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Journal of Power Sources 89 (2000) 256–259

JOURNAL OF POWER SOURCES

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Recommendations and conclusions from the advanced solid state lithium batteries workshop

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Received 1 September 1999; received in revised form 10 September 1999; accepted 6 January 2000

Abstract

This paper presents the results of several discussion sessions that were held during the workshop. The workshop participants gathered on the final morning of the conference to propose a set of recommendations for DOE management's consideration. In addition to this general discussion session, an advisory panel (composed of DOE management, national laboratory team leaders, representatives of battery developers and university researchers) was convened for 2 h to discuss major outcomes of the conference. The results of both of these sessions are reported in this paper. Specifically, this paper presents recommended research priorities for each of the battery components, anode, electrolyte and cathode, and a number of programmatic and organizational recommendations. © 2000 Elsevier Science S.A. All rights reserved.

1. Introduction

Following the two full days of technical presentations, questions and answers and discussions, the workshop participants gathered for the final morning of the conference to propose a set of recommendations for Department of Energy (DOE) management's consideration. In addition to this general discussion session, an advisory panel was convened for 2 h following the workshop and general discussion session. This advisory panel was composed of DOE management, national laboratory team leaders, representatives of battery developers and university researchers. Members of the advisory panel, and their affiliation, are shown in Table 1. The results of both of these sessions are reported in this paper.

The discussion session with the entire set of workshop participants was organized to be both directed and open. DOE management opened the session with a set of potential discussion topics. However, following this introduction, the participants were free to express opinions on and comment on any aspect of advanced battery research, technical or programmatic, that they chose to. The recommendations and suggestions of the workshop participants are presented below, organized into technical and programmatic recommendations and suggestions.

2. Technical recommendations and conclusions

In addition to the programmatic and organizational suggestions and recommendations described below, the workshop participants also spent a significant amount of the session discussing promising technical approaches and results. Listed below are a number of results and research priorities for each of the battery components, anode, electrolyte and cathode, that researchers discussed.

2.1. Anode

- *Improve fundamental understanding:* Researchers felt that establishing a stronger fundamental basis and improving the computational methods for understanding the anode was critical. Issues that they felt were particularly important to investigate included the anode interface, LiO_2 surface layer growth and passivating effects, and ion conduction across the interface. They then expanded their discussion to include fundamental calculations and modeling development coupled with experimental work. They noted that this type of coordinated investigation is most likely to offer significant breakthroughs and advances.

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PII: S0378-7753(00)00441-9

Table 1
Advisory panel members

Name	Affiliation
(1) Radislov Atanasoski	3M
(2) Vince Battaglia	Argonne National Laboratory
(3) Helen Cost	Daimler–Chrysler
(4) Dennis Dees	Argonne National Laboratory
(5) Jack Deppe	Abacus Technology
(6) Michel Gauthier	Hydro–Quebec
(7) Harold Haskins	Ford Motor
(8) Kenneth Heitner	Department of Energy
(9) John Kerr	Lawrence Berkeley National Laboratory
(10) Albert Landgrebe	International Electrochemical Systems
(11) Paul Maupin	Department of Energy
(12) Frank McLarnon	Lawrence Berkeley National Laboratory
(13) Jim McBreen	Brookhaven National Laboratory
(14) Bob Minck	Ford Motor
(15) Gholam Abbas Nazri	General Motors Research Laboratory
(16) Raymond Sutula	Department of Energy

• *Continue investigation of composite anode / modified carbon materials and intermetallic compounds:* Participants noted that these materials appear to offer significant promise of substantially improving the performance of advanced batteries.

• *Expand use of the advanced photon source (APS):* Nearly all of the researchers were enthusiastic about the use of the APS at Argonne National Laboratory. They recommended its continued use and asked whether it could not be used to investigate a wider range of fundamental issues than it is currently being used to address.

• *Continue investigation of corrosion issues:* Workshop participants were encouraged by the results presented in the corrosion arena and recommended that continued attention be paid in this area. They noted that current collector corrosion likely plays an important role in limiting cycle and calendar life in advanced batteries.

• *Continue adhesion research:* Participants also suggested that the issues of anode adhesion to the substrate continue to be investigated. In addition, they felt that additional research was required into the methods used for coating the active particles in the negative electrode.

2.2. Electrolyte

• *Improved safety:* The researchers also see great benefit in continuing the research into the causes of electrolyte breakdown and the ability to make the materials safer. These investigations serve to improve the community's fundamental understanding of the polymer materials and their behavior, and to improve the safety and eventual marketability of advanced batteries.

• *Composite electrolytes:* Most of the participants felt that Saad Khan's work on composite electrolytes showed significant promise and should be continued. The ability to separate the conduction mechanism from the mechanical strength of the material is seen as a major advantage.

• *Gelled polymers:* In addition to the composite electrolyte materials, the workshop participants felt that gelled polymers also offered a chance for a significant breakthrough in electrolyte performance and cost. They therefore recommended continued support of research into these materials.

• *Investigate additives on polymer backbone:* Finally, the participants mentioned that it would be advisable to continue to investigate the effects of additives on the polymer backbone. In particular, they recommended taking an engineering-like approach to choosing and evaluating the effects of additives on polymer mechanical and electrical properties.

2.3. Cathode

• *Basic understanding of cathode SEI:* Many of the workshop participants felt that the solid electrolyte interface was a major contributor to the technical barriers affecting advanced battery performance. They therefore recommended continued and enhanced attention be paid to the theory and experimental investigations of SEI composition, thickness and chemistry.

• *Lower voltage levels:* Based on the industry's continued move toward lower voltage systems, many researchers felt that investigations into high voltage cathodes were counterproductive. They therefore recommended that research be focused on lower voltage cathode materials.

• *Need for systematic evaluations:* Researchers believe that our fundamental understanding of cathode properties and behavior requires continued directed investigations, perhaps using advanced diagnostics tools such as the APS. Although researchers can make case by case evaluations and draw conclusions on specific materials, the ability to choose new materials and make performance predictions is still rather immature and would benefit from continued and systematic evaluations. Coupled with this recommendation was the acknowledgement that the community must continue to search for new cathode materials, including coated cathode materials, mixed oxides, chlorides and sulfides.

• *Cathodes must deliver enhanced energy capacity:* Many in the audience wished to reiterate that the community is ultimately searching for materials that exhibit enhanced energy capacity for extended calendar and cycle life, stability with respect to the electrolyte, and that are available at a reasonable cost. But, without a good energy capacity, the other properties of the cathode are practically irrelevant.

3. Programmatic recommendations and conclusions

One of the first topics to be opened during this discussion was the needs of the researchers. DOE requested that

the participants list those items that they felt were critical requirements for the researchers to do an effective job in maintaining a vigorous effort in the search for and understanding of high energy and high power batteries.

The researchers listed the following items.

• *Potential for international cooperation must exist*: Participants noted that a large supply of talent lies beyond the United States, and wished to emphasize the importance of establishing and maintaining working relationships with foreign researchers. In particular, they requested increased cooperation with Japan.

• *Maintenance of critical mass at labs*: Researchers at the national laboratories also spoke about the need for a minimum amount of support that is required to maintain a productive research program. The ability to fund graduate students and post-doctoral fellows was specifically mentioned. Partially in response, DOE management encouraged the labs to utilize their ''core program'' areas to gain more financial and administrative support.

• *Need to understand key problems of developers*: The researchers requested improved communication with the developers. In particular, they asked that a means be devised for developers to share their critical research needs with the laboratories without compromising their need to protect proprietary information. Many of the researchers, both those in predominantly fundamental research and those in more directed areas, expressed a need for a technical issues list on which to base their investigations.

• *Emphasize materials work*: The workshop participants were unanimous in their belief that revolutionary advances in advanced battery research would likely come from either fundamental or applied research into new materials. They therefore requested that DOE emphasize these investigations.

• *Need for uniform samples from industrial base*: A continuing issue in advanced battery materials research is the uncertain composition, history and manufacturing methods associated with materials. However, the participants did not offer a suggestion regarding how to achieve more uniform material samples.

• *Focus on ''engineering the polymer''*: Most of the workshop participants felt that utilizing an engineering approach to the creation of a new polymer electrolyte would pay more dividends than the standard scientific approach of create, analyze, publish, etc.

• *More focused workshops*: Workshop participants felt that focused workshops, such as the one represented in this special issue, provided significant benefits to both DOE management and the research community. Although most of the researchers attending the conference were aware of the work being done by others, the ability to sit and talk with others about their latest results and ideas is often the most fruitful aspect of a meeting such as this.

Workshop participants who work at the national laboratories then discussed some of their specific requirements and requests. They included the following items.

• *Cost information and guidelines*: Although the United States Advanced Battery Consortium (USABC) has provided cost targets for the intermediate and long-term, researchers felt that they would benefit from more detailed guidance regarding cost targets. Although each researcher can and does provide materials' cost estimates, the ability to factor in manufacturing and distribution costs is critical and likely requires the active involvement of both battery manufacturers and materials suppliers.

• *Short term ''seed money''*: Researchers felt that nearly all DOE research programs would benefit by setting aside a small amount of seed money each year. This money would be used to fund researchers not currently in the program and who propose ''out of the box'' solutions to critical problems. Unfortunately, it was not clear where this extra seed money would come from.

• *Need a road map or plan for implementation of new technology*: This issue was again related to the relationship between the researchers and the battery developers. Many in the audience felt unsure about ensuring the successful transfer of technology and information from their labs to developers and requested that this be defined.

• *Better definitions of problems vs. targets*: Some of the researchers felt that there is a continued disconnection between the identification of problems and the relationship of those problems to achieving technical targets. They requested that DOE work with them to arrive at a mutual understanding of the interrelationship between these two items. Related to this issue was the discussion of a need to create criteria at the materials levels that would lead to the attainment of the medium and long-term performance and life goals for advanced batteries.

• *Propose a realistic budget*: Laboratory researchers requested that DOE base the budgets provided to the labs on the work that is being requested of them. The intermediate and long-term goals of the USABC and Partnership for a New Generation Vehicles (PNGV), for high-energy and high-power batteries, respectively, require a certain minimum amount of support.

Several of the suggestions and recommendations dealt with the potential for improved BES/ETR (BES = Office of Basic Energy Sciences, ETR = Exploratory Technology Research Program supported by the Office of Advanced Automotive Technologies) communication and collaboration. Those suggestions included the following.

• *Create a joint BES/ETR roadmap*: Many of the researchers who are currently working within the BES or the ETR programs felt that increased coordination and collaboration between the programs would benefit both the DOE and the research community. Towards this end, several specific recommendations were put forward to encourage and foster improved interaction. (1) That BES and ETR develop a master calendar of activities and meetings to strengthen coordination. (2) That the programs attempt to coordinate an effort to market its researchers to the national laboratories' ''core funds''. (3) That DOE

create a joint roadmap describing where the department envisions the results of these two programs leading the battery community.

• *Improve input from developers to R&D community*: As mentioned above, the researchers expressed an interest in improved dialogue and collaboration with battery developers. The researchers requested improved communication with battery developers.

• *Consider add-on sessions to existing workshops (i.e. MnO_2) or ECS meetings*: An additional idea that was put forward in relation to the ''focused workshop'' item mentioned above was the possibility of organizing follow-on workshops or conferences. This approach would serve two purposes. (1) Bring together the battery research community on a more regular basis, and (2) would encourage participation in a common set of conferences, perhaps including those that are more likely to be attended by battery development personnel.

• *Invite BES to TAC meetings*: In order to help ensure that BES program participants understand the requests and needs of the USABC and PNGV, it is suggested that BES participants and management be invited to the TAC meetings. These meetings between DOE, USABC and PNGV members involve discussion of technical progress, problems and industry needs. Both battery groups have developed both intermediate and long-term targets for advanced batteries.

• *Focus BES efforts on science and technology*: Many of the participants felt that BES should not participate in investigations into materials development issues. Rather, BES and its researchers should focus on the science and electrochemistry of the materials being used in or proposed for use in advanced batteries.

Several of the suggestions and recommendations were primarily concerned with the organization and management of the ETR program. Those suggestions included the following.

• *Offer ETR researchers as consultants to developers*: In order to foster improved interaction between battery developers and researchers, it was suggested that national laboratory and university researchers consider working as consultants and technical experts for the battery developers.

• *Ensure appropriate developer involvement*: Some of the workshop participants, including some of the battery developer representatives, expressed the desire to have appropriate developer participation as opposed to simply increased participation. In particular, they suggested that developers send researchers to workshops and program review meetings, not project managers.

• *DOE / USABC should work to state problems in a non-proprietary manner*: This suggestion is related to the often-stated need of researchers to understand key problems of developers. In this instance, workshop participants requested DOE and consortium participation to help in bridging the gap between research direction and industry needs.

DOE management is taking these technical and programmatic recommendations into consideration and plans to utilize them to ensure that their programs and support to the scientific community yield the most useful results possible for the battery developer and research communities.

Acknowledgements

The author gratefully acknowledges the support of the US Department of Energy, Office of Advanced Automotive Technologies.