphitized and very corrosion-resistant carbon black for use in bifunctional air electrodes.
- CWRU has concluded from extensive studies of heat-treated macrocycles that a transition metal is essential to obtain very active O₂ reduction catalysts. Their studies further indicate that the transition metal is adsorbed principally by interaction with the residual N₂ in the heat-treated macrocyclic catalyst.
- Experiments at LBL demonstrated that a moving bed of Zn particles exhibit low ohmic resistance (i.e., minimizing parasitic voltage drop across the electrode itself) and it can be discharged at a superficial current density of 100 mA/cm².
- Pinnacle Research Institute (PRI) has observed that less electrical energy is required to electrodeposit (recharge at ~280 mA/cm² in alkaline solution containing 51 g/l Zn) Zn on a Mg substrate (0.52 Wh/g) than on a glassy carbon substrate (0.98 Wh/g). The Zn dendrites were easily removed from the Mg substrate, thus simplifying the production of a Zn slurry for use in a slurry Zn/air cell.

Aluminum/Air Battery R&D is directed at improving the performance of air electrodes and developing Al anodes with lower corrosion rates and higher open-circuit potential in alkaline electrolytes.

- Experimental and theoretical studies are underway at SRI International to elucidate the corrosion mechanism of Al alloys. The corrosion of various Al-Li-In (Group I), Al-Li-In-Bi (Group II), and Al-Mg-Mn-In (Group III) alloys in 4 M KOH at 50°C was investigated. The results indicate that none of the alloys studied appear to offer any advantages over Alloy BDW (Al-1 Mg-0.1 In-0.2 Mn) as a fuel for alkaline Al/air batteries.

Fuel Cell Research, managed by Los Alamos National Laboratory (LANL), includes research in several areas of electrochemistry, theoretical studies, fuel-cell testing, fuel processing, and membrane characterization. Major achievements of the fuel-cell program include:

- LANL has achieved a significant improvement in the performance of low-Pt-loading electrodes (0.4 mg/cm^2) by sputtering a thin layer of Pt (0.05 mg/cm^2) on the side of the electrode in contact with the Nafion membrane. The H_2 overpotential was reduced from 170 mV to 70 mV at 1 A/cm^2 with anodes containing the sputtered Pt.
- The Dow perfluorinated polymer evaluated by LANL produced a higher performance than that achieved with Nafion. A fuel cell operating on H_2/air (3/5 atm) attained 0.8 W/cm^2 at 71°C with the Dow membrane (125- μm thickness) while Nafion (175- μm thickness) tested under comparable conditions yielded only 0.4 W/cm^2 . The enhanced performance obtained with the Dow membrane is attributed to the lower molecular weight and the reduced thickness.
- LANL has demonstrated in long-term tests at 300 mA/cm^2 that fuel cells containing Nafion membranes with external humidification showed steady performance with no apparent dehydration problems for 1000 hours.

- EXAFS studies of pyrolyzed transition metal (Fe and Co) macrocycles (phthalocyanine and tetramethoxyphenylporphyrin) at BNL indicate that monodispersed, N_2 -coordinated, Fe and Co atoms are the electrocatalyst sites for O_2 reduction.
- LBL is developing photothermal deflection spectroscopy (PDS) for investigation of electrochemical interfaces. Preliminary experiments on the oxidation of methanol on Pt and an under-potential deposition process by which ad-atom catalysts are formed have shown that PDS is a very sensitive *in situ* method to study surface phenomena at electrode/electrolyte interfaces.
- Porous gas-diffusion electrodes containing high-area Pt supported on carbon were used by LBL to investigate the reduction of O_2 in KOH and K_2CO_3 . Poorer performance was observed in K_2CO_3 , which is attributed to the lower wetted areas and slow OH^- transport. The reduction current in KOH is kinetically limited, whereas in K_2CO_3 local pH changes occur in the pores of the electrode during reduction which result in lower performance than in KOH. This performance may be improved by modifications to the electrode structure. Models were developed for the porous electrodes which accounted for the diffusion and reaction of O_2 and ionic transport in KOH and K_2CO_3 . Good agreement was obtained between the model and performance data.

Management Activities

During 1987, LBL managed 25 subcontracts and conducted a vigorous research program in Electrochemical Energy Storage. LBL staff members attended project review meetings, made site visits to subcontractors, and participated in technical management of various TBR projects.

LBL staff members also participated in the following reviews, meetings, and workshops:

- 2nd International Battery Conference on Applications and Advances, California State University, Long Beach, CA, January 13-15, 1987.
- Gordon Research Conference on Electrochemistry, Santa Barbara, Ca, January 19-23, 1987.
- EPRI Molten Salt Battery Program Meeting, EPRI, Palo Alto, CA, January 23, 1987.
- DOE/EPRI Fuel Cell Workshop, Clearwater, FL, February 16-17, 1987.
- Energy and Resources Group Colloquium, University of California, Berkeley, CA, February 18, 1987.
- DOE/SNL Zn/Br₂ Battery Program Review, Danbury, CT, March 5, 1987.
- DOE/OESD Strategic Planning Meeting, Washington, DC, March 10-11, 1987.
- Aluminum/Air Battery Review Meeting, Washington, DC, March 12, 1987.
- National Association of Corrosion Engineers, CORROSION '87, San Francisco, CA, March 9-13, 1987.
- Industrial Research Meeting, LBL, Berkeley, CA, March 23-25, 1987.
- Fuel Cell Planning Meeting, EPRI, Palo Alto, CA, April 1-2, 1987
- International Conference on Localized Corrosion, Orlando, FL, June 1-5, 1987
- DOE/SNL Zn/Br₂ Battery Program Review, SNL, Albuquerque, NM, June 23, 1987
- Lithium/Iron Sulfide Battery Review and Planning Meeting, EPRI, Palo Alto, CA, June 25, 1987
- DOE/SNL Na/S Battery Program Review, SNL, Albuquerque, NM, July 21-22, 1987
- Fuel Cell Program Meeting, LANL, Los Alamos, NM, July 23, 1987
- Na/S Battery Review Meeting, EPRI, Palo Alto, CA, August 4, 1987
- 22nd IECEC, Philadelphia, PA, August 10-14, 1987

- DOE/OTS Battery Assessment Meeting, INEL, Idaho Falls, ID, September 9-10, 1987
- Zn/Air Battery Program Meeting, Washington, D.C., September 15, 1987
- DOE Electrochemical Energy Storage Program Lead Center Coordination Meeting, Washington, D.C., September 16-17, 1987
- Fall Meeting of the Electrochemical Society, Honolulu, HI, October 18-23, 1987
- DOE/EPRI Fuel Cell Workshop, Morgantown, WV, October 27-29, 1987
- 8th Battery and Electrochemical Contractors' Conference, Tysons Corner, VA, November 16-19, 1987
- Annual Meeting of the American Institute of Chemical Engineers, New York, NY, November 16-21, 1987
- DOE/SNL Na/S Battery Review, Tysons Corner, VA, November, 20, 1987
- DOE/SNL Zn/Br₂ Battery Review, Danbury, CT, December 9-10, 1987

MILESTONES FOR THE TECHNOLOGY BASE RESEARCH PROJECT

Milestones accomplished in Fiscal Year 1987 by the TBR Project include:

- *Initiate new R&D projects on electrocatalysis and novel electrolytes for fuel cells.*

Because of funding limitations, no new contract on electrocatalysis was placed by LANL in 1987. However, a renewal contract was placed with the University of Virginia to investigate binary and ternary Pt alloys for O₂ electrocatalysts. In addition, LANL is seeking cooperative agreements with industry to develop improved O₂ reduction electrocatalysts. Air electrodes obtained from ELTECH Systems, Inc. under a confidentiality agreement are being evaluated at LANL. Ion-conducting polymers obtained from Dow Chemical under a similar agreement are also being evaluated by LANL for use as electrolytes in fuel cells.

- *Initiate new R&D project on molten-salt batteries.*

On the basis of an RFP ("Applied Research on Novel Concepts for Advanced Batteries") issued by LBL in FY 1986, Gould, Inc. was awarded a contract on "Development of Low Melting Molten Salt Electrolyte to Eliminate Iron Disulfide Electrode Capacity Loss." After the award, Gould, Inc. transferred their personnel and equipment devoted to the molten-salt battery project from their facilities in Rolling Meadows, Illinois to Cleveland, Ohio. This move resulted in a considerable delay in the project, and consequently new R&D on molten-salt batteries was not initiated in 1987.

- *Establish an initial set of parameters for optimum membrane structures in fuel cells.*

On the basis of in-house experiments at LANL and discussions with fuel-cell researchers, the following physicochemical properties were specified for membrane structures in polymer-electrolyte fuel cells:

Thickness (mils)	2 to 7
H ⁺ resistance (ohm-cm ²)	0.1
Tensile strength (psi) at break	2500
Elongation (%) at break	100 to 150
Mullen burst strength (psi)	100 to 150
H ₂ permeability (cm ³ -mil/ft ² -h-atm)	260
O ₂ permeability (cm ³ -mil/ft ² -h-atm)	140
Minimum temperature (°C) of thermal/hydrolytic stability	150
Crease/crack (ability to withstand 5 folds in hydrated or dry)	Pass
Tear strength (ability to withstand tearing in hydrated or dry)	Pass
Minimum operational life (h) in an electrochemical cell	5000

- *Golno-go decision to continue development of the chemical-vapor-deposition process to protect low carbon steel or Al from corrosion in sulfide/polysulfide melts.*

The Institute of Gas Technology (IGT) was under subcontract to the IIT to prepare chemical-vapor-deposition (CVD) coatings for corrosion testing in Na/S and Li-alloy/FeS₂ cells. Because of the difficulties encountered, IGT decided to withdraw from the project. After consultation with LBL, and an assessment of the various CVD methods, a decision was reached to continue the effort on the preparation of CVD coatings at IIT. IIT has constructed laboratory space where a plasma-enhanced CVD process to prepare corrosion-resistant coatings is being evaluated.

- *Demonstrate reproducible performance and greater than 50% utilization of sulfur electrode in sealed cells with the new ANL glass electrolyte.*

A glass composition (mol%) of 42 Na₂O, 8 Al₂O₃, 5 ZrO₂ and 45 SiO₂ was identified as a potential solid electrolyte for Na/S cells. A new fabrication facility was built to produce glass tubes for cell tests. Using this facility, glass tubes of 30-cm length and 2- to 6-mm o.d. were successfully produced and tested in Na/S cells. A small cell containing 22 mAh of sulfur at 326°C achieved 100 cycles (2-3% DOD) at 0.4 mA/cm². This cell was able to discharge the sulfur electrode at 50-53% utilization, but the cell capacity declined after the 12th cycle at these deeper DODs. Cracks in the glass electrolyte in the vicinity of the metal-to-glass seal is a probable cause for the capacity decline. Further work is underway

to improve the thermomechanical compatibility of the glass electrolyte and the header material used in the cell and to reproduce cells that demonstrate high utilization of sulfur.

- *Achieve stable capacity (<10% decline in 500 cycles) and reproducible high performance in Li/FeS₂ cells.*

A 12-Ah Li-Al/LiCl-LiBr-KBr (310°C mp)/FeS₂-CoS₂ (85:15 mol%) cell (sealed prismatic bicell with 100-cm² separator of BN felt, cell KHP-4) has achieved greater than 500 cycles at a 2-h discharge rate and a 4-h charge rate at 400°C. The capacity decline remains at <3%, the coulombic efficiency is 98.5%, and the utilization is about 80% of the theoretical FeS₂ electrode (upper plateau) capacity.

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Energy Storage and Distribution of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. The support from the Department of Energy and the contributions to this project by the participants in the Technology Base Research Project are acknowledged. The assistance of Susan Lauer for coordinating the publication of this report and Garth Burns for providing the financial data are gratefully acknowledged.

ANNUAL REPORTS

1. "Technology Base Research Project for Electrochemical Energy Storage — Annual Report for 1986," LBL-23495 (July 1987).
2. "Technology Base Research Project for Electrochemical Energy Storage — Annual Report for 1985," LBL-21342 (July 1986).
3. "Technology Base Research Project for Electrochemical Energy Storage — Annual Report for 1984," LBL-19545 (May 1985).
4. "Annual Report for 1983 — Technology Base Research Project for Electrochemical Energy Storage," LBL-17742 (May 1984).
5. "Technology Base Research Project for Electrochemical Energy Storage, — Report for 1982" LBL-15992 (May 1983).
6. "Technology Base Research Project for Electrochemical Energy Storage — Report for 1981," LBL-14305 (June 1982).
7. "Applied Battery and Electrochemical Research Program Report for 1981," LBL-14304 (June 1982).
8. "Applied Battery and Electrochemical Research Program Report for Fiscal Year 1980," LBL-12514 (April 1981).

SUBCONTRACTOR FINANCIAL DATA - CY 1987

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Subcontractor	Principal Investigator	Project	Contract Value (K\$)	Term (months)	Expiration Date	Status in CY 1987*
<u>EXPLORATORY RESEARCH</u>						
Molten-Salt Cells						
Argonne National Laboratory	P. Nelson	Molten-Salt Cells	545	12	9-87	C
Gould, Incorporated	G. Barlow	Molten-Salt Electrolytes	113	12	7-87	R
Stanford University	R. Huggins	New Battery Materials	300	12	11-87	C
Ambient-Temperature Lithium Cells						
Duracell, Inc.	A. Dey	Li/SO ₂	1500	48	12-85	T
University of Pennsylvania	G. Farrington	Polymeric Electrolytes	85	12	2-88	C
University of Minnesota	W. Smyrl	Solid State Cells	169	12	6-88	R
EIC Laboratories, Inc.	K. Abraham	Secondary Li Batteries	150	12	6-87	T
<u>APPLIED SCIENCE RESEARCH</u>						
Lawrence Berkeley Laboratory	E. Cairns, L. DeJonghe, J. Evans, R. Muller, J. Newman, P. Ross, and C. Tobias	Electrochemical Energy Storage	1500	12	9-87	C
Zinc/Halogen Cells						
Illinois Institute of Technology	R. Selman	Zn Deposition	70	12	9-87	C
Brookhaven National Laboratory	J. McBreen	Zn Morphology	80	12	9-87	C
Lawrence Livermore National Laboratory	D. Miller	Transport Properties	0	12	9-87	T
Components for Alkali/Sulfur Cells						
Argonne National Laboratory	P. Nelson	Solid Electrolytes	330	12	9-87	C
Massachusetts Institute of Technology	H. Tuller	Li Conducting Glasses	100	12	6-87	C

Subcontractor	Principal Investigator	Project	Contract Value (K\$)	Term (months)	Expiration Date	Status in CY 1987*
<u>APPLIED SCIENCE RESEARCH - cont.</u>						
Corrosion Processes in High-Temperature, High-Sulfur-Activity Molten Salt						
Illinois Institute of Technology	R. Selman	Corrosion Resistant Coatings	162	12	11-87	C
Components for Ambient-Temperature Lithium Cells						
Case Western Reserve University	D. Scherson	Spectroscopic Studies	67	12	11-87	C
Jackson State University	H. Tachikawa	Raman Spectroscopy	53	12	6-87	C
Johns Hopkins University	J. Kruger	Corrosion/Passivity Studies	88	12	7-87	C
<u>AIR SYSTEMS RESEARCH</u>						
Metal/Air Cell Research						
Case Western Reserve University	E. Yeager	Air Electrodes	213	12	5-88	C
Pinnacle Research Institute	L. Morris	Zn/Air Battery	195	12	1-88	C
Aluminum/Air Battery R&D						
Lawrence Livermore National Laboratory	A. Maimoni	Al/Air Power Cell R&D	0	12	9-87	T
Fuel Cell R&D						
Los Alamos National Laboratory	J. Huff	Fuel Cell R&D	800	12	9-87	C
Brookhaven National Laboratory	J. McBreen	Fuel Cell Research	150	12	9-87	C

Executive Summary

* C = continuing, T = terminating, R = subject included in a request for proposals (RFP) issued by LBL in FY 1986.

LIST OF ACRONYMS

AES	Auger electron spectroscopy
AIAA	American Institute of Aeronautics and Astronautics
AIChE	American Institute of Chemical Engineers
ANL	Argonne National Laboratory
BNL	Brookhaven National Laboratory
CVD	chemical vapor deposition
CWRU	Case Western Reserve University
DHE	dynamic hydrogen electrode
DMDS	dimethyl disulfide
DOD	depth of discharge
DOE	Department of Energy
ECD	electrochemical deposition
EMF	electromotive force
EPRI	Electric Power Research Institute
ESCA	electron spectroscopy for chemical analysis
ETD	Exploratory Technology Development and Testing
EV	electric vehicle
EXAFS	extended X-ray absorption fine structure
FIC	fast ion conducting
FT	Fourier transform
FTIR	Fourier transform infrared spectroscopy
GC	glassy carbon
GDE	gas diffusion electrode
HOPG	highly oriented pyrolytic graphite
HPM	hot-pressing method
IAD	implicit alternating direction
IECEC	Intersociety Energy Conversion and Engineering Conference
IGT	Institute of Gas Technology
IIT	Illinois Institute of Technology
IRS	infrared reflectance spectroscopy
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LLNL	Lawrence Livermore National Laboratory
LUMO	lowest unoccupied molecular orbital
MEA	membrane-electrode assemblies
MIT	Massachusetts Institute of Technology
NMR	nuclear magnetic resonance
OCV	open-circuit voltage
OEP	octaethyl porphyrin
OESD	Office of Energy Storage and Distribution
OPG	ordinary pyrolytic graphite
OR	oxygen reduction
OTS	Office of Transportation Systems
PAA	polyacrylamide
PAN	polyacrylonitrile
PC	propylene carbonate
Pc	phthalocyanine

PDE	partial differential equation
PDS	photothermal deflection spectroscopy
PE-CVD	plasma-enhanced chemical-vapor deposition
PEM	proton-exchange membrane
PEO	poly(ethylene oxide)
PG	propylene glycol
PRI	Pinnacle Research Institute
PTFE	polytetrafluoroethylene
PVF	poly(vinylferrocene)
RCCE	rotating concentric cylinder electrode
RHE	rotating hemispherical electrode
RDE	rotating disk electrode
RRDE	rotating ring-disk electrode
SASB	steam-activated Shawinigan acetylene black
SEM	scanning electron microscopy
SERS	surface-enhanced Raman spectroscopy
SIMS	secondary ion mass spectroscopy
SNL	Sandia National Laboratories
TAA	tetraazaannulene
TBR	Technology Base Research
TDMS	thermal desorption mass spectroscopy
TEM	transmission electron microscopy
TETD	tetraethyl thiuram disulfide
THF	tetrahydrofuran
TMPP	tetramethoxylphenyl porphyrin
T.P.	two voltage plateaus
TSPc	tetrasulfonated phthalocyanine
U.P.	upper plateau
UPD	underpotential deposition
UV	ultraviolet
VLSI	very large-scale integration
XANES	X-ray near edge absorption spectroscopy
XPS	X-ray photoelectron spectroscopy

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