these batteries have been evaluated based on an electric utility load leveling mission. The lead/acid study also included a life-cycle environmental analysis.

Current work is being directed to the analysis of battery systems designed for use in electric vehicles. At present, an electric vehicle lead/acid battery and an electric vehicle nickel/zinc battery are being evaluated for their life-cycle energy use for the electric vehicle mission.

Future work will involve the analysis of all the major battery systems under development by DOE so that comparisons between the candidate batteries can easily be made.

Recent publications

1 Life-cycle energy analysis of the sodium–sulfur battery, Hittman Associates, Inc., Columbia, MD 21045, February, 1978.
2 Energy and environmental analysis of the lead/acid battery life cycle, *Hittman Associates, Inc., No. HIT-725*, Columbia, MD 21045, April, 1978.

DEVELOPMENT OF ELECTROCHEMICAL SYNTHESIS AND ENERGY STORAGE

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The overall aim of this program is to improve the energy efficiency, lower the capital cost, and increase the materials yield of electrochemical cell processes used for the conversion of chemical to electrical energy in galvanic cells, and for the production of materials by electrolysis. These goals are pursued in several partially interdependent projects.

Surface morphology of metals in electrodeposition

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. The morphology of copper deposited from acid solutions in a large flow channel is found to be similar at fixed fractions of the limiting current for $23\,000 < Re < 89\,000$. Zinc deposited from zinc halides shows grooved, striated profiles that follow the direction of electrolyte flow over the electrode surface. The model for electrodeposition of metals has been extended to include surface kinetics and it will be further developed to account for mass transfer boundary layers effects. Artificially induced secondary flows will be used to identify the mechanism responsible for the initiation and propagation of surface textures.

Anodic surface layers on battery materials

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. Current density, electrolyte concentration, and crystal orientation have been established as important factors for anodic film formation. Observations of the reaction of lithium with water vapor have confirmed that severe roughening of the metal substrate occurs. A combination of ion etching, Auger spectroscopy and ellipsometry will be used to derive the variation of structural and compositional film properties with film depth. Surface layers on Li in non-aqueous electrolytes will be investigated.

Analysis and simulation of electrochemical systems

Mathematical models are developed to predict the behavior of electrochemical systems and to identify important process parameters. The accuracy and completeness of the models are tested experimentally. Mass transfer coefficients for slow flow through a porous electrode have been measured in a bed of randomly packed spheres. Results indicate that the system can be modeled as a set of straight tubes if provision is made for channeling of flow. A high-pressure cell has been constructed to investigate removal of lead ions from aqueous streams. Flow redox energy storage systems are being optimized with respect to flow rate, current density, and energy efficiency for set ratios of day to night power costs. A model is being developed to describe the behavior of the LiAl–FeS_x battery, for which there is a major experimental program at Argonne National Laboratory. The computer program will include reaction rate distribution, ohmic potential drop, convection and diffusion of electrolyte, temperature rise, and cell potential.

Engineering analysis of gas evolution in electrolysis

In order to obtain a better understanding of the complex physical phenomena, liberation of gas from various electrode surfaces will be observed, using fiber optics, over broad ranges of composition, current density, and flow rate.

Bifunctional air electrodes for metal–air batteries

Multimetallic clusters will be deposited on pyrolitic graphite substrates by electrodeposition. Metals that are catalytically active for evolution and reduction of oxygen will be selected. Kinetic studies of the oxygen reaction on the graphite-supported clusters will be made on a rotating disk.

Electrochemical properties of NASICON

The nature of the phase changes in NASICON will be investigated. Dispersive measurements of ionic conductivity and electrode polarization will be made with pure electrodes, and information will be obtained on current distributions after short-time d.c. electrolysis.

Battery electrode studies

The behavior of electrodes in aqueous and molten salt electrolytes will be studied and means to improve their performance and lifetime investigated.

Recent publications

1 P. Fedkiw and J. Newman, Low Peclet number behavior of the transfer rate in packed beds, *Chem. Eng. Sci., 33* (1978) 1043.
2 J. A. Trainham and J. Newman, The effect of electrode placement and finite matrix conductivity on the performance of flow-through porous electrodes, *J. Electrochem. Soc., 125* (1978) 58.
3 M. Jaksic and C. W. Tobias, Effects of hydrodynamic flow on the development of the morphology of electrode-deposited zinc, *Ext. Abstr. 29th Meeting Int. Soc. Electrochemistry, Aug. 28 - Sept. 2, 1978, Part II,* p. 1164.
4 R. Atanasoski, H. Law and C. W. Tobias, Electrochemical reduction of potassium chloride in propylene carbonate electrolyte with aluminum anodes, *LBL-8505, December 1978.*
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8 R. Pollard and J. Newman, Transport equations for a mixture of two binary molten salts in a porous electrode, *J. Electrochem. Soc.*, in press *(LBL-8284, October 1978).*
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12 J. A. Trainham and J. Newman, A comparison between flow-through and flow-by porous electrodes for redox energy storage, *LBL-9331, June 1979.*
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16 P. Fedkiw and J. Newman, Numerical calculations for the asymptotic, diffusion dominated mass-transfer coefficient in packed bed reactors, *Chem. Eng. Sci., 33* (1978) 1563.

DEVELOPMENT OF EVALUATION TECHNIQUES FOR ELECTROCHEMICAL ENERGY STORAGE SYSTEMS

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The two primary objectives of this program are, first, the development of a quantitative rationale for the comparison and evaluation of promising