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Impact of Increased Electric Vehicle Use on Battery Recycling Infrastructure

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Abstract

State and Federal regulations have been implemented that are intended to encourage more widespread use of low-emission vehicles. These regulations include requirements of the California Air Resources Board (CARB) and regulations pursuant to the Clean Air Act Amendments of 1990 and the Energy Policy Act. If the market share of electric vehicles increases in response to these initiatives, corresponding growth will occur in quantities of spent electric vehicle batteries for disposal. Electric vehicle battery recycling infrastructure must be adequate to support collection, transportation, recovery, and disposal stages of waste battery handling. For some battery types, such as lead-acid, a recycling infrastructure is well established; for others, little exists. This paper examines implications of increasing electric vehicle use for lead recovery infrastructure. Secondary lead recovery facilities can be expected to have adequate capacity to accommodate lead-acid electric vehicle battery recycling. However, they face stringent environmental constraints that may curtail capacity use or new capacity installation. Advanced technologies help address these environmental constraints. For example, this paper describes using backup power to avoid air emissions that could occur if electric utility power outages disable emissions control equipment. This approach has been implemented by GNB Technologies, a major manufacturer and recycler of lead-acid batteries. Secondary lead recovery facilities appear to have adequate capacity to accommodate lead waste from electric vehicles, but growth in that capacity could be constrained by environmental regulations. Advances in lead recovery technologies may alleviate possible environmental constraints on capacity growth.

Introduction

This paper will consider how secondary lead facilities may be affected by the projected growth in the electric vehicle market, given the importance of maintaining environmental compliance. First, we review the literature on electric vehicle and lead-acid electric vehicle battery markets, lead industry characteristics, and environmental issues for secondary lead recovery. Second, we describe implications of electric vehicle market trends for lead waste from batteries. Third, we provide a summary on the lead recovery industry, including basic statistics and recovery methods. Fourth, we evaluate the ability of the lead recycling industry to accommodate lead from electric vehicle batteries. Finally, we examine environmental compliance of lead smelters, with special attention to ensuring

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environmental performance during power failures. This paper concludes that lead waste from electric vehicles is unlikely to exceed the capacity of the lead recovery infrastructure, although growth in that infrastructure faces significant environment constraints, which may require technological solutions.

Literature Review

Literature on electric vehicle market share, lead-acid electric vehicle battery market share, statistical and technological characteristics of the lead recycling industry, and environmental issues for secondary lead recovery is reviewed here. Estimates of expected numbers of electric vehicles have been made by the California Air Resources Board (CARB 1995), the Electric Vehicle Association of the Americas (EVAA) (1994), the Energy Information Agency (EIA) (1996), and others. These estimates use regulatory requirements for zero-emission vehicle (ZEV) sales and expected total vehicle sales to calculate expected sales of electric vehicles. For example, EIA estimates that 200,000 electric vehicles will be sold in 2003 (1996). EVAA also assessed the electric vehicle inventory (EVAA 1994). Older estimates do not take into account changes to California's ZEV requirements before 2003 that were enacted in the spring of 1996.

Lead-acid batteries may retain a share of the electric vehicle battery market, even after advanced batteries are available. Researchers at the University of California-Davis Institute for Transportation Studies see a role for lead-acid batteries in serving consumers for whom the added range of an advanced battery is not worth the cost. In contrast to the views expressed by CARB and many automakers that advanced batteries are essential to a viable electric vehicle, this market research indicates that a significant fraction of consumers interested in purchasing an electric vehicle would find the range of a lead-acid battery-powered vehicle to be satisfactory. Depending on the incremental cost incurred in purchasing an advanced battery powered vehicle, these consumers may or may not be willing to spend more to get a greater range (Kurani et al. 1996b).

The University of California-Davis Institute for Transportation Studies has developed another type of data relevant to estimating electric vehicle market shares through consumer preference surveys. These instruments test consumer choices among various vehicle attributes, and the results can be used to estimate consumer demand for electric vehicles in California. This research characterizes households that seem likely to purchase electric vehicles, and estimates that these households purchase 35-40% of vehicles sold in California (Kurani et al. 1996a). In one survey, 26% of respondents expressed interest in vehicles with ranges achievable by electric vehicles; 17% were interested in vehicles with ranges achievable with lead-acid batteries. These results suggest that consumer demand could support an electric vehicle market share consistent with the ZEV requirement (Kurani et al. 1996b).

In addition, the University of California-Davis research includes data related to lead-acid electric vehicle battery market share. The research examines consumer preferences for range and cost attributes of vehicles. These preferences can be used to estimate the fraction of electric vehicle buyers who might prefer a lower-range, less expensive vehicle that is within the technological capability of lead-acid batteries. The results suggest that lead-acid batteries may retain significant market share, even after more advanced batteries are mass produced (Kurani et al. 1996b).

Lead industry data are collected in industry surveys and were compiled by the Bureau of Mines until its closure in 1996. To ensure continuity in lead industry data, this function of the Bureau of Mines will continue as a responsibility of the U.S. Geological Survey. Annual Minerals Yearbook publications contain these data (Bureau of Mines 1993; 1992).

Technical descriptions of various lead recovery processes are found in the literature. Improvements to thermal smelting techniques are reported. For example, rotary furnace optimization is considered (Chavez et al. 1995), and new furnace technologies are examined (Ramus and Hawkins 1993). The literature devotes significant attention to improvements to hydrometallurgical and electrowinning processes for recovering lead from nonmetallic battery components (Olper and Morocutti 1995; Serracane 1990; Maja et al. 1990; Reynolds et al. 1989). A recent review of processes that use hydrometallurgy and electrowinning highlights the advantages and technical difficulties of these processes (Prengaman 1995). This review describes the following processes: RSR, Bureau of Mines, Engitec, Ginatta, Ammoniacal Ammonium Sulfate (AAS), $PbSO_4$ Slurry, and Placid. These processes all dissolve lead from nonmetallic lead wastes, then use electrowinning to deposit lead from solution. Differences among these processes include the techniques used to solubilize lead and the electrowinning methods (such as anode type).

Environmental regulatory compliance for smelters that process secondary lead has been addressed in the literature. The U.S. Environmental Protection Agency (EPA) promulgated a rule for lead and other air emissions from secondary lead smelters (final rule 60 Federal Register 32587; proposed rule 59 Federal Register 29750). Air emissions associated with secondary lead smelters have been considered in the context of lead-acid electric vehicle battery use (EPRI 1993). The possibility of using backup energy storage to prevent increased emissions during electric power failures has been addressed only very recently (Hunt 1996a).

The contribution to the literature provided by this paper is to examine industry trends, including electric vehicle battery use, and environmental constraints that form the context in which secondary lead recovery facilities may benefit from backup energy storage.

Effect of Electric Vehicle Market Trends on Lead Waste from Batteries

This section presents regulatory, technological, and consumer preference conditions that affect the quantity of lead waste generated from electric vehicle batteries. Quantities of lead-acid electric vehicle battery waste may increase if electric vehicle use increases. An estimate of lead waste from electric vehicle batteries illustrates this relationship.

Regulations that encourage the introduction of electric vehicles are spurring product development, and can be expected to determine market share, at least in the early years of technology implementation. Chief among these is CARB's ZEV requirement. Instituted in 1990, the ZEV requirement stipulated that the seven auto manufacturers that sell the most vehicles in California must offer for sale 2% ZEVs in 1998, 5% in 2001, and 10% in 2003 and thereafter. This requirement was changed in the spring of 1996 to eliminate sales requirements between 1998 and 2003. Instead, only the percentage requirement for 2003 remains in effect. Because regulations are expected to drive electric vehicle use, regulatory change strongly affects market share predictions.

Changes in CARB regulations encourage introduction of advanced batteries, rather than lead-acid batteries. Automakers and others have argued that electric vehicles cannot achieve widespread market share and public acceptance without better battery performance than lead-acid batteries can provide. By delaying the requirement, CARB avoided forcing the introduction of vehicles that rely on lead-acid batteries, which many automakers insisted would be an inferior product. By instituting a demonstration program and credit system to encourage advanced battery development, CARB incorporated into its policy a preference for electric vehicles with advanced batteries.

Lead-acid batteries now have the greatest share of the electric vehicle battery market, although a few electric vehicles are operating with other battery types. Nickel/metal hydride, nickel/cadmium, and sodium/sulfur are the other battery types that have been used in electric vehicles. Sodium/sulfur batteries are no longer manufactured. Mass production of advanced batteries, such as nickel/cadmium, nickel/metal hydride, sodium/nickel chloride, lithium ion, lithium polymer, zinc/bromine, and zinc/air for electric vehicles is planned (Kalhammer et al. 1995).

CARB's Battery Technical Advisory Panel estimated the earliest availability for candidate electric vehicle battery technologies as shown in Table 1 (Kalhammer et al. 1995).

Table 1. Estimated Availability of Electric Vehicle Batteries

Battery Type	Pilot Scale (hundreds/year)	Production Scale (10,000-40,000 / year)
Lead-acid (sealed)	1995	1997-1998
Nickel-cadmium (sealed)	1995	1997-1998
Nickel-metal hydride	1996-1997	1999-2001
Zebra	1996-1997	2000
Sodium-sulfur	1997	2000-2001[1]
Lithium-ion	1998-2001	2001-2002
Lithium polymer	1999	2002
Zinc-bromine	1996	1997
Zinc-air		
Mechanically recharged	1996	1998
Electrically recharged	1997 (?)	2000 (?)

Using estimates of numbers of existing electric vehicles and expected market share of electric vehicles, an estimate of lead waste from batteries was made. Assumptions used in this estimate are:

- Number of electric vehicles in the U.S. in 1994 equals 2000 (EVAA 1994).
- Expected electric vehicle sales in the U.S. in 2003 equals 200,000 (EIA 1996).
- Lead-acid battery replacement occurs on a 3-year replacement schedule.
- Lead-acid batteries have 100% market share for 1993-1995, decreasing to 30% for 2000 and beyond.
- Energy density of lead-acid batteries improves from 30 Wh/kg in 1995 to 50 Wh/kg in 2005.
- Battery mass per electric vehicle starts at 500 kg in 1995 and decreases with improved energy density (EVAA 1994; EPRI 1993).
- Lead-acid batteries are 73% lead by mass (Wagner 1996).

Given these assumptions, expected lead waste from electric vehicle batteries would increase as shown in Figure 1.

[1]Silent Power production schedule before their development program was discontinued.

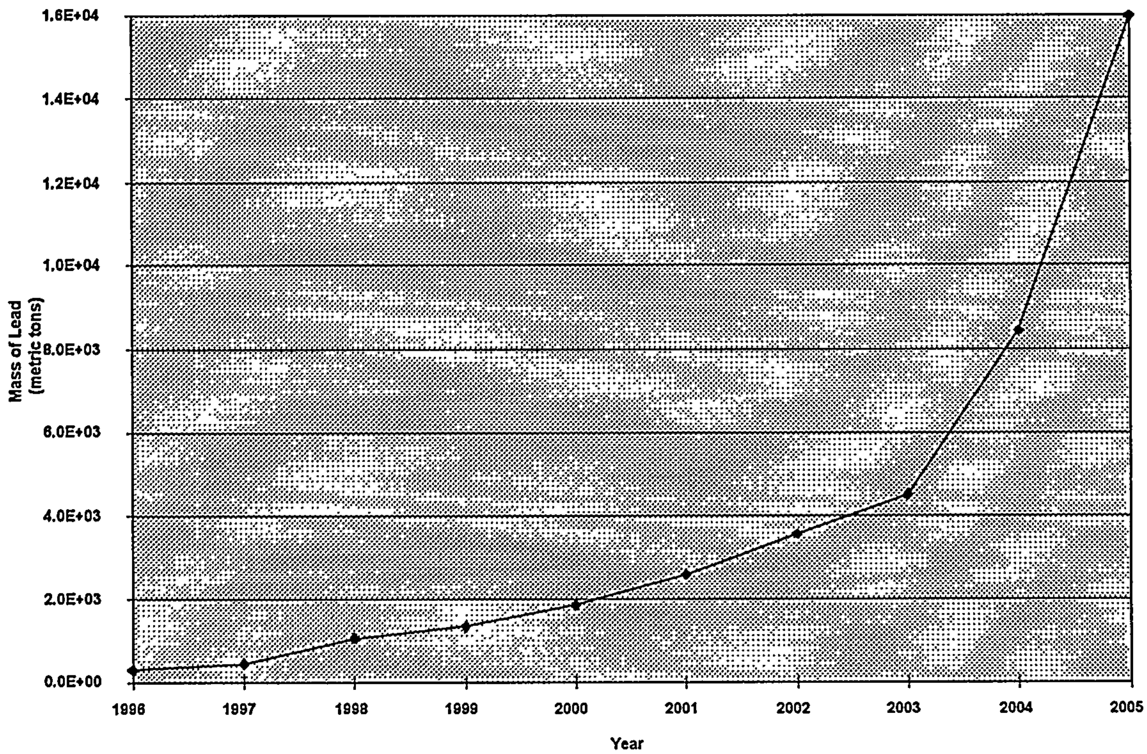

Figure 1. Projected Mass of Lead in Scrap EV Batteries

Lead Recovery

This section presents statistics and technological developments for the secondary lead recovery industry.

Secondary Lead Statistics

Historical trends in secondary lead recovery, lead recovery from batteries, estimated secondary lead recovery capacity, and scrap exports are shown in Figure 2. Domestic lead recovery at secondary lead smelters has been increasing steadily, following a major slowdown in the early 1980s (Will 1995; Bureau of Mines 1992; Bureau of Mines 1993; Smith 1996). This slowdown was related to low prices for lead that made recovery unprofitable. Domestic secondary lead production has remained at about 90% of secondary lead smelter capacity for the past few years (Smith 1996; Bureau of Mines 1992); (See Figure 2). Therefore, secondary lead

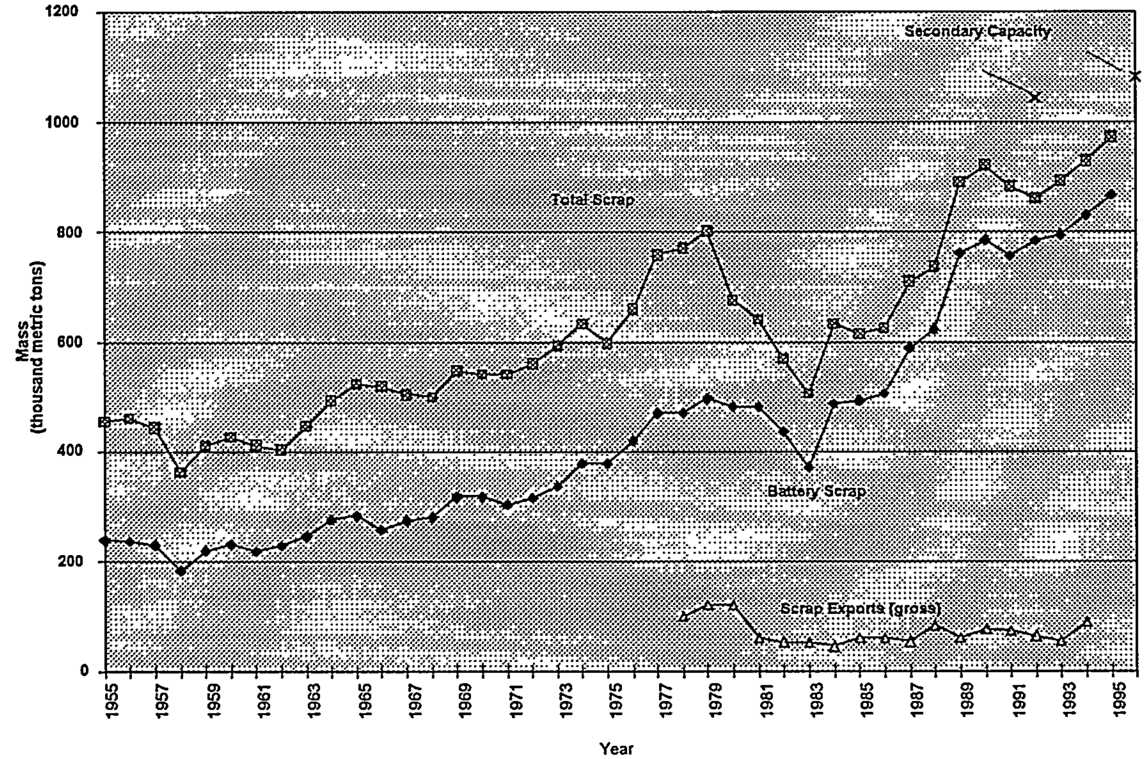

Figure 2. Lead from Battery Scrap, Total Scrap, Secondary Capacity, and Scrap Export in the U.S.

smelting capacity is now sufficient, but may need to be expanded if the upward trend in scrap mass continues. International shipments of lead waste have remained relatively constant at a small fraction of U.S. waste disposal, as indicated in Figure 2 (CRB 1996).

Batteries are by far the largest source of old scrap lead for secondary smelters (Bureau of Mines 1993). (See Fig. 3). The gap between total lead scrap and battery scrap has narrowed since the late 1970s. Similarly, lead consumption in batteries dominates the lead market, as shown in Figure 4 (Bureau of Mines 1992).

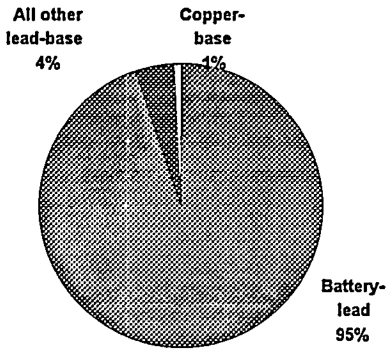

Figure 3. Types of Old Lead Scrap in the U.S. (1993)

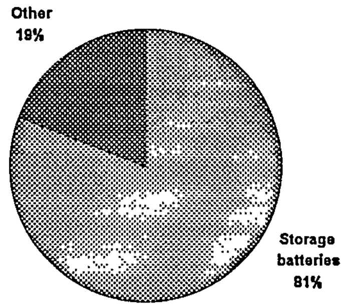

Figure 4. U.S. Consumption of Lead (1992)

Lead Recovery Technologies

New lead recovery technologies may be introduced if additional secondary lead recovery capacity is installed, or if older plants are replaced. If growth in secondary lead production continues (partly caused by electric vehicle battery waste), new lead recovery capacity will be needed to meet this demand. New technologies can facilitate lead emissions control, helping to ensure that electric vehicle battery waste is processed with minimal environmental effect. Lead recovery technologies may be divided into two basic types: pyrometallurgical and hydrometallurgical, plus electrowinning techniques.

Pyrometallurgical lead recovery techniques include a variety of thermal smelting approaches, which involve heating wastes in various types of furnaces to remove the lead they contain. Optimization of pyrometallurgical processes can achieve lead recovery rates that theoretically approach 100% (Chavez et al. 1995). Thermal smelting is best suited for recovering lead from the metallic components of lead-acid batteries. For recovering lead from lead salts in the battery active materials, hydrometallurgical and electrowinning processes afford environmental advantages, because these processes eliminate the need for smelting nonmetallic lead compounds at high temperatures (CARB 1995).

Hydrometallurgical and electrowinning processes are a more recent addition to commercial lead recovery techniques. These processes involve dissolving lead contained in nonmetallic battery components, such as lead sulfate, lead dioxide, and lead oxides from battery sludge. Once soluble species have been obtained, electrowinning is used to obtain metallic lead from the solution. In these processes, electrochemical reactions deposit lead at the cathode. Various anodes have been used (Prengaman 1995).

Research on hydrometallurgical systems was undertaken in the U.S. to reduce lead emissions and improve product quality (Cole et al. 1981). As of 1995, no commercial-scale processes of this type were in operation (Prengaman 1995). RSR, B.U.S. Engitec, and M.A. Industries pilot tested hydrometallurgical processes (Queneau and Troutman 1993). Challenges that face these processes include obtaining soluble species from insoluble lead compounds, preventing anodic deposition of lead dioxide, ensuring material compatibility, controlling gases, and treating sludges (Prengaman 1995).

Recycling Infrastructure Capacity Assessment

To understand how increasing electric vehicle use might affect secondary lead recovery, the estimated mass of lead from electric vehicle batteries in 2005 can be compared with secondary lead recovery capacity.

Figure 5 shows estimated electric vehicle battery lead mass in 2005 with 1996 non-battery scrap and 1996 scrap from other batteries. The total "pie" represents secondary lead recovery capacity in 1996. This figure shows that estimated electric vehicle battery lead mass in 2005 would be about 1% of 1996 secondary lead recovery capacity. Changes in capacity and other sources of lead are not estimated, but historical growth can be seen in Figure 2. Although there is considerable uncertainty associated with this estimate, the overall conclusion is that electric vehicle battery waste will account for only a small fraction of secondary lead production up to 2005.

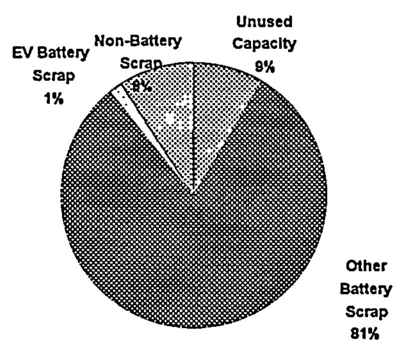

Figure 5. Estimated Utilization of Secondary Lead Capacity for EV Battery Lead

In contrast to the small effects expected at the national level, some regions, especially California, may experience much greater local change. CARB anticipates that California lead recovery facilities may greatly reduce imports of lead-acid batteries from other states if considerable lead-acid electric vehicle battery waste from California must be processed (CARB 1995).

New secondary lead recovery capacity may be needed to meet growth in secondary lead production. Air emissions constraints may affect what capacity, and what type, of secondary lead recovery facilities can be added. These air emissions issues will be described below.

Air Emissions of Lead from Secondary Lead Recovery Facilities

The Clean Air Act established a National Ambient Air Quality Standard (NAAQS) for lead at the level of 1.5 $\mu g/m^3$ for a 3-month average. The California standard is stricter, a 1-month average of 1.5 $\mu g/m^3$ (CARB 1995). These ambient air standards apply to air at the perimeter of lead recovery facilities. EPA's regulations that implement the Clean Air Act give responsibility to the states for establishing State Implementation Plans (SIPs) to maintain air quality in compliance with the NAAQS. States issue operating permits to industrial facilities to limit permissible emissions of pollutants. In addition to meeting the NAAQS for lead at its perimeter, a lead recovery facility must also comply with emissions limits established in its permit. This constraint may be more stringent in regions that already have relatively high emissions levels. In sum, emissions constraints in California and in areas with stringent regional limits create more challenging regulatory climates than elsewhere.

In addition to SIP-imposed emission caps and ambient air requirements, secondary lead smelters must comply with the Maximum Achievable Control Technology (MACT) rule that EPA finalized in 1995. The MACT standard requires that emission control technologies meet a lead emissions rate of 2.0 mg/dscm (dry standard cubic meter) (60 Federal Register 32587).

Lead recovery facilities have improved and can continue to improve their environmental performance using a variety of approaches, such as enhancing control equipment and improving lead recovery technology. Possible improvements to lead recovery technology include furnace optimization or hydrometallurgical/electrowinning processes presented above. An environmental performance challenge for lead recovery facilities is to ensure continuous emissions control during power failures, because control relies on electricity-dependent ventilation systems.

Power failures are a low (but non-zero) probability occurrence. In 1993, 52 disturbances to the U.S. electric system were reported. Of these, natural events, especially the weather, caused 23. Although the U.S. electric generating industry holds power reliability as an important goal, power disruptions caused by weather and other natural events will be difficult to reduce (EIA 1995).

Because power failures will occur, backup power systems can be used to provide uninterruptible power in industries for which the benefits of maintaining critical loads are worth the costs of the system. For lead recovery facilities that seek to improve environmental performance in the face of stringent emissions constraints, environmental benefits of backup power may be worth the cost. The costs and benefits of a backup power system can be compared to other compliance measures and to the risks of non-compliance.

GNB's Vernon facility recently improved its environmental performance during power failures by using a battery energy storage system (BESS) (Hunt 1996a). The BESS installed at GNB is rated at 3 MW, consists of a power-conditioning system, a valve-regulated lead-acid storage battery, and a control and monitoring system. The battery configuration is two parallel strings of 378 2-volt VRLA modules, operating at a nominal 756 V dc. The storage system began to operate in November 1995. It is designed to power the entire plant for up to 1 hour. Critical loads are supported long enough to allow processes to be terminated, if necessary, without the increase in lead emissions that might otherwise occur during a power failure. Fan and blower motors are needed to control exhaust emissions from the blast and reverberatory furnaces and to control lead dust from battery breaking (Hunt 1996a). In the event of an outage, the battery system automatically comes on line rapidly enough that plant operation is not affected. Since it became operational, the BESS has been used several times to provide backup during power failures (Hunt 1996b).

In addition to environmental benefits, backup energy storage can be used to reduce energy costs through peak shaving or by allowing the purchase of less expensive, interruptible service. GNB-Vernon is experimenting with the use of the backup energy storage system for peak shaving (Hunt 1996a). The BESS is sized to permit peak shaving without compromising backup power capability. In some service contracts with utilities, electricity customers may choose lower-priced, interruptible service (EIA 1995). In other industries, avoiding electricity outages through the use of backup energy storage may lead to considerable savings by eliminating ruined product and plant down time. If more advanced processes that have lower air emissions (such as hydrometallurgy and electrowinning) are implemented for reclaiming lead, protection from electric power interruptions will likely remain important because of the high cost of power interruptions in some of these processes.

Conclusions

Reducing air emissions from transportation is the major goal of regulations promoting growth in electric vehicle market share. Because electric vehicles are promoted as a "green" technology, environmental effects of electric vehicle battery recycling will be closely scrutinized. The secondary lead recovery industry is already subject to stringent environmental regulations. Growth in lead production at secondary lead facilities has been steady, and lead-acid electric vehicle batteries may contribute slightly to this growth in the near future. In certain regional markets, such as California, the growth in electric vehicle battery scrap may be larger than average, while the environmental constraints may be more stringent.

To increase production within environmental regulatory constraints, secondary lead recovery facilities may need to consider a variety of options to minimize environmental emissions. Emissions caps in facility operating permits may ultimately prove to be more of a near-term limiting factor for handling electric vehicle battery scrap than actual processing capacity. Battery energy storage that provides backup power is one way to ensure continuous environmental control during power failures, so that emissions caps are not exceeded. Emissions limits may also complicate installation of new secondary lead recovery capacity. Advanced lead recovery technologies, including hydrometallurgical and electrowinning processes, may help new facilities meet target emissions.

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