Work Plan Implementation:

Evaluation of Lead-acid Batteries as a Potential Priority Product

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SAFER CONSUMER PRODUCTS

Department of Toxic Substances Control

CalEPA
California Environmental Protection Agency

Introduction

The Department of Toxic Substances Control's (DTSC) Safer Consumer Products (SCP) regulations specify the process and criteria by which DTSC evaluates consumer products for possible designation as Priority Products. Every three years, DTSC issues a Priority Product Work Plan that "... identifies and describes the product categories that the Department will evaluate..." over the subsequent three years. DTSC's current 2015-2017 Work Plan includes seven product categories and lists the five policy priorities that informed their selection.

In 2016, recognizing the public health impact posed by lead contamination in the communities surrounding Exide Technologies' now shuttered battery recycling facility in Vernon, California, Governor Brown requested and the Legislature passed legislation[1] that provided $176.6 million to DTSC to investigate and clean up lead-impacted properties within an approximately 1.7-mile radius around the Exide facility (also referred to as the Preliminary Investigation Area). As an additional response, Governor Brown[2] and the Legislature[3] added lead-acid batteries to the 2015-2017 Work Plan for evaluation as a potential Priority Product.

As directed, DTSC is actively evaluating whether it should identify lead-acid batteries as a Priority Product under the SCP program. DTSC considers two primary factors when identifying a product-chemical combination as a Priority Product: (1) potential exposure to the chemical in the product, and (2) potential for exposure to that chemical to cause significant or widespread adverse impacts to human health or the environment. DTSC also considers the extent to which existing state and federal regulations may be addressing these concerns. And, DTSC considers available safer alternatives in its evaluation. See Article 3 of the SCP regulation[4] (§ 69503.2).

Lead-acid batteries have played a central role in automobiles and energy storage for over a century. Their affordability and performance in extreme heat and cold have allowed them to remain the dominant battery technology despite the known toxicity and hazards of their contents. This document gives a high-level overview of DTSC's initial research and identifies needs for further information on lead-acid batteries and their alternatives. It identifies specific data gaps and questions we hope our stakeholders can help answer. This document is meant to open a dialogue with manufacturers, government, academia, non-governmental organizations, and the public.

[1] Assembly Bill 118 (Santiago, Statutes of 2016) and Senate Bill 93 (De Leon, Statutes of 2016)
[2] February 17, 2016: https://www.gov.ca.gov/news.php?id=19317
[3] Added to the Health and Safety Code on September 13, 2016: § 25253.5. The department shall revise its 2015-2017 Priority Product Work Plan to include lead acid batteries for consideration and evaluation as a potential priority product.
[4] http://www.dtsc.ca.gov/LawsRegsPolicies/Regs/SCPA.cfm

Hazard Traits

To implement the SCP regulation, specific chemical regulatory (authoritative) lists were compiled that indicate hazard traits associated with each chemical. The merged list is considered the list of Candidate Chemicals for SCP. The Candidate Chemicals lead, arsenic, and sulfuric acid are found in lead-acid batteries and are discussed below. Additionally, large compendia of hazard information are available on each of these three chemicals, particularly lead and arsenic.

Lead is identified in 15 of the authoritative lists. According to these lists, the hazard traits include (in alphabetical order) bioaccumulation, carcinogenicity, cardiovascular toxicity, developmental toxicity, environmental persistence, hematotoxicity, nephrotoxicity, neurotoxicity, reproductive toxicity, and other toxicities.

Arsenic, found at low levels in lead-acid batteries and often added during secondary smelting,[5] is identified in 12 of the authoritative lists. According to these lists, the hazard traits include (in alphabetical order) carcinogenicity, cardiovascular toxicity, dermatotoxicity, developmental toxicity, hepatotoxicity, neurotoxicity, respiratory toxicity, and other toxicities.

Sulfuric acid (as mist) is identified in 4 of the authoritative lists. According to these lists, the hazard traits include carcinogenicity and respiratory toxicity. Also, contact with skin or eyes can result in severe burns.

Potential for Exposure

In addition to hazard traits, the potential for chemical exposure is evaluated for a potential Priority Product. Exposures related to lead-acid battery recycling facilities are well documented. A series of soil sampling efforts in the communities surrounding the Exide facility revealed elevated lead levels that exceeded DTSC's screening level for lead in residential soils. DTSC concluded that lead from Exide's operations may have extended as far as 1.7 miles from the facility. Following the closure of Exide in 2015, the only lead-acid battery recycling facility remaining in operation in California is the Quemetco facility in the City of Industry. DTSC is currently working with Quemetco to test for elevated lead levels in the residential soil surrounding the facility.

The conceptual exposure model shown in Figure 1 (see next page) captures key life cycle stages and potential routes of exposure for lead-acid batteries. Because the majority of lead used commercially in California is in 12V car batteries – a quantity that increases each year with the rising number of vehicles – such batteries are the focus in Figure 1. Potential exposures to lead occur during mining, primary smelting, recycling, secondary smelting, and manufacturing. There are, however, no active lead mines in California, no primary smelters in the United States, and only one operating secondary smelter in California (Quemetco, City of Industry). A growing portion of lead-acid battery recycling/smelting has been moving from the United States to Mexico (CEC, 2013).

[5] "Smelting" means to extract metal from its ore ("primary smelting") or recycled scrap ("secondary smelting") by a process involving heating and melting.

FIGURE 1:

Conceptual Exposure Model for Vehicle 12V Lead-acid Batteries

Lead & Arsenic

Source & Release Mechanism for Each Life Stage	Exposure Media	Exposure Route	Receptor: Worker	Receptor: Worker's Child	Receptor: Nearby Resident	Receptor: Consumer
Ore Mining (transported to Canada & Mexico) fugitive emissions	Dust	Inhalation	◆	●	◆	—
		Incidental Ingestion	◆	◆	◆	—
Primary Smelting (in Canada & Mexico) — fugitive & stack emissions	Fumes and Particles	Inhalation	◆	●	◆	—
		Incidental Ingestion	◆	◆	◆	—
Manufacture (six locations in California) — fugitive emissions	Particles	Inhalation	◆	●	◆	—
		Incidental Ingestion	◆	◆	◆	—
Vehicle Manufacture — fugitive emissions	Dust	Inhalation	◆	●	◆	—
		Incidental Ingestion	◆	◆	◆	—
Sales & Service (Replacement) — fugitive emissions	Dust	Inhalation	◆	●	◆	—
		Incidental Ingestion	◆	◆	◆	—
Consumer Use and DIY Replacement	Dust	Inhalation	—	—	—	●
		Incidental Ingestion	—	—	—	◆
Recycling Logistics (collection, stacking, wrapping, transport, storage, unwrapping) — fugitive emissions	Dust	Inhalation	◆	●	◆	—
		Incidental Ingestion	◆	◆	◆	—
Dismantling, Shredding & Secondary Smelting — leaks	Fumes and Particles	Inhalation	◆	●	◆	—
		Incidental Ingestion	◆	◆	◆	—
Illegal Disposal	Groundwater	Ingestion	—	—	?	—

Sulfuric Acid

Source & Release Mechanism for Each Life Stage	Exposure Media	Exposure Route	Receptor: Worker	Receptor: Worker's Child	Receptor: Nearby Resident	Receptor: Consumer
Production — spills		Dermal & Ocular	◆	—	—	—
Manufacture (filling) — spills		Dermal & Ocular	◆	—	—	—
Consumer Use & Refilling — leaks & spills		Dermal & Ocular	—	—	—	◆
Overcharging — explosion		Dermal & Ocular	—	—	—	◆
Recycling Logistics — leaks		Dermal & Ocular	◆	—	—	—
Dissmantling, Shredding & Secondary Smelting — fugitive & stack emissions		Dermal & Ocular	◆	—	—	—
Illegal Disposal	Groundwater	Ingestion	—	—	?	—

KEY: "Dust" refers to migration of lead into surrounding dust while "Particles" refers to more concnetrated emissions of lead.

◆ = complete exposure pathway of greater concern

● = complete exposure pathway of minor concern

— = incomplete exposure pathway

? = tentative exposure pathway in need of further evaluation

Lead-acid-battery manufacturing steps and potential exposures – which involve lead fumes, particles, and dust – are typically as follows (OSHA, 2004):

- Oxide and grid processing – oxide production, oxide receiving, oxide conveyance and classification, paste mixing, grid production and parts casting
- Plate processing – grid pasting, hydrosetting, parting, enveloping and wrapping, handling and transporting
- Battery assembly – stacking, group burning, intercell welding and post burning, formation (potential acid splash or mist)
- Battery repair (salvaging defective batteries) and reclaim (recycling scrap)
- Maintenance and servicing of lead-contaminated equipment

Lead-acid battery recycling includes the following steps (CEC, 2016):

- Logistics – collection, stacking, wrapping, transport, storage, unwrapping
- Processing – dismantling, shredding, separating, and secondary lead smelting

The blood from workers in lead-intensive industries is monitored for lead. Results routinely exceed the levels found in the general population and periodically exceed voluntary occupational limits (e.g., 30 µg/dL; ACGIH, 2004). Highly exposed workers are required to change duties until their blood levels return to below the allowable limit. Personal hygiene and facility housekeeping standards are critical to keeping blood-lead levels down yet are often not achieved. In some countries, blood-lead levels are even higher (Gottesfeld and Pokhrel, 2011) or simply unmonitored.

Studies find that contamination on worker clothing exposes children at home to lead (CDC, 2012), especially in less-developed nations (Gottesfeld and Pokhrel, 2011). Women exposed to lead sequester it in their bones and pass it on to their children when calcium is cycled during pregnancy and lactation (ATSDR, 2007). With no known threshold for the neurological adverse effects of lead in young children, these exposures are especially of concern (ATSDR, 2007).

Because consumers may be exposed to levels above safety limits when handling lead-acid batteries, the following label accompanies them in California (Lafond, 2011):

> WARNING: Battery posts, terminals, and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. Batteries also contain other chemicals[6] known to the State of California to cause cancer. Wash hands after handling.

Regulatory Context

DTSC considers whether existing laws provide adequate protections to potential exposure and adverse impacts. DTSC only lists a product-chemical combination as a Priority Product if the listing would

[6] Sulfuric acid mist

meaningfully enhance protection of public health and the environment. Notably, the contents of lead-acid batteries are regulated at the end of their life under a variety of federal and state laws, including the federal Resource Conservation and Recovery Act and the California Hazardous Waste Control Law. Specific requirements apply to storage, transportation, and treatment of the batteries.[7] Facilities that process spent lead-acid batteries must meet hazardous waste facility requirements and receive permits. To encourage the recycling of spent lead-acid batteries, the Legislature enacted a statute[8] to prohibit their disposal and require battery dealers to accept them from consumers. DTSC adopted regulations to facilitate such transactions.

As mentioned, in 2016, Governor Brown sought and received a $176.6 million appropriation to clean up lead-contaminated properties in the communities surrounding the Exide facility in Vernon. In July 2017, DTSC released its Exide Residential Cleanup Plan and Final Environmental Impact Report, which analyzed the impacts of cleaning up lead-impacted soil from approximately 2,500 properties within 1.7 miles of the facility, prioritizing those with the highest levels of lead in soil and the greatest risk of exposure.

Also under the special appropriation, DTSC's Program and Policy Support Division evaluated lead-acid batteries as part of the Community Protection and Hazardous Waste Reduction Initiative (CPHWRI). In addition to gathering information on alternatives to lead-acid batteries, CPHWRI gathered information about potential industry pilot studies to reduce lead exposures and impacts through improved manufacturing and recycling processes for lead-acid batteries. While the CPHWRI does not directly evaluate whether lead-acid batteries should be identified as a Priority Product, the information gathered and findings inform the SCP evaluation.

Other regulatory and statutory efforts in California regarding lead-acid batteries include the following:

- Senate Bill 14 requires large lead-acid battery manufacturers to prepare a Source Reduction Evaluation Review and Plan, Hazardous Waste Management Performance Report, and a Summary of Progress Report.
- Starting April 1, 2017, Assembly Bill 2153 requires manufacturers and retailers to each pay a $1 fee for each lead-acid battery manufactured or sold for deposit into the Lead-Acid Battery Cleanup Fund.
- As of July 2017, manufacturers of replacement lead-acid batteries are required to affix a recycling label to their batteries.
- California Division of Occupational Safety and Health is considering reducing the occupational exposure limit for lead from 50 to 10 $\mu g/m^3$.
- Office of Environmental Health Hazard Assessment continues to evaluate lead-containing consumer products for Proposition 65 warning labels.
- Biomonitoring California and the California Department of Public Health's Occupational Lead Poisoning Prevention Program continue to monitor blood-lead levels in selected populations.

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[7] California Code of Regulations, Title 22, Chapter 16, Article 7 – Requirements for Management of Spent Lead-Acid Storage Batteries

[8] Health and Safety Code, § 25215

- South Coast Air Quality Management District (SCAQMD) continues to issue and enforce air-emission permits for all of the lead-acid battery manufacturing sites and the single operating recycling/smelting site located within California (Quemetco). SCAQMD is currently considering Quemetco's permit request to increase throughput by 25%, which has triggered an Environmental Impact Report for this site as required by the California Environmental Quality Act.
- Further, SCAQMD manages Quemetco through the Assembly Bill 2588 Toxic "Hot Spots" program. In June 2017, SCAQMD approved a Risk Reduction Plan to reduce arsenic emissions.
- DTSC continues to issue and enforce hazardous waste permits for lead-acid battery manufacturers and the single operating recycling/smelting site located within California (Quemetco).

Markets and Trends

While the most common type of lead-acid battery is the 12V car battery, lead-acid batteries are also found in various other forms and functions (see Table 1). Although lead-acid batteries dominate many of these markets, alternative chemistries (e.g., lithium, sodium, nickel, zinc) are used as well.

Table 1. Types of lead-acid batteries

Category	Examples	
Vehicle starting, lighting, and ignition	Cars Motorcycles Trucks	Buses Recreational vehicles
Small, sealed forms	Consumer electronics	Mining lanterns
Mobility applications	Scooters Golf carts	Forklifts
Uninterruptible power supply	Emergency lighting Cell-phone towers	Hospitals Computer centers
Utility-scale energy storage	Wind farms	Solar installations

There are approximately 55 lead-acid battery manufacturing facilities in the United States, 6 of which are in California (BCI, 2016; DTSC, 2017). Several of the facilities located in California are owned by businesses that have an international presence, while others are single site.

Table 2. US recycling rates for lead-acid batteries

Year	US Recycling Rate
1980	70%
2000	93%
2004-2008	96%
2009-2013	99%

In the United States, the lead found in today's batteries comes from recycling (80%) and mining (20%). According to data collected by industry, the recycling rate for lead-acid batteries in the United States has improved over time to 99% today (Table 2) (BCI, 2009; BCI, 2014; USEPA, 2016). In addition to recovering lead, the plastic battery casings are processed into raw material for new products, while the sulfuric acid is recycled or neutralized. Although lead-acid batteries are nearly all recycled, the United States continues to add newly mined and imported lead into circulation each year to serve the growing number of vehicles.

An estimate of the amount of lead associated with lead-acid batteries flowing into and out of California's economy would be informative. Examples of similar accounting include a study from China (Liu *et al*., 2016) and recent US data (Turner, 2015). A full accounting would address the fraction of lead-acid batteries not recycled, the fraction recycled within the State, and the fraction recycled outside of California (including Mexico).

Lead-acid battery manufacturers are researching how to reduce the amount of lead in batteries. Research into low-to-no-emission recycling technology is also underway. For example, Aqua Metals Inc. recently opened a recycling plant in Reno, Nevada, that uses aqueous recovery technology, and Doe Run Co. is developing an aqueous recovery technology as well.

Available Alternatives

When deciding whether to list a product-chemical combination as a Priority Product, DTSC considers whether there is an available safer alternative that is functionally acceptable, technically feasible, and economically feasible. Currently, many battery alternatives exist at various stages of development. Notably, the European Union banned the use of lead in vehicles (European Council, 2000) yet has granted periodic extensions to the continued use of lead-acid batteries until a replacement is found.

A drop-in alternative to the 12V lead-acid battery entered the car market with the 2015 Mercedes S65 AMG Coupe (approximately 50,000 in Europe) and was built into the 2017 Hyundai Ioniq Hybrid and the Kia Niro (together selling around 4,000 per month in the United States). These are lithium-iron-phosphate 12V car batteries, and similar 12V batteries entered the motorcycle market in 2011.

Battery technologies are evolving quickly, as demonstrated by the recent progress in the various lithium-ion battery chemistries. Such progress, however, complicates the evaluation of lead-acid batteries and alternatives. Acknowledging such rapid change, the European Union reviews the continued necessity of lead in vehicle batteries every 4 to 5 years. The current proposal is to start the next review in 2021.

Safety

DTSC will incorporate safety concerns into the evaluation given that safety failures may cause exposures. Due to the evolution of hydrogen and oxygen gases when overcharged, lead-acid batteries can explode. A study by the National Highway Traffic Safety Administration found that battery explosions in 1993 injured 2,280 people with chemical burns, lacerations, or eye injuries (NHTSA, 1997).

While some lithium-ion chemistries also can explode when mishandled, the chemistry currently used in 12V car batteries (i.e., lithium-iron-phosphate) does not explode or combust during charge, discharge, or puncture, and the cathode material will not burn and is not prone to thermal runaway (Electropaedia, 2005).

Next Steps

To help our research, DTSC is seeking information about the use of Candidate Chemicals (such as lead, arsenic, and sulfuric acid) and other potentially hazardous chemicals in lead-acid batteries. Information on alternatives is also requested, including the ability to reduce the amount of hazardous chemicals in lead-acid batteries or recycle them using low (or no) emission methods (e.g., aqueous recovery). Because lithium-iron-phosphate batteries are already used on a small scale as 12V car and motorcycle batteries, information on this particular alternative is requested. For any potential alternative, information should include whether it is functionally acceptable, technically feasible, and economically feasible. Please also identify the primary hazard, safety, and recycling issues.

We will host a public workshop on these topics on Monday, November 6, 2017, in the CalEPA Headquarters building in Sacramento. Visit the SCP webpage[9] for the public workshop agenda. After the workshop, there will be an opportunity to submit information using the SCP information management system, CalSAFER, through December 6, 2017.

Questions for Stakeholders

To help our research, DTSC seeks information on lead-acid battery markets and exposures to chemicals (especially lead, arsenic, and sulfuric acid) throughout the battery life cycle. Similar information also is sought on alternatives.

1) Lead-acid-battery markets

a. What is the best way to classify the various forms, sizes, and applications of lead-acid batteries? What are the key performance characteristics for each?
b. Should a subset of the types of lead-acid batteries be the focus of evaluation?
c. What are the current trends and drivers in the lead-acid battery market?
d. What is the mass flow of lead into and out of California due to batteries?

2) Exposures

a. How can the conceptual exposure model (Figure 1) be improved? Are there missing activities, sources, and routes of potential exposure?
b. The recycling rate for lead-acid batteries has improved over time (see Table 2). What are the environmental impacts of the current annual loss rate of 1% (i.e., non-recycled batteries)? What are the anticipated trends for recycling in the future?

[9] http://www.dtsc.ca.gov/SCP/index.cfm

c. Recycling activities appear to result in the largest potential exposures to workers and nearby residents for lead (and arsenic). What are the current levels of exposure to these populations and best data sources to rely on to estimate exposure? How often do system upset and non-compliance situations occur?
d. As increasing numbers of batteries are shipped abroad for recycling (especially to Mexico), what are the levels of exposure there?
e. For sulfuric acid, manufacturing and re-filling activities likely result in the highest levels of exposure. Is information available on the frequency of acid burns (to skin and eyes) from such activities?

3) Safety

a. According to federal government statistics (NHTSA, 1997), thousands of lead-acid batteries explode annually when overcharged, resulting in injuries. Is there additional or more recent data on explosions for lead-acid batteries and their potential alternatives?
b. Is there a safety mechanism that could be added to prevent overcharging and subsequent explosion?

4) Alternatives

a. What are the possibilities and challenges to reduce the amount of lead used in lead-acid batteries? Does it vary by application?
b. How can recycling be performed that minimizes (or eliminates) lead and arsenic emissions?
c. Which applications could switch to lead-free alternatives?
d. What are the cost implications of switching?
e. For the alternative already in use today as a 12V vehicle battery (i.e., lithium-iron-phosphate), what are the exposure and safety concerns throughout the battery life cycle? Are there issues with recycling such batteries?

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