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Technology Base Research Project for Electrochemical Energy Storage: Executive Summary Report for 1988

May 1989

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TECHNOLOGY BASE RESEARCH PROJECT FOR ELECTROCHEMICAL ENERGY STORAGE

EXECUTIVE SUMMARY REPORT FOR 1988

Applied Science Division
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Berkeley, California 94720

Edited by Kim Kinoshita, Technical Manager

May 1989

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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

* 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.

to the TBR Project in CY 1988. This is a continuing project, and reports for prior years have been published; they are listed at the end of the Executive Summary.

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 was 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 key issues for this technology are to stabilize the performance of the FeS_2 electrode and to develop corrosion-resistant containment materials.

- Argonne National Laboratory (ANL) has achieved stable performance for over 280 charge/discharge cycles with a Li-limited cell (flooded electrolyte, upper-plateau Li alloy/FeS_2 cell) that was subjected to overcharge (*i.e.*, trickle charge at 2.5 mA/cm^2). The overcharge current was applied every 10 cycles. Coulometric and galvanic analyses indicated that overcharge at 2.5 mA/cm^2 did not produce a net change in the charge acceptance of the negative electrode.

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, and to determine the operating conditions that lead to Zn dendrite formation.

- LBL has completed the development of the first two-dimensional mathematical model of the porous Zn/ZnO electrode. This model predicted the influence of cell geometry and concentration gradients on the current density distribution, in good agreement with experimental measurements using microelectrodes in model Zn/NiOOH cells.

- LBL has successfully employed photothermal desorption spectroscopy (PDS) for *in situ* studies of Zn electrodes. Initial experiments with PDS clearly showed that the concentration of soluble Zn species is higher near the electrode surface during discharge; and for cathodic electrodeposition (charge) of Zn, the reverse is true.

- LBL has employed *in situ* videomicroscopy to observe the deposition of Zn in flowing alkaline electrolytes. It was observed that the growth of mossy Zn is generally initiated after a substantial thickness of compact Zn is deposited, and that the mossy Zn usually forms around a protruding nodule.

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.

- Illinois Institute of Technology (IIT) has observed that the grain size of the Zn deposit obtained in acidic $ZnBr_2$ electrolytes by pulse reverse voltage (PRV) was considerably smaller than that obtained at constant voltage. This result suggests that the more uniform crystal distribution and smaller grain size obtained by PRV are responsible for the decreased frequency of Zn dendrite formation.

- Brookhaven National Laboratory (BNL) has observed that electromigration in $ZnBr_2$ electrolyte is enhanced when the electrolyte contains quaternary ammonium complexes. Furthermore, the "bromine oil" that forms with these complexes is found to enhance Br_2 transport.

Improved Components for Alkali/Sulfur Cells, such as superior alternatives to the β''-Al_2O_3 ceramic electrolyte and the high-temperature sulfur-polysulfide electrode used in Na/S cells, stable Li-ion conductors for Li/S cells, optimized $NiCl_2$ electrodes for Na/$NiCl_2$ cells, and a class of organosulfur electrodes for low-temperature Na/β''-Al_2O_3 cells, are under investigation.

- Preliminary results obtained at LBL indicate that the addition of 0.2 wt% oxides of Ge, Nb, Mg or Zn all improved the total conductivity of β''-Al_2O_3 by lowering the grain-boundary resistance. Zinc oxide provided the greatest enhancement in conductivity.

- Investigations at LBL of novel, low-temperature (120-150°C) secondary cells that contain a liquid Na negative, β''-Al_2O_3 electrolyte, and a class of organosulfur (RSSR, R = aliphatic, aromatic, ethereal or fluorinated organic moiety) positives, showed that fluorinated organosulfur compounds in Na/RSSR cells yielded open-circuit voltages between 2.4-3.0 V, depending on the degree of fluorination.

- Experiments are underway at LBL to develop an advanced mathematical model of the sulfur electrode in Na/S cells. The model, consisting of a set of non-linear partial differential equations, describes the diffusion, migration, and convection processes that take place during operation of such a cell.

- ANL has identified a glass-ceramic composition [*i.e.*, ANL Glass (composition in mol%: 42 Na_2O, 8 Al_2O_3, 5 ZrO_2, and 45 SiO_2) and MgO-G ceramic (composition in mol%: 89 MgO, 1 Al_2O_3, 1 BaO, 1 CaO, and 8 B_2O_3)] for possible use as a glass-to-ceramic seal, that was successfully cycled 14 times from room temperature to 450°C without degradation.

- Massachusetts Institute of Technology (MIT) has observed that the addition of CaO to lithium borate glasses improves stability to high-activity Li environments but results in a lower ionic conductivity.

- Stanford University is exploring the development of alternative electrodes and electrolytes for Na/MCl_2 (M = Fe, Ni) cells. Their studies suggest that a number of Na alloys (Na-Pb, Na-Sn, Na-Bi, Na-Sb) offer interesting possibilities as negative electrodes in cells without the solid electrolyte, Na-β''-Al_2O_3.

Corrosion Processes in High-Specific-Energy Cells are under investigation, and the aim is to develop low-cost container and current-collector materials for use in nonaqueous, alkali/sulfur, and other molten-salt cells.

- Tests at IIT of Mo-, Mo_2C- and TiN-coated samples for 100 h in Na_2S_x melts at 330°C showed corrosion resistance similar to that of solid Mo.

- Johns Hopkins University has observed that Fe passivates in 0.5 M $LiClO_4$/PC containing >500 ppm H_2O because of the presence of an oxide film. Below the oxidation potential of PC, Fe passives in anhydrous 0.5 M $LiClO_4$/PC by the oxidative chemisorption of solvent molecules.

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 used high-resolution electron energy loss spectroscopy (HREELS) to detect the presence of carbonate-like species coordinated to K that was exposed to CO_2. This finding suggests that CO_2 undergoes partial polymerization on the K surface.

- Jackson State University has observed, by *in situ* Raman spectroscopy of 1000-Å thick layers of Li on Ag, that surface products such as Li_2CO_3 and lithium alkyl carbonate may form in propylene carbonate (PC).

- The University of Minnesota has observed that Na/V_6O_{13} cells with poly(ethylene oxide) (PEO) polymer electrolyte showed stability and rechargeability up to 11 cycles, and the Na anode showed no evidence of irreversibility.

- Studies as the University of Pennsylvania indicate that polymer electrolytes with mixed uni- and di-valent copper chloride are more thermally stable than the pure di-valent copper electrolyte of $CuCl_2PEO_8$. Cations with mixed valency in the PEO electrolytes provide a redox couple that may be promising electrode materials in solid-state batteries.

- LBL was able to successfully electrodeposit Mg using $Mg(BF_4)_2$ in tetrahydrofuran, however, the deposit was obtained at a lower current density than the well-known deposition of Mg from Grignard reagent. No further work on this project is planned at this time.

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.

- LBL developed a mathematical model of the $Na/FeCl_2$ battery that predicts the cell voltage as a function of the depth of discharge, and has been useful in showing porosity and volume fraction profiles and how they can affect cycle life.

- LBL is employing a number of sophisticated techniques for *in situ* studies of the electrode/electrolyte interface during anodic film formation. Light-scattering measurements and scanning tunneling microscopy have confirmed earlier conclusions from ellipsometer observations that silver oxide crystallites undergo redistribution during film formation.

- LBL has demonstrated the versatility of PDS for investigation of electrochemical interfaces. Many types of electrodes, including smooth Pt, Cu, polymer films on carbon or a fine screen, and porous UO_2, have been studied as electrode surfaces. Improvements in the technique have led to an enhanced signal-to-noise ratio, which has increased sensitivity and permitted shorter measurement times.

- Early results with Pt_3Sn (100) surfaces at LBL suggest that methanol electro-oxidation is catalyzed by the redox process of Sn that occurs at high anodic potentials (*i.e.*, $Sn^{2+} \rightarrow Sn^{4+}$).

- The effect of rising gas bubbles on mass transfer at vertical electrodes was investigated at LBL. Rising H_2 bubbles in the boundary layer were found to enhance the limiting current for Fe^{3+} reduction, but this enhancement was localized to a region corresponding to $\sim$5 times the bubble diameter.

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, that are needed for electrically rechargeable metal/air (Zn/air, Fe/air) cells; and novel alkaline Zn electrode structures, that could be used in either electrically recharged or mechanically recharged cell configurations.

- LBL has developed a quantitative method for determining the number of oxygenated carbon atoms in carbon black samples. The corrosion rate of these carbon blacks in alkaline electrolytes could be correlated to the concentration of oxygenated species.

- CWRU has concluded from extended X-ray absorption fine structure studies (EXAFS) of heat-treated cobalt tetramethoxyphenyl porphyrin (CoTMPP) that a significant amount of Co is retained in the N_4 centers, in agreement with studies at BNL. In other studies, CWRU has demonstrated that heat-treatment of Co-polystyrene polymer does not result in very active O_2 reduction catalysts because of the absence of nitrogen functionality.

- LBL has developed a new design for a Zn/air cell that contains a particulate Zn electrode. This cell differs from previous designs in that it does not require an external pump to circulate electrolyte. Instead, recirculation is achieved by natural convection. Preliminary discharge tests indicate that its performance is comparable to the Zn/air cell with a reticulated Zn electrode.

- Metal Air Technology Systems International (MATSI) has recently initiated a program to extend the LBL-developed concept of using a reticulated structure as a substrate for Zn deposition in secondary Zn/air cells. Preliminary results indicate that the entire Zn deposit can be discharged, and that dense, uniform Zn deposits are obtained on charge.

- Pinnacle Research Institute (PRI) has successfully demonstrated that a slurry Zn powder obtained from dendritic Zn can be discharged in a Zn/air cell. The results were comparable to those obtained with a commercial Zn powder in the same 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.

- SRI International is investigating solution-phase inhibition as an alternative to alloying as a means of reducing the corrosion rate of Al in alkaline media. The addition of potassium permanganate significantly improves the coulombic efficiency of Al dissolution in 4 M KOH at 50°C, at both high (400 mA/cm^2) and low (100 mA/cm^2) discharge rates.

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 during 1988 are listed below:

- Measurements at LANL indicate that the water drag across Nafion membranes in distilled water is 2.5 ± 0.5 molecules H_2O per proton and is independent of current density in the range 5-25 mA/cm^2.

- LANL has obtained enhanced performance in polymer-electrolyte membrane (PEM) fuel cells with thinner Nafion perfluorinated polymer and at higher air pressure. Changing the pressure from H_2/air (3/3 atm) to H_2/air (3/5 atm) produced cell voltage improvements at 1.4 A/cm^2 of 40, 150 and 250 mV with Nafion membrane thicknesses of 50, 100 and 175 μm, respectively. This enhancement is attributed to improved anode performance resulting from the increase in water transport from the cathode to anode.

- LANL has demonstrated that the addition of low amounts of O_2 to the CO-containing reformed H_2 stream produces anode performance (1 A/cm^2, 80°C) that is similar to that obtained with CO-free fuel. With ~500 ppm CO, ~5% O_2 in the H_2 feed stream is sufficient to almost completely restore the CO-free cell performance.

- BNL has initiated investigations of underpotential deposited (UPD) Cu on Pt as an electrocatalyst for methanol oxidation. XANES (X-ray absorption near-edge spectroscopy) studies of UPD Cu on supported Pt by BNL indicate that the adsorbed Cu has a +1 oxidation state. Results of this study also indicated very different bonding for H_2 and Cu on Pt surfaces.

Management Activities

During 1988, 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:

- Gordon Research Conference on Electrochemistry, Santa Barbara, CA, January 18-22, 1988.
- Overview of Sodium/Metal Chloride Battery Technology, Electric Power Research Institute (EPRI), Palo Alto, CA, February 9, 1988.
- Zn/Air Battery Discussion Meeting, EPRI, Palo Alto, CA, February 11, 1988.
- Na/S Battery Safety Task Force Review, Washington, D.C., February 24, 1988.
- DOE/EHV Battery R&D Program Planning Meeting, Washington, D.C., March 7-9, 1988.
- Fuel Cell/Battery Powered Bus System Program Kickoff Meeting, Washington, D.C., March 10, 1988.
- Fuel Cell Workshop, METC, Morgantown, WV, April 5-6, 1988.
- Zn/Br_2 Task Force Meeting, SNL, Albuquerque, NM, April 14, 1988.
- Zn/Br_2 Program Planning Meeting, EPRI, Palo Alto, CA, April 14, 1988.
- Fuel Cell Coordination Meeting, Washington, D.C., April 22, 1988.
- Air Systems Review Meeting, Cleveland, OH, April 25-26, 1988.
- Zn/Air Battery Evaluation Meeting, Cleveland, OH, April 27, 1988.
- Fourth Annual Energy Research Conference, Jackson, MS, April 27, 1988.
- 173rd Meeting of the Electrochemical Society, Atlanta, GA, May 15-20, 1988.
- 33rd International Power Sources Symposium, Cherry Hill, NJ, June 13-16, 1988.

- DOE/OTS Program Planning Meeting, Washington, D.C., June 17, 1988.
- Zn/Air Battery Design Review, Danbury, CT, August 10-11, 1988.
- Workshop on High-Temperature Batteries, Washington, D.C., August 16-17, 1988.
- Meeting on Zn/Air Conceptual Design and Cost Study, Washington, D.C., August 18, 1988.
- Fe/Air Battery Review Meeting, Pittsburgh, PA, August 24, 1988.
- Meeting on Zinc-Bromine Battery for Utility Load Management, EPRI, Palo Alto, CA, August 30, 1988.
- 39th ISE Meeting, Glasgow, Scotland, September 4-9, 1988.
- Status of Li-FeS System and Other Related Work at Electrofuel Manufacturing Co., EPRI, Palo Alto, CA, September 22, 1988.
- DOE Lead Center Coordination Meeting, Washington, D.C., October 5, 1988.
- Electric Systems Integration Project Review, Washington, D.C., October 6, 1988.
- 174th Meeting of the Electrochemical Society, Chicago, IL, October 9-14, 1988.
- Fuel Cell Seminar, Long Beach, CA, October 23-26, 1988.
- DOE/EHP Battery R&D Program Planning Meeting, Salt Lake City, UT, October 27, 1988.
- 15th Meeting of the Federation of Analytical Chemistry and Spectroscopic Societies, Boston, MA, October 30-November 4, 1988.
- Technology Base Research Project Review Meeting, LBL, Berkeley, CA, December 6-7, 1988.

MILESTONES FOR THE TECHNOLOGY BASE RESEARCH PROJECT

Milestones accomplished in Fiscal Year 1988 by the TBR Project include:

- *Go/no-go decision to continue development of the slurry electrode for Zn/air battery.*

  A meeting was held on April 27, 1988 in Cleveland, OH, to discuss the status of Zn/air battery technology. On the basis of the discussion at this meeting, as well as the presentations on Zn/air battery R&D at the Air Systems Research Review Meeting on April 25-26, 1988 held in Cleveland, OH, a recommendation was made to DOE to continue R&D on slurry Zn electrodes until April 1989. In addition, the TBR Project proposed to investigate the performance of reticulated structures as an alternative to slurry electrodes in Zn/air cells. A subcontract was issued to MATSI by LBL to assess the viability of reticulated structures in practical Zn/air cells.

- *Go/no-go decision to continue development of low-loading supported Pt/carbon catalysts to achieve the power density required for transportation applications.*

  Results obtained by LANL with PEM (polymer electrolyte membrane) fuel cells utilizing supported Pt catalysts with low Pt loadings ($\sim$0.4 mg/cm^2 Pt) showed performances comparable to PEM cells with much higher loadings (*i.e.*, 4 mg/cm^2 Pt). A PEM cell with Pt/C catalyst (0.45 mg/cm^2 Pt in anode and cathode) operated at a current density of 2 A/cm^2 and a cell voltage of 0.45 V on H_2 and air at 3 and 5 atm, respectively. Based on these results, it was recommended to DOE that the development of PEM fuel cells with electrodes containing Pt/C of low loading continue.

- *Demonstrate 10-20 thermal cycles with a new ceramic header material sealed to the ANL glass for Na/S cells.*

  ANL evaluated several composition of glasses from the $MgO-Al_2O_3-BaO-CaO-B_2O_3$ system to determine their stability in Na/S cell environments. Two glasses (designated MgO G and MgO J) were found that met the criteria of chemical stability and compatible thermal-expansion properties of ANL glass for Na/S cells. Two hermetic seals between ANL Glass and MgO G were made and successfully thermally cycled for 10-14 cycles from ambient to 450°C.

- *Demonstrate overcharge tolerance in stable, high performance Li alloy/FeS_2 cells.*

  An innovative application of a self-discharge mechanism in Li-alloy/FeS_2 cells was evaluated by ANL. This mechanism involves the following steps: (i) dissolution of Li (possibly as Li_2^+) at the Li-alloy electrode, (ii) diffusion of Li across the separator to the positive electrode, and (iii) electrochemical discharge of Li to Li^+ at the positive electrode. The self discharge of the cell by Li transport through the cell is the basis for overcharge protection. Li/Fe_2 cells operated at 400-425°C with LiCl-LiBr-KBr electrolyte sustained overcharge-tolerance rates of 2-3 mA/cm^2. These cells also showed stable performance for over 200 cycles.

- *Go/no-go decision to continue studies of Fe- and Co-pyrolyzed macrocyclic catalysts based on stability measurements in the PEM fuel-cell environment.*

  Pyrolyzed transition metal macrocycles have shown excellent catalytic activity for O_2 reduction in alkaline electrolytes. LANL investigated the electrocatalytic activity of Fe- and Co-pyrolyzed macrocycles in acid environments as an alternative to Pt in air cathodes. The results of their study indicate that the pyrolyzed macrocycles are stable in the PEM fuel cell environment. Based on

this observation and the encouraging results obtained with a new electrode structure containing Pt electrocatalyst, continuation of studies on pyrolyzed-macrocycle electrocatalysts was recommended to DOE.

ACKNOWLEDGEMENT

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ANNUAL REPORTS

1. "Technology Base Research Project for Electrochemical Energy Storage – Annual Report for 1987," LBL-25507 (July 1988).

2. "Technology Base Research Project for Electrochemical Energy Storage – Annual Report for 1986," LBL-23495 (July 1987).

3. "Technology Base Research Project for Electrochemical Energy Storage – Annual Report for 1985," LBL-21342 (July 1986).

4. "Technology Base Research Project for Electrochemical Energy Storage – Annual Report for 1984," LBL-19545 (May 1985).

5. "Annual Report for 1983 – Technology Base Research Project for Electrochemical Energy Storage," LBL-17742 (May 1984).

6. "Technology Base Research Project for Electrochemical Energy Storage – Report for 1982" LBL-15992 (May 1983).

7. "Technology Base Research Project for Electrochemical Energy Storage – Report for 1981," LBL-14305 (June 1982).

8. "Applied Battery and Electrochemical Research Program Report for 1981," LBL-14304 (June 1982).

9. "Applied Battery and Electrochemical Research Program Report for Fiscal Year 1980," LBL-12514 (April 1981).

SUBCONTRACTOR FINANCIAL DATA - CY 1988

Subcontractor	Principal Investigator	Project	Contract Value (K$)	Term (months)	Expiration Date	Status in CY 1988*
EXPLORATORY RESEARCH						
Molten-Salt Cells						
Argonne National Laboratory	C. Christianson	Molten-Salt Cells	350	12	9-88	C
Stanford University	R. Huggins	New Battery Materials	195	12	11-88	C
Ambient-Temperature Lithium Cells						
University of Pennsylvania	G. Farrington	Polymeric Electrolytes	53	12	2-89	C
University of Minnesota	W. Smyrl	Solid State Cells	169	12	6-88	C
APPLIED SCIENCE RESEARCH						
Lawrence Berkeley Laboratory	E. Cairns, L. DeJonghe, J. Evans, R. Muller, J. Newman, P. Ross, and C. Tobias	Electrochemical Energy Storage	1490	12	9-88	C
Zinc/Halogen Cells						
Illinois Institute of Technology	R. Selman	Zn Deposition	70	15	12-88	C
Brookhaven National Laboratory	J. McBreen	Zn Morphology	80	12	9-88	C
Components for Alkali/Sulfur Cells						
Argonne National Laboratory	C. Christianson	Solid Electrolytes	150	12	9-88	C
Massachusetts Institute of Technology	H. Tuller	Li Conducting Glasses	100	12	8-88	C

Subcontractor	Principal Investigator	Project	Contract Value (K$)	Term (months)	Expiration Date	Status in CY 1988*
APPLIED SCIENCE RESEARCH - cont.						
Corrosion Processes in High-Specific Energy Cells						
Illinois Institute of Technology	R. Selman	Corrosion Resistant Coatings	129	12	11-88	C
Johns Hopkins University	J. Kruger	Corrosion/Passivity Studies	88	12	7-88	C
Components for Ambient-Temperature Lithium Cells						
Case Western Reserve University	D. Scherson	Spectroscopic Studies	67	13	12-88	C
Jackson State University	H. Tachikawa	Raman Spectroscopy	53	12	6-88	C
AIR SYSTEMS RESEARCH						
Metal/Air Cell Research						
Case Western Reserve University	E. Yeager	Air Electrodes	177	12	4-89	C
Pinnacle Research Institute	H. Sierra Alcazar	Zn/Air Battery	173	12	4-88	C
Metal Air Technology Systems	R. Putt	Zn/Air Battery	119	12	9-89	C
Aluminum/Air Battery R&D						
SRI International	D. Macdonald	Al/Air Battery	75	13	3-89	C
Fuel Cell R&D						
Los Alamos National Laboratory	S. Gottesfeld	Fuel Cell R&D	800	12	9-88	C
Brookhaven National Laboratory	J. McBreen	Fuel Cell Research	150	12	9-88	C

* C = continuing, T = terminating

LIST OF ACRONYMS

AES	Auger electron spectroscopy
AIChE	American Institute of Chemical Engineers
AIS_t	area specific impedance
AN	acetonitrile
ANL	Argonne National Laboratory
BNL	Brookhaven National Laboratory
CC	constant current
CSPL	Chloride Silent Power Limited
CV	constant voltage
CVD	chemical vapor deposition
CVLC	constant voltage, limited current
CWRU	Case Western Reserve University
DMSF	dimethyl sulfone
DMSO	dimethyl sulfoxide
DOC	depth of charge
DOE	U.S. Department of Energy
DSC	differential scanning calorimetry
ECDMS	electrochemical deposition from molten salts
EEDS	ethoxyethyl disulfide
EHP	Electric and Hybrid Propulsion
EHV	Electric and Hybrid Vehicles
EPMA	electron probe microanalyzer
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
FLINAK	LiF-NaF-KF
FTIRRAS	Fourier transform infrared reflectance absorption spectroscopy
GDE	gas diffusion electrode
HOPG	highly ordered pyrolytic graphite
HREELS	high resolution electron energy loss spectroscopy
HTIE	high-temperature immobilized electrolyte
IAD	implicit alternating direction
IECEC	Intersociety Energy Conversion Engineering Conference
IIT	Illinois Institute of Technology
ISS	ion scattering spectroscopy
LANL	Los Alamos National Laboratory
LEED	low energy electron diffraction
LBL	Lawrence Berkeley Laboratory
MATSI	Metal Air Technology Systems International
MCCD	minimum constant current density
METC	Morgantown Energy Technology Center

MIT	Massachusetts Institute of Technology
OCV	open-circuit voltage
OESD	Office of Energy Storage and Distribution
OPG	ordinary pyrolytic graphite
OTS	Office of Transportation Systems
PAN	polyacrylonitrile
PB	polypyrrole black
PC	propylene carbonate
PDE	partial differential equation
PDS	photothermal deflection spectroscopy
PECVD	plasma-enhanced chemical-vapor deposition
PEM	proton-exchange membrane
PEO	poly(ethylene oxide)
PRC	pulse reverse current
PRI	Pinnacle Research Institute
PRV	pulse reverse voltage
RDE	rotating disk electrode
RHE	hydrogen reference electrode
SASB	steam-activated Shawinigan acetylene black
SCE	saturated calomel electrode
SEM	scanning electron microscopy
SERS	surface-enhanced Raman spectroscopy
SNL	Sandia National Laboratories
SPE	solid polymer electrolyte
TBR	Technology Base Research
TDS	thermal desorption spectroscopy
TGA	thermal gravimetric analysis
THF	tetrahydrofuran
TMPP	tetramethoxyphenyl porphyrin
TSPc	tetrasulfonated phthalocyanine
U.P.	upper plateau
UPD	underpotential deposition
VLSI	very large-scale integration
XANES	X-ray near edge absorption spectroscopy
XPS	X-ray photoelectron spectroscopy

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