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EXPLORATORY TECHNOLOGY RESEARCH PROGRAM FOR ELECTROCHEMICAL ENERGY STORAGE

EXECUTIVE SUMMARY REPORT FOR 1991

Energy & Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Edited by Kim Kinoshita, Technical Manager

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EXECUTIVE SUMMARY

The U.S. Department of Energy's Office of Propulsion Systems provides support for an electrochemical energy storage program, that includes research and development (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 Electric Vehicle Advanced Battery Systems Development (EVABS) Program and the Exploratory Technology Research (ETR) Program. The EVABS Program management responsibility has been assigned to Sandia National Laboratory (SNL), and the Lawrence Berkeley Laboratory* (LBL) is responsible for management of the ETR Program. The EVABS and ETR Programs include an integrated matrix of R&D efforts designed to advance progress on several candidate electrochemical systems. The United States Advanced Battery Consortium (USABC), a tripartite undertaking between DOE, the U.S. automobile manufacturers and the Electric Power Research Institute (EPRI), was formed in 1991 to accelerate the development of advanced batteries for consumer EVs. The role of the ETR Program is to perform supporting research on the advanced battery systems under development by the USABC and EVABS Program, and to evaluate new systems with potentially superior performance, durability and/or cost characteristics. The specific goal of the ETR Program is to identify the most promising electrochemical technologies and transfer them to the USABC, the battery industry and/or the EVABS Program for further development and scale-up. This report summarizes the research, financial and management activities relevant to the ETR Program in CY 1991. This is a continuing program, 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 program 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.

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* Participants in the ETR Program include the following LBL scientists: E. Cairns, K. Kinoshita and F. McLarnon of the Energy and Environment Division; and L. DeJonghe, J. Evans, R. Muller, J. Newman, P. Ross and C. Tobias of the Materials Sciences Division.

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

EXPLORATORY RESEARCH

The objectives of this program 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 **Na/polymer cell**. Each of these cells is considered to be an attractive candidate for EV applications, and should provide high performance at ambient or near-ambient temperatures.

- LBL has demonstrated that the use of a moderately alkaline electrolyte is very effective for extending the cycle life of Zn/KOH/NiOOH cells. A 1.35-Ah sealed, starved-electrolyte cell containing 3.2 M KOH - 1.8 M KF - 1.8 M K_2CO_3 retained 80% of its original charge after ~400 deep-discharge cycles and reached 570 cycles before its capacity fell below 60%. Scale up of Zn/KOH/NiOOH cells to 20 Ah (electrodes of ~15 × 15 cm) is underway, and the new electrolytes are being evaluated in these larger cells.
- LBL has initiated research to develop sodium/poly(ethylene) oxide/metal oxide electrode ($Na/PEO/MO_x$) cells that operate at lower temperatures than typically used with Li/polymer cells. Preliminary half-cell experiments at 90°C with $Na/PEO_8CF_3SO_3$ demonstrated several cycles at either 0.25 or 0.5 mA/cm^2. A metal oxide, $Na_{0.6}CoO_2$, for the cathode was synthesized in a single phase, and electrochemical testing is underway.

APPLIED SCIENCE RESEARCH

The objectives of this program 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 dendrites and mossy deposits.

- LBL has completed a videomicroscopic study of the Zn deposition process from alkaline electrolytes in a flow channel. Decreasing the zincate ion and increasing the OH^- ion concentrations promote the growth of Zn moss. At constant fraction of limiting current, the moss appears more readily when the current density and/or the flow rate is low.
- Brookhaven National Laboratory (BNL) has used extended x-ray absorption fine structure (EXAFS) and x-ray absorption near-edge spectroscopy (XANES) to study mossy Zn deposits that form in alkaline zincate electrolytes. The Zn that deposits at -65 mV (*vs* Zn wire reference electrode) is oriented with the c-axis parallel to the lines of current, whereas the deposit at -45 mV has a random orientation like that of a Zn foil.

Improved Components for Alkali/Sulfur Cells, such as superior alternatives to the high-temperature sulfur-polysulfide electrode for Na/S cells, are under investigation.

- LBL is investigating the influence of phosphorus on the sulfur electrode of the Na/S cell by equilibrium open-circuit potential measurements. Mixtures with P/S molar ratios from 0.143 to 0.60 and Na mole fractions from 0.0 to 0.4 were studied at 350 and 400°C. The Na/P_xS_y cells showed significantly higher cell voltages than Na/S cells, which is a strong indication that phosphorus may be a beneficial additive to the sulfur electrode.

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) is optimizing the quality of electrodeposited Mo_2C coatings to obtain long-term endurance in Na/S cells. IIT observed that complete removal of moisture from the electrolysis bath is necessary to obtain a reproducible, high quality coating. Coatings of an even better quality were obtained with a bath containing non-Li alkali molybdates and carbonates.
- A new project was initiated at Environmental Research Institute of Michigan (ERIM) to evaluate TiN-coated containment materials in Na/S cells. Preliminary studies at Ford Motor Company indicated that sputter-coated TiN on Al was resistant to attack in a polysulfide melt during the 72-h test. A reactive-sputtering system is being assembled at ERIM to dupli-

cate the quality of the coatings obtained at Ford, and to evaluate the corrosion-resistant properties of TiN for extended periods in polysulfide melts.

- Johns Hopkins University has observed that iron and 1018 carbon steel display an extensive and stable passive region in $LiAsF_6$/dimethoxyethane (DME). In a nominally dry $LiAsF_6$/DME solution (<100-ppm H_2O), the breakdown potentials of iron and carbon steel are 1300 mV (*vs* saturated calomel electrode, SCE) and 1050 mV, respectively. The adsorption of DME and the formation of carbon-based polymer film are believed to be responsible for passivation.

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* spectroscopic techniques and thermal analysis to study the Li/organic electrolyte and Li/poly(ethyleneoxide) interfaces. Interactions between Li and tetrahydrofuran, and the formation of Li-O and Li-CO_3 species, were detected. A new project was initiated in 1991 at CWRU to place greater emphasis on the investigation of the Li/polymer interface. Preliminary cyclic voltammetry studies of Au in contact with $LiClO_4$- poly(ethylene oxide) electrolyte at 55°C showed evidence for underpotential deposition (UPD) of Li.

- The University of Pennsylvania has investigated polymeric electrolytes formed by radiation-polymerization of various oligomers that contain different compositions of plasticizer (ethylene carbonate, EC, and propylene carbonate, PC) and 1 M $LiAsF_6$. Polymeric electrolytes with ≥50 wt% PC in mixtures with EC appear to exhibit acceptable electrochemical (reversible Li redox process) and physicochemical properties (ionic conductivity $>8 \times 10^{-4}$ at room temperature, glass-transition temperature of –94°C, amorphous structure from –90 to 150°C) for use in rechargeable Li cells.

- SRI International has developed a Li-ion conducting PEO-type polymer in which oxygen is replaced by sulfur. The best-performing polymer electrolyte, obtained from sulfur-substituted PEO (16.7% S) and tetraethylorthosilicate with a plasticizer, exhibited a conductivity of 7.5×10^{-4} ohm^{-1} cm^{-1} in a Li/Li cell.

- Jackson State University has evaluated the electrochemical properties of the C_{60} fullerene as an electrode material that may be useful in rechargeable Li cells. The cyclic voltammograms of C_{60} in $LiClO_4$/polyethylene glycol 400 dimethyl ether (PEG400DME) indicated five redox peaks which suggested the formation of C_{60}^{-}, C_{60}^{2-}, C_{60}^{3-}, C_{60}^{4-}, and C_{60}^{5-}. These anions dissolve in PEG400DME.

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. Improvements to the model of a solid-polymer-electrolyte (SPE) fuel cell were made to include the effects of electrode kinetics, mass transfer to the membrane-electrode interface, and thermal effects. Models were also developed for explaining electroless deposition and cathodic protection.
- LBL has observed by scanning tunneling microscopy (STM) that the transformation of nickel hydroxide to oxy-hydroxide during the charging of Ni electrodes in alkaline solution proceeds by nucleation and growth of the oxidized phase from the metal surface. Model calculations have shown that, because of the much higher conductivity of the oxidized material versus reduced material, the reaction front for the conversion propagates in a nonuniform fashion, leaving large amounts of unreacted material behind.
- LBL is using photothermal deflection spectroscopy (PDS) to study the electrooxidation of CH_3OH on Pt electrocatalyst. This study indicates that the rate-limiting step appears to be the transfer of oxygen from water to the Pt catalyst where it can react with CH_3OH to form CO_2. PDS is also being developed for the *in situ* detection of adsorbed intermediates during the electrooxidation of organic molecules on Cu. A Xe arc lamp is being used to obtain UV-visible absorption spectra of reduced intermediates that form during the electrocatalytic hydrogenation of nitrobenzene on Cu.
- LBL has observed that the surface composition of Pt (MPt_3) alloys for methanol electrooxidation is strongly dependent on the strength of the intermetallic Pt-M bond. In $CoPt_3$, for example, where the intermetallic bond is relatively weak, the lower surface energy of Pt produced pure Pt planes on both the [111] and [100] orientation.
- LBL confirmed that dispersed Pt-Ru has a much higher catalytic activity for the electrooxidation of vaporized methanol than Pt alone in 72 wt% Cs_2CO_3 at 120°C. Furthermore, a cell with 72 wt% Cs_2CO_3 exhibited much lower potential losses than a comparable cell operated with concentrated H_3PO_4 under similar conditions (80°C).

AIR SYSTEMS RESEARCH

The objectives of this program 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 catalytic activity for the reduction of O_2 at cobalt tetrasulfonated phthalocyanine (CoTsPc) adsorbed on ordinary pyrolytic graphite (OPG) in alkaline solution is enhanced by ~60 mV in the presence of alcohols. Further, the presence of methanol has no short-term deleterious effect on the kinetics for O_2 reduction on CoTsPc/OPG, which also exhibits negligible catalytic activity for methanol oxidation.

- A program was initiated at Eltech Research Corporation to investigate the viability of graphitized carbon blacks and metal oxides as electrocatalyst supports in bifunctional air electrodes for electrically rechargeable Zn/air cells. Graphitized carbon blacks of Monarch 120 and Shawinigan acetylene black, and the metal oxides of $NiCo_2O_4$, Co_3O_4, $Pb_2Ru_2O_7$ and $Pb_2Ir_2O_7$, have been prepared. Electrochemical tests will be underway shortly in small cells at Metal Air Technology Systems International (MATSI).

- LBL has initiated experiments to adapt the mechanically rechargeable Zn/air cell invented at LBL, which employed a reticulated Zn electrode structure to operate under natural convection, for electrically rechargeable cell configurations. A laser-Doppler velocimeter has been modified to measure the electrolyte velocity, and the expected signal was obtained. An algorithm has been developed to model the convective diffusion of the electrolyte in the porous electrode structure.

- LBL is evaluating commercial bifunctional air electrodes in Zn/air cells, as well as developing improved bifunctional air electrodes from metal oxide electrocatalysts. A bifunctional air electrode (BF-8) from Electromedia, Inc. was evaluated at constant-current rates and the Simplified Federal Urban Driving Schedule (SFUDS) in a Zn/air cell with an electrolyte of 45 wt% KOH and 40 g Zn^{2+}/l. Approximately 25 cycles were achieved, regardless of the discharge rates.

Fuel Cell Research at 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 1991 are listed below:

- LANL has found that processing membrane-electrode assemblies (MEA) with membranes that contain the Na^+ form rather than the H^+ form permits the use of higher processing temperatures, 185 *vs* 135°C. The MEA are more robust, have a lower impedance, and are more tolerant to adverse humidification conditions in fuel cells.
- LANL has characterized some of the H_2O-management properties of Nafion 117, membrane C, and an experimental Dow membrane. The Dow membrane appears to show the highest H_2O uptake and smallest water drag. These properties are beneficial for obtaining high performance in fuel cells with the Dow membrane.
- LANL has resolved the problem of membrane puncture that was observed in small fuel cells that contain thin membranes such as the 2-mil thick Nafion membrane. The problem was overcome by using a thin Teflon gasket in the membrane/electrode/gasket assembly to prevent the sensitive area of the membrane from direct exposure to the reactant gases.
- A large 50-cm^2 cell was operated at LANL which attained an initial performance of 2 A/cm^2 on O_2 (5 atm) without experiencing transport losses at the O_2 electrode. The initial performance on air (5 atm) showed only marginal losses up to 1 A/cm^2.
- It is concluded from the one-dimensional model developed by LANL that the counter fluxes of H^+ and O_2 in the fuel cell determine the degree of utilization of the catalyst layer along its thickness direction.
- Polymer membranes were synthesized at LANL from Nafion and siloxane monomers that are significantly stiffer than Nafion, and also exhibit a low tendency to take up methanol. These membranes may be effective in lowering the methanol solubility in fuel cells with polymer membranes.
- BNL is utilizing x-ray absorption spectroscopy (XAS) to investigate the properties of Pt/C and several of its alloys with Cr, Co, and Ni. The results indicate that alloying with Ni has a large effect on the d character of Pt, whereas Cr has little effect. Nickel forms a solid solution with Pt, with the Ni atoms substituting at Pt sites.

MILESTONES FOR THE EXPLORATORY TECHNOLOGY RESEARCH PROGRAM

Milestones accomplished in Fiscal Year 1991 by the ETR Program include:

- "Demonstrate high performance of new structures of the membrane-electrode assembly in polymer electrolyte fuel cells (PEFC) with Pt loadings ≤ 0.2 mg/cm^2"

The LANL test showed that the performance of a single cell with ≤ 0.175 mg/cm^2 Pt + 50-nm sputtered Pt is comparable to that obtained with ≤ 0.45 mg/cm^2 Pt loading.

- "Complete one-dimensional model for PEFC based on experimentally derived transport parameters"

The LANL model employs experimentally measured parameters such as water diffusion coefficient, electroosmotic drag coefficients, water sorption isotherms, and membrane conductivities. The model predicts a net-water-per-proton flux ratio of 0.2 H_2O/H^+ under typical operating conditions, which is much less than the measured electroosmotic drag coefficient for a fully hydrated Nafion 117 membrane.

- "Begin Zn/air cell development activities with the EVABS Program"

LBL and SNL have completed a joint program plan entitled "Program Plan for Development of Zinc/Air Batteries," which was submitted to DOE/HQ on May 2, 1991. In addition, we have provided our input to the Statement-of-Work for the Request for Quotations (RFQ) from SNL on "Development of a Metal/Air Battery for Electric Vehicles Applications." These activities are intended to provide a smooth transition for the Zn/air battery program as the emphasis of the program shifts from research at LBL to engineering development at SNL. It is anticipated that LBL will continue to work closely with SNL in the future by assisting with the evaluation of the responses to the RFQ, serving at program review meetings, and coordinating its research projects to support the battery development effort.

- "Go/no-go decision to continue investigations on molten-salt electrodeposition and chemical-vapor deposition (CVD) as methods to produce corrosion-resistant coatings for high-temperature batteries"

A renewal proposal was submitted by IIT to continue their studies on the use of molten-salt deposition and CVD to produce corrosion-resistant coatings. Based on the reviewers' comments and the evaluation by the ETR Program Selection Committee, it is recommended that the project should continue for another year. IIT was encouraged to transfer their technology to an industrial company.

- "Complete *ex situ* EXAFS studies of PbO_2"

A combination of XANES and EXAFS was used to determine the coordination number, symmetry and bond lengths for Pb^{2+} ions in aqueous solutions and Pb^{4+} ions in glacial acetic acid. Studies were also made on the two polymorphs of PbO and PbO_2. Features of the XANES spectra were interpreted in terms of hybridized orbitals, multiple scattering effects, and crystal-field splitting of d orbitals. All the Pb(IV) materials displayed a pre-edge feature due to 2p → 6s transitions. In the case of PbO_2 the intensity of this transition was correlated with the stoichiometry of the oxide. There were clear differences in the radial structure functions for α-PbO_2 and β-PbO_2 due to focusing effects in the latter. These peaks at large R values are a clear signature for fingerprinting the β-PbO_2 phase.

- "Complete EXAFS studies of adatom-modified Pt catalysts"

Underpotential deposited (UPD) Cu on Pt-supported-on-carbon electrocatalyst was investigated *in situ* in 0.5 M H_2SO_4 at 0.05 V (*vs* SCE) by XANES. By taking XANES spectra at the Cu K-edge and the Pt L_{111}-edge, it was possible to determine the valence state of Cu and observe modifications in the electronic structure of the Pt with adsorbed Cu. The XANES for UPD Cu shows that the adsorbed Cu has an oxidation state close to that of Cu^+. XANES features strongly indicate a tetrahedral coordination for the adsorbed Cu species. A reduction in intensity of the white line in the Pt XANES is consistent with a partial filling of empty Pt d-band vacancies by adsorption of Cu. Thus, UPD species can modify the electronic structure of Pt catalysts. The adsorbed Cu^+ species are apparently associated with HSO_4^- ions.

- "Initiate new research project on novel processing techniques to improve the surface properties of metals, alloys and seal components for batteries"

In March 1991, LBL published a notice in Commerce Business Daily to solicit research on novel surface processing techniques that could benefit batteries for EVs. Six proposals were received in response to our Request for Proposals (RFP), and they were reviewed by LBL and outside technical experts. On the basis of these reviews and other considerations such as qualifications, facilities, program management, business aspects, *etc.* , a subcontract was awarded to the Environmental Research Institute of Michigan (ERIM). The principal investigator is Dr. Thomas K. Hunt, who previously worked at Ford Motor Company on the sodium heat engine. The goal of the research project is to develop thin coatings of TiN to protect the surface of cell components for Na/S cells. The corrosion-resistant properties of TiN coatings which are sputter-deposited on Al substrates will be investigated under a variety of electrochemical conditions appropriate for Na/S battery operation.

MANAGEMENT ACTIVITIES

During 1991, 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 ETR projects. LBL staff members also participated in the following reviews, meetings, and workshops:

- FY 1993 DOE/CRE Program Planning Workshop, SERI, February 20-22, 1991
- Lithium-Ion Battery Meeting, SNL, February 22, 1991
- U.S. Advanced Battery Consortium Meeting, Highland Park, MI, April 19, 1991
- 179th Meeting of the Electrochemical Society, Washington, D.C., May 5-10, 1991
- IAPG Meeting, Albuquerque, NM, May 20, 1991
- 4th World Congress of Chemical Engineering, Karlsruhe, Germany, June 15-19, 1991
- 26th IECEC, Boston, MA, August 4-9, 1991
- 42nd Meeting of the International Society of Electrochemistry, Montreux, Switzerland, August 25-28, 1991
- LANL Fuel Cell Review Meeting, Washington, D.C., August 28, 1991
- U.S. Advanced Battery Consortium Meeting, LBL, Berkeley, CA, September 20, 1991
- 180th Meeting of the Electrochemical Society, Phoenix, AZ, October 13-17, 1991
- U.S. Advanced Battery Consortium Meeting, SNL, Albuquerque, NM, October 18, 1991
- Quarterly Project Review of Zn/NiOOH System, EPRI, Palo Alto, CA, October 22, 1991
- Annual Automotive Technology Development Contractors' Coordination Meeting, Dearborn, MI, October 28-31, 1991
- Workshop on Structural Effects in Electrocatalysis and Oxygen Electrochemistry, Cleveland, OH, October 29-November 1, 1991
- Workshop on DOE Carbon Foam Materials, SNL, Livermore, CA, November 6, 1991

ACKNOWLEDGMENT

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ANNUAL REPORTS

1. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1990," LBL-30846 (June 1991).
2. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1989," LBL-29155 (May 1990).
3. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1988," LBL-27037 (May 1989).
4. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1987," LBL-25507 (July 1988).
5. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1986," LBL-23495 (July 1987).
6. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1985," LBL-21342 (July 1986).
7. "Technology Base Research Project for Electrochemical Energy Storage - Annual Report for 1984," LBL-19545 (May 1985).
8. "Annual Report for 1983 - Technology Base Research Project for Electrochemical Energy Storage," LBL-17742 (May 1984).
9. "Technology Base Research Project for Electrochemical Energy Storage - Report for 1982" LBL-15992 (May 1983).
10. "Technology Base Research Project for Electrochemical Energy Storage - Report for 1981," LBL-14305 (June 1982).
11. "Applied Battery and Electrochemical Research Program Report for 1981," LBL-14304 (June 1982).
12. "Applied Battery and Electrochemical Research Program Report for Fiscal Year 1980," LBL-12514 (April 1981).

LIST OF ACRONYMS

AES	Auger electron spectroscopy
AFM	atomic force microscopy
BNL	Brookhaven National Laboratory
CMD	chemical manganese dioxide
CVD	chemical vapor deposition
CWRU	Case Western Reserve University
DC	direct current
DEC	diethyl carbonate
DMC	dimethyl carbonate
DME	dimethoxyethane
DMFC	direct methanol fuel cell
DOE	Department of Energy
DSC	differential scanning calorimetry
EC	ethylene carbonate
EMD	electrolytic manganese dioxide
EPRI	Electric Power Research Institute
ERIM	Environmental Research Institute of Michigan
ETR	Exploratory Technology Research
EV	electric vehicle
EVABS	Electric Vehicle Advanced Battery Systems
EW	equivalent weight
EXAFS	extended x-ray absorption fine structure
FTIRRAS	Fourier transform infrared reflectance absorption spectroscopy
GDL	gas diffusion layer
HOPG	highly ordered pyrolytic graphite
IECEC	Intersociety Energy Conversion Engineering Conference
IIT	Illinois Institute of Technology
ISE	International Society of Electrochemistry
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LEED	low energy electron diffraction
MEA	membrane electrode assemblies
MATSI	Metal Air Technology Systems International
MF	methyl formate

MSECD	molten salt electrochemical deposition
NMR	nuclear magnetic resonance
OCP	open circuit potential
OPG	ordinary pyrolytic graphite
PC	propylene carbonate
PDS	photothermal deflection spectroscopy
PECVD	plasma-enhanced chemical vapor deposition
PEM	proton-exchange membrane
PEO	poly(ethylene oxide)
PPO	poly(propylene oxide)
PTFE	polytetrafluoroethylene
pzc	point of zero charge
QCM	quartz crystal microbalance
RDE	rotating disk electrode
RFP	Request for Proposal
RFQ	Request for Quotations
RL	reaction layer
SCE	saturated calomel electrode
SEM	scanning electron microscopy
SERS	surface-enhanced Raman spectroscopy
SFUDS	Simplified Federal Urban Driving Schedule
SNL	Sandia National Laboratories
SPE	solid polymer electrolyte
STM	scanning tunneling microscopy
TEM	transmission electron microscopy
TEOS	tetraethylorthosilicate
TGA	thermogravimetric analysis
THF	tetrahydrofuran
TMPP	tetramethoxyphenyl porphyrin
TPD	temperature programmed desorption
UHV	ultrahigh vacuum
UPD	underpotential deposition
USABC	United States Advanced Battery Consortium
XANES	x-ray near edge absorption spectroscopy
XAS	x-ray absorption spectroscopy
XPS	x-ray photoelectron spectroscopy

SUBCONTRACTOR FINANCIAL DATA - CY 1991

Subcontractor	Principal Investigator	Project	Contract Value (K$)	Term (months)	Expiration Date	Status in CY 1991*
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	9-91	C
Acid Cells						
Brookhaven National Laboratory	J. McBreen	Battery Materials	100	12	9-91	C
Components for High-Temperature Cells						
Stanford University	R. Huggins	New Battery Materials	78	6	4-92	T
Corrosion Processes in High-Specific Energy Cells						
Illinois Institute of Technology	R. Selman	Corrosion Resistant	132	12	8-92	T
Environmental Research Institute of Michigan	T.Hunt	Secondary Batteries	105	12	8-92	C
Johns Hopkins University	J. Kruger	Corrosion/Passivity Studies	30	12	8-92	T
Components for Ambient-Temperature Nonaqueous Cells						
Case Western Reserve University	D. Scherson	Spectroscopic Studies	55	12	4-92	T
Case Western Reserve University	D. Scherson	*In Situ* Studies	86	12	7-92	C
Jackson State University	H. Tachikawa	Raman Spectroscopy	47	23	5-92	T
University of Pennsylvania	G. Farrington	Polymeric Electrolytes	50	12	7-92	T
SRI International	S. Narang	Polymeric Electrolytes	97	12	9-91	T
AIR SYSTEMS RESEARCH						
Metal/Air Cell Research						
Eltech Research Corporation	E. Rudd	Oxygen Electrodes	125	13	8-92	T
Case Western Reserve University	E. Yeager	Air Electrodes	150	12	4-92	T
Metal Air Technology Systems	R. Putt	Zn/Air Battery	50	5	5-91	T
Fuel Cell R&D						
Los Alamos National Laboratory	S. Gottesfeld	Fuel Cell R&D	1400	12	9-91	C
Brookhaven National Laboratory	J. McBreen	Fuel Cell Research	100	12	9-91	C

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* C = continuing, T = terminating

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