Title
Technology Base Research Project for Electrochemical Energy Storage: Executive Summary Report for 1990

Permalink
https://escholarship.org/uc/item/04h9n1gc

Author
Kinoshita, K.

Publication Date
1991-06-01

LBL-30845
UC-210

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE
DIVISION

Technology Base Research Project for Electrochemical Energy Storage

Executive Summary Report for 1990

June 1991

APPLIED SCIENCE
DIVISION

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

LBL-30845

TECHNOLOGY BASE RESEARCH PROJECT FOR ELECTROCHEMICAL ENERGY STORAGE

EXECUTIVE SUMMARY REPORT FOR 1990

Applied Science Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720

Edited by Kim Kinoshita, Technical Manager

June 1991

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Propulsion Systems, Energy & Hybrid Propulsion Division of the U.S. Department of energy under Contract No. DE-AC03-76SF00098.

EXECUTIVE SUMMARY

The U.S. Department of Energy's Office of Propulsion Systems provides support for an electrochemical energy storage program, which includes R&D on advanced rechargeable batteries and fuel cells. A major goal of this program is to develop electrochemical power sources suitable for application in electric vehicles (EVs). The program centers on advanced systems 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. The 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 1990. This is a continuing project, and reports for prior years have been published; they are listed at the end of the Executive Summary.

The general R&D 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.

---

* 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 Divisions.

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 new versions of the **Zn/NiOOH cell,** and a novel **Li/polymer/redox polymerization cell.** Each of these cells is considered to be an attractive candidate for EV applications, and may provide high performance at ambient or near-ambient temperatures. Research was also conducted on high-temperature **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. Several key issues for this technology are to: *i)* stabilize the performance of the FeS_2 electrode, *ii)* develop corrosion-resistant containment materials, and *iii)* identify improved sealant materials.

- LBL has been able to virtually eliminate the major problems restricting the cycle-life performance of Zn/KOH/NiOOH cells. A sealed, maintenance-free cell has accumulated 400 deep-discharge cycles with almost no shape change, and a vented cell has accumulated more than 800 deep-discharge cycles with about 30% capacity loss. The shape-change problem was overcome by use of carbonate- or fluoride-containing electrolytes. Dendritic shorting and reformation problems were solved by the use of a sealed, electrolyte-starved cell configuration in which O_2, generated during charge, scavenges incipient Zn dendrites that may be present.

- LBL has succeeded in cycling lithium/poly(ethylene) oxide/solid redox polymerization electrode (Li/PEO/SRPE) cells at lower temperatures than typically used with Li/polymer cells. The PEO electrolytes were modified so that they do not crystallize at lower temperatures, instead maintaining their amorphous character and reasonable ionic conductivity. At 20°C, the cells were cycled for greater than 100 cycles at a volumetric power density of 30 W/l. At elevated temperatures, 70-90°C, hundreds of cycles are readily achieved with an estimated specific power of 120 W/kg.

- Argonne National Laboratory (ANL) has developed new sealant materials (a mixed chalcogenide) which are electronic insulators and bond strongly to metals and ceramics, even after exposure to molten salt containing Li alloy or FeS_2 at 400-450°C. The mixed chalcogenide exhibited a bond strength that was about ten times stronger than that of commercially available bonding agents such as borosilicate glass and silane-based products.

- ANL has also fabricated a bipolar four-cell Li/FeS_2 stack with the new sealant materials which operated for >500 cycles with >98% coulombic efficiency.

- A mathematical model was developed by ANL which was able to predict the self-discharge rates of Li/FeS_2 cells. This semi-empirical model incorporated parameters such as the Li diffusion coefficient, electronic conductivity of electrolyte, and Li activities at the positive and negative electrodes.

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 implemented a one-dimensional, time-dependent model of the Zn/NiOOH cell to characterize the transport of soluble Zn species from the Zn electrode to the NiOOH electrode. This model predicted that the greater the amount of Zn allowed to leave and reenter the NiOOH electrode, the faster the rate and extent of shape change, with Zn material moving from the center towards the edges of the Zn electrode.
- LBL has developed two-dimensional mathematical models of current and potential distributions and mass-transfer processes in model Zn pore electrodes. The results from these models were in good agreement with the experimental data for a model pore obtained by optical probe beam deflection.
- Videomicroscopic recordings at LBL of the Zn deposition process in a flow channel has revealed that moss formation is initiated only after a more or less substantial "compact" layer is formed, when large protrusions appear on the surface. The mossy Zn deposits are formed in alkaline electrolytes over a wide range of current densities and flow rates.

Lead/Acid Cells use positive electrodes of lead oxides which exist in different phase compositions and stoichiometry. The character of the positive active material, which is formed electrochemically, has a major influence on the performance and life of the lead/acid battery. Thus, understanding the properties of these lead oxides and their changing properties during charge-discharge would be helpful in promoting longer cycle life.

- Brookhaven National Laboratory (BNL) has used extended x-ray absorption fine structure (EXAFS) and x-ray absorption near-edge spectroscopy (XANES) to study the oxides of Pb. A marked difference was observed in the x-ray absorption spectra of α-PbO_2 and γ-PbO_2. The stoichiometry of PbO_2 in the formed battery electrode was lower than that found for electrochemically or chemically prepared γ-PbO_2.

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

- ANL has developed a new fabrication technique which produced Ni electrodes for Na/$NiCl_2$ cells with higher and more uniform porosity. These electrodes had significantly lower impedance than the electrodes in the state-of-the-art cells.

- ANL has developed a technique to investigate the charging of Ni electrodes in Na/$NiCl_2$ cells. During charge $NiCl_2$ forms a poorly conducting layer on the surface of the Ni electrode, and increases the impedance. This layer increases in thickness and hinders further charge of the electrode.

- Stanford University has identified an intermediate phase (Na_6FeC_{18}) that forms during discharge of Na/$FeCl_2$ cells. In the case of Na/$NiCl_2$ cells, no intermediate phase forms during discharge. This study further concluded that the formation of eutectic compositions in the Na/$FeCl_2$ and Na/$NiCl_2$ cells at 370 and 570°C, respectively, limits their maximum operating temperatures to ~300 and ~500°C, respectively.

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 molten-salt cells.

- Illinois Institute of Technology (IIT) has successfully electrodeposited Mo_2C coatings on the internal surface of the cell casings for Na/S cells from Chloride Silent Power Ltd. (CSPL). In general, the test results at CSPL were encouraging but further optimization of coating quality is necessary for long-term endurance. Evaluation of electrodeposited Mo_2C-coated Ni in a Li/FeS_2 cell at ANL showed that these coatings are stable at 1 to 2.1 V (*vs* LiAl reference electrode) for 57 h. Corrosion was evident at 2.2 V, which is attributed to the presence of pinholes in the coating.

- Johns Hopkins University has observed that Armco iron and 1018 carbon steel, which are scratched to mechanically disrupt the air-formed film, are rapidly repassivated in dimethoxyethane (DME)/LiAsF6 containing 300-ppm water. The adsorption of DME molecules or the precipitation of an iron hexafluoroarsenate salt film is believed to be responsible for the rapid repassivation.

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 *in situ* Attenuated Total Reflection Fourier Transform Infrared Spectroscopy to study the lithium/poly(ethyleneoxide) interface. Spectral features were identified at about 1100 cm^{-1} which suggested that ether-type bonds were cleaved and alkoxide functionalities (*e.g.*, $—(CH_2)—O—Li^+$) were formed. This technique appears to be useful for investigating the chemical/electrochemical interactions at electrode/conducting polymer interfaces.
- The University of Pennsylvania has obtained encouraging results with Li-ion conducting polymers containing a plasticizer (propylene carbonate, polyethylene glycol dimethylether-Poly 500) and Li salts ($LiClO_4$, $LiCF_3SO_3$, $LiAsF_6$). The ionic conductivity of the polymer with Poly 500 was lower than that with PC, but its mechanical, thermal and transport properties were better. These electrolytes exhibited good electrochemical and mechanical properties in preliminary studies over 20-30 Li plating/stripping cycles in small cells.
- SRI International has developed a Li-ion conducting polysiloxane which has one of the highest ionic conductivities (1.8×10^{-4} ohm^{-1} cm^{-1} after exposure to MeCN) at room temperature reported so far.
- Jackson State University has observed by *in situ* Raman spectroscopy that Li is more reactive in diethyl carbonate (DEC) than in dimethyl carbonate. However, the addition of methyl formate to DEC suppressed the reactivity of Li.

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

- LBL has developed mathematical models to understand transport and kinetic phenomena occurring in electrochemical systems. A model has been developed to predict the response to alternating current of a redox species with soluble reactants and products in a flow-through porous electrode. Another model was developed which accounts for adsorption of chemical species on the electrode, the chemical or electrochemical reaction of the adsorbed species, and convective transfer during cyclic voltammetry.

- LBL employed laser Raman spectroscopy and cyclic voltammetry to investigate anodic Zn films in 1 M KOH. Evidence was obtained for the formation of a $Zn(OH)_2$ film during the active portion of the anodic potential sweep. Near the active-passive transition potential, the diffusion of hydroxide ions to the metal/film interface becomes rate limiting, and a film containing kinetically less-favored ZnO is formed.
- LBL is developing photothermal deflection spectroscopy (PDS) to study the electrooxidation of CH_3OH on Pt electrocatalyst. Preliminary studies of Pt electrooxidation suggest a two-reaction pathway whereby $Pt(OH)_2$ is formed by an electrochemical step and dehydrates by a chemical step to form PtO. This second step removes oxygen from the surface, which is just the opposite of what is needed for CH_3OH oxidation. This suggests that slowing the rate of dehydration could improve the overall reaction rate for CH_3OH electrooxidation.
- LBL has observed that the single-crystal face of the ordered alloy Pt_3Sn is not as good an electrocatalyst for methanol electrooxidation in sulfuric acid as a low-index single-crystal Pt with electrodeposited Sn.
- A novel system was designed at LBL to study the coalescence of small gas bubbles that are generated during electrochemical gas evolution. A high-speed, spatially resolved photodetector and data acquisition unit, with laser imaging, was used to follow the coalescence event. The coalescence of small gas bubbles (*e.g.*, 500-1000 µm) was observed.

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.

- CWRU has observed that the pyrochlore, $Pb_2Ru_2O_{7-y}$, shows good activity for the reduction of O_2 in alkaline solution. The pyrochlore showed a higher activity than the perovskite metal oxide, $SrFe_xRu_{1-x}O_{3-y}$, which also contains Ru. However, the perovskite may be useful as an electrocatalyst support because of its metallic conductivity.
- LBL has successfully demonstrated the mechanical evacuation/refilling of a Zn/air cell with a particulate Zn electrode and electrolyte. The regeneration of Zn particles from alkaline zincate solution was also demonstrated with an energy consumption of as low as 2.3 kWh/kg Zn.
- Metal Air Technology Systems International (MATSI) has discovered that a higher KOH concentration of 45 wt% is beneficial for obtaining high surface area and electroactive Zn deposits during charge of Zn/air cells with a reticulated Cu-foam structure for the Zn electrode. Two or three layers of Celgard 3401 were demonstrated to be sufficient to effectively eliminate the probability of cell shorting by Zn dendrites.

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 1990 are listed below:

- LANL has developed a novel minicell which was used to investigate oxygen reduction at a Pt/recast Nafion interface. The rate of oxygen reduction decreased as the temperature was increased to 80°C, which was attributed to the loss of water from the Nafion film.
- LANL utilized ^1H NMR to measure the the self-diffusion coefficient of protons in Nafion with different degrees of hydration. The results indicate that the diffusion coefficient decreases with a decrease in the water content.
- A one-dimensional model was developed by LANL to describe the complete proton exchange membrane (PEM) fuel cell. The model shows that the electroosmotic water drag causes a local depletion of water near the anode, which becomes more severe at higher current densities.
- A new test stand was designed and built at LANL. A single cell was operated for over 2100 h before it was voluntarily terminated because of equipment failure.
- International Fuel Cells, which has a subcontract with LANL, tested PEM fuel cells with low Pt loadings. They were able to duplicate the results obtained at LANL in small 5 cm × 5 cm

cells, and they showed that an alternate membrane ("Membrane C") gave performance comparable to other experimental membranes.

- BNL has investigated underpotential deposited (UPD) Sn on Pt as an electrocatalyst for methanol oxidation. EXAFS studies indicate the presence of Sn–O interactions, which vary in a continuous and reversible fashion with potential. These interactions are most probably the reason for the observation that UPD Sn on Pt is a good catalyst for the direct oxidation of methanol.

MILESTONES FOR THE TECHNOLOGY BASE RESEARCH PROJECT

Milestones accomplished in Fiscal Year 1990 by the TBR Project include:

- "Go/no-go decision on the use of non-Pt electrocatalysts in PEM fuel cells"

This study indicates that the currently available organo-metallic macrocycles (FeTMPP, CoTMPP) are not sufficiently electrocatalytically active to serve as a substitute for Pt. The best results for oxygen reduction were obtained with 1.65 mg/cm^2 CoTMPP, but this was still not as good as that obtained with 0.4 mg/cm^2 Pt.

- "Determine the effect of impurities such as sulfur and fluoride ions on the performance of MCl_2 electrodes"

A small addition (2 wt%) of sulfur or fluoride ions enhances the utilization of active material and reduces the area-specific resistance in the $NiCl_2$ electrode. When the content of the additive was increased to 20 wt%, no significant increase in performance was observed.

- "Demonstrate a new cell design for Zn/air cells that has a particulate Zn electrode and circulating electrolyte"

Small laboratory-scale Zn/air cells (80 cm^2 and 400 cm^2 air electrode area) have been tested. Natural convection of alkaline electrolyte was observed to occur in the cell with a particulate Zn electrode. The results of this study were published in *J. Appl. Electrochem.*, **21(2)**, 105 (1991).

- "Initiate R&D on novel methods for *in situ* characterization of electrode surfaces"

PDS has been adapted at LBL for the *in situ* characterization of Pt and Zn electrodes in electrochemical cells. The results of these studies are described in an LBL report (LBL-27081, April 1989), and a monograph to be published by John Wiley.

- "Demonstrate high performance in PEM fuel cells with lower Pt loadings, equivalent to 0.5-g Pt/kW"

The LANL study indicates that 0.8 W/cm^2 can be obtained in a PEM fuel cell with a 5-mil thick membrane and only 0.4-g Pt/kW.

- "Complete EXAFS study of Zn electrolyte complexes"

EXAFS analysis of dissolved ZnO in alkali solution indicates the presence of $Zn(OH)_4^=$ ions with a Zn-O bond length of 1.97 Å. In 0.1 M $ZnBr_2$, the Zn^{++} ions are mostly coordinated to water. However, with increasing concentration there is an increase in coordination with Br^- ions, until Zn-O complexes are completely eliminated and only $ZnBr_4^=$ ions are observed.

- "Complete EXAFS study of carbon-supported pyrolyzed macrocycle electrocatalyst for oxygen reduction"

The experimental data for both pyrolyzed FeTMPP and CoTMPP suggest that the metal atom is coordinated to four nitrogen atoms in much the same way as that for the original macrocycle. Furthermore, this study concluded that the monodispersed Fe and Co atoms are the electrocatalysis sites.

- "Complete development of a time-dependent, one-dimensional mathematical model of the Zn/NiOOH cell"

The LBL model suggests that the non-uniformity of the current density, particularly the differences between charge and discharge, contributes to shape change of the Zn electrode. Furthermore, the different rates of chemical precipitation/dissolution alone cannot account for the process of shape change.

- "Complete development of improved design for advanced Na/MCl_2 cells"

Cell modeling studies indicated that higher surface area of solid electrolyte and thinner metal chloride electrodes are needed to achieve high-performance cells. It is suggested that a multitube design consisting of many long, small-diameter cells should be capable of producing higher performance.

- "Complete development and test of peripheral metal/ceramic seals for Li-alloy/FeS_2 cells"

A modified-chalcogenide sealant material showed improved wetting and better contact with Mo. A four-cell Li/FeS_2 stack with this new sealant material completed more that 500 cycles (2500 h) of operation with >98% coulombic efficiency.

- "Complete life test at high current density of a single PEM cell with low Pt loading"

The LANL test showed that no performance degradation was observed with 0.45 mg/cm^2 Pt loading in over 1200 h of continuous operation at 0.60-0.75 A/cm^2.

MANAGEMENT ACTIVITIES

During 1990, LBL managed 15 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:

- IECEC Planning Meetings, Reno, NV, January 24-25, 1990
- DOE/EPRI Workshop to Identify Battery Requirements for Low-Maintenance Lead-Acid Battery Storage, EPRI, Palo Alto, CA, February 7-8, 1990
- Lead Center Coordination Meeting, LBL, Berkeley, CA, February 12, 1990
- Zinc Battery R&D Review Meeting, LBL, Berkeley, CA, February 13-15, 1990
- SNL Zinc/Bromine Battery Review Meeting, SNL, Albuquerque, NM, February 26-27, 1990
- Al/Air Battery Review Meeting, Washington, D.C., April 17, 1990
- 177th Meeting of the Electrochemical Society, Montreal, Canada, May 6-11, 1990
- Direct Methanol/Air Fuel Cell Workshop, Washington, D.C., May 14-16, 1990
- Alkaline Zinc Battery Meeting, LBL, Berkeley, CA, May 21-22, 1990
- PEM Fuel Cell Meeting, Washington, D.C., June 22, 1990
- 34th International Power Sources Symposium, Cherry Hill, NJ, June 25-28, 1990
- EPRI Solid Oxide Electrochemistry Workshop, Palo Alto, CA, July 11, 1990
- 25th IECEC Meeting, Reno, NV, August 12-17, 1990
- 41st Meeting of the International Society of Electrochemistry, Prague, Czechoslovakia, August 19-24, 1990
- International Battery Association Meeting, Tokyo, Japan, August 29-30, 1990
- Lead Center Meeting, ANL, Argonne, IL, September 5, 1990
- Electric Vehicle Project Review Meeting, ANL, Argonne, IL, September 6-7, 1990
- Workshop on Rechargeable Lithium Polymer Batteries, Kirkland, WA, October 11-13, 1990
- 178th Meeting of the Electrochemical Society, Seattle, WA, October 14-19, 1990
- Annual Meeting of the AIChE, Chicago, IL, November 11-16, 1990
- Fuel Cell Seminar, Phoenix, AZ, November 25-28, 1990

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Propulsion Systems, Energy & Hybrid Propulsion Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. The support from DOE and the contributions to this project by the participants in the TBR Project are acknowledged. The assistance of Ms. Susan Lauer for coordinating the publication of this report and Mr. Garth Burns for providing the financial data are gratefully acknowledged.

ANNUAL REPORTS

1. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1989," LBL-29155 (May 1990).
2. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1988," LBL-27037 (May 1989).
3. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1987," LBL-25507 (July 1988).
4. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1986," LBL-23495 (July 1987).
5. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1985," LBL-21342 (July 1986).
6. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1984," LBL-19545 (May 1985).
7. "Annual Report for 1983 - Technology Base Research Project for Electrochemical Energy Storage," LBL-17742 (May 1984).
8. "Technology Base Research Project for Electrochemical Energy Storage - Report for 1982" LBL-15992 (May 1983).
9. "Technology Base Research Project for Electrochemical Energy Storage - Report for 1981," LBL-14305 (June 1982).
10. "Applied Battery and Electrochemical Research Program Report for 1981," LBL-14304 (June 1982).
11. "Applied Battery and Electrochemical Research Program Report for Fiscal Year 1980," LBL-12514 (April 1981).

SUBCONTRACTOR FINANCIAL DATA - CY 1990

Subcontractor	Principal Investigator	Project	Contract Value (K$)	Status Term (months)	Expiration Date	in CY 1990*
EXPLORATORY RESEARCH						
Molten-Salt Cells						
Argonne National Laboratory	C. Christianson	Molten-Salt Cells	275	12	9-90	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	1800	12	9-90	C
Acid Cells						
Brookhaven National Laboratory	J. McBreen	Zn Morphology	100	12	9-90	C
Components for High-Temperature Cells						
Argonne National Laboratory	C. Christianson	Solid Electrolytes	225	12	9-90	C
Stanford University	R. Huggins	New Battery Materials	100	6	5-91	T

Subcontractor	Principal Investigator	Project	Contract Value (K$)	Status Term (months)	Expiration Date	in CY 1990*
APPLIED SCIENCE RESEARCH - cont.						
Corrosion Processes in High-Specific Energy Cells						
Illinois Institute of Technology	R. Selman	Corrosion Resistant Coatings	132	12	2-91	C
Johns Hopkins University	J. Kruger	Corrosion/Passivity Studies	90	12	8-91	C
Components for Ambient-Temperature Nonaqueous Cells						
Case Western Reserve University	D. Scherson	Spectroscopic Studies	51	12	4-91	C
Jackson State University	H. Tachikawa	Raman Spectroscopy	47	12	6-91	C
University of Pennsylvania	G. Farrington	Polymeric Electrolytes	47	12	5-91	C
SRI International	S. Narang	Polymeric Electrolytes	97	1	9-91	C
AIR SYSTEMS RESEARCH						
Metal/Air Cell Research						
Case Western Reserve University	E. Yeager	Air Electrodes	196	12	4-91	C
Metal Air Technology Systems	R. Putt	Zn/Air Battery	149	16	5-91	T
Fuel Cell R&D						
Los Alamos National Laboratory	S. Gottesfeld	Fuel Cell R&D	1300	12	9-90	C
Brookhaven National Laboratory	J. McBreen	Fuel Cell Research	100	12	9-90	C

---

* C = continuing, T = terminating

LIST OF ACRONYMS

AES	Auger electron spectroscopy
AIChE	American Institute of Chemical Engineers
ASI	area specific impedance
AN	acetonitrile
ANL	Argonne National Laboratory
ATRFTIRRAS	attenuated total reflection Fourier transform infrared reflectance absorption spectroscopy
BNL	Brookhaven National Laboratory
CSPL	Chloride Silent Power Limited
CTE	coefficient of thermal expansion
CVD	chemical vapor deposition
CWRU	Case Western Reserve University
DEC	diethyl carbonate
DHE	dynamic hydrogen electrode
DMC	dimethyl carbonate
DME	dimethoxyethane
DOD	depth of discharge
DOE	U.S. Department of Energy
DSC	differential scanning calorimetry
EMF	electromotive force
EPRI	Electric Power Research Institute
ETD	Exploratory Technology Development and Testing
EV	electric vehicle
EXAFS	extended x-ray absorption fine structure
FTIRRAS	Fourier transform infrared reflectance absorption spectroscopy
HOPG	highly ordered pyrolytic graphite
IAD	implicit alternating direction
ID	inner diameter
IECEC	Intersociety Energy Conversion Engineering Conference
IFC	International Fuel Cells, Inc.
IIT	Illinois Institute of Technology
ISE	International Society of Electrochemistry
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LEED	low energy electron diffraction
LEISS	low energy ion scattering spectroscopy
M&EA	membrane/electrode assemblies
MA	methyl acetate
MATSI	Metal Air Technology Systems International

MF	methyl formate
MSECD	Molten Salt Electrochemical Deposition
NMR	nuclear magnetic resonance
OPG	ordinary pyrolytic graphite
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)
PGSE	pulsed-field-gradient, spin-echo NMR
PTFE	polytetrafluoroethylene
RF	radio frequency
SCE	saturated calomel electrode
SEM	scanning electron microscopy
SFUDS	simplified federal urban driving schedule
SNL	Sandia National Laboratories
SRPE	solid redox polymerization electrode
SPE	solid polymer electrolyte
STM	scanning tunneling microscopy
TBR	Technology Base Research
TEM	transmission electron microscopy
TMPP	tetramethoxyphenyl porphyrin
TSPP	tetra kis(sulfonated) porphyrin
TTAPP	tetra kis(4-trimethyl ammonium phenyl) porphyrin
UHV	ultrahigh vacuum
UPD	underpotential deposition
VLSI	very large-scale integration
XANES	x-ray near edge absorption spectroscopy
XAS	x-ray absorption spectra
XRD	x-ray diffraction
XRM	x-ray microanalysis