Recent Work

Title
EXECUTIVE SUMMARY REPORT FOR 1983: TECHNOLOGY BASE RESEARCH PROJECT FOR ELECTROCHEMICAL ENERGY STORAGE

Permalink
https://escholarship.org/uc/item/3sq6b5h6

Author
Lawrence Berkeley National Laboratory

Publication Date
1984-05-01
EXECUTIVE SUMMARY REPORT FOR 1983:
TECHNOLOGY BASE RESEARCH PROJECT FOR
ELECTROCHEMICAL ENERGY STORAGE

May 1984

TWO-WEEK LOAN COPY
This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
EXECUTIVE SUMMARY REPORT

FOR 1983

TECHNOLOGY BASE RESEARCH PROJECT FOR ELECTROCHEMICAL ENERGY STORAGE

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

Edited by Kim Kinoshita, Technical Manager

May 11, 1984

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Energy Systems Research, Energy Storage Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.
EXECUTIVE SUMMARY

The Lawrence Berkeley Laboratory (LBL) is the Lead Center for management of the Technology Base Research (TBR) Project, which is supported by DOE's Office of Energy Systems Research, Energy Storage Division. The purpose of this project is to provide the research base which supports DOE efforts to develop electrochemical technology for electric vehicle and stationary energy storage applications.

The general objective of the TBR project is to help provide advanced electrochemical systems that can satisfy stringent performance and economic requirements for electric vehicle and stationary energy storage applications. The specific goal of the project is to identify the most promising electrochemical technologies and transfer them to industry and/or another DOE program for further development and scale-up.

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 assessment of fuel cell 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 four major project elements: Electrochemical Systems Research, Supporting Research, Electrochemical Processes, and Fuel Cells for Vehicles. This report summarizes the research, financial, and management activities relevant to the TBR project in CY 1983. Highlights of each project element are summarized according to the appropriate battery system or electrochemical research area.
Electrochemical Systems 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 system performance goals. Research projects were conducted on advanced intermediate-temperature battery systems, ambient-temperature lithium cells, and metal/air batteries.

Intermediate-Temperature Lithium Cells

- The University of Tennessee has achieved improved specific energies for Na/β"-alumina/SCl₃⁺ in AlCl₃-NaCl cells that are "sulfur-rich" (S/Al molar ratio > 0.15).
- The research effort on sodium/alkali nitrate cells at Argonne National Laboratory (ANL) was ended due to problems encountered with instability of β"-alumina in the presence of LiNO₃ + NaNO₃ and operating temperatures that are 80-100°C higher than the goal of 200°C.

Ambient-Temperature Rechargeable Lithium Cells

- Duracell has discovered several new electrolyte salts (EX1 = LiGaCl₄/SO₂, EX2 = LiAlCl₄/SO₂) and positive-electrode materials (CX1 = CuCl₂/graphite and CX2 = CuCl₂) for ambient-temperature rechargeable lithium batteries. The Li/CX1 system with EX2 electrolyte has an open-circuit voltage of 3.43 V and a theoretical specific energy of about 1100 Wh/kg; experimental cells have demonstrated 200-300 cycles at a 50% depth-of-discharge. Deep discharge of CX1 to lower than 2.6 V caused some irreversible damaged and reduced the cycle life substantially. The Li/CX2 system with EX2 electrolyte has an open-circuit voltage of 3.29 V and a theoretical specific energy of about 520 Wh/kg; experimental cells have shown good rate capability and good cycle life on deep discharge.
Tests at EIC Laboratories, Inc. indicated that sulfolane-based organic electrolytes in ambient-temperature lithium batteries may be stable at temperatures up to 70°C. Co-solvents, such as SO₂ and methyl formate, were used as additives to enhance the stability of sulfolane electrolytes towards Li. SO₂/sulfolane showed good stability in storage with Li at 70°C, and methyl formate allowed 88% Li-cycling efficiency in a 1:1 mixture with sulfolane.

Metal/Air Batteries

Westinghouse Electric Corp. has observed that improvements in performance of >20 mV can be achieved in bifunctional air electrodes that have been fabricated with a "pore-former" such as guanine. A low loading level (1-2%) of fine (-600 mesh) particles of guanine, which is soluble in KOH, was found to be most beneficial.

Case Western Reserve University has developed an electrocatalyst, which is obtained by heat treating (450°C) a metal-free tetramethoxyphenyl porphyrin supported on acetylene black with added hydroxides of Ni, Fe, and Co, that has shown promising activity for both O₂ reduction and generation.

Major achievements of the aluminum/air program include:

- ELTECH Systems Corporation was selected the prime-industrial subcontractor for aluminum/air battery R & D.

- ELTECH Systems Corporation achieved 1400 simulated-driving cycles in their life testing of a cathode with improved structure and cobalt meso-tetra-p-methoxyphenyl porphyrin electrocatalyst. This result is only 100 cycles less than the program goal of 1500 driving cycles.
Lawrence Livermore National Laboratory (LLNL) has successfully operated an integrated system consisting of a single-wedge cell and a crystallizer/hydrocyclone separator for a mechanically-rechargeable aluminum/air battery. A 600 cm² wedge cell (60° angle) with 3.3 liters of electrolyte was discharged for 6 hr at 140 A.

The project to develop a rapidly-refuelable, full-scale Al/air multicell at Lockheed Missiles and Space Corporation has been completed.

Supporting 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 program provide research that supports a wide range of battery systems -- alkaline, flow, molten salt, non-aqueous, and solid electrolyte. Other projects are directed at research on improving the understanding of electrochemical engineering principles, surface analysis of electrodes, and electrocatalysis.

Alkaline Cells

Optical microscopy studies are underway at LBL and Lockheed to understand the electrochemical phenomena occurring at Zn electrodes in alkaline electrolytes. These experiments are complemented by modeling studies at LBL. The results of these studies confirm that a dissolution-precipitation mechanism controls film formation during discharge of zinc electrodes, and the onset of film formation has been found to depend strongly on the solubility of zinc-bearing species in the electrolyte.

The effect of adding a less-polar organic solvent to alkaline KOH electrolyte is being investigated at LBL as a means to reduce the solubility of the zincate ion, and thereby extend the lifetime of the zinc electrode. Experiments indicated that methanol reduced...
zincate solubility by about 70% for a 30% KOH - 40% water - 30% methanol electrolyte; however, methanol was oxidized to a considerable extent on the NiOOH electrode.

Experiments are underway at LBL to investigate the electrical and electrochemical behavior of particulate electrodes, which may be attractive for high specific-power requirements in secondary batteries. The experimental apparatus has been built and potential transient measurements on metallic particles (Cu, Zn-coated Cu, and Zn-coated polymer) have begun.

Research and development projects on separators to improve the cycle life of batteries were expanded. Research to develop improved separators for alkaline batteries was initiated at Brigham Young University (BYU) and Pinnacle Research Institute (PRI). BYU has fabricated separators containing complexes of crown ether-KSCN and polypropylene that exhibited an uptake of 4 M KOH which increased linearly with the percentage of complex. PRI has determined that hybrid separators with a 15% degree-of-grafting are not as effective as ion-exchange membranes towards zincate selectivity. However, when the degree-of-grafting is increased to > 36%, the selectivity is as good as that of ion-exchange membranes. Cycle-life testing of alkaline-zinc cells containing supported-liquid membrane separators, conducted at Castle Technology Corp., continues to show the absence of cell failure by dendrite shorting after 300 cycles (2 hr discharge rate and 4 hr charge rate with 20% overcharge) at 100% DOD.

Semiconductor-electrochemical measurements at SRI International have revealed that the NiO electrode is a p-type or n-type semiconducting oxide, depending on its potential. These types of measurements have also shown that Li$^+$ ions do not necessarily increase the conductivity of the p-type oxide; instead their presence increases the overpotential for $O_2$ evolution.
Ohio State University is conducting an evaluation of thermodynamic properties of hydroxide electrolytes and an electrochemical investigation of nickel-battery electrodes. Cycling tests of rolled and bonded nickel electrodes indicated that rapid degradation occurs at elevated temperatures, 60 - 100°C.

Zinc/Halogen Cells

Zinc deposition studies at LBL and the Illinois Institute of Technology (IIT) indicate that the surface morphology of the electrodeposit is controlled by experimental parameters such as current density, mass-transfer rate, and electrolyte pH and composition. LBL has observed that at <80 mA/cm², a striated zinc deposit was obtained in 1 M ZnCl₂; but at 100 mA/cm², a macroscopically-smooth deposit was formed in both laminar and turbulent flow. IIT has observed that the growth rate of dendrites increases with an increase in electrolyte convection.

Brookhaven National Laboratory (BNL) has found that the rate of zinc deposition on the basal plane of a zinc-single crystal is at least an order of magnitude faster than that on the plane which is perpendicular to the basal plane. BNL has also observed that additives (PbO, Ti⁺³, and BiO₃) greatly affected the deposition of zinc on glassy carbon in zinc halide electrolytes. In 3 M ZnCl₂, deposition of Pb, Bi, and Tl occurred at 400 mV, 800 mV, and 50 mV, respectively, positive to the potential for zinc deposition.

LLNL has completed measurements at 25°C of the mutual-diffusion coefficient for high-purity solutions of ZnCl₂ from 0.0747 to 3.4931 M. Densities for 24 ZnCl₂-KCl mixtures were also measured. These data are needed to model and interpret the behavior of zinc flow batteries.
Molten Salt Cells

- Heat-generation measurements of Li-alloy/FeS$_2$ cells by Gould, Inc. indicated that the discharge process was endothermic during the first-voltage plateau (1.8 V) and became exothermic during the second, lower-voltage plateau (1.2 V). These results suggest that, in principle, a discharge current can be selected at which the total, integrated heat generation during discharge vanishes. If the heat generation at high-discharge rates vanishes, then this could significantly affect the thermal management of the battery.

- Stanford University has found that a number of vanadium oxide bronzes ($\beta$-Li$_y$M$_x$V$_2$O$_5$ with M = Li, Na, K, and Li$_{1+y}$V$_3$O$_8$) showed rapid lithium-insertion kinetics; this behavior may be useful for positive-electrode materials for molten-salt systems. Encouraging results were obtained for Li$_{1+y}$V$_3$O$_8$ electrodes that were cycled.

- ANL has observed that the addition of Al has a beneficial effect on the performance of Li-Si electrodes in Li-alloy/FeS$_2$ cells; the optimum amount of Al has not yet been established. Other studies indicated that the resistance of Li-Si can be reduced by the addition of 7.5 wt% Bi or Sn.

Solid Electrolytes for Alkali/Sulfur Cells

- Experiments are underway at LBL to understand the degradation mechanism of $\beta''$-alumina, and at Rockwell International to improve its toughness. Changes in the electrolyte due to chemical coloration, sodium deposition, and sulfur-side attack have been observed by electrochemical and acoustic-emission techniques at LBL. Rockwell observed an increase in strength of $\beta''$-alumina with the addition of 15 vol% ZrO$_2$; only a small increase in resistivity resulted.

- Massachusetts Institute of Technology (MIT) is synthesizing and characterizing glasses of the composition $A^+_{2+x}M^{3+}M^{4+}_{1-x}Si_{6}O_{15}$ ($A$ = K, Na; $M$ = Ti, Zr, Y, Nd, La) and Na$_2$O-NaCl-B$_2$O$_3$; initial measurements of ionic conductivity are encouraging.
Argonne National Laboratory has prepared NASIGLAS (Na\textsuperscript{+} Super Ionic Glass, Na\textsubscript{1+x}Zr\textsubscript{2-x}Si\textsubscript{3-x}P\textsubscript{3-x}O\textsubscript{12-2x/3}), which are analogs of the crystalline superionic conductor NASICON, that show encouraging results in molten sodium. A review of the literature on glass chemistry suggested that a form of NASIGLAS can be developed that will be resistant to sodium attack and will have a resistivity of less than 100 ohm-cm at 300°C.

LBL has developed a sophisticated macroscopic model of transport properties of sodium/polysulfide melts which considers sodium cations and seven different polysulfide anions as the melt components. This model successfully predicts the melt diffusion coefficient.

Components for Ambient-Temperature Lithium Cells

Experimental studies at LBL indicated that lithium nitride provides an ionically-conducting, protective layer on lithium electrodes in non-aqueous electrolytes. Other experiments at LBL showed that the iodine/iodide couple promises to be a viable reaction for the positive electrode in Li/propylene carbonate cells.

Electrochemical experiments at the University of Pennsylvania indicated that conductive-polyacetylene materials lack promise for use as battery electrodes for electric vehicles.

Efforts continue at Case Western Reserve University to develop multi-block copolymers for use as membranes in lithium batteries. Difficulties have been encountered in their synthesis due to the sensitivity of the initiator to moisture.

The experimental results obtained at the Institute of Gas Technology indicated that MoS\textsubscript{2} is the preferred electrocatalyst of the many tested for the sulfide/polysulfide redox couple.
Cross-Cutting Research

- The paper by J. Newman (LBL) entitled "Current Distribution on a Rotating Disk Below the Limiting Current," J. Electrochem. Soc. 113, 1235 (1966), has been recognized by Citation Classic as a highly-cited publication in electrochemical engineering.

- A limiting-current model for the potential and concentration distribution for a flow-by electrode was developed at LBL; it shows that the maximum solution-phase potential drop is dependent upon one relevant parameter - the product of the electrode width and the reciprocal of the penetration depth.

- Experiments at LBL on gas evolution at a micro-mosaic electrode showed that the enhancement in mass transfer due to bubble disengagement was small when compared to that due to bubble coalescence.

- Illinois Institute of Technology has completed the survey and compilation of heat- and mass-transfer correlations. About 420 mass-transfer correlations from 260 papers and about 450 heat-transfer correlations from 240 papers have been collected.

Electrochemical Processes

The objectives of this project element are to identify, evaluate, and initiate development of efficient electrochemical energy conversion technology. Several approaches to achieve this objective are considered in the TBR project. These include projects to (a) improve components for electrochemical systems such as membranes, electrodes and cell containers; and (b) research to improve the materials utilization and efficiency of electrochemical processes such as metal reduction, electroorganic synthesis, and water electrolysis. Efforts in area (b) have been recently phased out of the TBR project, but several subcontracts have continued due to no-cost time extensions that were granted to permit completion of the projects.
Membranes

- Multi-component transport studies to improve the efficiency of Nafion membranes have been completed at Electrochemical Technology Corporation (ETC) and BYU. ETC determined that the transference number for sodium through the membrane was 0.959 at current densities from 100 mA/cm² to 7500 mA/cm². Reverse-osmosis measurements at BYU showed that the water transport through Nafion decreased with an increase in the external concentration of NaOH, and increased with an increase in temperature.

Air Electrodes

- LBL has determined the current efficiencies for oxygen evolution, carbon dissolution, and carbon gasification during exposure of carbon black to anodic potentials in alkaline solutions. The current efficiencies were found to depend dramatically on potential, temperature, and the presence of an oxygen-evolution catalyst like Co₃O₄.

- Case Western Reserve University has discovered that μ-oxo-iron (III) meso-tetra-p-methoxyphenyl porphyrin, (Fe-TMOO)₂O, which was heat-treated at 850°C, has quite high activity for oxygen reduction in concentrated H₃PO₄ (85 wt%) at 100°C, comparable to or even higher than that of highly-dispersed Pt.

Corrosion

- Experiments are underway at ANL to develop new alloys for positive-side current collectors and containment materials in Na/S and Li/S cells. Studies of the sulfidation of unalloyed metals at 350°C indicated that candidate base metals, such as nickel and iron, showed positive deviation from a parabolic rate of sulfide-scale formation in less than a day. The sulfide scales that formed on alloying elements, such as Al and Mo, remained diffusion-controlled throughout the four-day test period.
Initial results of static tests on Mo at LBL showed that it is resistant to corrosion at 400°C in Li$_2$S-S melts.

**Electrolytic Processes**

- MIT has shown that impurities such as boron and sulfur caused passivation of the cathode during electrodeposition of magnesium from an anhydrous molten salt. This project has attracted the attention of domestic light-metal producers, which have shown interest in supporting further research of this type at MIT.

- The optimum conditions for the paired oxidation of glucose to gluconic acid and reduction of glucose to sorbitol were established by the University of California at Los Angeles.

**Fuel Cells for Vehicles**

The objectives of this project element are to identify, evaluate, and initiate development of fuel cell technology for transportation applications. This effort involves basic research to improve the performance of fuel cell systems for use in transportation applications and applied research to establish proof-of-concept.

- LBL has determined that the solubility-diffusivity and kinetic behavior of oxygen in tetrafluoroethane-1,2 disulfonic acid (TFEDSA) is similar to that in trifluoromethane sulfonic acid. A reaction order of unity for oxygen reduction in TFEDSA was determined.

- BNL has concluded from their cyclic-voltammetry experiments that platinum, even when it is not in contact with Nafion, can still be utilized in electrochemical reactions such as those occurring in solid-polymer electrolyte cells.

- Analysis by Los Alamos National Laboratory (LANL) of data on transport rate of species through Nafion membranes suggested that transport properties are affected by water and the structure of the polymer. Water transport through Nafion 117 was found to be approximately four times faster than that through Nafion 125.
A study of the electronic structure of the PtO molecule has been initiated at LANL using ab initio quantum-mechanical calculations.

A control and measurement system for six single cell, phosphoric acid-test stations has been fabricated, and testing has begun at LANL. The 5- and 25-cm² single cells showed identical IR-free performance.

LANL has reviewed the thermodynamics of methanol reforming and initiated experimental measurements on the kinetics and mechanism of this reaction. LANL has proposed that the reaction pathway for methanol reforming on CuO-ZnO catalysts involves Cu-Zn active sites, which are assumed to exist in either an oxidized state, that is stabilized by the interaction between CuO and ZnO, or a reduced state.

United Technologies Corporation has discovered that at high temperature (180°C), the CO-tolerance of Pt in concentrated phosphoric acid was superior to that of their proprietary electrocatalysts; but at lower temperatures (100°C and 140°C), the proprietary electrocatalysts showed better CO-tolerance.

General Electric Company has contacted eleven membrane vendors in their search for an alternative to Nafion. Four different types of low-cost, commercially available membranes were received and evaluated; only one exhibited stability at 82°C.

The design of the major components for a 20 kW phosphoric acid, fuel cell-power plant has been completed by Energy Research Corporation; the fabrication and assembly of the fuel cell stack and reformer are underway.

Planned Activities in 1984

New research projects planned include:

1. Expand industrial participation in R & D of molten-salt batteries.
2. Investigate methods to reduce carbon corrosion.

3. Expand the R & D effort on air electrodes.

4. Investigate methods to inhibit corrosion of components for Na/S cells.

5. Investigate the effects of heat treatment and microstructure on the performance of fuel cell electrocatalysts.


Management Activities

During 1983, LBL managed 36 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 participated in the following reviews, meetings, and workshops:

- Review of the Sodium/Sulfur Battery Program held at Ford Motor Co. in Dearborn, MI on February 25, 1983.
- Review of the Technology Base Research Project held in Rockville, MD on May 24-25, 1983.
- Review of the Zinc/Bromine Battery Program held at EXXON Research in Linden, NJ on May 26, 1983.
- EPRI Fuel Cell Workshop held in Long Beach, CA on July 11-12, 1983.
- Workshop on Electrochemical Energy Sources, sponsored by DARPA Materials Research Council, held in La Jolla, CA on July 11-12, 1983.
- Review of the Ford Aerospace Sodium/Sulfur Battery Program held in Newport Beach, CA on July 18-19, 1983.
Milestones accomplished in 1983 by the TBR project include:

- ELTECH Systems Corporation was selected the industrial-prime contractor for development of the aluminum/air battery. The award was based on a competitive RFP(Request-for-Proposal) issued by Lawrence Livermore National Laboratory.

- A workshop on the Electrochemistry of Carbon was held at Case Western Reserve University, Cleveland, Ohio, which identified approaches to reduce carbon corrosion in electrochemical systems such as metal/air batteries and phosphoric acid fuel cells. Recommendations from this workshop served to guide research to mitigate carbon corrosion.

- Research at the Massachusetts Institute of Technology has led to the identification of glasses in the lithium borate family that appear to be stable in the presence of molten Li-Sn alloys at 377°C. These encouraging results have contributed to the decision to continue development of lithium-conducting glasses at MIT.

- Ellipsometry and impedance techniques were used by Lawrence Berkeley Laboratory to determine the structure of surface layers on lithium electrodes in organic electrolytes. Films formed on lithium in propylene carbonate solutions consist of compact and porous layers. Improvement in the performance of lithium electrodes will require an increase in the ionic conductivity of the compact layer.
An analysis of the published thermodynamic data required to assess the performance of alkaline batteries was completed by Ohio State University. This study showed that considerable uncertainties exist in the thermodynamic data, and that experimental measurements are necessary to correct these deficiencies.

A review of the DOE-sponsored program on molten salt batteries was held at Argonne National Laboratory. The review committee concluded that efforts should be continued to develop high-performance, rechargeable batteries based on the use of molten salt electrolytes.
### Subcontractor Financial Data - CY 1983

<table>
<thead>
<tr>
<th>Subcontractor</th>
<th>Principal Investigator</th>
<th>Project</th>
<th>Contract Value (K$)</th>
<th>Duration (months)</th>
<th>Expiration Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ELECTROCHEMICAL SYSTEMS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of Tennessee</td>
<td>G. Mamantov</td>
<td>Na/SCl₄(NaCl-AlCl₃)</td>
<td>43</td>
<td>16</td>
<td>12-83</td>
</tr>
<tr>
<td>ANL</td>
<td>M. Roche</td>
<td>Na/NaNO₃</td>
<td>200</td>
<td>12</td>
<td>9-83</td>
</tr>
<tr>
<td>Duracell International, Inc.</td>
<td>A. Dey</td>
<td>Li/SO₂</td>
<td>1500</td>
<td>39</td>
<td>12-84</td>
</tr>
<tr>
<td>EIC Laboratories, Inc.</td>
<td>B. Brummer</td>
<td>Li/Sulfolane/TiS₂</td>
<td>112</td>
<td>12</td>
<td>4-84</td>
</tr>
<tr>
<td><strong>Metal/Air</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Westinghouse Corporation</td>
<td>E. Buzzelli</td>
<td>Fe/Air</td>
<td>281</td>
<td>12</td>
<td>2-84</td>
</tr>
<tr>
<td>Case Western Reserve University</td>
<td>E. Yeager</td>
<td>Air Electrodes</td>
<td>166</td>
<td>12</td>
<td>2-84</td>
</tr>
<tr>
<td>LLNL</td>
<td>J. Cooper</td>
<td>Al/Air R&amp;D</td>
<td>1740</td>
<td>12</td>
<td>9-83</td>
</tr>
<tr>
<td><strong>SUPPORTING RESEARCH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Alkaline</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lockheed Missiles and Space Co.</td>
<td>T. Katan</td>
<td>Reaction Profiles</td>
<td>80</td>
<td>16</td>
<td>9-83</td>
</tr>
<tr>
<td>Castle Technology, Inc.</td>
<td>J. P. Pemsler</td>
<td>Liquid Membranes</td>
<td>77</td>
<td>12</td>
<td>4-84</td>
</tr>
<tr>
<td>Pinnacle Research</td>
<td>R. Yeo</td>
<td>Zn/NiOOH Separators</td>
<td>115</td>
<td>12</td>
<td>6-84</td>
</tr>
<tr>
<td>Brigham Young Univ.</td>
<td>D. Bennion</td>
<td>Zn/NiOOH Separators</td>
<td>92</td>
<td>12</td>
<td>7-84</td>
</tr>
<tr>
<td>SRI International</td>
<td>M. McKubre</td>
<td>Electrode Kinetics</td>
<td>77</td>
<td>12</td>
<td>2-84</td>
</tr>
<tr>
<td>Ohio State University</td>
<td>D. Macdonald</td>
<td>Cell Thermodynamics</td>
<td>75</td>
<td>12</td>
<td>6-84</td>
</tr>
<tr>
<td>Ohio State University</td>
<td>D. Macdonald</td>
<td>Electrode Restructuring</td>
<td>53</td>
<td>12</td>
<td>12-83</td>
</tr>
<tr>
<td><strong>Zinc/Halogen</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois Institute of Technology</td>
<td>J. R. Selman</td>
<td>Zn Deposition</td>
<td>111</td>
<td>29</td>
<td>8-83</td>
</tr>
<tr>
<td>BNL</td>
<td>J. McBreen</td>
<td>Zn Morphology</td>
<td>60</td>
<td>9</td>
<td>9-83</td>
</tr>
<tr>
<td>LLNL</td>
<td>D. Miller</td>
<td>Transport Properties</td>
<td>45</td>
<td>6</td>
<td>9-83</td>
</tr>
<tr>
<td>Subcontractor</td>
<td>Principal Investigator</td>
<td>Project</td>
<td>Contract Value (K$)</td>
<td>Duration (months)</td>
<td>Expiration Date</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>------------------------</td>
<td>--------------------------------------</td>
<td>---------------------</td>
<td>-------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Molten-Salt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gould, Incorporated</td>
<td>H. F. Gibbard</td>
<td>Li/FeS₂ Thermal Management</td>
<td>119</td>
<td>18</td>
<td>1-84</td>
</tr>
<tr>
<td>Stanford University</td>
<td>R. Huggins</td>
<td>New Battery Materials</td>
<td>355</td>
<td>11</td>
<td>9-83</td>
</tr>
<tr>
<td>ANL</td>
<td>J. E. Battles</td>
<td>Advanced Battery Research</td>
<td>502</td>
<td>12</td>
<td>9-83</td>
</tr>
<tr>
<td>Solid Electrolytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rockwell International, Inc.</td>
<td>F. Lange</td>
<td>Improved β-Al₂O₃</td>
<td>142</td>
<td>12</td>
<td>6-84</td>
</tr>
<tr>
<td>Massachusetts Institute of Technology</td>
<td>B. Wuench</td>
<td>Superionic Conductors</td>
<td>78</td>
<td>12</td>
<td>2-83</td>
</tr>
<tr>
<td>Massachusetts Institute of Technology</td>
<td>H. Tuller</td>
<td>Li Conducting Glasses</td>
<td>114</td>
<td>12</td>
<td>11-83</td>
</tr>
<tr>
<td>ANL</td>
<td>J. E. Battles</td>
<td>Glass Electrolytes</td>
<td>155</td>
<td>12</td>
<td>9-83</td>
</tr>
<tr>
<td>Ambient-Temperature Lithium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>University of Pennsylvania</td>
<td>G. Farrington</td>
<td>Polymeric Electrolytes</td>
<td>120</td>
<td>12</td>
<td>2-84</td>
</tr>
<tr>
<td>Case Western Reserve University</td>
<td>M. Litt</td>
<td>Polymeric Electrolytes</td>
<td>161</td>
<td>17</td>
<td>1-84</td>
</tr>
<tr>
<td>Institute of Gas Technology</td>
<td>R. Remick</td>
<td>Polysulfide Electrocalysis</td>
<td>46</td>
<td>12</td>
<td>10-83</td>
</tr>
<tr>
<td>Cross-Cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois Institute of Technology</td>
<td>J. R. Selman</td>
<td>Transport Correlations</td>
<td>43</td>
<td>30</td>
<td>8-83</td>
</tr>
<tr>
<td>ELECTROCHEMICAL PROCESSES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Membranes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrochemical Technology Corporation</td>
<td>T. Beck</td>
<td>Transport Theory</td>
<td>36</td>
<td>12</td>
<td>5-83</td>
</tr>
<tr>
<td>Brigham Young University</td>
<td>D. Bennion</td>
<td>Transport Phenomena</td>
<td>36</td>
<td>12</td>
<td>4-83</td>
</tr>
<tr>
<td>Air Electrodes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case Western Reserve University</td>
<td>E. Yeager</td>
<td>Macrocyclic Catalysts</td>
<td>136</td>
<td>12</td>
<td>2-84</td>
</tr>
<tr>
<td>Corrosion</td>
<td>J. E. Battles</td>
<td>Polysulfide Containment</td>
<td>243</td>
<td>12</td>
<td>9-83</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Massachusetts Institute of Technology</td>
<td>D. Sadoway</td>
<td>Transport Phenomena</td>
<td>33</td>
<td>9</td>
<td>5-83</td>
</tr>
<tr>
<td>University of California at Los Angeles</td>
<td>M. Baizer</td>
<td>Electroorganic Synthesis</td>
<td>114</td>
<td>16</td>
<td>3-84</td>
</tr>
<tr>
<td>FUEL CELLS FOR TRANSPORTATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LANL</td>
<td>J. Huff</td>
<td>Fuel Cell R&amp;D</td>
<td>2500</td>
<td>12</td>
<td>9-83</td>
</tr>
<tr>
<td>BNL</td>
<td>J. McBreen</td>
<td>Fuel Cell Research</td>
<td>300</td>
<td>12</td>
<td>9-83</td>
</tr>
</tbody>
</table>
This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.