SAND--97-2343C
SAND97-2343C
CONF-971096--

Recycling Readiness of Advanced Batteries for Electric Vehicles

Rudolph G. Jungst
Sandia National Laboratories
Albuquerque, New Mexico 87185

Abstract

Maximizing the reclamation/recycle of electric-vehicle (EV) batteries is considered to be essential for the successful commercialization of this technology. Since the early 1990s, the U.S. Department of Energy has sponsored the ad hoc Advanced Battery Readiness Working Group to review this and other possible barriers to the widespread use of EVs, such as battery shipping and in-vehicle safety. Regulation is currently the main force for growth in EV numbers and projections for the states that have zero-emission vehicle (ZEV) programs indicate about 200,000 of these vehicles would be offered to the public in 2003 to meet those requirements. The ad hoc Advanced Battery Readiness Working Group has identified a matrix of battery technologies that could see use in EVs and has been tracking the state of readiness of recycling processes for each of them. Lead-acid, nickel/metal hydride, and lithium-ion are the three EV battery technologies proposed by the major automotive manufacturers affected by ZEV requirements. Recycling approaches for the two advanced battery systems on this list are partly defined, but could be modified to recover more value from end-of-life batteries. The processes being used or planned to treat these batteries are reviewed, as well as those being considered for other longer-term technologies in the battery recycling readiness matrix. Development efforts needed to prepare for recycling the batteries from a much larger EV population than exists today are identified.

Introduction

A practical method for recycling batteries from electric vehicles is viewed as an essential component for the successful implementation of this transportation technology. Disposal of electric vehicle batteries is possible, but is likely to be costly, and detracts from the environmental benefits of a zero emission vehicle. The major roadblock to EV acceptance is cost and therefore disposal cannot be afforded, especially if the waste contains valuable materials. Most developers of power sources for electric vehicles therefore have a goal of recycling as much material as possible at the end of its life. Less demanding, secondary uses for the power source may help to extend its term of operation, or in some cases refurbishment may be possible. Eventually, however, it will need to be processed in such a way that all the valuable components and materials can be reused. This may not constitute recycling in the regulatory sense, but the concept is to minimize the amount of material that will be landfilled and maximize the recovered value.

The information that is presented in this paper is largely derived from discussions within a working group that has been established by the U.S. Department of Energy to identify

DISCLAIMER

issues that could form roadblocks to the widespread acceptance of EVs. One of the critical areas that has been recognized in this regard is recycling. Both generic information about the regulatory aspects of collection and processing of waste batteries and specific details of the process feasibility and cost for relevant battery systems are included. The readiness of recycling is being tracked for both near-term (3 - 5 years) and long-term (>5 years) battery technologies that appear to be feasible for use in electric vehicle applications.

The Ad Hoc Advanced Battery Readiness Working Group

The genesis of the Advanced Battery Readiness Working Group was in 1990, when the U.S. Department of Energy held a planning meeting[1] to identify potential battery-related barriers that might impede the acceptance of electric vehicles by commercial industry and by the American public. This initial meeting focused on the high temperature sodium-beta batteries (sodium/sulfur and sodium/metal chloride) that were at the time the advanced batteries considered to be the leading contenders for near-term use in this application. Three general areas were identified at the meeting as being worthy of further study: battery shipment, EV crashworthiness, and battery disposal. During subsequent meetings of the ad hoc EV Battery Readiness Working Group, EV crashworthiness was modified slightly to in-vehicle safety and battery disposal was broadened to battery reclamation/recycle, but the overall goal of the Working Group has remained the identification of barriers to EV commercialization from the battery point of view. Sub-working groups were established in each of the three main areas and have met regularly to highlight and address roadblocks in their respective fields.

As battery technology has advanced, the focus of the Working Group has also widened beyond the sodium-beta batteries in order to continue to cover the range of chemistries most likely to predominate in the evolving EV market. In 1996, the decision was made to change the name of the working group to the ad hoc Advanced Battery Readiness Working Group in order to better reflect the fact that its primary mission was to investigate issues resulting from the use of advanced batteries, rather than technologies such as lead-acid where there is already an existing infrastructure that can handle activities such as battery shipping and recycling for EVs. The Working Group membership consists of experts from both industry and government in areas such as battery development, manufacturing, and recycle; hazardous waste regulation, treatment, and disposal; electric vehicle design, manufacture, safety, and infrastructure needs; and automotive dismantlement and recycling. Government organizations include participants from the Department of Energy and its National Laboratories, the Environmental Protection Agency, the Department of Transportation, and the National Highway Traffic Safety Administration.

The Reclamation/Recycle Sub-Working Group is chaired by Sandia National Laboratories and has as its mission statement "to ensure that a cost effective means exists for the collection and reclamation/recycle of electric vehicle batteries at end-of-life." This group reviews information on the feasibility and cost of proposed recycling processes for electric vehicle batteries; investigates and comments on proposed regulatory changes affecting advanced battery waste collection, recycling, and disposal; and discusses the impact of the supply and market value of battery materials on the prospects for designing cost-effective reclamation/recycle methods.

Electric Vehicle Population and Battery Technologies

The anticipated growth in the number of electric vehicles that will be on the road over the next few years has been a subject of intense interest for automotive manufacturers, battery developers, and suppliers/recyclers of battery materials. An acceleration in this growth is anticipated to occur in the near future, but only a relatively small number of EVs are presently in service and the growth has historically been slow[2] (see Table 1). It is difficult to accurately predict from this trend when significant numbers of operating EVs may begin to accumulate.

Table 1. Number of Electric Vehicles in the US by Year

Year	Number of Existing EVs
1992	1607
1993	1690
1994	2224
1995	2860
1996	3306
1997	3925

The projected growth in the number of electric vehicles over the next 5 years is being motivated by legislative regulation rather than market demand. Initiatives such as the California Air Resources Board (CARB) zero emission vehicle (ZEV) program and others patterned on it in some of the northeastern states mandate that a certain percentage of the vehicles sold by the major automotive manufacturers be zero emission (i.e. battery or hydrogen fuel cell powered) beginning in 1998. The numbers required by these programs are initially small, but become significant by 2003, when ZEVs must account for 10% of all passenger vehicles and light-duty trucks sold in the covered regions by large and intermediate volume manufacturers[3,4]. Table 2 shows the expected yearly EV placements through 2003 for the three states that presently have ZEV programs in place. Assuming that the requirements will be met, these levels probably represent the majority of the EVs that will enter service over the next five years. Actual numbers will be somewhat higher because fleet sales are not included, nor is production of EVs by small volume manufacturers and by converters, which are not covered under the ZEV rules and agreements. There will also be some EV sales and leases in areas without ZEV programs, but most likely fewer than under the influence of the mandates. The total amount of demand for this product that will be generated over the 1998-2003 time period is therefore somewhat uncertain, although several hundred thousand EVs per year by 2003 certainly appears to be possible, as long as the ZEV requirements are not modified.

Table 2. ZEV Annual Requirements from 1998 - 2003

Year	California	New York	Massachusetts
1998	748	7800	
1999	1500	7800	
2000	1502	7800	3750 (3 yr. cum.)
2001		19,500	
2002		19,500	
2003	130,000	39,000	25,000

Preparation of the infrastructure to support these electric vehicles (charging stations, mechanical support, battery collection and recycling capability, etc.) and also expanding critical raw material supplies and manufacturing facilities to produce the number of vehicles required to meet consumer demand must be timed properly to support this rapidly changing electric vehicle population. Producers of battery materials are already trying to estimate what the impact of large numbers of EVs might be on the demand for their products and the resulting need for expanded production plants. In fact, the establishment of new, large-scale battery recycling facilities will probably take years to complete, particularly when the time to obtain operating permits is considered. It is precisely these long time scale infrastructure roadblocks that the Working Group is seeking to identify so that solutions can be found and implemented soon enough to avoid impacting the EV commercialization effort.

Since the initial California proposal was made, the program has been modified from mandates to memoranda of agreement (MOAs) for the first 3 years with the 7 major auto manufacturers with the most sales in that state. Table 3 shows the MOA numbers for the California program by manufacturer for 1998 - 2000. The requirement for the 2003 year remains at 10% of vehicle sales, which would equate to approximately 130,000 total vehicles in California. Translating these numbers to battery recycling needs becomes more complicated, however, since the manufacturers have a choice of several different battery technologies and their choices could change as improved batteries are developed. Table 4 shows the battery types that are currently planned by the manufacturers. In addition, the California program has incentive provisions for multiple ZEV credits depending on the specific energy of the battery being used, so the numbers in Table 3 most likely do not represent the number of vehicles that will actually be operated.

Table 3. MOA Commitments for Placing Vehicles in California

Year	GM	Ford	Toyota	Honda	Nissan	Chrysler	Mazda	Total
1998	182	181	135	101	70	51	28	748
1999	365	363	271	202	141	103	55	1500
2000	366	363	271	203	141	103	55	1502

Table 4. Battery Types being Considered by EV Manufacturers

EV Manufacturer	Lead-Acid	Nickel/Metal Hydride	Lithium-ion
GM	X	X*	
Ford	X		
Toyota		X	
Honda		X	
Nissan			X
Chrysler	X		
Mazda	X		

*Near future (1998)

It can be seen that the lead-acid battery will remain a significant part of the battery mix, at least during the early years of the ZEV programs. A number of manufacturers are planning to offer advanced batteries, mainly nickel/metal hydride, but Nissan has proposed a lithium-ion battery system. Other battery types are being used by the intermediate volume manufacturers that will be brought into some of the programs in 2003. These include nickel/cadmium and sodium/nickel chloride. Table 5 shows a matrix of near- and

Table 5. Recycling Progress Chart (Based on Battery Chemistry)

	Pb-Acid	Ni/Cd	Ni/MH	Li-Ion	$Na/NiCl_2$	Zn-Air	Li-Polymer	Li/FeS_2
(Standards) & Regulations Identified	Y	Y	Y	?	Y	Y	Y	Y
Recycling Processes Identified	Y	Y	Y	Y	Y	Y	Y^-	Y
Pre-feasibility Cost Study Done	Y	Y	Y	Y	N	Y^e	N	N
Processes Selected for Development	Y	Y	Y	Y	N	Y^e	Y^-	N
Permits Issued	Y	Y	Y	Y	N	N^e	Y	Y
Batteries Recycled on a Commercial Scale	Y	Y	Y	Y	N	N^e	Y	Y
5-kWh Battery Recycled on a Pilot Scale	Y	Y	N	N	?	N^e	N	N
Collection System Established	?	?	?	?	?	?	?	?

Y^- indicates partial recycling

Y^e indicates this is done in Europe

N^e indicates this will be completed as part of current European fleet test

? indicates information is unknown

long-term battery technologies for EVs that has been assembled by the Reclamation/Recycle Sub-Working Group to aid in evaluating progress in developing a recycling capability for each system. This includes several battery technologies not mentioned previously. Zinc-air batteries are being evaluated in Europe for fleet applications, but the infrastructure needed for the mechanically recharged system that is being considered will limit its impact for consumer use, at least while the user population is small and somewhat diffuse. The long-term advanced lithium batteries represented by the lithium-polymer and lithium/iron disulfide systems are not developed fully enough to be commercially used in electric vehicles. This may occur in the future, but probably not within the time window from 1998 to 2003. Table 5 identifies milestones along the path for development of reclamation/recycle processes for EV batteries. Significant ground work has already been done for the advanced battery technologies as a result of the use of smaller versions of the same chemistry in consumer electronics in many cases. However, there is still much work to be completed, particularly on dealing with disassembly and deactivation issues for batteries containing reactive metals (e.g. lithium, sodium, etc.). Details regarding recycling plans for some of the battery chemistries more likely to see widespread use will be given below.

Readiness of Recycling Processes for EV Batteries

Lead-Acid and Nickel/Cadmium

Lead-acid batteries will provide a significant portion of the power need for electric vehicles in the near-term. However the large distribution, collection, and recycling infrastructure that has been established to support the millions of industrial and starting, lighting, and ignition (SLI) batteries that are sold annually is projected to be able to easily absorb the additional lead-acid electric vehicle batteries that will likely be produced over the next 5 - 10 years. Assuming electric vehicle sales of 200,000 in 2003, a 30% market share for lead-acid in 2000 and beyond, a 3-year replacement schedule for lead-acid batteries, and an improvement in lead-acid specific energy to 50 Wh/kg by 2005, the projected amount of electric vehicle battery lead mass in 2005 is still only 1% of the total 1996 secondary lead processing capacity[5]. The historical growth in the amount of lead scrap has been on the order of 5% per year for the past 10 years. Thermal smelting has been the method of choice for recovering secondary lead, although hydrometallurgical and electrowinning processes have environmental advantages due to reduced lead emissions. Barring a significant tightening of environmental controls on lead recovery facilities, existing capacity should be more than adequate to maintain the present high level of lead-acid battery recycling. There may be some regional recycling capacity problems that will surface and these may require shifts in transportation patterns of scrap batteries to different recovery locations.

Nickel/cadmium batteries also have an existing recycling process that can be extended to cover EV-size batteries. Recycling of cadmium is necessary both because its toxicity makes disposal impractical and because cadmium supplies are less abundant than those of more common elements such as nickel. INMETCO, a producer of the remelt alloy that is used as a raw material by the stainless steel industry, accepts a number of different battery types for recycling, including nickel/cadmium. Initial operations with nickel/cadmium began in 1990, but at first only the nickel parts were processed by INMETCO, while the cadmium was separated and purified at other facilities for reuse. At the end of 1995, technology acquired from SAFT NIFE AB was put into operation at INMETCO, giving them the capability to recover high purity cadmium by distillation on site. INMETCO presently has a 5,000 ton per year capacity for cadmium and cooperates with the Portable Rechargeable Battery Association in its collection program for nickel/cadmium batteries. The cadmium recovery unit can be expanded in capacity, which may be necessary if significant numbers of EVs use this battery technology. Since there is presently only one facility in the U.S. that can recover cadmium, it may be economically preferable to establish other recycling locations near areas that generate large numbers of waste nickel/cadmium batteries, although this would require obtaining new operating permits for them in most cases.

Nickel/Metal Hydride

The nickel/metal hydride battery is one of the advanced technologies that is likely to see near-term use in electric vehicles. It is the advanced battery that has been chosen by three of the seven largest automotive retailers in California. The high content of nickel and iron, which are desirable for formulating stainless steels, means that it is a good feedstock for the standard INMETCO process for making remelt alloy. INMETCO has evaluated nickel/metal hydride batteries extensively and has confirmed that this is indeed the case. Small nickel/metal hydride cells have been processed at their plant for several years. Although the INMETCO process appears to be feasible and profitable, it has also been suggested that even more of the inherent value can be recovered from this battery by recovering the specialty metals. These materials are essentially ignored by the INMETCO process. The nickel/metal hydride battery contains significant amounts of such materials, mainly as constituents of the hydride alloy (see Table 6). Vanadium, zirconium, chromium, cobalt, and certain rare earth elements are among the more likely possibilities. A study of the economics of recovery of the materials in this battery has been done[6] and shows that reclamation/recycle can be quite profitable for this system. The estimated return for nickel/metal hydride could be as much as $6/kWh of batteries in the most favorable case studied. Table 7 shows that about half of the recovered value from a prototype physical separation/chemical leaching and electrowinning process is derived from the hydride alloy material. The chemical feasibility of other hydrometallurgical processes has also been investigated, but detailed cost comparisons have not been made. Selection of the preferred process for enhanced recovery of valuable materials from the nickel/metal hydride system is therefore still pending. Some additional time will be required for pilot studies to prove that the process can be scaled up successfully. The general approach has been to depend on the standard INMETCO process as the primary method for the near-term while efforts continue to develop enhanced recovery methods.

Table 6. Material Breakdown of Typical Nickel/Metal Hydride Batteries with Different Types of Hydride Alloys (% by Wt)

Material	AB_2 Alloy	AB_5 Alloy
Nickel	24.0	29.2
Iron	43.5	43.5
Vanadium	7.1	
Zirconium	2.5	
Chromium	2.1	
Lanthanum		3.2
Praseodymium		1.4
Cobalt		1.7
Oxygen	4.3	4.3
Potassium Hydroxide	3.0	3.0
Water	6.0	6.0
Leveling Agents	1.0	1.0
Polypropylene	5.0	5.0
Other	1.5	1.7

Table 7. Estimated Credits for By-Products Recovered from Nickel/Metal Hydride Batteries by a Physical Separation/Chemical Process ($/20-kWh Battery)

Product	AB_2 Alloy	AB_5 Alloy
Nickel	95	95
Nickel/Iron Scrap	211	211
Steel Scrap	10	10
Polypropylene	4	4
Hydride Alloy Scrap	362	316
Total	682	636

Lithium-Ion

One major automotive manufacturer (Nissan) is proposing to use an advanced lithium-ion battery in an EV beginning in 1998. Lithium-ion cells are already competing favorably with nickel/metal hydride in consumer electronics applications and the market for small lithium-ion cells is increasing rapidly. Sony has announced plans to increase production to 15 million per month in 1997 and as high as 30 million per month thereafter[7]. Larger versions of the lithium-ion battery can possibly grow in popularity for electric vehicles due to their light weight and high specific energy and power, although safety is still a concern. A recycling process for small lithium-ion cells has been implemented by Sony Corporation in partnership with Sumitomo Metals and Mining Co., Ltd. to support their battery products for consumer electronics. Table 8 lists the metal content of a Sony lithium-ion

Table 8. Lithium-ion Battery Metals

Metal	Approximate Weight %
Iron	20 - 25
Cobalt	15 - 20
Aluminum	5 - 10
Copper	5-10
Lithium	2-4

battery. The Sony lithium-ion battery design uses a $Li_{1-x}CoO_2$ cathode and cobalt is the most valuable material that can be recovered from this system. The value of the pure cobalt in a kg of batteries is about $8. Besides cobalt, which is recovered as cobalt chloride, iron and copper are also recycled by the Sony process.

Several manufacturers are producing variations on the same basic cell chemistry, some of which involve other metal oxides than cobalt as the cathode material. The Sony recycling process is claimed to work for these situations (e.g. a nickel oxide cathode), but the economics would not be expected to be as favorable because cobalt prices are about 5 - 6 times higher than nickel. Although price fluctuations do occur, the value of cobalt has historically been much higher than nickel. Some other cathode options such as manganese could be still less valuable on recovery than nickel. It will be important to maximize the recovery and reuse of all of the battery constituents, including the less valuable ones like lithium, carbon, and organic electrolytes, in order that recycling generate as much revenue as possible. Thus far, comprehensive recycling of the lithium-ion battery system has not yet been achieved, although progress is being made with certain materials, such as lithium.

Even though it does not constitute a large fraction of the weight of a lithium-ion battery, the lithium it contains does present difficulties for the processor of battery waste. It has been amply demonstrated by several companies that the reactivity of lithium metal can be controlled while it is being deactivated by use of alkaline solutions and/or cryogenic temperatures. However, few lithium batteries that approximate the size of EV systems have been deactivated and disposed of by any method. Recently, a project has been completed by ToxCo that demonstrates the safe disposal of a 570 pound lithium/thionyl chloride battery from a Minuteman missile silo. Each battery contains about 23 pounds of lithium. In this particular case, the battery was frozen in liquid nitrogen, sheared into thirds, and then shredded. Lithium salts, aluminum, nickel, and stainless steel were recovered for recycling. A contract to process more than 4,000 of these batteries over several years has subsequently been awarded to ToxCo[8]. This is not the same as treating tens or hundreds of thousands of EV batteries per year, but does show that it is possible to safely process batteries with a scale similar to those that will be used in EVs.

Sodium/Nickel Chloride and Zinc-Air

Sodium/nickel chloride and zinc-air battery systems are being demonstrated in electric vehicles in Europe, but have not been proposed for use by major auto retailers in the U.S.

A conceptual recycling scheme has been discussed for sodium/nickel chloride by AEG, and it appears that it should be possible to recover some of the more valuable constituents, such as the nickel. Little has been done until recently to begin pilot tests on the process. Reactivity concerns with the sodium in this system should be no worse than those faced with lithium batteries, but it will need to be deactivated. Overall, there is an excellent prospect that a cost neutral recycling process can be developed, and demonstrations of at least portions of such a procedure should be started.

The zinc-air battery system that is presently being demonstrated is recharged by mechanical replacement of the zinc plates. As such, it is more appropriate in the near-term for fleet situations that can support a central regeneration center for the zinc cassettes. Zinc-air EV batteries will most likely be confined to this niche market for the foreseeable future. Although the zinc plates can be regenerated, the system will eventually wear out and need to be recycled. Details of a recycling process have not been worked out, but an examination of the materials used in the zinc-air battery indicates that most are relatively non-hazardous. Caustic electrolyte is probably the worst hazard that would be encountered during battery tear down and treatment.

Lithium-Polymer and Lithium/Iron Disulfide

These two battery systems still require considerable development before being made available commercially, and therefore will not figure into the spectrum of electric vehicle technologies in the near- or even mid-term. Eventually, they may be manufactured for EVs as well as other uses. At this stage of development, there has been little specifically done on recycling processes for either system, partly because the materials of construction have still not been completely defined. However, it can be assumed that at least some of the work currently going on to look at methods for handling and processing lithium will also be relevant for these two lithium battery technologies.

The main difference between lithium-polymer batteries and the lithium-ion chemistry that has been already been commercialized by several manufacturers is that the lithium-polymer system will contain a solid electrolyte rather than a mixture of organic liquids. Most of the solids being investigated are ionically conductive organic polymers. An analysis of the value of the materials that could be recovered from a typical prototype lithium-polymer battery design has been done. Quite a large part of the recoverable value in this system comes from the polymers and other organics. This is in contrast to the lithium-ion case where most of the value resides in the metal recovered from the metal oxide cathode.

Conclusions

Established battery technologies (lead-acid, nickel/cadmium) can take advantage of existing collection and recycling capabilities to serve a rapidly growing number of EVs. In particular, thermal smelting processes that refine secondary lead from scrap lead-acid batteries should be able to easily absorb the projected number of EV batteries. The advanced battery system that is most often mentioned by potential EV manufacturers is nickel/metal hydride. This battery can be recycled using pyrometallurgical methods originally developed for small cells from consumer electronics applications. A second advanced battery system that is proposed by one EV manufacturer is lithium-ion. Progress has recently been made in developing a process to recover some of the more valuable metals from this battery. There are opportunities to enhance the economics of recycling for both the nickel/metal hydride and lithium-ion systems by recovering and reusing more of the battery materials. Battery systems that have been chosen for use by intermediate or low volume EV manufacturers are less likely to have operating recycling facilities, although in some cases an analysis of a conceptual recycling plan may have been carried out. This is the case with the sodium/nickel chloride battery. If a battery has a niche market in a particular area at first, such as fleets (e.g. the mechanically recharged zinc-air battery), it also is less likely to have an operational recycling system. Finally, long-term advanced battery systems like lithium-polymer and lithium/iron disulfide have not been fully defined at this point and therefore the recycling prospects are also less clear. Certain elements can be appropriated from processes used for other batteries that contain similar materials, but other aspects will have to be newly developed. There do not appear to be insurmountable roadblocks if investigation of recycling continues in parallel with battery development.

Acknowledgments

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000. The author also expresses his appreciation to many others who shared information used in this paper. These include the California Air Resources Board, the New York State Department of Environmental Conservation, the Massachusetts Department of Environmental Protection, and the attendees at the meetings of the ad hoc Advanced Battery Readiness Working Group.

References

1. P. Patil, G. L. Henriksen, D. R. Vissers, and C. Christianson, "Shipping, Use and Disposal/Recycle Considerations for Sodium/Beta Batteries in EV Applications," presented at the DOE/EPRI Beta (Sodium/Sulfur) Battery Workshop VIII, Chester, England (June 1990).

2. "Alternatives to Traditional Transportation Fuels 1995," Energy Information Administration, U.S. Department of Energy, DOE/EIA-0585(95), December 1996.

3. News Release, "US Electric Vehicle Sales Projected at Nearly 40,000 Units in the Year 2000," The Freedonia Group, Inc., January 15, 1997.

4. "City/State Action may Leverage Electric Vehicles," Electric Vehicle Progress, **19** No. 14, July 15, 1997.

5. Laura Vimmerstedt, Rudolph Jungst, and Carol Hammel, "Impact of Increased Electric Vehicle Use on Battery Recycling Infrastructure," Proceedings of the 8th International Seminar on Battery Waste Management, October 28 - 30, 1996.

6. J. C. Sabatini, E. L. Field, I-C. Wu, M. R. Cox, B. M. Barnett, and J. T. Coleman, "Feasibility Study for the Recycling of Nickel Metal Hydride Electric Vehicle Batteries," National Renewable Energy Laboratory, NREL/TP-463-6153, January 1994.

7. Batteries International, issue 31, April 1997, p 12.

8. News Release, "ToxCo Wins Major Lithium Recycling Contract," ToxCo, July 21, 1997.

M98000239

Report Number (14) SAND--97-2343C

CONF-971096--

Publ. Date (11) 199709

Sponsor Code (18) DOE/EE, XF

UC Category (19) UC-1500, DOE/ER

DOE