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BATTERY AND ELECTROCHEMICAL SYSTEMS PROGRAM SUMMARY FY 1977

April 1978

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Energy Technology
Division of Energy Storage Systems

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**BATTERY AND ELECTROCHEMICAL SYSTEMS
PROGRAM SUMMARY
FY 1977**

**Edited by
William H. Webster
Program Manager**

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April 1978

**U.S. DEPARTMENT OF ENERGY,
Assistant Secretary for Energy Technology
Division of Energy Storage Systems
Washington, D.C. 20545**

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FOREWORD

The President's National Energy Plan for 1977 calls for the United States to reduce its dependency on foreign oil by conserving its petroleum and natural gas reserves. The Department of Energy's Division of Energy Storage Systems (STOR) is supporting intensive programs to save oil by developing new and/or improved battery systems for electric vehicle, photovoltaic, wind, and utility applications. In addition, electrochemical processes are being studied by STOR to increase the efficiency of industrial processes, such as the manufacture of aluminum.

At present, utility companies are meeting their peak power demands with petroleum-based fuels or natural gas-fired generators or both. A high efficiency (75 percent) and low cost (\$30/kWh) battery storage system could be charged by coal-fired or nuclear baseline generators during off-peak hours. These battery storage systems would then help meet those peak demands. Studies have indicated that such a system will save from 0.5 to 1.0 million barrels of oil per day by the year 2000.

The success of wind and photovoltaic energy conversion systems for residential, commercial, and industrial applications is highly dependent on the development of a cost-effective battery storage system to provide power during periods of no wind or sunlight. The use of 3 to 9 million electric cars by the year 2000 will result in an oil saving from 35 to 90 million barrels per year.

During FY 1977, STOR committed \$13.3 million of its funds to these electrochemical programs and managed an additional \$5.6 million for the Division of Transportation Energy Conservation to develop near-term batteries for electric vehicles.

This publication consists of summaries of all these programs, including contractors, major subcontracts, names of program managers, funding, and a brief description of the objectives and status of each program.

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I. ADVANCED BATTERY SYSTEMS

Argonne National Laboratory

Lithium/Metal Sulfide Battery
Development

Dow Chemical U.S.A.

Sodium-Sulfur Battery System

Ford Motor Company

Sodium-Sulfur Battery
Development

Energy Development Associates

Zinc-Chlorine Battery System

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Lithium/Metal Sulfide Battery Development	Argonne National Laboratory Chemical Engineering Division Argonne, IL 60439	R. K. Steunenberg 312/739-7711

Contract #W-31-109-Eng-38

October 1976--September 1977 (\$5200K)--The objective of this program is to develop lithium-aluminum/metal sulfide batteries for electric vehicle propulsion and for stationary energy storage applications such as load leveling. Rechargeable batteries having much higher specific energy and specific power than existing commercial systems are required for these applications. Approximately one-half of the funding for this project is used for a comprehensive development effort at ANL, which consists of cell chemistry, materials development and testing, electrode development, cell and battery engineering, and systems studies. The other half of the project involves development and procurement subcontracts with industrial firms. The purpose of these subcontracts are to: (1) transfer the technology to industry; (2) augment the base technology development; (3) develop sources of materials and components; (4) develop cell

and battery fabrication and quality control procedures; and (5) provide for the fabrication of test cells and batteries.

The major emphasis of this program consists of developing battery cells containing lithium-aluminum alloy in the negative electrode and a metal sulfide such as FeS or FeS₂ in the positive electrode. The electrolyte is eutectic LiCl-KCl (mp 352°C). The cells for the electric-vehicle battery that are currently being developed are rectangular, about 13 x 13 cm or 13 x 18 cm, and 2-4 cm thick. The proposed cells for the stationary energy storage batteries are in the form of a 25-cm cube and contain multiple electrodes. The specific energies produced by the lithium/metal sulfide cells are in the general range of 100-150 W-hr/kg.

Assessment studies have indicated that storage batteries having a lifetime of 8 to 12 years and a capital cost in the range of \$20-30/kW-hr of storage capacity would be competitive with alternative approaches to the bulk storage of electrical energy generated during off-peak periods by coal or nuclear plants, or by solar, wind, and other sources. Similar assessments have shown that batteries capable of powering electrical vehicles having a range greater than

100 miles (specific energy, 120-160 W-hr/kg), acceleration typical of current compact automobiles, a lifetime of 5 to 10 years, and a cost of \$35-40/kW-hr could be marketed competitively as a second car. Commercialization studies have indicated that manufacturing cost could be in the range of \$20-25/kW-hr.

Much of the cell development effort during the current period is directed toward improving the cell performance through systematic design modifications. Emphasis is placed on the use of designs and materials that are amenable to commercial production. As part of the cell development program, more innovative approaches to cell designs are also explored. The materials development effort is mainly concerned with separators of various forms and materials, improved electrical feedthrough designs, and alloys and coatings for current collectors. The materials work also includes extensive corrosion testing of candidate materials for construction and postoperative examination and evaluation of cells. Cell chemistry studies include assessment of alternative electrolytes, evaluation of electrode additives, identification of the mechanisms of the reactions that occur in operating cells, and improvements in preparative methods for electrode materials.

Coordinated with the development of cells is the design of batteries for the electric vehicle and stationary energy storage applications. The Mark I electric vehicle battery, which will be the first full-scale (30-50 kW-hr) lithium-aluminum/metal sulfide battery, is scheduled for testing in FY 1978, first in the laboratory and later in a van. Conceptual design studies of a 516-MW battery module for stationary energy storage applications have also been completed. Current plans call for the testing of this module in the BEST (Battery Energy Storage Test) Facility in FY 1982.

MAJOR PUBLICATIONS

Gay, E. C., D. R. Vissers, F. J. Martino, and K. E. Anderson, "Performance Characteristics of Solid-Lithium-Aluminum Alloy Electrodes," J. Electrochem. Soc., 123(11), 1591-1596 (Nov. 1976).

Steunenberg, R. K., "Lithium-Aluminum/Metal Sulfide Batteries," AIAA Future of Aerospace Power Symposium, St. Louis, MO, March 1-3, 1977.

Melendres, C. A. "Kinetics of Electrochemical Incorporation of Lithium into Aluminum," J. Electrochem. Soc., 124(5), 650 (1977).

Melendres, C. A. and C. G. Sy, "Anodic Formation of Sulfide Films on Iron in Molten LiCl-KCl," J. Electrochem. Soc., 124(7), 1060 (1977).

Mathers, J. P., T. O. Olszanski, and J. E. Battles, "Evaluation of Porous Paper and Felt Ceramics for Electrode Separators in High-Temperature Li-Al/LiCl-KCl/FeS_x Cells," J. Electrochem. Soc., 124(8), 1149 (1977).

Selman, J. R., D. K. DeNuccio, C. G. Sy, and R. K. Steunenbergh, "Emf Studies of Lithium-Rich Lithium-Aluminum Alloys for High-Energy," J. Electrochem. Soc., 124(8), 1160, (1977).

Shimotake, H., P. A. Nelson, L. G. Bartholme, "Development of Li-Al/FeS_x Cells for Load-Leveling Applications," World Electrochemical Congress, Moscow, U.S.S.R., June 21-25, 1977.

Gay, E. C., H. Shimotake, W. E. Miller, R. C. Elliott, and P. A. Nelson, "Advances in the Development of Li-Al/FeS₂ Cells for Electric-Automobile Batteries," 12th IECEC Conference, Washington, DC, Aug. 28-Sept. 2, 1977.

Miller, W. E., V. Kolba, A. Chilenskas, and K. Gentry, "The Design and Development of a 30 kW-hr Lithium-Aluminum/Iron Sulfide Electric Vehicle Battery," 12th IECEC Conference, Washington, DC, Aug. 28-Sept. 2, 1977.

Shimotake, H., "The Role of High-Temperature Batteries in the Energy Problem," IUPAC Post-Congress Symposium, Kyoto Kaikan, Okazaki, Kyoto, Japan, Sept. 12-13, 1977.

DOE PROGRAM MANAGER: A. Landgrebe (202) 376-9421

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Lithium/Metal Sulfide Battery Program	Atomics International Division of Rockwell International	S. Sudar

October 1976--September 1977 (\$475K)--The overall objective of this project is the development of lithium/iron sulfide batteries for stationary energy storage applications such as electric utility load-leveling. A lithium-silicon alloy is used as the active material in the negative electrodes, and the positive electrodes contain iron sulfide. The cells use an electrolyte of molten LiCl-KCl and are operated at temperatures above 400°C.

Development work is under way on inexpensive, long-life positive electrodes of iron sulfide having high active-to-structural weight ratios and the lowest possible voltage loss. High purity ceramic separators and other components that are resistant to attack in the cell environment are also being developed. In this contract period, a number of small, compact bicells with electrodes 5 cm² in area (FeS positive and Li₄Si negative electrodes) underwent performance testing, and a 1.0 kW-hr demonstration cell was placed into operation.

An instrumented 1.0 kW-hr cell is being constructed for thermal characterization of large cells.

MAJOR PUBLICATIONS

Lee, H. M., and S. Lai, "Corrosion of Ceramics in Molten/LiCl-KCl Mixtures," Fall Meeting of Electrochemical Society, Las Vegas, NV, Oct. 17-22, 1976.

Lai, S., and A. F. Sammells, "Improved Negative Electrodes for Lithium/Iron Sulfide Batteries," 12th Intersociety Energy Conversion Conference, Washington, DC, Aug. 28-Sept. 2, 1977.

Sudar, S., L. A. Heredy, J. C. Nall, and L. R. McCoy, "Development Status of Lithium-Silicon/ Iron Sulfide Load-Leveling Batteries," 12th Intersociety Energy Conversion Conference, Aug. 28-Sept. 2, 1977.

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Lithium/Metal Sulfide Battery Program	Gould, Incorporated	R. Rubischko

October 1976--September 1977 (\$403K)--One of the objectives of this program is the development of a prismatic cell design for an uncharged Li-Al/FeS cell with hot-pressed, 13 x 18 cm electrodes that can produce high specific energy. In this contract period, Gould completed the fabrication of six of this type of cells. Four of these cells have been sent to ANL for testing and two were kept at Gould for testing.

Gould is planning to fabricate 50 upper-plateau FeS₂ cells. These cells will be fabricated in accordance with a requirement matrix that provides for varied compositions and thicknesses of electrodes as well as a wide range of current collector candidates. This matrix test is expected to produce statistical data on cell performance and the effects of design variations on performance.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Lithium/Metal Sulfide Battery Program	Carborundum Company	R. Hamilton

October 1976--September 1977 (\$545K)--The principal objective of this contract is to develop fabrication techniques for porous, ceramic papers suitable for use as separators in lithium-aluminum/metal sulfide cells. The experimental procedures for paper making have been reestablished on the basis of previous experience, and application of the process to the preparation of boron nitride paper is under investigation. Particular attention is directed toward the use of binders to increase the strength of the paper. Samples of the paper are being provided to ANL for testing and evaluation.

In this period, the Carborundum Company produced boron nitride roving at the rate of about 15 kg/month. The material is being stockpiled as roving for later conversion to either fabric or felt separators. A preliminary cost estimate by Carborundum has indicated that the manufacturing cost of boron nitride separators should be about \$12.50/m² (\$1.25/ft²) at moderately high production rates. However, Carborundum noted that considerable

developmental effort remains to be done to optimize the felt fabrication process, to convert from a laboratory process to a production process, and to design a production plant.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Lithium/Metal Sulfide Battery Program	Catalyst Research Corporation	D. Harney

October 1976--September 1977 (\$91K)--Catalyst Research has fabricated and delivered to ANL an FeS₂ cell using their ultradry room (air atmosphere) for assembly. The negative electrodes of this cell were constructed using a dip-casting procedure developed by Catalyst Research in which liquid Li-Al is cast onto a stainless steel screen in an inert-atmosphere glove box. It is expected that operation of this cell will provide valuable information on the performance of this type of negative electrode and on fabrication techniques for cells in a dry air environment. Catalyst Research is also planning on fabricating carbon-bonded positive electrodes for ANL.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Lithium/Metal Sulfide Battery Program	Eagle-Picher Industries	R. Hudson

October 1976--September 1977 (\$390K)--Eagle-Picher is currently fabricating 55 cells of a mixed variety, i.e., FeS and FeS₂ types that are either charged or uncharged. The cells are divided into nine groups with various design changes incorporated in each group: for example, variation in the ratio of positive to negative electrode capacity, increasing the diameter of the positive lead to 0.64 cm, use of Y₂O₃ felt rather than BN cloth as a separator, and an improved method of attaching a honeycomb current collector to the positive current lead. Results of these design variations are being evaluated by comparing cell performance to that of the baseline cells. The objectives of the design variations are to improve the specific energy over that of the baseline designs and to examine alternative materials. Provisions for modifying the cold-pressing operation to increase the electrode size to 13 x 18 cm are also under way.

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Development of the Hollow Fiber Sodium-Sulfur Battery	Dow Chemical Company 2800 Mitchell Drive Walnut Creek, CA 94548	Earl Wagener 415/944-2086

Contract No. EY-C-02-2565

March 11, 1977--December 1977 (\$591K)--Development of the glass hollow fiber sodium-sulfur cell can result in rechargeable batteries having energy densities and power densities of about 200 watt hours per kg and 180 watts per kg, respectively. The cell utilizes the thin walls of fine hollow glass fibers as the solid electrolyte, and liquid sodium anolyte being contained inside the lumen of the fibers. The sulfur-sulfide catholyte is outside of and surrounds the fiber. Many thousands of these fibers, typically 50 μ I.D. and 80 μ O.D., are bundled in parallel to give a cell with extremely high electrode and electrolyte surface area and very low internal resistance. The cell does not degrade on deep charge-discharge cycling, keeping essentially all its capacity after hundreds of cycles and many months of continuous operation.

Small 0.5 A-hr cells have operated continuously as long as 384 days and 9,068 cycles at the 1.6 hour rate before failing. Larger 6 A-hour cells have operated up to 97 days of continuous cycling (217 cycles) to 75% depth. Cell failure due to fiber breakage has almost been eliminated by close attention to quality control and by removing all the oxide from the sodium anolyte. Most failures now are associated with the tubesheet-fiber interface.

The tubesheet must be impermeable. Since it is made by fusing low melting glass frit, methods of grinding the glass to a frit and fusing it around the fibers without weakening the fibers at the seal are being investigated.

The cells are encased in stainless steel and techniques were developed to assemble and weld the case without causing stresses on the glass fiber assembly.

This necessitated some stainless steel to aluminum welds and some flexible connections.

A cell testing system to charge-discharge up to 24 cells has been built. It can charge-discharge at various rates to voltage limits or on timed cycles.

Cell voltages, currents, and resistances are recorded. A conservative cost-for-sale for the bare cell of \$25.10 per kw-hr was obtained by analyzing the production steps necessary to make 400 ampere-hour, 50 ampere cells at a rate of 1,250,000 a year.

The goals of this development effort include increasing the lifetimes of the cells and increasing the "yield" of good cells. Scale-up from the 3,000 fiber 6 ampere-hour cell has begun. Preliminary designs on adapting the hollow fiber cell to the large BEST load leveling facility have been started. Designs to insure that the 40 ampere-hour and the proposed 400 ampere-hour cells will be safe are being tested.

MAJOR PUBLICATIONS

Levine, C. and J. Anand, "The Sodium-Sulfur Battery with Glass Electrolyte," presented at the Electrochemical Society Annual Meeting, Atlanta, GA, October 9-14, 1977.

DOE PROJECT MANAGER: K. Klunder (202) 376-9254

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Sodium-Sulfur Battery Development Program	Ford Motor Company Engineering & Research Staff Dearborn, MI 48121	Armen Topcuzian 313/323-0727

Contract No. EY-C-02-2566

June 1976--October 1977 (3.2 \$M)--Materials limitations remain the main obstacle to successful development of the sodium-sulfur battery. Development efforts this year have been concentrated on four areas: materials for the sulfur container, conductive ceramic electrolyte, cell design and analysis, and installation of facilities for cell fabrication and testing.

Many materials have been screened by static corrosion tests in Na_2S_4 at elevated temperatures, but no technical grade metal has been found that simultaneously offers sufficient stability to corrosion by molten sodium polysulfides, and suitable electronic conductivity through its surface film to function effectively as a current collector/electrode. Several materials have been identified that appear stable and conductive--carbon or graphite, doped rutile, certain conductive glasses, and oxides of some metals. Most of these

materials are difficult to fabricate or are fragile. Coating techniques are being evaluated for applying various corrosion resistant layers to metallic containers. Those systems, shown superior in static tests, are being evaluated in prototype cells. One materials system has been cycle-tested for over 8 months and shown a capacity decrease of less than 10 percent.

Development efforts for beta"-alumina ceramic electrolyte consist of processing improvements for cost reduction and for controlling grain size, chemical homogeneity and dimensional control of larger tubes (3.3 cm OD x 25 cm long). Improved facilities for powder preparation, green forming, sintering, characterizing, and sealing were developed. The design for a pilot plant for ceramic production was completed and facilitization begun. Operation is planned for the summer of 1978.

Prototype cells were fabricated and tested to evaluate many variations in materials and sulfur electrode designs. Cells with 150 Ah theoretical capacity ($\text{S--Na}_2\text{S}_3$) have yielded 112 Ah @ C/16 and 82 Ah @ C/6 rates. Smaller prototype cells (100 Ah th. cap.) have yielded up to 85 Ah and 160 Wh/kg, both at C/14 rate.

Pre-pilot facilities for cell assembly and filling at rates up to 100 cells/month were installed and are presently in operation at lower rates. Automatic test control and data acquisition for 35 individual cell stations are now operational at Aeronutronic Division, Ford Aerospace and Communications Corporation. These stations are suited for testing large cells and can control load currents up to 50 amperes. Twenty additional automatically controlled test stations are in operation at the Ford Research Laboratory.

The ultimate goals of the program are to design and develop a 5 MWh energy storage system, and to install and demonstrate its operation at the BEST facility. A second goal is to develop a battery for powering an electric vehicle.

MAJOR PUBLICATIONS

Mikkor, M., R. W. Minck, F. A. Ludwig, and N. K. Gupta, "Effect of Electrode Shape and Additives on Performance of the Na/S Cells," Electrochem. Soc. Meeting, October 1976.

Weiner, S. A., "The Sodium-Sulfur Battery," 27th Power Sources Conference, June 1976.

Weiner, S. A. "Chemistry of Sodium-Sulfur Battery," American Chem. Society, August 1976.

Weiner, S. A. "Review of the Ford Na-S Battery Program," ERDA Battery Conference Coordination Meeting, January 1977, Germantown, MD. Also presented to BEST Facility--Workshop II, February 1977, New Orleans, LA.

Unnewehr, L. E., R. W. Minck, and C. Owens, "Application of Ford Na-S Battery in Electric Vehicles," Paper 770382 SAE, February 1977, Detroit, MI.

Tischer, R., and F. Ludwig, "The Sulfur Electrode in Non-Aqueous Media," Advances in Electrochemistry and Electrochemical Engineering, Vol. 10, H. Gerischer and C. Tobias, Editors, John Wiley and Sons (1977).

Ludwig, F., "Applications of Carbon in the Sodium-Sulfur Battery," 13th Biennial Conference on Carbon, Extended Abstracts, pg. 39, Irvine, CA, July 1977.

DOE PROGRAM MANAGER: K. Klunder (202) 376-9254

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Sodium-Sulfur Battery Development	Aeronutronic Division Ford Aerospace & Communications Corporation Newport Beach, CA 92663	R. A. Harlow 714/759-5798

June 1976--October 1977 (\$1.34 M)--The Aeronutronic Division, FACC program consists of materials development, cell design and analysis, facilitization for the manufacture and evaluation of cells, and development of assembly procedures for high rate production. Major accomplishments for the period include: identification of a promising container materials system that has allowed cell operation for 8 months with <10% capacity loss; design and prototype cells; creation of a 35 station automatic cell testing facility and a 20-cell quality assurance test station; and initial evaluation of the 26 prototype cells.

During later stages of this contract, Aeronutronic Division will assume responsibility for the construction of a 5 MWh battery for delivery to BEST Facility. This task includes: facilitization for increased cell production

rates; manufacturing development for cost reduction and quality control; design and evaluation of requisite charge and thermal control systems for the battery; and validation of performance characteristics for the full battery and smaller modules.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Sodium-Sulfur Battery Development	University of Utah Department of Materials Science and Engineering University of Utah Research Institute Salt Lake, UT	R. S. Gordon 801/581-6612

June 1976--October 1977 (1.09 \$M)--The U of U program consists primarily of those process developments necessary for high rate production of high quality beta"-alumina ceramic electrolyte tubes. These efforts include: powder preparation procedures for obtaining suitable purity, chemical homogeneity and handling characteristics; forming processes to achieve uniform properties and dimensional control; high rate sintering methods to provide densification and dimensional control without exaggerated grain growth or unacceptable soda loss; and development of NDT procedures for quality control. An adjunct effort consists of developing and characterizing Ta-doped rutile tubes for possible use as the sulfur container. The UURI program consists of acquiring space and developing pilot plant facilities for high rate ceramic production.

Major accomplishments for the period include improvements in all above areas resulting in routine production (up to 100 tubes/month) of 3.3 x 25 cm (OD x L) tubes having conductivity exceeding $0.2 \text{ (Ohm-cm)}^{-1}$, strengths exceeding 25 kpsi, and microstructures containing few grains larger than $50 \mu\text{m}$. Substitution of 2-5 \$/lb alumina powder in place of 10-15 \$/lb powder previously used can now be used without adversely affecting ceramic properties. A pilot plant for high rate ceramic production was designed, necessary equipment ordered, and the building modifications begun to meet the July 1978 startup date.

MAJOR PUBLICATIONS

Virkar, Anvil V., and Ronald S. Gordon, "Application of Load-Relaxation Techniques to Study Subcritical Crack Growth in Brittle Materials," J. American Ceramic Soc. 59 (1-2), 68-71 (1976).

Virkar, Anvil V., and Ronald S. Gordon, "Fracture Properties of Polycrystalline Lithia-Stabilized Beta"-Alumina," J. American Ceramic Soc. 60 (1-2), 58-61 (1977).

Youngblood, G. E., A. V. Virkar, W. R. Cannon and R. S. Gordon, "Sintering Process and Heat-Treatment Schedules for Conductive, Lithia-Stabilized Beta- Al_2O_3 ," Bulletin J. American Ceramic Soc. 56 (2), 206-210 (1977).

Singh, J. P., A. V. Virkar, and R. S. Gordon, "Thermal Shock Behavior of Lithia-Stabilized Beta-"Alumina," J. American Ceramic Soc. (in press).

Virkar, A. V., G. R. Miller, and R. S. Gordon, "Resistivity-Microstructure Relationships in Lithia-Stabilized Polycrystalline Beta"-Alumina," J. American Ceramic Soc. (in press).

Virkar, A. V., and R. S. Gordon, "Evolution of Microstructures and Properties in Lithia-Stabilized Polycrystalline Beta"-Alumina,"; and A. D. Jatkari, I. B. Culter, and R. S. Gordon, "Conversion Catalysis and Microstructure Control in the Sintering of Lithia-Stabilized Beta"-Alumina," Proceedings of Sixth International Materials Symposium--Ceramic Microstructures, August 25-27, 1976, University of California, Berkeley, Edited by R. M. Fulrath and J. A. Pask, Ceramic Microstructures - 1976, Westview Press, Boulder, CO.

Youngblood, G. E., G. R. Miller, and R. S. Gordon, "Relative Effects of Phase Conversion and Grain Size on Sodium Ion Conduction in Polycrystalline, Lithia-Stabilized Beta"-Alumina," J. Ceramic Soc. (submitted for publication).

Johnson, O. W., and G. R. Miller, "A Metal-Clad Electronic Ceramic Container and Electrode System," Bulletin American Ceramic Soc., p. 706, Aug. 1977.

Gordon, R. S. "The Processing and Characterization of Beta"-Alumina Ceramics for Use in the Sodium-Sulfur Battery," Proceedings of the U.S.--Japan Seminar on Basic Science of Ceramics 1975 on Processing, Kinetics and Properties of Electronics and Magnetic Ceramics, Editors W. Komatsu, R. M. Fulrath, Y. Oishi, M. Koizumi, and S. Somiya, sponsored by Japan Society for the Promotion of Science and the U.S. National Science Foundation, pp. 117-124 (1976).

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Zinc-Chlorine Battery System	Energy Development Associates 1100 Whitcomb Avenue Madison Heights, MI 48701	Peter Carr 313/583-9434

Contract No. E-(11-1)-2966

June 1975--December 1977 (\$614K)--The objective of the contract is to continue research and development of the zinc-chlorine secondary battery system in the first phase and then, based on the current state-of-the-art available at that time, build and test two 50kWh battery systems to be delivered to DOE for further evaluation and qualification testing at the end of the contract.

The electrochemical couple involved in the system is zinc-chlorine which has a potential of 1.12 V, is reversible, and has a theoretical energy density of 380 Wh/lb. The basic cell design uses graphite for both electrodes, the chlorine electrode being porous and used in the flow-through mode in a circulating electrolyte loop. The cell uses no separator, yet is capable of >80 percent coulombic efficiency with suitable design and operating conditions.

A unique feature of the battery system is the storage of the chlorine evolved in charge, in a separate storage compartment, and in the form of chlorine hydrate. This substance is a solid at atmospheric pressure and temperature less than 10°C. It may be formed in water or electrolyte, at all concentrations, ranging from a slurry to a dense cake. It may be readily decomposed to yield gaseous chlorine for discharge. The battery operates at ambient temperatures and pressures, and the system is sealed.

Using basically inexpensive materials and showing promise of very long life, the system is potentially useful for vehicle propulsion and for load leveling applications. Projected battery costs range from \$25-50 kWh in a mature market.

The major achievement in FY 1977 was the design, development and fabrication of a packaged 50 kWh experimental battery module for vehicle applications. In this development program, the following specific accomplishments were made.

- o Developed a lightweight stack structure (2kgm/kWh)
- o Developed a photochemical H₂/Cl₂ recombination system

- o Established relationship between pH and temperature on H₂ evolution and pH on CO₂ evolution
- o Minimized parasitic currents in the common electrolyte system
- o Developed magnetically coupled (rare earth magnets) electrolyte and gas pumps
- o Developed gas pump hydrate former/store
- o Developed a simple single point battery control system
- o Developed a "Kynar" lined battery case
- o Designed a self-contained battery package

A 25 kWh breadboard battery was used to develop and integrate the battery system and from this model the 50 kWh battery was developed. Life testing has continued and 800+ cycles without deterioration in performance have been recorded for single cells on a 75 percent depth of discharge cycle over 2 years of testing. Cycle testing is continuing but already represents a satisfactory life for vehicle battery applications.

In parallel with the cost shared DOE/EDA vehicle battery program, a load leveling zinc-chlorine battery program, co-funded by the Electric Power

Research Institute and EDA, is also being carried out.

DOE PROGRAM MANAGER: K. Klunder (202) 376-9254

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Zinc-Chlorine Battery System	Gulf and Western Advanced Development and Engineering Center	J. Kiwalle

June 1976--June 1977 (\$142K)--This subcontract was initially let as a battery design and fabrication program but was subsequently modified to a component development activity. The major components developed were:

- o Rare earth magnetic couplings for pump drives
- o Chiller and main electrolyte heat exchangers
- o Float and solenoid valves
- o Hydrate compaction feasibility studies

II. NEAR-TERM BATTERY SYSTEMS

Argonne National Laboratory

Ambient Temperature Batteries

Argonne National Laboratory

Applications of Batteries for
Solar Energy Storage

Naval Research Laboratory

Improvement of the Lead-Acid
Battery for Load Leveling
Applications

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Ambient Temperature Batteries	Argonne National Laboratory Chemical Engineering Division Argonne, IL 60439	N. P. Yac 312/729-7711

Contract #W-31-109-Eng-38

October 1976--September 1977 (\$1,108K)--This project is directed to the development and demonstration of near term battery technology for electric vehicles in support of the Electric and Hybrid Vehicles Research, Development, and Demonstration Act of 1976, P.L. 94-413. A small effort is also included in this project on the development of near term batteries for bulk electrical energy storage. Verification and qualification of the battery technology developed under this project and other DOE battery projects will be conducted in the National Battery Test Laboratory located at ANL. Implementation and operation of this laboratory is included in this project. Other activities to support this program include a small supporting research group at ANL, and the coordination and support of the activities of the National Battery ad hoc Advisory Committee.

The near term electric vehicle batteries covered under this project include the lead-acid, nickel/zinc and nickel/iron systems. The major development efforts on these batteries are being subcontracted, on a cost-sharing basis where possible, with battery manufacturers who have developed the background technologies. The role of ANL is to assist DOE with the management and coordination of these industrial contracts under a uniformly directed plan. The basic research group at ANL provides support to the industrial contracts.

The strategy of the battery development plan initially is to explore several promising approaches that exist for the battery systems under cost-sharing arrangements with industry, and later one or two battery systems will be selected for full-scale demonstration. The end products of this project are the delivery and demonstration of several full-scale electric vehicle batteries. The technology and the economics of the near term batteries will be adequately demonstrated within the 5-year schedule of this program.

During the current contract period, final design and cost reports for lead-acid, nickel/zinc, and nickel/iron electric vehicle batteries were

issued by 10 battery manufacturers under contract to ANL. The manufacturers participating on this effort were: lead-acid batteries--ESB, Inc., Globe-Union, Eltra, and Gould, Inc.; nickel/zinc batteries--Yardney Electric, Energy Research Corporation, Gould, Inc., and Eagle-Picher Industries; and nickel/iron batteries--Westinghouse and Eagle-Picher Industries. The follow-on research, development and demonstration program will be initiated in FY 1978.

Work is in progress on the construction and implementation of the National Battery Test Laboratory (NBTL). The computer hardware, interfacing equipment and data storage and display units have been installed and tested. According to the present schedule, in 1978, the NBTL will have the capability of concurrently testing 100 cells and two 30-40 kw-hr batteries. The test equipment is designed to allow data acquisition while cells or batteries are being added or removed from the system.

The work being carried out by supporting research groups at ANL is primarily directed to research projects of fundamental interest to the development of ambient temperature batteries. During 1977, an analysis was made on

the thermal phenomena for lead-acid batteries, a mathematical model was developed to describe the behavior of a porous nickel oxide electrode, and a series of experiments were performed to obtain measurements in an apparatus simulating the performance of a porous electrode. These efforts will continue in 1978, and new projects will be undertaken in response to needs expressed by battery developers.

DOE PROGRAM MANAGER: R. Shivers (202) 376-9267

MAJOR PUBLICATIONS

Choi, K. W. and N. P. Yao, "An Engineering Analysis of Thermal Phenomena for Lead-Acid Batteries During Recharge Processes," U.S. ERDA Report ANL-77-24, April 1977.

U.S. ERDA Report ANL/OEPM-77-4, "The National Battery Test Laboratory--Design Report April 1976 - April 1977," 1977.

Varma, R. and N. P. Yao, "Stibine and Arsine Generation From A Lead-Acid Cell

During Charging Under Utility Load-Leveling Duty Cycle," U.S. ERDA Report ANL/OEMP 77-5, 1977.

Choi, K. W. and N. P. Yao, "Thermal Analysis of Lead-Acid Batteries for Load-Leveling Applications," Extended Abstracts Fall Meeting The Electrochemical Society October 9-14, p. 250-254, 1977.

The following reports represent the results of the Design and Cost Studies carried out by battery manufacturers under contract with ANL.

Nickel/Zinc

ERDA Report No. ANL-K76-3543-1, Yardney Electric Division Reference No. 21636, "Final Report-Design and Cost Study-Zinc/Nickel Oxide Battery for Electric Vehicle Propulsion," Contract No. 31-109-38-3543, October 1976.

ERDA Report No. ANL-K-3541-1, Energy Research Corporation, "Design and Cost Study

of Nickel-Zinc Batteries for Electric Vehicle," Final Report, Contract No. 31-109-38-3541, October 1977.

ERDA Report No. ANL-K-77-3558-1, Gould Report No. 762-003-1, "Develop Nickel-Zinc Battery Suitable for Electric Vehicle Propulsion," Contract No. 31-109-38-3558, February 1977.

ERDA Report No. ANL-K-77-3542-1, Eagle-Picher Industries, Inc., "Design and Cost Study for Nickel-Zinc Battery Manufacture, Electric Vehicle Propulsion Batteries," Contract No. 31-109-38-3542, June 1977.

Lead-Acid

ERDA Report No. ANL-K-77-3621-1, ESB, Incorporated, "Cost and Design Study to Develop Lead Acid Batteries for Electric Vehicle Propulsion," Contract No. 31-109-38-3621, February 1977.

ERDA Report No. ANL-K-77-3624-1, Globe-Union, "Design and Cost Study for

Development of Lead-Acid Batteries Suitable for Electric Vehicle Propulsion,"
Contract No. 31-109-38-3624, August 1977.

ERDA Report No. ANL-K-77-3628-1, Eltra, "Development of a Lead Acid Battery
Suitable for Electric Vehicle Propulsion, Final Report, Task A, Design and Cost
Study," Contract No. 31-109-28-3628, August 1977.

Gould, Inc., "State of the Art Lead-Acid Electric Vehicle Batteries," Contract
No. 31-109-38-3659, October 1977 (to be issued).

Nickel/Iron Oxide

Eagle-Picher Industries, "Design and Cost Study for Nickel/Iron Oxide Electric
Vehicle Battery," Contract No. 31-109-38-3709, October 1977 (to be issued).

Westinghouse, "Design and Cost Study for Nickel/Iron Oxide Electric Vehicle
Battery," Contract No. 31-109-38-3723, October 1977 (to be issued).

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Lead-Acid Electric Vehicle Batteries	C&D/Eltra Corporation Plymouth Meeting, PA 19462	Charles Fleischmann

Contract No. 31-109-38-3628

October 1976--September 1977 (\$28K, FY 76-77)--Eltra Corporation shall provide a design and cost study for improved and advanced lead-acid electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

ERDA Report No. ANL-K-77-3628-1, Eltra Corporation, "Development of a Lead Acid Battery Suitable for Electric Vehicle Propulsion, Final Report, Task A, Design and Cost Study," Contract No. 31-109-28-3628, August 1977.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Lead-Acid Electric Vehicle Batteries	ESB, Incorporated Yardley, PA 19067	George Hartman 215/493-3601

Contract No. 31-109-38-3621

October 1976--September 1977 (\$25K, FY 76-77)--ESB, Inc., shall provide a design and cost study for improved and advanced lead-acid electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

ERDA Report No. ANL-K-77-3621-1, ESB, Incorporated. "Cost and Design Study to Develop Lead Acid Batteries for Electric Vehicle Propulsion," Contract No. 31-109-38-3621, February 1977.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Lead-Acid Electric Vehicle Batteries	Globe-Union Milwaukee, WI 53201	Conrad Weinlein 414/228-2173

Contract No. 31-109-38-3624

October 1976--September 1977 (\$36.6K, FY 76-77)--Globe-Union shall provide a design and cost study for improved and advanced lead-acid electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

ERDA Report No. ANL-K-77-3624-1, Globe-Union, "Design and Cost Study for Development of Lead-Acid Batteries Suitable for Electric Vehicle Propulsion," Contract No. 31-109-38-3624, August 1977.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Lead-Acid Electric Vehicle Batteries	Gould, Incorporated Rolling Meadows, IL 60008	Hans F. Espie 312/640-4411

Contract No. 31-109-38-3639

October 1976--September 1977 (\$29K, FY 76-77)--Gould, Incorporated shall provide
a design and cost study for improved and advanced lead-acid electric vehicle
batteries. The study will verify the state-of-the-art of the batteries and
identify areas of improvement for future development efforts. The study will
also provide estimates of battery costs for pilot scale and production scale of
manufacture. Recommendations for test procedures and test standards will also be
included. A final report on this study was submitted to Argonne National Laboratory
in 1977.

MAJOR PUBLICATION

Gould, Inc., "State of the Art Lead-Acid Electric Vehicle Batteries," Contract
No. 31-109-38-3639, October 1977 (to be issued).

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Nickel/Zinc Electric Vehicle Batteries	Eagle-Picher Industries Joplin, MO 64801	Rex Erisman 417/623-8000

Contract No. 31-109-38-3542

October 1976--September 1977 (\$15K, FY 76-77)--Eagle-Picher Industries shall provide a design and cost study for improved and advanced nickel/zinc electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

ERDA Report No. ANL-K-77-3542-1, Eagle-Picher Industries, Inc., "Design and Cost Study for Nickel-Zinc Battery Manufacture, Electric Vehicle Propulsion Batteries," Contract No. 31-109-38-3542, June 1977.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Nickel/Zinc Electric Vehicle Batteries	Energy Research Corporation Bethel, CT 06801	Martin Klein 203/792-1460

Contract No. 31-109-38-3541

October 1976--September 1977 (\$15K, FY 76-77)--Energy Research Corporation shall provide a design and cost study for improved and advanced nickel/zinc electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

ERDA Report No. ANL-K-3541-1, Energy Research Corporation, "Design and Cost Study of Nickel-Zinc Batteries for Electric Vehicle," Final Report, Contract No. 31-109-38-3541, October 1977.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Nickel/Zinc Electric Vehicle Batteries	Gould, Incorporated Rolling Meadows, IL 60008	Robert Fedor 312/640-4378

Contract No. 31-109-38-355E

October 1976--September 1977 (\$24.7K, FY 76-77)--Gould, Inc., shall provide a design and cost study for improved and advanced nickel/zinc electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

ERDA Report No. ANL-K-77-3558-1, Gould Report No. 762-003-1, "Develop Nickel-Zinc Battery Suitable for Electric Vehicle Propulsion," Contract No. 31-109-38-3558, February 1977.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Nickel/Zinc Electric Vehicle Batteries	Yardney Electric Company Pawcatuck, CT 02891	Harvey Seiger 203/599-1100

Contract No. 31-109-38-3543

October 1976--September 1977 (\$24K, FY 76-77)--Yardney Electric Company shall provide a design and cost study for improved and advanced nickel/zinc electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

ERDA Report No. ANL-K76-3543-1, Yardney Electric Division Reference No. 21686, "Final Report-Design and Cost Study-Zinc/Nickel Oxide Battery for Electric Vehicle Propulsion," Contract No. 31-109-38-3543, October 1976.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Nickel/Iron Oxide Electric Vehicle Batteries	Eagle-Picher Industries Joplin, MO 64801	William Harsh 417/623-8000

Contract No. 31-109-38-3709

October 1976--September 1977 (\$15K, FY 76-77)--Eagle-Picher Industries shall provide a design and cost study for improved and advanced nickel/iron oxide electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

Eagle-Picher Industries, "Design and Cost Study for Nickel/Iron Oxide Electric Vehicle Battery," Contract No. 31-109-38-3709, October 1977 (to be issued).

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Design and Cost Study for Nickel/Iron Oxide Electric Vehicle Batteries	Westinghouse Electric Corporation R&D Center Pittsburgh, PA 15235	Ronald E. Vail 412/256-3623

Contract No. 31-109-38-3723

October 1976--September 1977 (\$30K, FY 76-77)--Westinghouse Electric Corporation shall provide a design and cost study for improved and advanced nickel/iron oxide electric vehicle batteries. The study will verify the state-of-the-art of the batteries and identify areas of improvement for future development efforts. The study will also provide estimates of battery costs for pilot scale and production scale of manufacture. Recommendations for test procedures and test standards will also be included. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATION

Westinghouse, "Design and Cost Study for Nickel/Iron Oxide Electric Vehicle Battery," Contract No. 31-109-38-3723, October 1977 (to be issued).

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Application of Batteries for Solar Energy Storage	Argonne National Laboratory 9700 South Cass Avenue Argonne, IL 60439	N. P. Yao 312/739-7711

Contract #W-31-109-Eng-38

October 1976--September 1977 (\$100K)--The objective of this project is to develop a set of specifications and recommendations for the development of near-term and advanced battery technology for the storage of solar energy in practical commercial applications. This objective is achieved through application assessment studies, cost and design studies, and through laboratory performance tests on small-scale systems. The assessment effort is expected to provide initial recommendations and specifications for battery development, and to be followed by two other parallel efforts of short-term (2-year) and long-term (5-year) development activities. The short-term development is aimed at generating baseline performance data and design data with existing battery/solar technology, and refining the cost and design application assessment studies. The long-term program concerns developing selected advanced battery technologies and generating

the baseline performance and design data for the advanced solar/battery system technologies.

An assessment study completed in 1977 identified the battery system interfacing and the battery performance and cost requirements for solar photovoltaic power systems. The information contained in this study, together with the results from the workshop on batteries for solar photovoltaic systems, scheduled for January 1978, will serve to generate the basic information required for the formulation of a program plan. The program plan, which will be prepared during FY 1978, will identify the technology development programs.

MAJOR PUBLICATION

ERDA Report No. ANL/OEPM-77-3, by Bechtel Corporation, "Final Report on Battery Storage Performance Requirements for Terrestrial Solar Photovoltaic Power Systems," August 1977.

DOE PROGRAM MANAGER: Rufus Shivers (202) 376-9267

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Battery Storage Performance Requirements for Terrestrial Solar Photovoltaic Power Systems	Bechtel Corporation San Francisco, CA	W. J. Stolte 415/768-5430

Contract No. 31-109-38-2962

October 1976--September 1977 (\$58K)--This project consisted of a study to assess the performance requirements for near- and mid-term batteries for application to solar photovoltaic power systems. The study evaluated a broad spectrum of photovoltaic applications in terms of the types of loads served and the characteristics of the system components. Four applications, representative of low, intermediate and high power systems, were examined in detail. The characteristics for the batteries in each application were determined and an economic analysis was made to determine the allowable battery break-even costs. The study identified the most promising battery/solar systems application and specific battery technologies that require development, and presented guidelines for development programs.

MAJOR PUBLICATION

ERDA Report No. ANL/OEPM-77-3, by Bechtel Corporation, "Final Report on Battery Storage Performance Requirements for Terrestrial Solar Photovoltaic Power Systems," August 1977.

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Improvement in the Lead-Acid Storage Battery for Load-Leveling Applications	Naval Research Laboratory Inorganic and Electrochemistry Branch Chemistry Division Washington, DC 20375	A. C. Simon 202/767-2631

Contract #EC-77-A-31-1002-01

January 1977--December 1977 (\$165K)--For the near-term, the lead-acid battery is the only electrochemical storage system that economically or practically can be considered for energy storage. Even this system is marginal from an economic standpoint. Therefore, the purpose of this investigation is to explore means for increasing the efficiency of this battery system through improved manufacturing steps or changes in the battery materials. The present battery uses less than 50 percent of the active materials required in its manufacture, for example, and improvements of this utilization or prolonged life of the battery would do much to make this system more attractive from an economic standpoint. Our prior investigations have shown that this poor utilization of the active material is mainly due to the formation of an electrochemically inactive form of PbO_2 . Pulsed nuclear magnetic resonance study revealed the presence of a hydrogen

nuclear species in formed and cycled lead dioxide battery plates, while this hydrogen species was found to diminish by about 80 percent in chemically prepared beta-PbO₂. Plates cycled to failure also showed a loss in this hydrogen signal. A neutron diffraction study of the atomic structure has also showed differences in chemically prepared beta-PbO₂ and active material taken from electrolytically prepared PbO₂ plates, confirming earlier differential thermal analysis-found differences, and suggesting that the electrochemically reactive form of PbO₂ is altered structurally during cycling, either being converted to the chemical modification or into another form with similar reduced electrochemical activity.

Since the PbO₂ crystals obtained from active material are of very small size, it has not been feasible to study structure by the use of single crystals, and x-ray diffraction methods have had to be devised to determine atomic spacings. This has now proven successful. By a combination of x-ray and neutron diffraction studies, this method is capable of determining the O and H atom spacings in the lattice, other interatomic distances in the sample, and also of yielding thermal parameters and coordination numbers. The method has been found in good agreement with published data on beta-PbO₂ and is now being used in an effort to follow

the changes that occur in the lattice parameters during the cycling of batteries to failure. Since very little success has been achieved in attempts to modify the ratio of electrochemically active to inactive PbO_2 by trial and error, it has become extremely important to understand this mechanism.

Another portion of the investigation is directed toward the determination of the role that antimony plays in preserving the cohesion of the active material and preventing softening and shedding. Through a study of alloys containing various amounts of antimony and comparison with alloys containing none, an attempt is being made to determine the minimum amount that is necessary for this purpose and whether other means can be found to obtain similar characteristics in the active material. Minimizing or eliminating antimony from the grid alloys is extremely important in relation to reducing self-discharge, avoiding the generation of stibine, and reducing the frequency of water additions to batteries in service. This portion of the investigation is closely coupled to the research activities of the various battery companies, and a large number of the samples being studied are from cycling tests on actual batteries prepared and cycled by the various companies.

Another portion of the investigation is directed toward determining the kinetics

of some of the battery processes by using an image analyzer in conjunction with metallurgical cross sections, and analyzing the extent of reaction at various depths in the electrode cross section. By varying various parameters such as current density, specific gravity of electrolyte, temperature, etc., under controlled conditions, the effect on the rate and depth of reaction can be determined and the necessary data can be obtained for realistic projections as to the behavior of scaled-up cells with thicker plates, different electrode spacings, and other characteristics for which there is no present experience.

MAJOR PUBLICATIONS

Simon, A. C., S. M. Caulder, and E. E. Wells, "Prospects and Potential of Advanced Lead Acid Batteries," Proceedings of the Symposium on Lead-Acid Batteries for Utility Applications, Workshop II, EPRL EM-399-SR, Washington, DC (1977).

Caulder, S. M. and E. E. Wells, "Lead-Acid Battery Research at NRL," presented at the Symposium on Lead-Acid Batteries for Utility Applications, Washington DC, December 9-10, 1977.

Caulder, S. M. and A. C. Simon, "Research on the Lead Dioxide Electrode," presented at the ERDA Battery Contractor's Coordination Meeting, Germantown, MD, January 27-28, 1977.

DOE PROGRAM MANAGER: R. Shivers (202) 376-9267

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Study of Mechanisms Affect- ing the Performance of Lead-Acid Battery Systems	Naval Postgraduate School Department of Mechanical, Engineering Monterey, CA 93940	J. Perkins 408/646-2216

January 1976--December 1977 (\$15K)--The Naval Postgraduate School is operating model cells containing grids of Pb-Ca or Pb-Sb alloy and in one of following three operational regimes: trickle discharge, float, and repeated deep discharges. Samples taken from these cells are subjected to direct microscopic examination by optical and scanning electron microscopy to obtain a correlation between micro-structure and electrochemical history.

MAJOR PUBLICATIONS

Perkins, K., J. L. Pokorny, and M. T. Coyle, "A Review of Materials and Mechanisms Which Affect the Performance of Lead-Acid Storage Batteries," Materials Science and Engineering, 28, 167 (1977).

Perkins, K. and M. T. Coyle, "Observation of a Substructural Network in the Positive Plates of Lead-Acid Storage Batteries," J. Electrochemical Society, 124, 524 (1977).

III. SUPPORT R&D FOR NEAR-TERM AND ADVANCED BATTERIES

University of Florida

Monitoring Purity of Salts

University of Florida

BN Paper Separators

Lawrence Berkeley Laboratory

Fundamental Investigations
Aqueous Systems

Linfield Research Institute

Zinc Secondary Electrodes

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Electrochemical Methods for Monitoring Purity of Molten Salts	University of Florida Department of Chemistry Gainesville, FL 32611	H. A. Laitinen 904/392-0555

Contract #E-(40-1)-4947

June 1976--December 1977 (\$38K)--The initial objective of this project was to evaluate and develop electroanalytical methods for monitoring the purity of LiCl-KCl electrolyte for the lithium-metal sulfide battery program. Several methods such as pulse polarography, cyclic voltammetry, and anodic stripping analysis have been applied to moisture and trace metal contaminants. Upon consultation of ANL, a practical set of simple tests was recommended to allow determination of alkalinity by aqueous titration, carbonate by gravimetry, and lithium metal by gas chromatographic detection of hydrogen.

Moisture determination is complicated by the equilibrium between H_2O , OH^- , and $\text{O}^=$. Work has proceeded in two directions: (1) That the reduction of chromate in molten LiCl-KCl is affected by moisture. Although the moisture-limited current responds to moisture concentration, it appears not to be simply

diffusion-limited. (2) The second approach is through the direct measurement of oxide ion activity by membrane potential measurements. A membrane of zirconia stabilized by 8 percent yttria has shown nearly theoretical nernstian response to oxide ion. The response is slow, and improvements are being sought.

Consultation with ANL led to enlargement of the initial objectives to include examination of spent electrolyte from dissected used cells. A method was devised for filtering the electrolyte from battery segments furnished by ANL without exposure to the atmosphere. In addition to the procedures applied to unused electrolyte, methods are being developed to look for sulfide, polysulfide, and iron, and to examine sections of melt for variations in Li/K ratio. A sensitive titrimetric method for H_2S is being adapted for sulfide and polysulfide determinations. Quality control procedures for Li_2S , FeS and FeS_2 and other sulfides are objectives.

MAJOR PUBLICATIONS

Uchida, I., and H. A. Laitinen, J. Electrochem. Soc., 123, 829 (1976).

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Separators for Lithium/ Aluminum-Iron Sulfide Batteries	University of Florida Department of Chemical Engineering Gainesville, FL 32611	Robert D. Walker, Jr. 904/392-0884

Contract #EY-76-S-05-4874, Mod. M003

October 1976--September 1977 (\$45K)--In the recent past, separators for these batteries have been based on a woven mat of BN roving. These separators proved adequate but suffered from several inherent limitations arising from the coarseness of the woven mat. This project is concerned with making a paper-like sheet having more uniform characteristics, especially on a microscopic basis. Separators having compositions of 80-95 wt.% BN or Y_2O_3 fibers and 5-20 st.% chrysotile asbestos (fuel cell grade) have been found to have adequate physical and mechanical characteristics, and some of these have performed well in test cells. During the past year, a substantial portion of the effort has involved adapting a laboratory paper machine to the preparation of a continuous sheet. That work is still incomplete, but substantial progress has been made. In addition, an apparatus has been constructed for measuring the contact angle between fused LiCl-KCl

eutectic and a separator sheet. A few measurements have been made, and these demonstrate quite clearly the poor wetability of BN and the good wetability of Y_2O_3 and asbestos.

DOE PROGRAM MANAGER: S. Ruby (209) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGERS</u>
Development of Electro-chemical Synthesis and Energy Conversion	Materials and Molecular Research Division Lawrence Berkeley Laboratory Berkeley, CA 94720	James W. Evans Rolf H. Muller John Newman Charles W. Tobias 415/843-6079

October 1977--September 1978 (\$300K)--The development of efficient and economical methods for the storage and conversion of electrical energy is investigated in five interdependent problem areas. Improvements in energy efficiency and space-time yield, and the exploration of new possibilities for electrochemical technology are the objectives of this program.

Anodic surface layers--Direct experimental evidence about properties and modes of formation of anodic surface layers on materials of interest for battery applications is being obtained in order to define the physical condition of surface layers with desirable electrochemical properties and to find means for their consistent generation. Different optically dominant processes in the anodic oxidation of Zn in aqueous KOH have been identified as surface roughening,

accumulation of dissolved reaction product, and formation of solid film. Application of mass-balance considerations has been shown to expand greatly the utility of ellipsometer measurements. An ultrahigh vacuum system has been built, in which surface layers can be gradually thinned by ion etching, while being observed by ellipsometry and Auger spectroscopy. Modes of formation of anodic surface layers on battery materials and their composition--and porosity--profiles will be determined.

Surface morphology of metals--The role of the electric field and the solution-side mass-transport in the electrocrystallization of metals is being investigated in order to determine mechanisms of growth and propagation of surface imperfections. A mathematical model has been formulated to describe progressive changes in a sinusoidal surface profile during electrodeposition under primary current distribution. A study of the morphology of Zn electrodeposited from ZnCl_2 solution on rotating disk electrodes is in progress with the purpose of defining conditions under which zinc can be effectively cycled as a galvanic electrode. Deposition from ZnBr_2 and alkaline zincate solutions will also be investigated.

Alkali metals in nonaqueous solvents--The feasibility of a new technology for the production of alkali and alkaline earth metals by electrolysis at ambient temperature is being investigated. A solvent purification scheme, adaptable for large-scale use, has been developed for the preparation of propylene carbonate. Precise measurements of current efficiency are being carried out in a 1 ampere cell. Various alternatives are under investigation for the collection of solid or liquid potassium.

Analysis and simulation of electrochemical systems--Mathematical models are developed to predict the behavior of electrochemical systems and to determine the important factors which govern the optimum use of energy and capital. A general method has been developed to solve the creeping-flow equations in an arbitrarily-shaped tube. A one-dimensional model for a flow-through porous electrode reactor, operating below the limiting current, has been developed. The numerical simulation of porous flow-through electrodes will be directed to the definition of optimum systems parameters. Experimental mass-transfer correlations will be used to determine an upper limit for the rate of removal of dilute contaminate ions from waste streams.

Current and power inefficiency in aluminum reduction cells--The electrochemical reduction of aluminum oxide to aluminum in the Hall Cell occurs well below the efficiency expected on theoretical grounds. It has been demonstrated that this inefficiency arises from the circulation of the molten electrolyte which is primarily due to electromagnetic stirring. In order to find cell designs that minimize this circulation, techniques developed previously for the calculation of melt circulation in induction furnaces will be applied to the prediction of circulation in Hall Cells. Cooperation with the Kaiser Aluminum's Reduction Research Center is planned.

The ultimate goal of this program is to improve the energy efficiency, to lower the capital cost and to increase the materials yield of galvanic and electrolyte cell processes for the storage of energy and the production of materials.

MAJOR PUBLICATIONS

Muller, R. H. "Recent Advances in Some Optical Experimental Methods," Electrochim. Acta 22, 951 (1977).

Muller, R. H., "Ellipsometry of Electrochemical Surfaces Layers," Optical Polarimetry, Instrumentation and Applications, Soc. Photo-Opt. Instr. Engrs., Proc. Vol. 122, Bellingham, WA (1977).

Smith, C. G., and R. H. Muller, "Interpretation of Ellipsometer Observations of Anodic Films," Optical Polarimetry, Instrumentation and Applications, Soc. Photo-Opt. Instr. Engrs., Proc. Vol 112, Bellingham, WA (1977).

Trainham, J. A., and J. Newman, "Minimum Concentration Attainable in a Porous Flow-Through Electrode Reactor," J. Appl. Electrochem., 7, 287 (1977).

Fedkiw, P., and J. Newman, "Simulation of a Packed Bed as an Array of Periodically Constricted Tubes: I. Creeping Flow," LBL-5199, July 1976.

Fedkiw, P., and J. Newman, "Simulation of a Packed Bed as an Array of Periodically Constricted Tubes: II. Developed Mass Transfer at High Peclet Number of Creeping

Flow," LBL-5406, July 1976.

White, R., J. A. Trainham, J. Newman, and T. W. Chapman, "Potential-Selective Deposition of Copper From Solutions Containing Iron and Complexed with Chloride," J. Electrochem. Soc., 124, 669 (1977).

Newman, J., "Simultaneous Reactions at Disk and Porous Electrodes" (the part on porous electrodes describes work for the Division of Energy Storage Systems), Electrochim. Acta, 22, 903 (1977).

Fedkiw, F., and J. Newman, "Mass Transfer at High Peclet Numbers for Creeping Flow in a Packed-Bed Reactor," AIChE J., 23, 255 (1977).

Trainman, J. A., and J. Newman, "A Flow-Through Porous Electrode Model: Application of Metal-Ion Removal From Dilute Streams," J. Electrochem. Soc., accepted for publication (LBL-6041, January 1977).

White, R. E., "Simultaneous Reactions on a Rotating-Disk Electrode," (the part on the deposition of copper from iron-containing solutions describes work for the Division of Energy Storage Systems), Ph.D. thesis (LBL-6094, March 1977).

Fedkiw, P., and J. Newman, "Low Peclet Number Behavior of the Transfer Rate in Packed Beds," *Chem. Eng. Sci.*, submitted (LEL-6074, March 1977).

Trainham, J.A., and J. Newman, "The Effect of Electrode Placement and Finite Matrix Conductivity on the Performance of Flow-Through Porous Electrodes," *J. Electrochem. Soc.*, submitted (LBL-6260, May 1977).

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Research on Alkaline Zinc Secondary Electrodes with Emphasis on Life Improvement	Linfield Research Institute McMinnville, OR 97128	Drannan C. Hamby 503/472-3730

Contract #EY-76-S-06-2434

June 1977--October 1978 (\$35K)--The main emphasis of this program is to obtain information which will be useful in extending the cycle life of alkaline zinc secondary batteries.

Alkaline batteries with zinc negatives are considered to be a possible intermediate solution to the need for improved batteries for electric vehicle propulsion. Limited cycle life in cells designed to yield high energy density continues to be a problem. Performance failure is commonly linked to the redistribution of active material within a cell due to the solubility of zinc species in alkaline solution. Bennion, Newman and co-workers have proposed two single dimension models of zinc electrode, the y dimension model which involves lateral material movement over the electrode, and the x direction model which deals with redistribution of material perpendicular to the apparent electrode surface. Each model

has been used to predict a number of observables which are important in cell operation, e.g., the y dimension model has been used to predict fluid flow rates and lateral material redistributions as well as concentration changes and variations in cell terminal potential difference during cycling. Previous experimental work has demonstrated good agreement between predicted and observed lateral material redistributions and average volumetric fluid flow rates. The present project includes an experimental investigation of the predicted concentration variations in cells with normal convection.

The x direction model has grown out of efforts to understand the behavior of the porous zinc secondary electrode operated under conditions of severely limited convective flow. Under these conditions, the rate of lateral shape change is decreased but electrode performance is still observed to deteriorate with cycling. The determination of the causes of the progressive development of large anodic overpotential on porous zinc electrodes operated under limited flow conditions is one aspect of the present program.

MAJOR PUBLICATIONS

Choi, K. W., D. N. Bennion and J. Newman, J. Electrochem. Soc., 123, 1616 (1976).

Sunu, W. G. and D. M. Bennion, "Extended Abstracts No. 22," Electrochem. Soc. Fall Meeting, Las Vegas, NV, October 1976.

Choi, K. W., D. Hamby, D. N. Bennion, and J. Newman, J. Electrochem. Soc., 123, 1628 (1976).

Sunu, W. G, B. M. Eliash, and D. N. Bennion, "Extended Abstracts No. 45," Electrochem. Soc. Fall Meeting, Atlanta, GA, October 1977.

Hamby, D. C. and J. Wirkkalla, J. Electrochem. Soc., submitted for publication, October 1977.

Hamby, D. C. and J. Wirkkalla, "Further Experimental Tests of the Convective Flow Theory of Zn Secondary Electrode Shape Change, I," J. Electrochem. Soc., submitted, October 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

IV. EXPLORATORY BATTERY COUPLES

NASA Lewis Research Center

Brookhaven National Laboratory

EIC Corporation

Electrochimica Corporation

Argonne National Laboratory

General Electric R&D

University of Tennessee

Redox Flow Cell Development

Hydrogen/Halogen Storage
System

Alkali Metal/Sulfur Battery

Cathode Materials for Lithium
Batteries

Advanced Battery Research

Zn/Br₂ Battery

Cathodes for Molten Salt
Batteries

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Redox Flow Cell Development and Demonstration Project	Lewis Research Center National Aeronautics and Space Administration Cleveland, OH 44135	Lawrence H. Thaller (216) 433-4000, ext. 314

Contract No. DOE/NASA Interagency Agreement E(49-28)-1002

January 1, 1977--December 30, 1977 (\$375K)--The objective of this project is to develop and demonstrate the technical feasibility of a Redox Flow System of sufficient energy storage capacity to provide useful operating experience and preliminary cost data as basic inputs for the design and construction of commercial systems.

During the calendar year 1977 only key issues that directly influence the fundamental feasibility of the overall Redox concept are being addressed to enable an assessment to be made of the ultimate practical performance, potential, and future for the NASA version of Redox Flow Cells for energy storage. To make these assessments, three different but highly related interrelated areas of effort must come to fruition during this time period. They are listed in order of importance.

1. Based on past advances in the membrane development in terms of resistivities, ionic selectivities, as well as gathered data on solution effects and performance in Redox Flow Cells, future membrane advances or lack thereof should be predictable. Work will be directed towards being able to estimate and predict the ultimate capabilities of ion exchange membranes for the Redox application.
2. The anode and cathode Redox couples must be selected and their kinetics understood to assure proper and predictable performance levels in actual Redox Flow Cells. This must include the selection of acceptable electrode structure and materials.
3. The modeling activities now underway for Redox installations must be completed to the point where system costs, performance and the influence on them of various key parameters (current density, solution concentration, etc.) can be used to accurately project and predict the quantitative significance of these interactions.

The cell emf, the membrane resistivity, solubility and cost of active materials are such that their trade-off interrelationships to achieve system acceptability

as determined by a systems model are more significant than preselecting component performance goals independently. Bearing this in mind, a first estimate suggests that the membrane area resistivity goal is expected to be less than 2.0 ohm-cm^2 . As the work progresses, the system model will be updated and exercised to better define these specific goals.

ACCOMPLISHMENTS/STATUS - SEPTEMBER 1977

1. The work evaluating various Redox couples upon the chromium +2/+3, iron +2/+3, titanium +3/+4 and bromine -1/0 couples. They are being investigated both at the Lewis Research Center and the laboratories of Giner, Inc. (Contract NAS3-20794). Electrode structures and possible electrocatalysts are being evaluated in an attempt to speed up some of the slow Redox couples ($\text{Cr}^{+2}/\text{Cr}^{+3}$ in particular). A satisfactory pair of Redox couples and set of electrode structures has not as yet been found. The field has been narrowed down to considering iron +2/+3 used with chromium +2/+3 as the primary contender and titanium +3/+4 used with bromine -1/0 as a possible alternative system. Since last year, the kinetics of the titanium half cell have been increased by a factor of about five using a tungsten screen instead of graphite cloth.

2. The membranes under development by Ionics, Inc. (Contract NAS3-20108) have shown an improvement in their ability to prevent cross mixing of ions by a factor of about eight compared to those achieved last year. The ionic resistance of these membranes must now be reduced by a factor of about ten to achieve the internal resistance desired for the Redox Flow Cell.

DOE PROGRAM MANAGER: W. Webster (202) 376-9279

MAJOR PUBLICATIONS

From Last Reporting Period

Thaller, Lawrence H., "Electrically Rechargeable Redox Flow Cells," Ninth Intersociety Energy Conversion Engineering Conference, NASA TM X-71540, San Francisco, CA, August 26-30, 1974.

Warshay, Marvin, and Lyle O. Wright, "Cost and Size Estimates for an Electrochemical Bulk Energy Storage Concept," Energy Storage Session of the 148th Meeting of the Electrochemical Society, NASA TM X-71805, Dallas, TX, October 5-7, 1975.

Prokopius, Paul R., "Model for Calculating Electrolytic Shunt Path Losses in Large Electrochemical Energy Conversion Systems," NASA TM X-3359, NASA, Washington, DC, April 1976.

From This Reporting Period

O'Donnell, Patricia, Randall F. Gahn, and William Pfeiffer, "The Redox Flow System for Solar Photovoltaic Energy Storage," NASA TM X-73562, November 1976.

Reid, Margaret A. and Randall F. Gahn, "Factors Affecting the Open-Circuit Voltage and Electrode Kinetics of Some Iron/Titanium Redox Flow Cells," ERDA/NASA 1022/77/10, May 1977.

Miller, Riley O., "Electrochemical Behavior of 0.2 to 3 Molar Ferrous Chloride-Ferric Chloride Mixtures on Edge-On Pyrolytic Graphite Rotated Disk Electrodes," ERDA/NASA/5022/77/2, July 1977.

O'Donnell, P. M., D. W. Sheibley and R. F. Gahn, "Anion Exchange Membranes for Electrochemical Oxidation Reduction Energy Storage Systems," ERDA/NASA/1002/77/2, August 1977.

1976 Annual Report, "Redox Flow Cell Project," draft in review.

Ciprios, G., W. Erskine, Jr. and P. G. Grimes, "Redox Bulk Energy Storage System Study by Exxon Research and Engineering Company," NASA Contract Report No. CR-135206, February 10, 1977.

DOE PROGRAM MANAGER: William H. Webster (202) 376-9279

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Synthesis and Characterization of Improved Ion Selective Semipermeable Anion Exchange Membranes	Ionics, Inc. 65 Grove Street Watertown, MA 02172	Samuel S. Alexander (617) 926-2500

Contract Nos. NAS3-20108, June 1976-August 1977 (\$110K)

DEN-3-1, September 1977-April 1978 (\$70.6K)

The objective of this contract is the manufacture and evaluation of improved anion selective membranes suitable for use in an electrochemical Redox Energy Storage System now in development at the Lewis Research Center of NASA.

Under Task I, eight membrane systems will be investigated, including three systems which showed promise in the previous contract.

In Task II, six candidate membrane systems are to be selected and improved, including three membranes recommended on the basis of the previous contract effort. These were the 103QZL-219, A3L-96 and B2L-095 membranes. The long range goals of Task II are to optimize the membrane properties of selectivity,

resistivity, and durability by investigation of the synthesis variables relevant to each system.

Under Task III, six optimized membranes will be scaled up to a maximum size of 5 sq. ft. area per membrane and evaluated for uniformity of physical and electrochemical properties. The optimized membranes will be tested for Fe^{+3} transfer at various FeCl_3 concentrations, resistivity in NaCl and HCl and HCl solutions, and transference numbers in Fe, Cr, and Ti chloride solution.

The work under contract NAS3-20108 was completed in August 1977 and the final report has been submitted for NASA review and approval. This contract period highlighted the value of the novel approach of using self-crosslinking polymers as the ion exchange materials. The technique resulted in materials with significantly higher ion exchange capacities and improved ionic selectivities. The selectivities of the membranes that were produced using this technique are typically a factor of 10 better than those produced with crosslinking agents that did not contain any ion exchange groups, and membranes are now available with cross mixing half-lives of up to the order of 2×10^5 hours.

The follow-on contract (DEN-3-1) will (1) attack the reduction of membrane

resistance by reducing substrate thickness and/or membrane modification, (2) try to explain and eliminate the increase of membrane resistance with time when operating in a Redox cell, (3) determine the limits one might expect for future membranes of this type, and (4) continue a low level search for improved membrane systems.

MAJOR PUBLICATIONS

Ionics, Inc., "Anion Selective Membranes," Final Report Contract NAS3-18897, NASA CR-134931, 1976.

Ionics, Inc., "Anion Permselective Membranes," Final Report Contract NAS3-20108, Draft in review.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Advanced Screening of Redox Couples and Electrode Materials	Giner, Inc. 14 Spring Street Waltham, MA 02154	Jose' Giner (617) 899-7270

Contract No. NAS3-20794,

July 1977-July 1978 (\$39.5K)--The objective of this work is to investigate in greater depth some problems which must be solved in order for the chromium II-chromium III redox couple to be a viable candidate for a bulk energy storage system.

The first phase of the work has been a literature survey of the solubility and stability of the chromium II and chromium III salts and laboratory investigations of methods of preparation from commercial material. A 2.5M solution of CrCl_2 in approximately 1M HCL was prepared by reacting Cr metal with 6M HCL. Most of the metal reacted readily with the acid. Reaction of Cr metal with 12M acid was largely incomplete, apparently due to passivation of the metal surface by the concentrated acid. Studies are now being carried out on the stability of chromium II solutions in the presence of different additives to see which might accelerate

or inhibit the thermal decomposition. Future work will investigate the electrode kinetics on a variety of electrodes and the stability of chromium II solutions in the presence of these electrodes.

MAJOR PUBLICATIONS

Giner, Inc., "Screening of Redox Couples and Electrode Materials," Final Report, Contract NAS3-19760, NASA CR-134705.

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
An Electrochemically Regenerative Hydrogen- Halogen Energy Storage System	Brookhaven National Laboratory Department of Applied Science Upton, NY 11973	S. Srinivasin 516/345-4494

October 1977--September 1977 (\$325K)--The electrochemically regenerative hydrogen chlorine system is attractive for energy storage applications because of its high roundtrip efficiency ($> 70\%$). It is a battery with fluid reactants and consequently can be sized independently for power and energy. Hence, it is ideal for use in either daily or weekend energy storage cycles. The possibility exists for using the electrochemical cell for water electrolysis or even as an energy conversion device.

The initial difficulties with mass transport limitations at the chlorine electrode have been overcome by modifying the electrode design. Electric-to-electric efficiencies of 72% at 200A/ft.^2 and 61% at 300A/ft.^2 have been demonstrated. Activation and concentration polarizations at both electrodes are small and the overall efficiency is controlled mainly by membrane resistivity. Membrane

resistivity measurements for temperatures in the range 25-90°C and HCL concentrations in range of 5-35% indicate that efficiencies of >70% can be expected. An unsteady state heat and mass balance analysis for the system has been completed. The system cools during charge and heats during discharge.

The areas of work will be (1) Definition of System Processes and Optimization of System Design; (2) Materials Studies; (3) Chlorine Storage; and (4) Technoeconomic Assessments of the System. System optimization studies will include both experimental and theoretical work on the effect of acid concentration, temperature, pressure, electrolyte flow rate and current density of cell performance. These results will be used as input in the design of a 5KW system and in predicting the effects of scaleup.

The ultimate goals of the program are to design, develop, and demonstrate a 5MW H₂-Cl₂ energy storage system. It will be installed and tested at an electric utility site.

MAJOR PUBLICATIONS

Srinivasin, S., R.S. Yeo, and A. Beaufriere, "The Hydrogen-Halogen Energy Storage

System: Preliminary Feasibility and Economic Assessment," Proceedings of the Second Information Meeting for Hydrogen Contractors in ERDA Hydrogen Energy Program, Airlie, VA, November 8-9, 1976, in press.

Beaufrere, A., R.S. Yeo, and S. Srinivasin, "A Hydrogen-Halogen Energy Storage System for Electric Utility Applications," Proceedings of Twelfth Inter-Society Energy Conversion Engineering Conference, Washington, D.C., August 29-September 2, 1977, Paper No. 779148.

R.S. Yeo, and S. Srinivasin, "An Evaluation of the Electrochemically Regenerative Hydrogen-Chlorine Cell for Energy Storage Applications," To be Presented at the Electrochemical Society Meeting, Atlanta, GA, October 9-14, 1977.

DOE PROGRAM MANAGER: W. Webster (202) 376-9279

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
An Electrochemically Regenerative Hydrogen- Halogen Energy Storage System	General Electric Co.	J. F. McElroy

July 1977--September 1977 (\$80K)--The General Electric Company will fabricate and deliver to BNL a 0.05 ft² H₂-Cl₂ cell complete with chlorine/hydrochloric acid systems and instrumented so as to be capable of providing performance data as a function of temperature and pressure. The General Electric Company will also build a similar unit, evaluate its performance, and make recommendations for improving cell design.

MAJOR PUBLICATIONS

McElroy, J. F., "Status of H₂/O₂ Solid Polymer Electrolyte Fuel Cell Technology," Paper Presented at National Fuel Cell Seminar, Boston, MA, Extended Abstracts p. 95. June 21-23, 1977.

McElroy, J. F., "Solid Polymer Electrolyte Fuel Cells, Proceedings of Fuel Cell Powered Vehicle Workshop," Los Alamos, NM, August 15-17, 1977, in press.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
An Electrochemically Regenerative Hydrogen- Halogen Energy Storage System	Energy Development Associates	G. Hart

July 1977--September 1977 (\$28.5K)--Energy Development Associates will investigate the chlorine electrodes with special emphasis on its production and utilization as a liquid at temperatures between 30 and 90°C. Also included will be a techno-economic assessment of the chlorine/hydrochloric acid subsystem. The permeability of fluoroplastic materials to chlorine and hydrogen chloride will also be determined.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
An Electrochemically Regenerative Hydrogen- Halogen Energy Storage System	Bechtel Corporation Associates	H. Hipkin

February 1977--September 1977 (\$56K)--Bechtel Corporation will carry out a technoeconomic assessment of the H_2-Cl_2 system. This will include a conceptual design study of a $10/20MW_e$ - 200 MWh system for electrical utility peaking applications. Various schemes of reactant storage will be considered.

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Ambient Temperature Lithium/Sulfur Secondary Batteries	EIC Corporation Newton, MA 02158	R. David Rauh 617/965-2710

Contract No. EY-76-C-02-2520

December 1976--November 1977 (\$150K)--This program deals with the development of an ambient temperature Li/S battery of the configuration $\text{Li}/\text{Li}_2\text{S}_n$, organic solvent/C, where the cathode material is dissolved in the electrolyte. Prototype cells containing approximately 5M dissolved S have been discharged and cycled at 25 to 50°C. At 50°C, where most experiments were performed, capacities exceeding 1.2 e⁻/S can be achieved at discharge rates exceeding 4 mA/cm² (approximately C/4, in a practical cell), while discharge of S_n^{-2} down to Li_2S (approximately 1.8 e⁻/S) can be achieved at 1 mA/cm².

Li shows good stability toward the oxidizing electrolyte, due to the familiar phenomenon of its surface passivation. As a consequence, despite the intimate contact between the Li anode and the S_n^{-2} cathode, the cell can be recharged. At least 120 low capacity cycles (0.1 e⁻/S) have been demonstrated at 50°C,

with the average efficiency of 95%. Higher capacity cycles are somewhat less efficient. About 50 cycles of >85% efficiency have been obtained at a depth of 0.5 e⁻/S, after which the efficiency degrades. Experiments show that this degradation is not due specifically to anode failure, but rather to accumulation of solid Li₂S in the anode compartment, preventing it from recharge. Methods are currently being sought to enhance its solubility in the tetrahydrofuran-based electrolyte.

The efficiency of the Li anode has been determined to be equal to that of the entire cell. Therefore, any Li dendrites isolated on the anode during cycling are dissolved via the self-discharge reaction

This maintains the materials balance in the cell, a major requirement for its practical success.

MAJOR PUBLICATIONS

Rauh, R. D., J. M. Marston and S. B. Brummer, "Electrochemistry of Sulfur in Organic Solvents," Fall Meeting of the Electrochemical Society, Dallas, TX, 1975.

Rauh, R. D., F. S. Shuker, J. M. Marston and S. B. Brummer, "The Li/Dissolved S Secondary Battery," Spring Meeting of the Electrochemical Society, Washington, D.C., 1976.

Rauh, R. D., G. F. Pearson and S. B. Brummer, "Capacity, Rate Capabilities and Rechargeability of a Li/Dissolved S Secondary Battery" in Symposium on Electrode Materials and Processes for Energy Conversion and Storage, The Electrochemical Society, 1977.

Abraham, K. M., S. B. Brummer and R. D. Rauh, "A Novel Na/S Battery Using A Soluble S Cathode," *ibid.*

Rauh, R. D., F. S. Shuker, J. M. Marston, S. B. Brummer and J. Inorg, "Formation of Lithium Polysulfides in Aprotic Media," J. Inorg. Nuclear Chemistry, in press.

Rauh, R. D., G. F. Pearson and S. B. Brummer, "Rechargeability Studies of Ambient Temperature Lithium/Sulfur Batteries," Proc. 12th IECEC, Washington, D.C., August 28 to September 2, 1977.

Abraham K. M. and R. D. Rauh, "Studies of Polysulfide Coordination and Electrochemistry in Non-aqueous Solvents," Fall Meeting of the Electrochemical Society, Atlanta, GA, 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
"Synthesis and Evaluation of Cathode Material for Rechargeable Lithium Batteries"	Electrochimica Corporation 2485 Charleston Road Mt. View, CA 94040	M. Eisenberg 415-961-7400

Contract No. EY-76-C-03-1253

June 1976--September 1977 (\$122K)--The object of this program initially was to study two classes of transition metal sulfides, namely, the cubic structure sulfospinel and layered structure disulfides both simple and mixed. Later, on the suggestion of Argonne National Laboratory/(ANL), the pyritic compounds FeS_2 and CoS_2 were added. The objective is the synthesis and evaluation of these new cathode materials for rechargeable lithium batteries, both ambient using organic electrolyte systems and possibly for high temperature batteries such as developed by ANL. The primary concern is with sulfospinel and layered dichalcogenides capable of intercalation of lithium ions. The fundamental objective with both types of materials is retention of the structure as cycling proceeds.

The tasks of the program include a literature search on synthetic methods and properties of certain base materials, development of synthesis methods,

preparation and delivery of samples to ANL, and initial evaluation tests in secondary organic electrolyte cells.

After an investigation of alternative methods for the synthesis of the compounds, a two-zone quartz furnace design was evolved which provides separate control for the sulfur vapor pressure. The 5-inch diameter of the hot zone permits synthesis of considerable quantities of material at any one time up to 150g. Conditions of synthesis have been studied by x-ray analysis and through electrochemical evaluation by two methods:

1. A polarization study cell with a reference electrode, and
2. In complete cells of a spiral C-cell structure.

In the area of sulfospinel the compound CoTi_2S_4 appears preferable on the basis of capacity yield and a cycling ability up to a 2-electron discharge.

In the area of substituted (mixed) disulfides, compounds $\text{Mo}_x\text{Ti}_{1-x}\text{S}_2$ and $\text{Cr}_x\text{Ti}_{1-x}\text{S}_2$ have indicated lower charging voltages apparently due to their better intrinsic conductivity.

In the area of pyrites, both materials studied were capable of cycling in the organic electrolyte with CoS_2 performing better at higher C.D.'s. This may be due to our use of natural FeS_2 ore instead of a pure synthetic material. A number of materials submitted to ANL were cycled successfully at current densities up to 40 mA/cm^2 . On the other hand in the organic electrolyte system current densities are more limited and the rechargeability of the lithium anode requires further investigation.

As a result of these initial studies, new promising materials have been formulated and will be investigated from the point of view of practical battery operating parameters.

MAJOR PUBLICATIONS

Eisenberg, M. and M. Wills, "Pyritic Sulfide Cathode Materials for Rechargeable Organic Electrolyte Cells," Abs #11 Electrochem Soc., 152nd Meeting, Atlanta, GA, October 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Advanced Battery Research	Argonne National Laboratory Chemical Engineering Division Argonne, IL 60439	M. F. Roche 312/739-7711

October 1976--September 1977 (\$200K)--The objective of this program is to find new combinations of electrochemical couples and electrolytes that show promise for the development of high-performance, rechargeable batteries that use low-cost, abundant materials. The ultimate goal of this effort is to devise a battery system that will match the performance of lithium-aluminum/iron sulfide and sodium/sulfur batteries. The cell systems to be investigated are selected on the basis of existing data in the literature and preliminary laboratory-scale tests. The more promising cell systems are then assembled and tested in the laboratory to determine their electrochemical performance characteristics and to identify suitable materials for the cell components. These screening tests are followed by further testing and evaluation in larger, sealed cells.

To date, development studies have focused on cells having calcium or magnesium alloy negative electrodes, metal sulfide positive electrodes, and molten-salt

electrolytes. Of the various calcium-alloy electrodes that have been tested (Ca-Mg-Si, CaMg_2 , CaAl_2 , and Ca_2Si), the Ca-Mg-Si system has shown the best performance characteristics; the most promising positive electrode in a calcium cell has been NiS. For the magnesium cells, the negative electrodes that were tested included MgZn (liquid), Mg_2Al_3 , and Mg_2Cu ; all these tests were conducted with an FeS_2 positive electrode and NaCl-MgCl₂ electrolyte.

MAJOR PUBLICATIONS

Steunenberg, R. K. and M. F. Roche, "Electrochemistry of Lithium/Metal Sulfide and Calcium/ Metal Sulfide Cells Using Molten Salt Electrolytes." Paper presented at the Electrochemical Soc. meeting, Philadelphia, PA, May 8-13, 1977.

Preto, S. K., L. E. Ross, A. E. Martin and M. F. Roche, "Calcium/Iron Sulfide Secondary Cells," Paper presented at the Electrochemical Soc. meeting, Philadelphia, PA, May 8-13, 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DGE BATTERY PROJECT SUMMARY--OCTOBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Assessment of the Zinc-Bromine Battery for Utility Load Leveling	General Electric Company Corporate Research and Development Schenectady, NY 12301	D. Chatterji F. G. Will

Contract No. EY76-C-02-2950

June 1976--January 1977 (\$366K)--An assessment of electrochemical systems for possible applications in utility load leveling reveals the zinc-bromine battery as a fundamentally attractive candidate. It is based upon the use of abundant inexpensive reactants, is capable of attaining good energy efficiency, features simple construction and operates at ambient temperature. Excessive self-discharge and short cycle life have discouraged investigators until very recently. The former is caused by the fast diffusion of bromine to the zinc electrode and direct chemical reaction, the latter by cell shorting due to zinc dendrites.

Our approach to solving these problems has been to use a cation exchange membrane, electrolyte circulation and optimized electrolyte composition. The electrodes in our cell are all-carbon structures. In small laboratory cells of 4 cm² area, the rate of self-discharge has been decreased to 0.1% per hour, and a cycle life

of two thousand 2 1/2-hour cycles at 25 ma/cm^2 has been demonstrated. During these two thousand cycles, the only apparent deterioration consisted of a decrease in the energy efficiency from originally 75% to 60%. The conductivity of the membrane in inorganic solutions of various composition, the diffusion of bromine through and the effect of bromine on the membrane have been studied in detail. The gradual occlusion of heavy metal ion impurities by the membranes has been identified as the cause for the gradual decrease in efficiency. It has been found that this effect is reversible by a simple acid treatment and the Br_2 does not affect the membrane at temperatures lower than 40°C in the time period of observation, that is, 1200 hours. The electrolyte composition has been optimized with respect to producing good zinc deposit morphology and high conductivity in both the liquid electrolyte and the ion exchange membrane. A variety of membranes have been studied regarding chemical stability, rate of Br_2 permeation and conductivity and the optimum membrane has been selected. The long-term reductive and oxidative stability of a very effective zinc dendrite inhibitor has been demonstrated. It has also been shown, however, that the inhibitor produces a resistive film on the membrane which limits the usefulness of the inhibitor in zinc-bromine cells with ion exchange membranes. We are using porous carbon

substrates for our zinc deposits. The effect of pore size and pore diameter and the effect of electrolyte flow rate, current density and deposit thickness on the zinc distribution within the porous substrate as compared to flowing parallel to it has also been determined. A variety of novel all-carbon structures for the zinc and the bromine electrode have been developed and tested. The specific resistance of these structures and their chemical stability have been determined. Bench-type cells with 125 cm^2 electrode area (each electrode) have been designed and are being tested. These cells deliver 5W continuous power at 25 ma/cm^2 for 4 hours with an energy efficiency in excess of 70%, not counting pumping losses. The design is such that individual cells can be stacked in electrical series using bipolar electrodes.

MAJOR PUBLICATIONS

Will, F. G. and H. S. Spacil, "Thermodynamic and Kinetic Considerations on Zinc-Halogen Batteries," Spring Meeting Electrochemical Society, Philadelphia, PA, to appear in Symposium Proceedings, May 1977, in print.

Will, F. G., "The Zinc-Bromine Battery: Possible Candidate for Electric Vehicles

and Load Leveling," Proceedings of 12th Intersociety Energy Conversion Engineering Conference, Washington, D.C., September 1977.

DOE PROGRAM MANAGER: W. Webster (202) 376-9279

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
High Energy Cathodes and Anodes for Molten Salt Batteries	Department of Chemistry The University of Tennessee Knoxville, TN 37916	Gleb Mamantov 615/974-3349

Contract No. EY-76-S-05-5053

June 1976--May 1978 (\$60K)--This program involves primarily the research and development of a new cathode system using tetravalent sulfur in low-melting acidic chloroaluminates ($\text{AlCl}_3\text{-MCl}$ mixtures where M^+ is an alkali cation, typically Na^+ , and AlCl_3/MCl mole ratio is greater than one). We have extended the studies of the electrooxidation of sulfur to acidic $\text{AlCl}_3\text{-NaCl}$ mixtures in the temperature range $130\text{-}250^\circ\text{C}$ using cyclic voltammetry, normal and differential pulse voltammetry and controlled-potential coulometry. The oxidation of sulfur proceeds through multistep electron transfers from S_8 to S_8^{2+} , S(II) and SCl_3^+ , respectively; the reduction of sulfur leads to sulfide (or AlSCl). The cation SCl_3^+ is apparently stable only in acidic chloroaluminate compositions. The existence of S(IV) as SCl_3^+ and of elemental sulfur as S_8 in the acidic melts is indicated by Raman spectroscopy.

The charge-discharge characteristics of the cell

have been investigated in the temperature interval 130-250°C. The open circuit voltage is 4.18V; the potentials of the tungsten spiral immersed in the melt containing dissolved $\text{SCl}_3\text{AlCl}_4$ and of the sodium electrode vs. an Al(III)/Al reference electrode (in an $\text{AlCl}_3\text{-NaCl}_{\text{sat.}}$ melt) were 2.49 and -1.69V, respectively. One cell has been discharged and charged 20 times at current densities of 10 and 50 mA/cm^2 . The discharge curves show two plateaus; the first plateau involves the reduction of sulfur and has a closed circuit voltage (CCV) of 3.1 to 3.6 V (this value depends on the current density and the temperature). The CCV of the second plateau (which involves the formation of the sulfide ion) ranges from 2.8 to 2.2V.

MAJOR PUBLICATIONS

Mamantov, G., R. Marassi and J. Q. Chambers, U.S. Patent 3,966,491, June 29, 1977.

Mamantov G. and R. Marassi, U.S. Patent Application SN 734,836, allowed July 19, 1977.

Mamantov, G. and R. Marassi, J. P. Wiaux, S. E. Springer and E. J. Frazer, "Abstract #89," Fall Meeting of the Electrochemical Society, Atlanta, GA. October 9-14, 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

V. METAL/AIR BATTERIES

Lawrence Livermore Laboratory

Metal/H₂O/Air

Lockheed Missiles and Space Company

Li/H₂O/Air for Automotive Propulsion

Westinghouse Electric Corporation

Fe/Air Battery for Electric
Vehicles

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Lithium-Air Battery Research	Lawrence Livermore Laboratory Chemistry and Materials Science Department Livermore, CA 94550	John F. Cooper 415/447-1100

Contract #W-7405-eng-48

October 1977--November 1978 (\$160K)--The Lithium-Air Battery Research Program is being conducted as a cooperative effort involving the Lawrence Livermore Laboratory and Lockheed Missiles and Space Company (Palo Alto, CA). The ultimate project goal is to determine the feasibility of a metal-air fuel cell as an automotive power source. The motivation for this research comes from the exceptional performance of the lithium-air cell (projected energy and power densities, 300-400 Wh/kg at 100 W/kg) which makes possible an electric vehicle with the range and performance of common gasoline-driven subcompacts. In this concept, the metal must be externally regenerated from the fuel cell's reaction products. The energy and dollar costs of the recycling process (including the capitalization of recycling and distribution centers) are the critical parameters in the feasibility of this concept.

The joint project has been divided into three major areas: (1) fundamental studies of fuel cells of the lithium-water type (prime responsibility LLL); (2) development of a prototype fuel cell (LMSC with LLL); and (3) a study of the reprocessing of spent fuel (LLL, LMSC).

Fundamental Studies of Fuel Cells of the Lithium-Water Type

(1) Based on the studies of the lithium electrode completed last year, LLL is investigating the half cell reactions of calcium and aluminum in strong alkali to determine their suitability as automotive power sources. The steady state behavior (voltage-current curves, coulombic efficiency) of calcium has been examined over a range of system parameters of interest in battery development (initial study completed October 1977).³ Similar studies of the aluminum electrode are to begin in November 1977. (2) Exploratory research for analogous galvanic cells will continue throughout FY 1978. The use of Na, Mg, and alloys of calcium and/or aluminum will be investigated in combination with aqueous-based electrolytes for their potential in fuel cell applications. These studies are aimed at both elucidating film properties (through inference from the effects of dopants) and developing low cost electrodes.

Development of a Prototype Metal/Air Fuel Cell

In support of the effort at LMSC, this laboratory is developing and testing a single cell prototype hardware on a scale suitable for an automotive power source. Each cell consists of two square anodes (900 sq.cm each), connected in parallel and separated by an air cathode.

This unit cell case measures 3 x 33 x 40 cm. and weighs 400 grams. The purposes of the model are (1) to develop and test hardware designed for rapid addition of metal fuel plates and (2) to allow accurate determination of the total system weight and cost of large scale production.

Reprocessing Study

Current processes reported in the literature for the production of lithium from its compounds have been reviewed at an earlier stage of this project. Energy and dollar costs of reclaiming lithium from cell reaction products were found to be prohibitively high. An advanced concept for lithium production is being evaluated experimentally. The technique involves a mercury (or an analogous low melting alloy) electrode separating an aqueous cell from a fused salt cell. The behavior

(polarization curves, coulombic efficiency) of the lithium amalgam and lithium electrodes are being determined independently.

Similar reviews on the processing of calcium and aluminum will be completed during FY 1978.

Summary

The fundamental objective of this research is to develop an electric power source capable of providing an electric vehicle with the range, speed, and convenient refueling capability necessary for successful competition with small, internal combustion engine vehicles. Current research is intended to provide an accurate assessment of the feasibility of the lithium-air system. In addition, the program emphasizes the search for alternative base-metal/aqueous electrolyte negatives of similar high performance and of improved economy.

MAJOR PUBLICATIONS

O'Connell, L. G., et. al., "The Lithium-Water Air Battery: A New Concept for Automotive Propulsion," UCRL-51811, University of California, Lawrence Livermore Laboratory, May 1975; see also, J. F. Cooper, and L. G. O'Connell, "Notes on the

Lithium-Water-Air Battery Electric Vehicle Report," MISC-2135, Lawrence Livermore Laboratory, November 1975.

Cooper, J. F., P. K. Hosmer, and R. V. Homsy, "The Anodic Behavior of Aqueous Lithium Hydroxide Solutions," J. Electrochem. Soc., 125, p. 1 (1978).

Cooper, J. F. and P. K. Hosmer, "The Behavior of the Calcium Electrode in Aqueous Electrolyte," Paper, Electrochemical Society Fall Meeting, Atlanta, GA, October 1977, preprint Lawrence Livermore Laboratory, UCRL-79457, October 1977.

Homsy, R. V., "Industrial Production of Lithium Metal: A Review of the Literature," UCRL-52124, University of California, Lawrence Livermore Laboratory, August 1976.

DOE PROJECT MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Li-H ₂ O-Air Battery for Automotive Propulsion	Lockheed Missiles and Space Company, Inc. 3251 Hanover Street Palo Alto, CA 94304	E. L. Littauer 415/493-4411

Contract #EY-76-C-03-1262

October 1977--September 1977 (\$183K)--The objective of this program is to determine the technical and economic feasibility of using the lithium-water-air electrochemical system as a power source for automotive propulsion. The lithium anodes would be periodically replaced along with the electrolyte and the lithium salts in the electrolyte reduced to metallic lithium in a separate process to complete the use cycle. The program is a cooperative effort with Lawrence Livermore Laboratory who is examining some of the basic mechanisms of the anodic dissolution reaction and new concepts for efficient industrial reprocessing of lithium.

Cell tests were made with cathodes catalyzed with 1 mg/cm² of platinum which delivered 360 mW/cm² power. Power density of 440 mW/cm² was realized with a cell with a black platinum catalyzed cathode. Lithium utilization efficiencies

of over 80 percent were achieved during cell tests. The initial goal of the experimental effort was 300 mW/cm^2 . A performance comparison of $\text{Li-H}_2\text{O-Air}$ and baseline $\text{Li-H}_2\text{O}$ cells showed that identical control logic is applicable. Power varies as a function of flow rate, electrode spacing and electrolyte molarity. A five cell battery was designed, fabricated and tested. It delivered over 250 watts. Alternative routes for lithium recovery with greatly reduced energy consumption have been identified.

The original concept appears technically feasible. Remaining technical issues include maximizing the efficiency of anode utilization under varying loads during long discharges, the production of inexpensive cathodes with low polarization and long life, and the problems inherent in parallel manifolding of cells in a flowing electrolyte.

Other topics which will have to be addressed include: (1) the construction and test of multikilowatt modules (2 kW or greater) possessing design features which allow for rapid and simple anode replacement and (2) minimization of system cost by extensive use of nonmetallic constructional materials. It is anticipated that the information generated in this program will indicate if a high energy density

metal air primary system can, in fact, represent a technically and economically feasible approach to the development of a full performance electric vehicle.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Iron-Air Battery Development Program	Westinghouse Electric Corporation Research and Development Center Pittsburgh, PA 15235	Edward S. Buzzelli 412/256-3519

Contract #EY-76-C-02-2949

June 1977--May 1978 (\$330K)--The development of the Iron-Air Battery for Electric Vehicle Propulsion covers several research and development areas. During the first research phase of the contract, major emphasis is placed on the performance and life characteristics of the individual air and iron electrodes. The goals for this year's contract are to demonstrate bifunctional air electrode characteristics compatible with a cell, suitable for the commuter electric vehicle mission. These goals are: 500 cycles life with an air electrode that weighs .2 grams/cm² and contains less than 1 ng per cm of silver catalyst. The air electrodes performance level should be stable for the cycling period with voltages of 100 mV below an Hg/HgO reference electrode at 25 mA/cm² current density and 200 mV below Hg/HgO at 100 mA/cm² current density. The air electrode should have a charging voltage of +.55V vs. Hg/HgO at 25 mA/cm². The goals for the iron

electrode have been to demonstrate a stable capacity for 200 cycles at .4 ampere hours per gram of electrode with a voltage better than 0.90 vs. Hg/HgO at the 4 hour discharge rate when the thickness is .2-.4 cm, all while using 20 percent or less overcharge to maintain stable performance during discharge. The iron electrode should also have a charging voltage of less than -1.00 volts vs. an Hg/HgO reference electrode at a current density of 50 mA/cm².

The development phase of the contract has demonstrated the performance and life characteristics of various iron-air cells. The performance characteristics of the iron-air cell have demonstrated the necessary power and energy storage characteristics which are compatible with the commuter electric vehicle mission. Demonstration of cell power characteristics of 70 mW/cm² at current densities of less than 125 mA/cm² have been achieved and can be translated to a full size iron-air battery which could provide 40 kW power for acceptable vehicle acceleration. In terms of the overall battery system, this is a sustained power equivalent of about 90 watts per kilogram. The goals for the energy storage density during the first year's contract were to demonstrate cells with 110 watt hours per kilogram energy storage capacity at the 4 hour discharge rate with the

proper power characteristics. Cells presently deliver 80-90 wh/kg. A portion of the iron-air cell development program is devoted to the demonstration of the cell performance characteristics that most nearly represent a near-term energy efficiency of about 50 percent. During this contract period, a variety of iron-air cell designs will be tested and evaluated to demonstrate the cell design effects on performance. Preliminary tests will also be carried out with the auxiliary air and electrolyte supply systems to observe the cells performance characteristics and life, with the auxiliary systems.

The ultimate objective of the iron-air battery development program is to provide a low-cost, long-life power propulsion system for the commuter electric vehicle. The goals for the finally developed battery system are: an ambient temperature system that will store 110 watt hours per kilogram with a power capability of 90 watts per kilogram with 1000 cycles life, and less than 10 percent deterioration in overall performance with about 55 percent energy efficiency. These characteristics are felt to be compatible with a commuter vehicle with a range of about 150 miles per battery cycle, acceptable vehicle acceleration and low operating costs.

MAJOR PUBLICATIONS

Buzzelli, E. S., "Performance Characteristics of Alkaline Electrolyte Iron-Air Cells," 150th meeting, The Electrochemical Society, Las Vegas, NV, October 1976.

DOE PROGRAM MANAGER: W. Webster (202) 376-9279

VI. SOLID ELECTROLYTES

Lincoln Laboratory
Stanford University

New Solid Electrolytes
Lithium Ion Conductors

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGERS</u>
Research and Development on Superionic Conductors	Massachusetts Institute of Technology Lincoln Laboratory Lexington, MA 02173	H. Y-P. Hong J. A. Kafalas 617/862-5500, Ext. 488

Contract #E-(49-18)-2295

July 1977--June 1978 (\$251K)--The objective of this program is to discover and develop new alkali-ion solid electrolytes for batteries having both high energy density and high specific power, as well as for thermoelectric generators and alkali-metal processing systems. The program includes both a systematic search for new superionic conductors and an evaluation of promising materials to determine their suitability for practical use. The evaluation consists of characterization of the electrical properties, development of ceramic fabrication procedures, and testing of ceramic specimens in test cells under projected battery operating conditions.

Previous exploratory research at Lincoln Laboratory led to the discovery of two new superionic conductors, NASICON ($\text{Na}_3\text{Zr}_2\text{PSi}_2\text{O}_{12}$) and LISICON ($\text{Li}_{14}\text{ZnGe}_4\text{O}_{16}$). During the past year, a procedure has been developed for

fabricating closed-end NASICON ceramic tubes with densities exceeding 98 percent of theoretical. Specimens having a conductivity of $0.4 \text{ }^{-1}\text{cm}^{-1}$ at 300°C , the same as that of Na-beta'-alumina, have been prepared by this procedure, which includes final sintering at 1230°C . Initial stability tests are very promising, one tube having survived 4 months at a current density of approximately 100 mA/cm^2 at 300°C in a Na-Na test cell.

One goal of the present project is to complete the evaluation of NASICON by determining the stability of ceramic specimens in Na-S test cells. We also plan to initiate ceramic development and testing for LISICON or analogs in which the Si content is increased for improved stability. In addition, the exploratory program will be continued, and we will evaluate the applicability of any promising new Na^{+} or Li^{+} superionic conductors to high-energy-density storage systems.

MAJOR PUBLICATION

Kafalas, J. A., "New Na^{+} and Li^{+} Superionic Conductors," paper presented at 4th Biennial Air Force Electrochemistry Conference, U.S. Air Force Academy, Colorado Springs, CO, April 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
New Battery Materials	Stanford University Department of Materials Science and Engineering Stanford, CA 94305	Robert A. Huggins 415/497-4110

Contract #EC-77-S-02-4506

April 1977--September 1978 (\$320K)--This program is being undertaken to explore new materials for use in advanced battery systems. One of the major directions being pursued relates to the discovery and development of solid electrolytes and ion-transparent separators that might be used in lithium battery systems. Another involves work on materials that might be useful as positive electrode constituents in lithium-based batteries. Efforts are also being undertaken to better understand the mechanisms and kinetics of the processes occurring in the negative electrode materials currently being used in the high temperature systems being developed by others under the support of the Energy Storage Division.

Work on solid electrolytes is focused primarily upon materials with three general types of crystal structure. One of these is the anti-fluorite type, in which doping with certain aliovalent species can produce very large concentrations of

crystallographic defects, and thus large increases in ionic conductivity. A second group is materials with tetrahedral anionic groups between which cations, such as lithium, have high mobility among dilutely populated, almost equivalent sites. The third structure of interest for lithium solid electrolytes is that of Li_3N , which is of a very open layer type, and is a very good two-dimensional lithium ionic conductor.

Electrode materials being investigated include the LiAl negative electrode phase, as well as several inter-metallic and oxide phases of interest for use in positive electrodes. Special attention is being given to materials which are mixed ionic-electronic conductors and in which the electrode reaction takes place by the insertion of mobile species into the crystal structure. In favorable cases, electrodes containing such materials ("solid solution electrodes") can have significant advantages over conventional displacement-reaction electrodes because of the lack of microstructural changes during the charge-discharge cycle in the former case. Such changes are often the source of electrode shape changes and capacity loss in some present battery systems.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

VII. INDUSTRIAL ELECTROCHEMISTRY

Argonne National Laboratory

Industrial Electrochemical
Processes

Diamond-Shamrock

Oxygen Cathode for Chlor-Alkali
Cells

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Energy Conservation in Industrial Electrochemical Processes	Argonne National Laboratory 9700 South Cass Avenue Argonne, IL 60439	N. P. Yao 312/739-7711

Contract #W-32-109-Eng-38

October 1976--September 1977 (\$111.5K)--The objective of this project is the development of technology for improving the energy efficiencies of industrial electrochemical processes. The near-term development efforts are directed primarily toward achieving a 10 percent improvement in the process energy efficiencies, principally in the aluminum and chlor-alkali industries, by the year 1985. The longer-term program is concerned with the development of advanced electrolytic technologies with the goal of an overall 30 percent improvement in energy efficiency by the year 2000 in the electrochemical industry sector. This is to be achieved by parallel efforts directed at: (1) strengthening of the fundamental understanding of the industrial processes by basic research and physical-chemical data collection; (2) improving the energy efficiency of present industrial technologies by process modifications; and (3) the development of new, more energy efficient technologies. Four subsectors of this industry have been

selected as immediate target areas. Aluminum and chlorine-caustic production were selected because together they consume 90 percent of all electrical energy used by electrochemical industries. Electrohydrometallurgy and electro-organic processes are included since they are projected to be large energy users in the mid- to long-term future.

During the current contract period, a draft R&D Program Plan for Energy Conservation in the Industrial Electrolytic Sector was prepared for DOE. This plan proposes seven subprograms with 47 specific projects directed to reducing the specific energy consumption within this section by 10 percent in 1985, and 30 percent by 2000.

MAJOR PUBLICATIONS

ERDA Report No. ANL/OEPM-77-1, "Proceedings of the Workshop on Energy Conservation in Industrial Electrochemical Processes," 1977.

Beck, T. R., "Final Report on Improvements in Energy Efficiency of Industrial Electrochemical Processes," ERDA Report No. ANL/OEPM-77-2, January 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
A Study to Assess Improvements for Energy Efficiency for Industrial Electrochemical Processes	Electrochemical Technology Corporation	Theodore R. Beck 206/632-5965

Contract #31-109-38-3438

October 1976--September 1977 (\$32.7K)--This contract involved the preparation of a report to provide information needed to define the criteria for implementing a research and development program for improving the energy efficiency of industrial electrochemical processes. The study addressed the following topics: (1) evaluate the state-of-the-art of industrial electrolytic processes with respect to electrical energy usage; (2) estimate possible energy savings that could be affected by improvements on technology; (3) describe methods for achieving energy savings; and (4) outline a program of research, development and demonstration for those processes that promise substantial savings. A final report on this study was submitted to Argonne National Laboratory in 1977.

MAJOR PUBLICATIONS

Beck, T. R., "Final Report on Improvements in Energy Efficiency of Industrial Electrochemical Processes," ERDA Report No. ANL/OEPM-77-2, January 1977.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DGE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Oxygen Electrodes for Energy Conversion and Storage	Diamond-Shamrock Corporation P.O. Box 348 Painesville, OH 44077	D. F. Lieb 216/352-9311

Contract #EC-77-C-02-4146

September 1977--September 1978 (\$300K)--This project involves a joint effort of the Diamond-Shamrock Corporation and Case Western Reserve University to develop high performance O_2 cathodes and anodes for alkaline and acid electrolytes with emphasis on high activity-stable O_2 electrocatalysts of reasonable cost. Such improved O_2 electrodes will have major impact on energy conversion and storage in the following areas:

Chlor-alkali industry--A new generation chlor-alkali cell utilizing air-consuming O_2 cathodes instead of hydrogen evolving cathodes will give a 25 percent reduction in the electrical energy consumed in the process. The use of O_2 cathodes in membrane cells will eliminate environmental problems associated with mercury cells and asbestos diaphragm cells.

Fuel cells and other air-consuming batteries--The irreversibility of air-consuming

O₂ electrodes imposes serious restrictions on such devices in conversion and storage applications including peak shaving-load leveling in the electric utilities, waste H₂ utilization in the industrial electrolytic industry and vehicle propulsion (e.g., iron-air cells).

Water electrolyzers--Water electrolyzers coupled with fuel cells offer promise for energy storage provided the O₂ electrode voltage losses can be reduced to a small fraction of those with present commercial electrolyzers and fuel cells.

During the first year, emphasis will be on O₂ cathodes for applications in chlor-alkali cells and will include the following tasks:

1. Catalyst synthesis and characterization (CWRU): choice of catalyst systems, catalyst preparation, physical and chemical characterization of catalysts, screening for electrocatalytic activity for O₂ reduction, mechanistic studies of promising systems, and development of predictive base.
2. Electrode structures (CWRU): development of new electrode structures for O₂ cathodes for chlor-alkali cell application, fabrication of small test electrodes and their evaluation.

3. Electrode fabrication and evaluation (Diamond-Shamrock): choice of systems, electrode fabrication, in-cell testing including life tests in laboratory chlor-alkali cells.

Project management is the responsibility of Diamond-Shamrock Corporation as prime contractor with Case Western Reserve University as subcontractor.

MAJOR PUBLICATIONS

Yeager, E., "Application of Electrode Kinetics Principles to Energy Conservation Problems," Proceedings of Workshop on Energy Conservation in Industrial Electrochemical Processes, Part 1: Invited Presentations, Argonne National Laboratory, August 10-12, 1976.

Yeager, E., "Mechanisms of Electrochemical Reactions on Non-Metallic Surfaces," Electro-catalysis on Non-Metallic Surfaces, NBS Special Publication 455, pp. 203-220, 1976.

Yeager, E., "Recent Advances in the Understanding of Electrocatalysis and Its Relation to Surface Chemistry," proceedings of the Symposium on Electrode Materials and Processes for Energy Conversion and Storage, the Electrochemical Society,

Philadelphia, pp. 8-13, May 1977. (ONR Technical Report 46, Case Western Reserve University, Cleveland, Contract N00014-74-C-0953, Project NR359-451, May 1977.)

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
O ₂ Electrocatalyst Preparation and Characterization	Case Laboratories for Electro- chemical Studies Cleveland, OH 44106	E. B. Yeager 216/368-3626

Contract #31-109-38-3438

October 1976--September 1978 (\$225K)--Case Western Reserve University will carry out Tasks 1 and 2. Personnel will include faculty, senior staff, postdoctoral and graduate students of Case Laboratories for Electrochemical Studies and the Chemistry Department.

VIII. STUDIES

Science Applications, Inc.

Electric Vehicle Battery
Assessment

U.S. Geological Survey

Lithium Resource Study

Westinghouse

Energy Storage for Photovoltaics

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Environmental Impact Assessment of Electric and Vehicle Batteries	Science Applications, Inc. 1200 Prospect Street P.O. Box 2351 La Jolla, CA 92037	Richard Callahan 714/459-0211

Contract No. EC-77-C-02-4526

September 1977--December 30, 1977 (\$50K)--SAI is conducting an assessment of the potential environmental impacts of near term and advanced battery systems proposed for use in electric vehicles. Included in the study is technology assessment of candidate battery systems presently envisioned, and assessment of the laws and regulations affecting the battery program, particularly as related to toxic materials transportation, disposal, and reclamation, a description of the present battery industry including raw materials availability and supply, manufacturing of batteries and electrolytes, shipping and handling of batteries, recycling and disposal of batteries and electrolytes, and existing pollution control technology. Within the limits of available data, these topics will also be discussed for advanced battery systems. The potential environmental impacts of each of the proposed battery systems will be discussed from the mining and milling stage

through smelting, manufacturing, electrolyte production, transportation, usage, recycling, and disposal. The impacts to be addressed include air quality, water quality, solid waste, geology and land use, species and ecosystems, accidents and natural disasters, and socioeconomic implications. The result of the project will be a succinct overview of potential technological and environmental problems associated with the battery program of DOE.

DOE PROGRAM MANAGER: S. Ruby (202) 376-9311

DOE BATTERY PROJECT SUMMARY--OCTOBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
An Interagency Agreement Between DOE and USGS to Study Lithium Resources in the U.S.	U.S. Geological Survey Office of Energy Resources Branch of Chemical Resources Denver, CO 80225	James D. Vine, Coordinator Lithium Resource Appraisal Group 303/234-3494

Agreement signed April 25, 1977 (\$80K, divided as follows: \$40K from the Division of Energy Storage Systems, and \$40K from the Division of Uranium Resources and Enrichment)--The objective of this agreement is to test new concepts to explain the origin and distribution of lithium deposits in brines and sedimentary rocks. These concepts need to be confirmed and expanded by studying fresh samples that can be obtained only by drilling or trenching in selected geologic environments. The ultimate objectives are to formulate guidelines to search for new lithium resources and increase identified reserves. The first drilling target selected is the Clayton Valley brine field in western Nevada where the Foote Mineral Company has been recovering lithium carbonate from subsurface brines for the past 10 years. A contract for drilling has been awarded to Drilling Services, Inc., 1521 South Indian Bend Road, Tempe, Arizona 85281. Drilling is scheduled to begin the end of September and continue into the first part of October. The samples collected

during the drilling program will provide the basis for geochemical and mineralogical studies. This data, in turn, will provide the basis for comparison with other areas to be drilled in the future. No major publications have resulted from the agreement to date.

DOE PROGRAM MANAGER: Robert J. Wright, Chief, Geologic Branch, Division of Uranium Resources and Enrichment (301) 353-3144.

DOE BATTERY PROJECT SUMMARY--SEPTEMBER 1977

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Energy Storage for Photovoltaic Conversion	Westinghouse Electric Corporation Research and Development Center Pittsburgh, PA 15235	W. Feduska 412/256-7726

National Science Foundation Contract NSF-C-7522180

Program Monitor - DOE, Energy Storage

July 1976--July 1977 (\$229K)--Westinghouse Electric Corporation is conducting a study to evaluate battery energy storage of photovoltaic derived electricity in the 1985-1995 time period. The study will also define technical and implementation problems for both dispersed and utility central station systems and provide recommendations regarding these problems. This is a 12-month study sponsored by the National Science Foundation and monitored by DOE. The program entailed six tasks: 1) systems analysis, 2) component requirements, 3) conceptual design, 4) storage system evaluation and screening, 5) preliminary design, 6) R&D requirements and utilization plan. In addition to completing

these tasks, useful means of dissemination of the information obtained in the study were described.

Residential Systems. This effort of the program was concerned with electrical storage for on-site photovoltaic residential total energy systems. The study analyzed seven sites, representing most regions of the United States and determined that electrical storage by batteries is a vital element in ensuring the viability of solar total energy residences, whether they be autonomous (no utility connection) or utility connected. The study evaluated nine battery storage types: state-of-the-art lead-acid, advanced technology lead-acid, lithium-aluminum/iron sulphide, lithium-silicon/iron sulphide, two types of sodium-antimony trichloride, lithium/titanium disulphide and zinc-chlorine. Here, the state-of-the-art lead-acid battery represented the base case. The study found that the advanced technology lead-acid system has a decided economic advantage over its closest competitors. It was also determined to be the superior system with regard to general maintainability, life, acceptability, and availability of materials for large volume production. The battery size requirement in the residences studied is from 15 to 25 kWh capacity at a nominal 200V. Peak demand is about 15KW for 10 minutes. The inverter to be used with the 200V

residential battery has been determined to be a single phase bridge, self-commuted type.

The battery in a residential total energy photovoltaic system: 1) provides energy when direct solar is not available, 2) provides power above the solar capability, 3) averages auxiliary (non-solar) power. A small (1.5 KW) engine-generator for an autonomous home or a utility connection is used to supply auxiliary energy.

Projected implementation of solar residential total energy systems, including battery storage, is dependent upon the achievement of the 1985 goals of the National Program, a modest government precommercialization program and a comprehensive policy to implement this program.

Utility Systems. This portion of the contract was undertaken to establish the nature, mode of operation and usefulness of a battery energy storage plant used in conjunction with a photovoltaic plant in preselected utilities--Salt River Project and Florida Power and Light, in the time frame 1985-1995.

The battery plant was sized at 125 MW (500 MWh), using a modular concept. It is

envisaged that the photovoltaic plant will be dispatched whenever it is available, during the sunlit hours of the day. The battery storage, provided by charging from base load equipment off-peak, is dispatched to handle the peak loads that are present during the twilight hours, when the solar plant output is rapidly dropping off.

Nine candidate battery systems (same as for the residence) were evaluated for which a system evaluation and screening was developed. A weighted evaluation criterion indicated that, among the competing technologies, the advanced technology lead-acid was clearly the highest ranked for further development. Excluding state-of-the-art lead-acid, four other technologies were in a virtual tie for second consideration. Of these four second place candidates, the zinc-chlorine technology was considered more favorably, because it is already in an advanced stage of development, as a total battery system. Therefore, the advanced technology lead-acid and zinc-chlorine were further studied.

Designs were then executed for a modular 125 MW (500 MWh) battery plant size, complete with auxiliary and safety equipment considerations. The interfacing battery power conversion equipment was resolved to be a simple line commutated inverter-converter.

The total bus bar energy costs for the state-of-the-art lead-acid, the advanced technology lead-acid and the zinc-chlorine batteries were determined--(74, 51 and 77 mills/KWh, respectively).

For both the residence and utility studies, an assessment was made of the candidate batteries, with regard to technical obstacles to be overcome, to insure their development by defining an R&D plan in each case. Then institutional and environmental problems were related that will have to be overcome to enable using battery storage in these applications. Finally, means for dissemination of the information gleaned in this study to various government and private agencies, universities and industry were described.

DOE PROGRAM MANAGER: R. Shivers (202) 376-9267

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGERS</u>
Energy Storage for Photovoltaic Conversion	Burt, Hill and Associates	S. L. Nearhoof P. R. Rittleman

July 1976--July 1977 (\$3.4K)--Burt, Hill and Associates assisted in residential architect-engineer related matters pertaining to the photovoltaic-battery powered residences evaluated on the program. In particular, they provided preliminary total energy system design layouts for the residence, including the battery storage; addressed building code requirements, taxes, insurance, financing, legal matters, and incentives related to implementation and usage of such residences in the time frame 1985-1995.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Energy Storage for Photovoltaic Conversion	University of Pennsylvania	W. L. Worrell

July 1976--July 1977 (\$6.8K)--Dr. Worrell rendered assistance in the battery-related aspects of the program both for the residential and for the utility systems studies. In particular, he assisted in selecting candidate batteries for residential and utility systems, utilizing photovoltaic systems involving battery characteristics, reliability, life, capital, operating and maintenance costs, convenience of use, safety aspects, environmental aspects, preliminary designs and specifications. Also, he assisted in weighting the various parameters used in screening the candidate batteries. Then he assisted in defining technical obstacles to be overcome, and an R&D plan to overcome them. Finally, he assisted in suggesting a plan to disseminate the information derived on the program.

MAJOR SUBCONTRACTORS

<u>TITLE</u>	<u>INSTITUTION</u>	<u>PROJECT MANAGER</u>
Energy Storage for Photovoltaic Conversion	University of Pennsylvania	M. Wolfe

July 1976--July 1977 (\$3K)--Dr. Wolfe provided the following solar-related information, needed for the utility analysis of the program.

1. A definition of solar cell characteristics, including the I-V characteristics as a function of temperature and irradiation using the 16% efficiency silicon solar cell specified for ERDA E(11-1)-2744, "Conceptual Design and Systems Analysis of Photovoltaic Power Systems."
2. The hourly electrical output from an individual cell mounted in a flat plate, vertical axis tracking configuration with the tilt of the mounting surface at 50° from the horizontal. The Aerospace weather tape for the Miami area which was supplied by Westinghouse was used for the simulations.
3. The effects of shading were considered for an array packing factor of 33%. Differences in the electrical output throughout the day (particularly in the evening) were delineated.