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TECHNOLOGY BASE RESEARCH PROJECT FOR ELECTROCHEMICAL ENERGY STORAGE: Executive Summary Report for 1986

June 1987

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LBL-23494

TECHNOLOGY BASE RESEARCH PROJECT FOR ELECTROCHEMICAL ENERGY STORAGE

EXECUTIVE SUMMARY REPORT FOR 1986

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

Edited by Kim Kinoshita, Technical Manager

June 1987

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.

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 1986. 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.

*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.

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 and ambient-temperature lithium cells.

Molten-Salt Cells based on lithium alloy negative electrodes and metal disulfide positive electrodes can 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 over 400 cycles and 5400-h operation at 397°C with a small prismatic upper-plateau Li-Al/FeS_2 cell with LiCl-LiBr-KBr electrolyte. The cell performance (coulombic efficiency >90%, utilization 89%) remained nearly constant throughout the cycle test (discharge at 50 mA/cm^2 for 4 h, charge at 25 mA/cm^2 to a cut-off voltage of 2.05 V). Based on the stable cycle life demonstrated in this cell test, at least 1000 cycles with ≤20% capacity loss should be achievable.

- Gould, Inc. has observed that identical Li-alloy/FeS_2 cells containing LiCl-LiF-LiI electrolyte, which were cycled at 350 and 450°C, lost upper-plateau capacity at the rate of 0.14 and 0.29% per cycle, respectively. The life of the cell operated at 350°C was also significantly longer than that of the cell operated at 450°C, i.e., 250 vs 115 cycles. These results, and observations from other tests, clearly demonstrate that capacity decline is reduced at lower operating temperatures, and reaction kinetics are also lower.

Ambient-Temperature Lithium Cells have the potential for high specific energy and specific power, but they typically exhibit short lifetimes when tested under deep-discharge regimens. Various anodes containing Li combined with metal oxide cathodes in an organic-electrolyte system are being investigated to develop ambient-temperature Li cells which do not have the safety and cycle-life problems associated with elemental Li.

- The draft final report from Duracell, Inc. on studies of the ambient-temperature $Li/LiAlCl_4$-SO_2/C system has been completed. The capability of the inorganic electrolyte systems to accept overcharge was demonstrated, but is limited by the chemical stability of the separator to the overcharge products. Further research studies to improve the cycle life, specific energy, and stability of separators are recommended.

- A novel low-temperature chemical synthesis method has been developed by EIC Laboratories, Inc. to produce Li anode materials such as Li-Al, Li_xWO_2, $Li_xFe_2O_3$ and $LiCoO_2$. Cycle tests of these materials in cells with $LiClO_4$-propylene carbonate and metal oxide cathodes (V_2O_5, Fe_2O_3, Cr_3O_8) are underway.

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 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 zinc as the negative electrode, and it is this electrode that typically limits the lifetime of these cells. Efforts are underway to identify cell components that will improve the cycle-life performance of the Zn electrode.

- LBL has achieved more than 500 deep-discharge (100%) cycles with a pulse-charged ZnCa/KOH-KF/NiOOH cell. The performance of this system is expected to be comparable to that of standard Zn/KOH/NiOOH batteries, because the Ca and KF additions replaced equal quantities of Zn and KOH.

- LBL has used micro-electrodes to provide new insight into the chemical and transport processes that occur in secondary porous Zn electrodes in KOH electrolytes. Preliminary measurements show significant variations in local Zn species concentrations, and only modest variations in local hydroxyl-ion concentra-

tion. The response of the micro-electrodes also indicates that higher KOH concentrations stabilize the supersaturated zincate solution.

- SNL has found that replacement of a tertiary hydrogen by a methyl group in sulfonated polyphenylenes enhances the stability of the membrane in alkaline ferro/ferricyanide electrolytes.

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.

- LBL has observed that the current efficiency for Zn deposition from acidic chloride solutions increased with Zn concentration and decreased with pH. The presence of impurities (i.e., Ni, Fe and Cd) was found to lower the current efficiency.

- Illinois Institute of Technology (IIT) investigated the kinetics of Zn dissolution at a rotating hemispherical electrode in brominated (0.05-0.35 M) $ZnBr_2$, and concluded that the exchange current density is ~20 mA/cm^2.

- EXAFS (extended X-ray absorption fine structure) studies on Zn electrolytes (acidic and basic) at Brookhaven National Laboratory (BNL) were able to determine the bond distances in Zn complexes. A tetrahedral $Zn(OH)_4^{=}$ species with a Zn-O distance of 1.77 Å was detected in alkaline electrolytes. In $ZnBr_2$ electrolytes, the Zn-Br distance is 2.37 Å and the Zn-O distance is 1.83 Å.

- Lawrence Livermore National Laboratory (LLNL) has completed isopiestic measurements of the $ZnCl_2$-H_2O system over the concentration range 0.31358 to 13.143 mol/kg. These data show fairly good agreement, within 0.1 to 0.5%, with previous isopiestic data for concentrations up to 11 mol/kg.

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

- A novel, low-temperature (120-150°C) secondary cell has been developed at LBL which contains a liquid sodium negative, β''-Al_2O_3 electrolyte, and a class of organosulfur positives. The Na/tetraethylthiuram disulfide cell, which has a theoretical specific energy of 360 Wh/kg (OCV = 2.3 V), has been studied in most detail. Small-scale laboratory cells were capable of peak discharge rates of over 100 mA/cm^2, and cycling at 5 mA/cm^2 was demonstrated.

- ANL has selected a glass electrolyte with the composition (mol%) of 42 Na_2O, 8 Al_2O_3, 5 ZrO_2 and 45 SiO_2 for further testing in Na/S cells. Small-scale cells (1-3 mAh) were successfully cycled at 3 to 6 mA/cm^2 for 36 to 40 cycles (10-20% DOD) before a capacity loss was observed.

- Massachusetts Institute of Technology (MIT) has observed that the addition of KCl to potassium borate generally enhances K^+ transport in these glasses. At a fixed O/B ratio of 1.7, K^+ conductivity increased monotonically with increasing chloride content.

- Stanford University is exploring the use of compositions from the Li-Si-S system for both positive electrode and electrolyte materials. The Li-Si-S phase diagram and Gibbs free energies of formation of Li_2SiS_3 and Li_4SiS_4 have been determined from electrochemical measurements. X-ray diffraction analyses have indexed for the first time the lattice parameters of Li_2SiS_3 and Li_4SiS_4.

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.

- Work at ANL to develop new alloys for positive current collector and containment materials for Na/S cells was completed. The corrosion behavior of 33 metals and alloys in S and NaS_x at 350°C was examined. It was concluded that the continued development of new alloys would probably not result in an alloy material of sufficient low cost, low density and low corrosion rate to be useful for Na/S cells.

- IIT observed no weight loss or discoloration of Mo_2C coatings in Na_2S_3 melt after 24 h at 300°C. However, in Na_2S_4 at 310°C, a black color was observed on the surface after 24 h immersion. Results to date are encouraging and suggest that Mo_2C appears to resist S attack.

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

- Mercury porosimetry measurements at LBL show that Li_3N layers formed by reaction of Li with gaseous nitrogen are microporous, with most of the pore radii less than 25 A. The slow filling of these pores and reaction of Li with the electrolyte at the base of the pores were observed by impedance spectroscopy.

- Case Western Reserve University (CWRU) has completed testing of ultrahigh vacuum apparatus and spectroscopic techniques for investigations of alkali and alkaline-earth metals. Auger electron spectroscopy measurements indicate that K free of impurities can be deposited on Ni substrates, and that K on the surface shifts the desorption of CO to higher temperatures. These findings will be useful for understanding the interaction of decomposition products (i.e., CO) from the reaction of propylene carbonate (PC) and alkali and alkaline earth metals.

- A research project has been initiated at Jackson State University to study the electrode/electrolyte interface by *in situ* Raman spectroscopy. Preliminary measurements indicate that Li_2O and Li_2CO_3 are formed during the electrodeposition of Li on Ag from 0.75 M $LiAsF_6$ in PC.

- The University of Minnesota was awarded a contract from a RFP on applied research on novel concepts for advanced batteries. A research project has been initiated to investigate the electrochemical performance of thin-film polymer electrolytes and electrodes.

- The University of Pennsylvania has found that the ionic transport of Ni^{2+} in $NiBr_2$ complexes with poly(ethylene oxide) (PEO) can be activated by hydration and dehydration of the sample. At 145°C, the Ni^{2+} transport number for a dehydrated sample is <0.1, and it increases to 0.7 upon hydration.

- Experiments at LBL showed that 0.3 to 20 ppm H_2O in PC electrolytes can be detected by electrochemical measurements using cyclic voltammetry and rotating disk electrodes. The onset of reduction of H_2O occurred over a wide range of cathodic potentials (vs K/K^+ reference electrode), depending on the electrolyte. In KPF_6/PC, H_2O reduction occurred at 0.48 V, whereas in $KAlCl_4$/PC, reduction occurred at 2.8 V. Experiments to understand these results are underway.

- Johns Hopkins University has observed that the presence of small quantities of H_2O has a strong influence on the corrosion of Armco Fe in 0.5 M $LiClO_4$-PC. In nominally dry PC, only small pits ($\sim$20 μm) which are widely separated are formed. Aggressive pitting corrosion is evident in 50 mol% PC/50 mol% H_2O; both large pits and numerous small pits are formed, but the surface still appears to be highly polished. These results can be explained by classical corrosion theory.

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.

- Mathematical models are being developed at LBL to (i) predict the response to alternating current signals of a redox reaction with soluble reactants and products in a flow-through porous electrode, and (ii) to calculate the frequency response of a rotating disk electrode. Electrosorption phenomena and double-layer theory are being incorporated into the models.

- LBL has observed that the reduction rate for the aqueous sulfide-polysulfide redox couple is enhanced by the addition of 13 mol% dimethylformamide (DMF) to the solution. A porous electrode in the aqueous polysulfide solution containing DMF provides electrode performance that is more than satisfactory for high-performance photoelectrochemical cells or redox cells.

- A micro-mosaic electrode with an electrochemical redox system was used by LBL to study the onset of convection in a fluid with a time-dependent density profile contained in a deep cell. This study showed that a sharp increase in mass-transfer rate occurs immediately after the first deviation from convection-

free behavior on electrodes which are much smaller than the wavelength of the disturbance (e.g., such as those caused by gas evolution).

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 (zinc/air, iron/air) cells; and novel alkaline Zn electrode structures, which could be used in either electrically recharged or mechanically recharged cell configurations.

- LBL has demonstrated that flow-through porous electrodes for Zn deposition provide encouraging performance in electrically rechargeable Zn/air cells. Zinc loadings of 160 mAh/cm^2 were obtained at 10 mA/cm^2, with minimal change in the original structure of the porous substrate as the cell was cycled. Based on data from 1.5-Ah prototype Zn/air cells employing such electrodes, it is projected that a 32-kWh battery should be capable of achieving 110 Wh/kg, with a peak power of 140 W/kg, efficiency of 60%, and a materials cost of <$20/kW.

- CWRU has observed that heat treatment of the polymers polypyrrole and polyacrylonitrile mixed with Co salt produces very active O_2 reduction catalysts. Their activity is comparable to that of highly dispersed Pt and heat-treated Co porphyrins, but they are much lower in cost.

- Experiments at LBL demonstrated that Zn can be readily deposited on Zn-coated Cu particles in alkaline zincate solutions. A superficial current density (current per unit area of cell cross section) of 300 mA/cm^2 with an electrical energy consumption of 2.7 kWh/kg Zn was achieved.

- Pinnacle Research Institute (PRI) has observed that the addition of 15 g/l sorbitol + 25 g/l SiO_2 to 12 M KOH at 55°C enhanced the utilization (78 vs 35%) and capacity (191 vs 87 Ah/l) of Zn in powder slurry electrodes, compared to electrolytes with no additives.

Aluminum/Air Battery R&D is directed at improving cell components and solving system integration problems, including the following: (i) air cathode development, (ii) hydrargillite crystallization and separation, (iii) integrated experiments involving a coupled cell/crystallizer, (iv) cell design, and (v) development of improved aluminum anodes. Major achievements of the program include:

- The development of Al/air batteries for electric vehicles has reached the stage that a review committee has recommended transfer of management responsibility of the program from LLNL to SNL. As a result of this recommendation, SNL will assume management responsibility for the engineering development of the Al/air battery and ancillary components, and LBL will retain management responsibility for research on electrodes.

- Experiments were performed at LLNL which showed that a crystallizer/separator with a lamella settler can be started and shut down many times without plugging the lines with solid products. Systems analysis by LLNL indicate that a battery consisting of 100 cells (600-cm^2 electrode area) with 2-mm electrode spacing and integrated to a 40-l crystallizer should be capable of delivering 15 to 20 kW.

- Eltech Systems Corporation has built and tested a 5-cell stack, which achieved maximum power density in 4 M NaOH at 400 mA/cm^2 with an Al alloy containing In and Ga. The continuous feed of the Al wedge-shaped anode, rapid mechanical rechargeability, high durability of the cathode structure, and continuous, moderate-term operation (10 h) were demonstrated.

- Experimental and theoretical studies are underway at SRI International to elucidate the corrosion mechanism of Al alloys. An experimental cell was designed that allowed the separate examination of H_2 evolution and Al electrodissolution reactions in alkaline solution. At 25°C, pure Al showed an active-to-

passive transition, a passive region, and transpassive dissolution region in which the current varies linearly with voltage.

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 in contact with Nafion. Oxygen reduction performance with 0.35 mg/cm^2 Pt was comparable to that obtained earlier with electrodes containing 4 mg/cm^2 Pt.

- Preliminary evaluation of the Dow perfluorinated polymer by LANL indicates that higher performance should be possible with this material in fuel cells than that achieved with Nafion.

- Methanol reforming on ZnO-CuO catalysts produces equilibrium concentrations of 1 to 3% CO, which are too high for PEM fuel cells. LANL has found that partial oxidation of CO by the addition of a small amount of air to the reformate gas can reduce the CO level to below 0.01%.

- EXAFS studies of pyrolyzed transition metal (Fe and Co) macrocycles (phthalocyanine and tetramethoxyphenylporphyrin) at BNL indicate the presence of reduced metal and some other unidentified material. The pyrolyzed sample remaining after leaching the reduced metal still exhibits catalytic activity for O_2 reduction. The remaining material, which is presumed to be the catalyst, has a radial distribution function that is similar to that of the original transition metal macrocycle.

- Oxygen reduction measurements for high-area Pt supported on carbon black porous gas-diffusion electrodes in K_2CO_3 and KOH have been carried out by LBL. 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.

MANAGEMENT ACTIVITIES

During 1986, LBL managed 30 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:

- Air Systems Review Meeting, Cleveland, OH, April 14-15, 1986.
- First International Workshop on High-Temperature Molten Salt Batteries, ANL, Argonne, Il, April 15-18, 1986.
- Alkali Metal Thermoelectric Converter Workshop, JPL, Pasadena, CA, April 23-24, 1986.
- Spring Meeting of the Electrochemical Society, Boston, MA, May 4-9, 1986.
- Phosphoric Acid Fuel Cell Review Meeting, EPRI, Palo Alto, CA, May 28, 1986.
- International Congress on Corrosion and Electrochemical Behavior of Metals in Non-Aqueous Solutions, Capri, Italy, June 3-6, 1986.
- 32nd International Power Sources Symposium, Cherry Hill, PA, June 9-12, 1986.
- Alcoa Laboratories Centennial Technical Symposium, Farmington, PA, June 9-13, 1986.
- DOE/SNL/LBL Lead Center Coordination Meeting, Washington, DC, June 25-26, 1986.
- EPRI Battery Evaluation Meeting, EPRI, Palo Alto, CA, July 7, 1986.
- SNL/EPRI Na/S and Zn/Br_2 Review Meeting, EPRI, Palo Alto, CA, July 8-9, 1986.
- NATO/IDA Workshop on Heat Engines and Batteries for Power Generation, Alexandria, VA, July 16, 1986.
- Gordon Research Conference on Physical Electrochemistry, New London, NH, August 11-15, 1986.
- 37th Meeting of the International Society of Electrochemistry, Vilnius, USSR, August 24-29, 1986.
- 21th Intersociety Energy Conversion Engineering Conference, San Diego, CA, August 25-29, 1986.
- Office of Energy Storage and Distribution Review Meeting, Seattle, WA, August 27-28, 1986.
- LBL/SNL Lead Center Meeting, Washington, DC, September 24-25, 1986.
- Fall Meeting of the Electrochemical Society, San Diego, CA, October 19-24, 1986.
- National Fuel Cell Seminar, Tucson, AZ, October 26-29, 1986.
- Fuel Cell Management Meeting, Washington, DC, November 13-14, 1986.
- SNL/EPRI Na/S and Zn/Br_2 Review Meeting, Washington, DC, December 1-4, 1986.
- Technology Base Research Project Review Meeting, Washington, DC, December 16-17, 1986.

MILESTONES FOR THE TECHNOLOGY BASE RESEARCH PROJECT

Milestones accomplished in Fiscal Year 1986 by the TBR Project include:

- An extensive study of Pt_xCr_{1-x} alloys at the University of Virginia indicate these alloys show improved electrocatalysis for O_2 reduction. These results are sufficiently encouraging that further experiments with binary alloys will be continued, and the research will be expanded to include ternary alloys.

- The corrosion behavior of 33 metals and alloys have been examined in sulfur and sodium polysulfides at 350°C by ANL. From these studies it has been concluded that continued development of new alloys will probably not result in a material with sufficiently low cost, low density, and low corrosion rate to be useful as a positive current collector/containment material for Na/S cells.

- ANL has completed a series of tests of the Li-Al/25 mol% LiCl-37 mol% LiBr-38 mol% KBr/FeS_2 (upper plateau) bicells with 100-cm^2 BN-felt separators. These tests established the following prospects for the new Li-Al/FeS_2 cells:

Specific energy	175-200 Wh/kg @ 4-h rate
Specific power	$\geqslant$200 W/kg @ 80% DOD
Cycle life	$\geqslant$1000 cycles to 100% DOD

- A glass electrolyte with the composition (in mol%) 42 Na_2O, 8 Al_2O_3, 5 ZrO_2 and 45 SiO_2 has been tested in Na/S cells by ANL. Small-scale cells (1-3 mAh capacity) were successfully cycled at 3 to 6 mA/cm^2 (C/4-C/8 rate) for 36 to 40 cycles (10-20% DOD) before failure at the containment seals occurred.

- LLNL completed tests with an Al/air cell assembly (two Eltech EL-2 cells) that was coupled to a crystallizer/separator (lamella settler) subsystem. These tests revealed operational problems with the cell/separator assembly: (i) anode dissolution in the cell was irregular, and (ii) partial plugging of various cell components by solid products was encountered. The lamella settler/crystallizer was able to maintain a low solid particle concentration in the cell, and it was able to agglomerate the reaction products. The results of these tests suggested several modifications to the system to improve its overall performance.

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. The fuel cell effort at LANL was partially supported by the U.S. Department of Energy, Office of Vehicle and Engine Research and Development. The support from the Department of Energy and the contributions to this project by the participants in the Technology Base Research Project are acknowledged.

ANNUAL REPORTS

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

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

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

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

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

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

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

SUBCONTRACTOR FINANCIAL DATA - CY 1986

Subcontractor	Principal Investigator	Project	Contract Value (K$)	Term (months)	Expiration Date	Status in CY 1986
EXPLORATORY RESEARCH						
Molten-Salt Cells						
Argonne National Laboratory	P. Nelson	Molten-Salt Cells	300	12	9-86	C
Gould, Incorporated	G. Barlow	Molten-Salt Electrolytes	113	12	7-87	R
Stanford University	R. Huggins	New Battery Materials	246	12	11-86	C
Ambient-Temperature Lithium Cells						
Duracell, Inc.	A. Dey	Li/SO_2	1500	48	12-85	T
University of Pennsylvania	G. Farrington	Polymeric Electrolytes	82	12	2-87	C
University of Minnesota	W. Smyrl	Solid State Cells	169	12	6-87	R
EIC Laboratories, Inc.	K. Abraham	Secondary Li Batteries	150	12	6-87	R
APPLIED SCIENCE RESEARCH						
Lawrence Berkeley Laboratory	E. Cairns, L. DeJonghe, J. Evans, R. Muller, J. Newman, P. Ross, and C. Tobias	Electrochemical Energy Storage	1500	12	9-86	C
Zinc/Halogen Cells						
Illinois Institute of Technology	R. Selman	Zn Deposition	71	12	9-86	C
Brookhaven National Laboratory	J. McBreen	Zn Morphology	100	12	9-86	C
Lawrence Livermore National Laboratory	D. Miller	Transport Properties	65	12	9-86	C
Components for Alkali/Sulfur Cells						
Argonne National Laboratory	P. Nelson	Glass Electrolytes	250	12	9-86	C
Massachusetts Institute of Technology	H. Tuller	Li Conducting Glasses	100	12	5-87	C

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

SUBCONTRACTOR FINANCIAL DATA - CY 1986

Subcontractor	Principal Investigator	Project	Contract Value (K$)	Term (months)	Expiration Date	Status in CY 1986
APPLIED SCIENCE RESEARCH - cont.						
Corrosion Processes in High-Temperature, High-Sulfur-Activity Molten Salt						
Argonne National Laboratory	P. Nelson	Polysulfide Containment	200	12	9-86	T
Illinois Institute of Technology	R. Selman	Corrosion Resistant Coatings	163	12	10-86	C
Components for Ambient-Temperature Lithium Cells						
Case Western Reserve University	D. Scherson	Spectroscopic Studies	62	12	11-86	C
Jackson State University	H. Tachikawa	Raman Spectroscopy	53	12	3-86	C
Johns Hopkins University	J. Kruger	Corrosion/Passivity Studies	88	12	7-87	C
AIR SYSTEMS RESEARCH						
Metal/Air Cell Research						
Case Western Reserve University	E. Yeager	Air Electrodes	213	12	4-87	C
Pinnacle Research Institute	L. Morris	Zn/Air Battery	225	12	12-86	C
Aluminum/Air Battery R&D						
Lawrence Livermore National Laboratory	A. Maimoni	Al/Air Power Cell R&D	495	12	9-86	C
Fuel Cell R&D						
Los Alamos National Laboratory	J. Huff	Fuel Cell R&D	440	12	9-86	C
Brookhaven National Laboratory	J. McBreen	Fuel Cell Research	230	12	9-86	C

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