

*Interplan Corporation, 100 North Hope Avenue, Santa Barbara, CA 93110 (U.S.A.)*

The objective of this subcontract is a cost analysis study of the ESS vehicle candidates such as battery/flywheel, dual fueled hybrid, liquid hydrogen and hydride categories, and a study on the marketability of ESS vehicles.

*Brookhaven National Labs., Upton, NY 11973 (U.S.A.)*

The objective of this subcontract is to conduct work of the Chemical Storage Panel by selecting and directing panel members to fulfill the objectives of the Energy Storage Study; to assist in adding hydrogen storage data to the National Energy Storage Data Base; to provide additional support to other study panels as needed.

*Battelle, Pacific Northwest Labs., Battelle Boulevard, Richland, WA 99352 (U.S.A.)*

The objective of this subcontract is to conduct the work of the Mechanical Storage Panel by selecting and directing panel members to fulfill study objectives and schedule; to assist in adding mechanical energy storage data and to provide additional support to other panels as required.

## **NEW BATTERY MATERIALS**

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This program is being undertaken to explore new materials for use in advanced battery systems, and to understand and evaluate relevant structural, thermodynamic, and kinetic parameters. 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 or negative electrode constituents in lithium-based batteries. Efforts are also being undertaken to understand better the mechanisms and kinetics of the processes occurring in the electrode materials currently being used in the

high temperature systems being developed by others under the support of the Department of Energy.

Work on solid electrolytes has been focused primarily upon materials with three general types of crystal structure. One of these is the anti-fluorite type; doping of ternary lithium oxides with aliovalent cations (e.g.,  $\text{Al}^{3+}$  for  $\text{Li}^+$ ) in this structure can produce very large concentrations of crystallographic defects, and thus large increases in ionic conductivity. Another material with this structure,  $\text{Li}_2\text{NH}$ , was discovered to be a very good lithium ionic conductor at ambient temperatures ( $3 \times 10^{-4} \text{ ohm}^{-1} \text{ cm}^{-1}$  at  $25^\circ\text{C}$ ). A second group are oxides with tetrahedral anionic groups between which cations, such as lithium, percolate among dilutely populated almost equivalent sites. Anion-substitution solid solution effects in materials based on the lithium orthosilicate and orthophosphate structures have also been shown to produce high lithium conductivities ( $1.24 \times 10^{-1} \text{ ohm}^{-1} \text{ cm}^{-1}$  at  $400^\circ\text{C}$ ). The third material of interest for lithium solid electrolytes is  $\text{Li}_3\text{N}$ , which has an open layer type structure, and is a very good two-dimensional lithium ionic conductor ( $1.2 \times 10^{-3} \text{ ohm}^{-1} \text{ cm}^{-1}$  at  $25^\circ\text{C}$ ). In addition to this work on solid electrolytes, some attention has been given to the possible use of several intermediate-temperature molten salts in lithium systems.

Electrode materials investigated have included the  $\text{LiAl}$  negative electrode phase, as well as a number of other inter-metallic phases in systems such as  $\text{Li-Ga}$ ,  $\text{Li-Sn}$ , and  $\text{Li-In}$ . Several groups of materials are also being investigated for use as positive electrode constituents in lithium systems. These include  $\text{FeAsS}$ ; iron, nickel, and cobalt tri-arsenides, and a number of ternary transition metal oxides. Special attention has been 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 the source of electrode shape changes and capacity loss in some present battery systems.

## Recent publications

- 1 B. A. Boukamp and R. A. Huggins, Fast ionic conductivity in lithium nitride, *Mater. Res. Bull.*, 13 (1978) 23.
- 2 W. Weppner and R. A. Huggins, Electrochemical methods for determining kinetic properties of solids, *Annu. Rev. Mater. Sci.*, 8 (1978) 269.
- 3 R. A. Huggins, Crystal structures and fast ionic conduction, in P. Hagenmuller and W. van Gool (eds.), *Solid Electrolytes*, Academic Press, New York, 1978, p. 27.
- 4 R. A. Huggins and A. Rabenau, What is special about fast ionic conductors?, *Mater. Res. Bull.*, 13 (1978) 1315.
- 5 B. A. Boukamp and R. A. Huggins, Ionic conductivity in lithium imide, *Phys. Lett.*, 72A, (1979) 464.
- 6 C. John Wen, W. Weppner, B. A. Boukamp and R. A. Huggins, Thermodynamic and mass transport properties of  $\text{LiAl}$ , to be published in *J. Electrochem. Soc.* (7 Feb. 1979).

- 7 R. A. Huggins, Evaluation of properties related to the application of fast ionic transport in solid electrolytes and mixed conductors, in P. Vashishta, J. N. Mundy and G. K. Shenoy (eds.), *Fast Ion Transport in Solids, Electrodes and Electrolytes*, North Holland, Amsterdam and New York, 1979.
- 8 B. A. Boukamp, I. D. Raistrick and R. A. Huggins, Use of low frequency a.c. measurements in solid state electrochemistry, in P. Vashishta, J. N. Mundy and G. K. Shenoy (eds.), *Fast Ion Transport in Solids, Electrodes and Electrolytes*, North Holland, Amsterdam and New York, 1979.
- 9 W. Weppner and R. A. Huggins, Thermodynamic stability of the solid and molten electrolyte  $\text{LiAlCl}_4$ , in P. Vashishta, J. N. Mundy and G. K. Shenoy (eds.), *Fast Ion Transport in Solids, Electrodes and Electrolytes*, North Holland, Amsterdam and New York, 1979.
- 10 R. A. Huggins, Solid electrolytes, to be published in *Proc. NATO Sci. Inst. on Materials for Advanced Batteries*, Plenum Press, New York, 1979.
- 11 C. J. Wen, W. Weppner, B. A. Boukamp and R. A. Huggins, Electrochemical investigations of solubility and chemical diffusion of lithium in aluminum, in press.

## ELECTRICAL CONDUCTION AND CORROSION IN LITHIUM CONDUCTING GLASSES

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The objective of this project is to investigate and characterize the electrical and corrosion-resistant properties of fast lithium ion conducting glasses which appear to be highly promising candidates for use as solid electrolytes in high energy density batteries.

This program consists of three major efforts related to the development of a glassy solid electrolyte: glass formability and processing studies, charge transport studies, and corrosion resistance investigations. At this preliminary stage, emphasis has been directed towards identifying compositions in the lithium borate system which are reasonably good glass formers as well as fast ion conductors. Glass processing steps including (a) powder preparation, (b) melting procedures, (c) chill techniques, and (d) post fabrication annealing treatments, were correlated with the final morphology of the glasses produced. These included degree of crystallization, phase separation, and cracking. Compositions with  $\text{Li}_2\text{O}/\text{B}_2\text{O}_3$  ratios of 0.1 - 0.7 were investigated. Glasses with up to  $\text{Li}_2\text{O}/\text{B}_2\text{O}_3 = 0.5$  were readily formed, while glasses with even higher lithium contents could be produced by adding salts such as  $\text{LiCl}$ .

The above studies demonstrated that it is possible to obtain glasses in the lithium borate system over a wide range of Li/B ratios. Effects of widely varying alkali contents on both the transport and corrosion resistant properties of such glasses are now being investigated.