

Use of lead reclamation in secondary lead smelters for the remediation of lead contaminated sites

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Abstract

The EPA has estimated that there are over 3,000 sites across the United States contaminated with lead. Techniques to remediate these sites include standard stabilization/disposal technologies, reclamation of lead using secondary lead smelters, soil washing and biological removal technologies.

This paper presents the results of a study recently conducted by the Center for Hazardous Materials Research (CHMR), in conjunction with a major lead smelter, which demonstrates that secondary lead smelters may be used economically to reclaim lead from a wide range of lead-containing materials frequently found at Superfund sites. Such materials include battery case materials, lead dross, and other debris containing between 3% and 70% lead.

During the study, CHMR and the smelter reclaimed lead from five sets of materials, including two Superfund sites containing primarily battery cases, and one battery breaker/smelter site with a variety of lead-containing materials. Between 20 and 1500 tons of materials from these sites were excavated and processed at the smelter, while the research team assessed the effects on furnace operation and performance. Two additional sets of materials, one from the demolition of a house containing lead-based paint, and the other consisting of blasting abrasive material from work on a bridge coated with lead paint, were also processed in the smelter. The results showed that it was technically feasible to use the secondary lead smelter to reclaim lead from all of the materials.

CHMR also assessed the economics of using secondary lead smelters to reclaim lead from Superfund sites, and developed a method for estimating the cost of reclaiming lead. This method develops cost as a function of material excavation, transportation and processing costs combined with cost benefits received by the smelter (in the form of recovered lead, reduced fuel usage and/or reduced iron usage). The total remediation costs using secondary lead smelters for the sites and materials studied varied between \$80 and \$374 per ton, based on January 1994 market prices for lead. The costs were primarily a function of lead concentration, the market price for lead, distance from the smelter, and the amount of materials which become incorporated into slag from the process, although other factors affected the economics as well. Materials with high concentrations of lead were significantly less expensive to remediate than those with

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low concentrations. The cost to remediate materials which left few slag residues in the furnace was significantly lower than the cost to remediate materials which contained significant slagging components.

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1. Introduction

Lead is used in the production of various consumer and commercial items, from automobile and equipment batteries to paints to crystal. This widespread use has made it one of the most common contaminants at sites on the National Priorities List (NPL). The most common current treatment of lead contaminated wastes at Superfund sites is immobilization, either on-site or in a landfill. Remedial approaches which involve recovery of lead are preferred over immobilization, which wastes the lead. One such remedial approach, which is the focus of this paper, is the use of secondary lead smelters to recover lead.

The initial sections of this paper provide a brief overview of the sources and types of lead contamination, as well as current lead site remediation technologies. These sections serve to provide a basis of comparison of the use of smelters with other available technologies. The results are presented from a study of secondary lead smelting as a reclamation technology for lead-containing waste material at Superfund sites. The economics of reclamation are examined to determine if the technology is economically competitive with other technologies. Finally, a prognosis is given for the use of secondary lead smelters for lead recovery.

2. Sources of lead contamination

The prevalent use of lead in paints, gasoline additives, and other products resulted in wide dispersion throughout the environment. A review of the literature [1–11] reveals the following sources of lead in the environment: lead acid battery breaking activities; primary and secondary lead smelting and refining; production of lead acid batteries; production, storage and distribution of gasoline with leaded additives; solder use and manufacture; plumbing; ceramics and crystal manufacture; paints (houses, bridges, ships), and paint abrasive blasting material; wire manufacture and coating; automobile demolition (auto fluff); construction demolition (typically in plumbing and paints); production and use of fishing sinkers; pesticide production and use; cathode-ray tube production and use; rifle ranges and munitions dumps, including state game land and military ranges; ammunition and explosive manufacturing; sewage sludge; by-products from metal production (e.g., electric arc furnace dust from steel production); radioactive shielding (from X-ray machines to reactors); and other metals mining, smelting, and alloying (copper, zinc, cadmium and chromium).

These uses and sources of lead have contributed to many types of lead-contamination, including lead-contaminated soils, battery breaker sites, and integrated breaker/smelter sites. These are discussed below.

2.1. Lead contaminated soils

Lead in soils can come from a variety of sources. The range of lead contamination from 436 Superfund sites surveyed is between 0.16 and 366,000 mg/kg, compared to approximately 2 to 200 ppm in typical uncontaminated soils [12, 13], and 51,000 mg/kg in lead ores used at a major primary lead smelter [14]. Lead has been detected in soils in urban environments at concentrations of up to 15,000 mg/kg, due to a combination of automobile exhaust, lead paints and batteries [15]. Lead is commonly found in soils at battery breaker sites in concentrations up to 100,000 mg/kg [8] and at gun clubs, with concentrations up to 10,000 mg/kg [9].

Small amounts of lead are naturally present in the form of galena (PbS), although upon exposure to air it is converted to carbonates, sulfates, oxides and sulfosalts. Anthropomorphic lead sources in soils typically include acetates, organometallic compounds, oxides, elemental lead, sulfates, halides, sulfides, and silicates [16].

The United States Environmental Protection Agency (EPA) has set acceptable lead levels in soils at a range of between 500 and 1000 mg/kg. Other limits may be used based primarily on the likely uptake of lead in children or the proximity of the site to residential areas [17].

2.2. Battery breaker site materials

The components of lead-acid batteries include the battery case, lead electrodes (typically screens), spacers that separate the electrodes and prevent shorting, sulfuric acid and lead oxide paste (battery paste). In the past, the lead in lead-acid batteries was commonly removed by cracking or breaking the battery shell, draining the sulfuric acid into surface impoundments or lagoons, and pulling out as much of the metallic and paste (PbSO₄) lead as possible.

The battery cases, spacers, and some of the paste were often improperly disposed or piled. Battery cases were often disposed in drainage ditches and pits, and then buried with soil. Sometimes the cases were burned in pits on site to recover additional lead. These materials, when segregated from the soil, have lead concentrations ranging from 5000 to 200,000 mg/kg. Battery cases historically were made from ebonite rubber, which is a hard, black rubber containing coke and coal dusts. In the late 1970s, battery manufacturers switched to polypropylene cases, which are readily recycled.

Among the materials typically found at battery breaker sites are [1, 4, 18]: broken or whole battery cases, lead scrap, battery paste (or mud), sulfuric acid, PbSO₄, lead debris and (if the battery parts were burned) partially incinerated battery parts and pieces. There were approximately 20 battery breaker sites on the NPL in 1991 [4].

2.3. *Integrated breaker/smelter site materials*

Some battery breaking plants also reclaimed lead on-site at smelting facilities. These facilities would sell the recycled lead to battery manufacturers for use in the production of new lead-acid batteries. Materials found at these sites include the same materials found at battery breaker sites, as well as alloys, slag, emissions control dusts, dross, lead oxides, and calcium sulfate sludge from emissions scrubbers.

2.4. *Other lead-containing materials*

Other lead-containing materials frequently found at Superfund sites include lead munitions and shot, automobile fluff and lead additive residues. Lead is very common, and its forms vary greatly: one site, for example, contains over 10 million kg of lead-containing plastic wire insulation, and a second site contains 20 million kg of broken lead-containing crystal, accumulated over several decades.

3. Available remediation technologies

There are several options for treating lead-contaminated sites, including soil washing or extraction, immobilization, and reclamation. There are many variations of each type of remediation technology. A survey of RODs [19] indicated that over 70% percent of lead-contaminated sites were treated with some type of immobilization technology, usually stabilization or disposal in a landfill permitted to receive hazardous waste. Less than 10% were treated using washing (size separation or extraction) technologies, and less than 10% were treated using a reclamation process to recover usable lead. The remainder were treated using thermal technologies such as incineration because the material was contaminated with organic and heavy metal contamination. Incineration destroys the organic material, but there is typically lead-contaminated ash remaining after treatment. This ash usually retains the metals and therefore may also be hazardous and require treatment and disposal.

The current treatment technologies are described briefly below.

3.1. *Solidification/stabilization*

Solidification/stabilization technologies reduce the leachability of contaminants in the soil. Stabilization refers to the use of reagents to produce an end product that has about the same consistency as the original waste, with the contaminants essentially encapsulated in the original particles. Solidification involves mixing the waste with ingredients, such as binders or concrete, in cement mixers, pug mills, or other types of equipment to produce blocks of material with considerable strength. The main goal is to lock the contaminants into the material so they do not leach out [1, 4, 21]. The two technologies are often used together [20, 21].

3.2. *Vitrification*

Another type of immobilization is in situ or ex situ vitrification. This process converts the soil and contaminants into an inert glass and crystalline material. A typical vitrification system uses large electrodes, which, when placed in the ground, heat and melt the contaminants and soil. Volatile organic contaminants, if there are any present, are collected at the surface. After the electrodes are removed, the material cools. The void created by the melting is filled in with clean material [22].

3.3. *Capping*

Capping a waste site reduces the mobilization of the lead by containing it on the site. This prevents direct contact of the contaminated material with the public and the surroundings. Capping is attractive for lead-contaminated soils, since the lead is often relatively immobile in some soil systems [3]. Capping may be performed with compacted clay, synthetic liners or both.

3.4. *Landfilling*

Landfilling of hazardous waste requires that the waste is first treated to meet treatment standards set by the EPA. Under the Land Disposal Restriction (LDR) standards, the waste must be treated so that the lead is either removed or rendered immobile in the material before it can be land disposed [21]. Most Resource Conservation and Recovery Act (RCRA) hazardous waste landfills offer several treatment options, including solidification and stabilization. Occasionally, some waste is exempted from these standards if the required treatment is unavailable [23].

3.5. *Washing*

Washing usually involves slurring the waste with an aqueous solution, and then physically or chemically removing the contaminants using acid, chelating agents, size separation, or solvents. Some soil washers separate the heavy metals based on the principle that most contaminants are concentrated in the finer soil fractions. These technologies remove the finer soils (which must be treated or disposed) and return the coarse material to the site as clean soil [27].

Although washing is generally used for soils, some companies are developing technologies to remove and wash the battery-case material. These systems use gravity separation or other techniques to segregate the battery cases from soil, rocks, or other debris, and scrubbers are used to thoroughly wash the cases. The clean battery cases can then be landfilled as non-hazardous waste [25, 26]. It is difficult to remove all the lead from ebonite battery cases, because the lead permeates the slightly porous ebonite.

Most soils washing technologies produce either a soils fraction with high lead concentration or an hydroxide sludge, which must be disposed. However, several

recently developed technologies purport to remove lead from contaminated soils and produce metallic lead as a product [27], eliminating the need to dispose of residuals.

Solidification/stabilization, capping and washing have been proven to be effective in remediating heavy metals in soils [4, 18]. The use of these technologies, however, has not been as successful when there is large debris, such as battery cases or metallic lead, in the waste stream. The next section describes the use of existing secondary smelting technology to reclaim lead from such material.

4. Lead reclamation using secondary lead smelters

Secondary lead smelters typically reclaim lead from spent lead-acid batteries. The use of secondary lead smelters to reclaim lead from Superfund or other waste feeds involves slight modifications to the normal smelting process. This section provides a description of typical secondary lead smelting processes, as well as the modifications required to process the waste material.

4.1. Typical smelting operations

As part of normal secondary lead smelting operations using reverberatory and blast furnace combinations, spent batteries received at a smelter are crushed to release the sulfuric acid. Next they are processed through a sink/float system to separate the battery cases. The plastic is typically recycled on-site for use in the production of new battery cases.

Reverberatory furnaces are charged with material from the sink/float system as well as other lead-containing material, and are fueled with natural gas and oxygen. These furnaces are tapped for slag, which typically contains 60–70% lead, and a pure (soft) lead product.

Blast furnaces are charged with the slag generated from the reverberatory furnaces as well as other lead-containing materials, and are fueled by coke, iron, and air enriched with oxygen. Iron and limestone are added as fluxing agents to enhance the lead production in the furnace by preventing much of the lead from remaining in the blast furnace slag. Typical feed concentrations for coke, iron, and limestone are 5.7, 8, and 0.9 wt. %, respectively [28]. The blast furnaces are tapped continuously to remove lead and intermittently to remove the slag. The blast slag, which contains primarily silica, iron oxides, and some lead, is transported to an off-site landfill for disposal.

Lead produced in the blast and reverberatory furnaces is transferred to the refining process where additional metals are added to make specific lead alloys. The lead is then sent to the casting operations where it is molded into ingots for use in the manufacture of new lead-acid batteries. Waste materials from Superfund and other sites are fed either to the blast or reverberatory furnaces, depending on the material type, particle size, density, and other parameters. The modifications made to enable processing of this waste material are discussed in the following section.

4.2. Use of secondary smelters in lead reclamation from waste material

Prior work involving the use of secondary lead smelters to reclaim lead focussed on battery cases. In general, waste material was simply put through a smelter to dispose of it. There were no quantitative attempts made to analyze the effects on the furnace, or determine if the reclamation itself was successful [28]. One goal of this research was to determine how the smelter furnaces react to the addition of various waste materials.

The first step in the reclamation process, seen in Fig. 1, is acquiring and transporting the material to a secondary lead smelter. Generally, this involves excavation or collection, pre-processing, and transport to the smelter. The lead-containing waste material is typically excavated from lead-acid battery Superfund sites or collected from other sources, such as bridge blasting or demolition operations.

Next, the material may require processing prior to entering the furnace. Pre-processing includes screening to remove soil, large stones, or non-contaminated debris. Materials larger than 12 in. cannot be fed into the reverberatory furnaces. These larger materials may cause jams in the belt system that feeds the reverberatory furnace, or they may remain unburnt in the furnace for too long a period of time. The soil and debris removed during pre-processing may be treated using one of the technologies described above, since soil cannot be processed through a secondary smelter.

The pre-processed material is mixed with regular furnace feed from the crushing and sink/float system. The feed rate is determined by lead content, size of the material, fuel values, and other parameters.

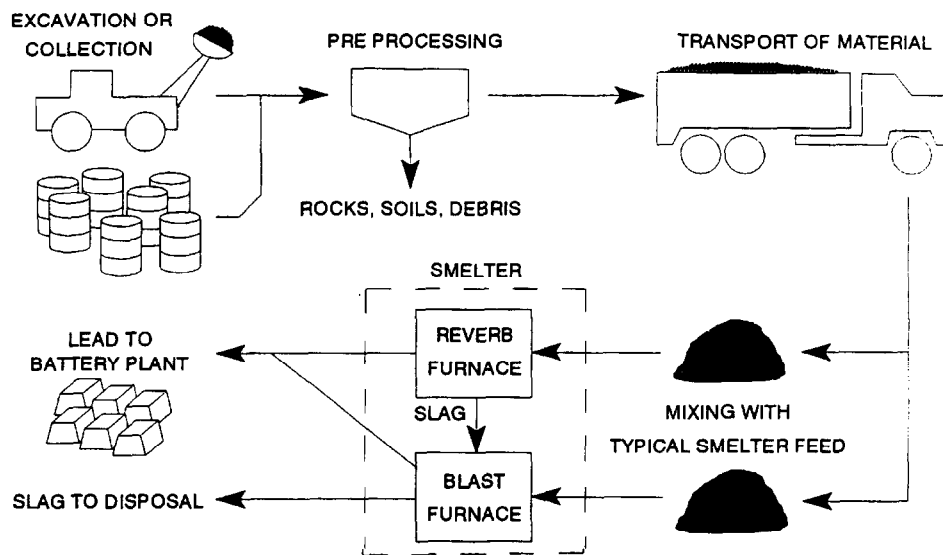


Fig. 1. Schematic of reclamation process.

The next section describes how this technology was tested using a variety of materials from four sites and material collected from a bridge blasting operation.

5. Evaluation methodology, sites, and materials

The basic methodology during the project was to acquire quantities of the materials to be tested, characterize these materials, process them through the secondary smelter, and observe their effects on the furnaces through sampling and data collection. The primary objective of the tests was to determine how much and what types of materials could be fed to the furnaces without causing shutdowns or otherwise adversely affecting smelter furnace performance.

5.1. Acquisition of materials

Materials from three Superfund sites as well as two additional sets of lead-containing materials were processed during this project. The following sections provide a short description of each of the five evaluations. The feed rates are presented as weight ratios of test material to total furnace feed. Table 1 presents a summary of the materials tested and the evaluations.

Tonolli Superfund site

The Tonolli site is a 30 acre battery breaking and smelting facility located in Nesquehoning, PA. Piles of ebonite rubber and polypropylene battery case pieces were tested, without any pre-processing. The material had an average lead concentration of 3.5%. Approximately 84 tons of material were fed at a ratio of 10% through a reverberatory and blast furnace. The material was too large to be readily processed in the reverberatory furnace, but was successfully processed in the blast.

Hebelka Superfund site

The Hebelka site is a former automobile junk and salvage yard located in Weisenburg Township, PA. The site contained battery case debris mixed with soil that had an average lead concentration of 14.7%. Approximately 20 cubic yards of material were transported to the smelter. This material was first reduced in size to less than $\frac{1}{4}$ in. with a hammermill. The material was successfully fed to the reverberatory furnace at a feed ratio of 17%.

Demolition waste

Demolition waste was obtained from a Housing and Urban Development (HUD) project. The waste consisted of demolition debris (mainly wood) coated with lead based paint and had a lead composition of between 0.5 and 1%. The test material was shredded in a pallet shredder before it was smelted. The demolition debris was processed through both reverberatory furnaces at feed ratio of 10% test material, by weight. At this weight ratio the test material comprised 50% of the *volume* fed to the

Table 1
Summary of demonstration sites

Source	Tonolli site	Hebelka site	Demolition waste	NL Industries site	PennDOT
Site type	Integrated battery breaker, smelter, and refiner	Automobile junk and salvage yard	Not applicable	Integrated battery breaker, smelter, and refiner with on-site landfill	Bridge blasting operation to remove lead paint
Length of test	5 d	1 d	2 d	Preliminary: 4 d Full: 3 month	1 day
Material type	Rubber and plastic battery cases	Rubber and plastic battery cases with some soil	Demolition debris coated with lead paint	Lead slag, debris, dross, ingots; battery case pieces, baghouse bags, pallets, cans	Iron shot bridge blasting material
Amount processed	84 ton	8 ton	4 ton	1570 ton	6 ton
Percent test material in feed	10%	17%	5%	20-50%	13%
Lead concentration	3.5%	14.7%	1%	Preliminary: 57% Full: 30-50%	3.2%
Pre-processing	None	Reduced to less than 1/4 in. in a hammermill	Reduced in size with a pallet shredder	Large pieces removed for processing in the blast furnace	None
Difficulties encountered	Attempted to process in reverb, but material was too large	None	Initial feed ratio was too high	Reverb could not process 100% waste material	Material was too moist to process in reverb furnace

furnace. This high volumetric ratio caused malfunctions in the furnaces, so the feed ratio was reduced to 5%, at which point the material was successfully fed.

NL industries superfund site

The NL Industries site in Pedricktown, NJ, was an integrated battery breaking, smelting, and refining facility with its own on-site landfill. There were a wide variety of materials at the site including lead slag, dross, debris, ingots, hard heads (large chunks of metallic lead), battery case debris, baghouse bags, and contaminated pallets and iron cans. The evaluation was conducted in two parts: a preliminary investigation and a full-scale investigation.

During the preliminary investigation, approximately 370 tons of all types of the above materials were processed. Analyses revealed an average lead concentration of 57%. The larger pieces of debris were removed and processed through a blast furnace, while the bulk of the material was fed into a reverberatory furnace at feed ratios of up to 100%. The feed was sufficiently dense to cause breakdowns in the reverberatory furnace conveyor feed system, so the feed ratio was reduced to 50% test material, by weight.

During the full-scale operation, approximately 1200 tons of material were transported to the smelter over a three month period. For the first two months, the test material, which contained approximately 50% by weight lead, was processed in the reverberatory furnace, with a feed ratio of 20–30%. The ratio was limited due to high amounts of calcium in the NL material. The excess calcium slowed the operation of the furnaces.

The test material for the last month of the investigation consisted mainly of larger pieces of slag and debris with an average lead concentration of 30%. This material was charged directly to one of the blast furnaces, at a feed ratio of approximately 30%.

Pennsylvania department of transportation

The Pennsylvania Department of Transportation (PennDOT) used an iron-shot abrasive blasting material to remove old lead-based paint from a bridge in Belle Vernon, PA. Sixteen 55 gallon steel drums of this material, containing an average of 3.2% lead, were processed at the smelter.

The material contained too much moisture to be incorporated into the reverberatory feed. The test material, including the drum, was fed to one of the blast furnaces at a feed ratio of approximately 13%, by weight. The bridge blasting material was primarily iron (60%) with 5% calcium and 5–10% moisture content.

Bypass 601 site material

Material was obtained from the Bypass 601 Superfund site in Concord, NC. The material consisted of battery cases, mixed with soil. Overall, it contained approximately 1% lead. The material contained approximately 80% soil and 20% battery cases. Based on this, the use of the reclamation technology was deemed not to be feasible, unless a suitable separation method for the cases and soil was developed. Although relatively simple size separation methods for separating the soil from the battery cases exist, they did not appear likely to be economically viable, because the

soil contained significant rocks and other debris which would remain with the battery cases, and because much of the lead would go with the soil. Therefore, the site was dropped from consideration by this study.

5.2. Smelter furnaces

The secondary smelter used for the study has two reverberatory furnaces and two blast furnaces. Each reverberatory/blast combination is similar in design and construction, as well as production potential. During the evaluation, one furnace (either the reverberatory or blast, depending on the waste material) was charged with regular smelter feed and the other was charged with regular feed mixed with certain amounts of the waste material. This provided control and test furnaces, and comparisons could be made between the two. Because the furnaces normally undergo wide fluctuations in production, the comparisons were only valid when the furnaces were fed materials over four to six shifts.

Reverberatory furnaces are often used to remove metallic lead, and to produce a fused slag feed for the blast furnaces. The reverberatory furnace has a 2–3 h residence time. The most serious problem encountered by introducing new feeds into the system was the stacking of unburnt material inside the furnace. This can cause impaired performance or even damage to the furnace. This condition takes from one to several hours to occur, so the furnaces were still monitored after the test feed was stopped.

Blast furnaces are used to reduce lead oxides to metallic lead, and remove them as product. The blast furnace has a residence time of several hours. Therefore, the monitoring of the blast furnace charged with test material was continued for several hours after the waste feed is discontinued. This allowed time to more accurately determine if the test feed had any positive or negative effects on the blast furnace.

5.3. Data and sample collection

Project personnel were at the secondary smelter to collect samples and data to assess the furnace performance, characterize the input material, and characterize the furnace outputs. Table 2 shows the parameters that were measured and how they were obtained. The input material parameters were characterized to provide information related to the feed, so that comparisons of the effects of different feeds could be made. The furnace performance parameters, such as air flow, oxygen usage, fuel usage, and furnace feed rates provided measurements of the furnace performance while the experiments were conducted, principally indicating when production levels were falling or materials were clogging the furnace. The output parameters were the most important ultimate measurements of furnace performance – including both production rates and quality, as well as residuals generation.

The data generated from measurements and sample analyses were used to compare the performances of the test and control furnaces. The amount of lead in each product is useful in making a mass balance for the lead. The other parameters, such as oxygen, air, and fuel, are useful in determining the cost for processing the test material.

Table 2
Input, output, and operating parameters [31]

Input material characterization	Furnace performance parameters	Furnace output parameters
Total lead (S)	Test material in the feed (M)	Lead production rates (M)
Sulfur (S)	Air flow (M)	Slag production rates (M)
Silica (S)	Percentage oxygen enrichment (M)	Slag viscosity (O)
Calcium (S)	Fuel usage (M)	Percentage lead in the slag (S)
Moisture content (S)	Lead inputs (S)	Percentage sulfur in the slag (S)
Density (M)	Iron inputs (S)	Back pressure (M)
Particle size distribution (M)	Percentage test material in feed (M)	Sulfur dioxide emissions (M)
Btu value (S)		Calcium sulfate sludge (S)

(S) = sample, (M) = measurement, (O) = operator observation.

6. Results and discussion

In general, the study demonstrated that various materials may be processed in secondary lead smelters with relatively few effects on overall furnace performance. The most significant effects were caused by processing materials in a furnace without properly pre-processing it, or by processing too much material at one time. For example, the Tonolli feed was too large to be processed effectively in the reverberatory furnaces. This caused the furnace production to slow down significantly. Later, battery case material from the Hebelka site was successfully processed in the reverberatory furnace after it had been shredded in a hammermill to a particle size of less than $\frac{1}{4}$ in. The NL Industries site material was initially unsuccessfully processed at 100% feed ratio, because it was too dense for the feed system. When the ratio of test material to total feed was lowered to 50%, the material was processed with few problems.

The lead and slag production from the furnaces varied with each evaluation. Table 3 shows three lead and slag production parameters derived from the daily production of lead and slag at the smelter. The demolition material evaluation is not included in Table 3 because this test was performed primarily to qualitatively determine if the furnaces could process the light, wooden material.

6.1. Lead-production ratio

The lead-production ratio is the ratio of the amount of lead produced by the furnace processing test material to that produced by the furnace processing regular feed. This parameter can be determined for the reverberatory furnaces only when the furnaces are fed waste material feed, but can be determined for the blast furnaces in all cases, since the blast furnaces indirectly receive the test feed through the reverberatory slag. A value greater than 1 indicates that the furnace processing the mix of test and regular feeds produced more lead than the control furnace. The lead-production ratios for all the test cases, except the NL Industries material were approximately 1,

Table 3
Lead and slag production comparisons

Furnace	Parameter	Evaluation ^a			
		Tonolli	Hebelka	NL Industries	PennDOT
Reverb	Wt.% test feed	N/F	17%	20–50%	N/F
	percentage Pb in test feed	N/F	14.7%	57%	N/F
	Pb prod. ratio	N/F	1.20	0.90	N/F
Blast	Wt.% test feed	10%	N/F	30%	13%
	percentage Pb in test feed	3.5%	N/F	30%	3.2%
	Pb prod. ratio	1.35	0.85	1.25	1.08
	Pb loss ratio, L_R	0.6	*	1	2.6
	Slag ratio	0.97	1.00	0.97	0.97

^a *composition of blast slag was not analyzed. N/F means that the test material was not fed to that furnace.

indicating that the use of test feeds did not significantly affect furnace production. For the NL Industries material, the lead-production ratio for the reverberatory furnace is consistently below 1, averaging 0.9 over the three month period in which the materials were added to the furnace. However, during the same time period, the blast furnace associated with the test reverberatory furnace produced significantly more lead than its control counterpart. It appeared that the use of the test material shifted the production from the reverberatory to the blast furnace. This shift is attributed to the relatively high concentration of antimony in the waste feed material, which tends to be removed in the blast furnace.

6.2. Lead-loss ratio

The secondary lead smelter has two major outlets for the lead input: production and blast furnace slag (waste). The lead-loss ratio (L_R) is the ratio of the loss of lead in the slag from the test furnace (total slag produced in the test furnace multiplied by lead concentration in that slag) to the loss of lead in the control furnace. This ratio can only be calculated for the blast furnaces because the blast slag is a waste product from the process. An L_R value greater than 1 means that more lead is lost in the blast slag produced by the furnace(s) processing test material than in the control furnace(s).

The Tonolli evaluation produced a much lower L_R than 1, while the value for the PennDOT evaluation was 2.6. The composition of the blast slag produced in the Hebelka evaluation was not determined. The apparent low value during the Tonolli experiment is most likely due to normal variations in the furnace operations and sampling procedures, and it is not attributable to a significant increase in efficiency. Over the course of the experiment with the PennDOT materials, the lead concentrations in the slag were high and appeared to be climbing in both furnaces. Therefore, it is difficult to determine how significant the apparent increase in lead loss was. However, there is reason to believe that some of the increased L_R was due to the feed,

since approximately twice as much iron than is usually fed was added during the course of the experiment, and additional iron may tend to bind some of the lead to the slag. Lead concentration in the slag and quantity produced when the NL Industries site material was processed were not different than when typical feed was processed.

6.3. Slag-disposal ratio

The slag-disposal ratio (S_R) is the amount of blast slag produced by the test furnace divided by the amount of slag produced by the control furnace. This is another term that is exclusive to the blast furnaces because reverberatory slag is fed to the blast furnace, while the blast slag is disposed. In all of the evaluations, the S_R was effectively 1, which means the test and control furnaces produced nearly equal amounts of blast slag.

6.4. Feed ratios

Secondary lead smelters normally accept feed materials derived principally from the breaking and demolition of lead-acid batteries. These normal feedstocks consist primarily of lead grates, terminals, and sludge from the batteries. This material typically contains 60–70% lead, by weight, with the remaining materials consisting of plastic, rubber, wood scrap, sulfur, dirt and residues from the batteries, and moisture and oxides combined with the lead. Superfund wastes and other materials, which contain lower concentrations of lead and higher concentrations of other constituents that may be harmful to the furnaces, must be blended with normal feed prior to being fed to the furnaces.

The mix ratio of normal feed to waste materials was one of the parameters tested during this study. Based on furnace performance and operations results, it was possible to determine whether the furnace performed successfully or unsuccessfully at any given feed ratio. A test is considered to be unsuccessful if the feed ratio of test material has to be lowered, or discontinued altogether.

The tests show that the successful mix ratios are strongly a function of the percentage of lead in the waste material. Fig. 2 shows the feed ratios which were successful, plotted against the percentage of lead in the *waste* material (i.e., prior to blending with normal feed). The results are nearly linear from streams containing 3% lead to those containing 60% lead. This delineates the region marked successful on the figure. When the feed ratios versus lead concentration for unsuccessful runs are plotted, a second region (the unsuccessful area) emerges. Finally, a third region, in which no tests were performed, is also marked on the figure. No test feed with more than 60% lead was fed to the furnaces, so the regions in the range above 60% lead cannot be determined from the experimental results.

6.5. Effects of certain material components on furnace performance

Some materials, particularly ebonite battery cases (which contain coal or coke dusts), represent a potentially significant source of energy to the furnaces. The battery

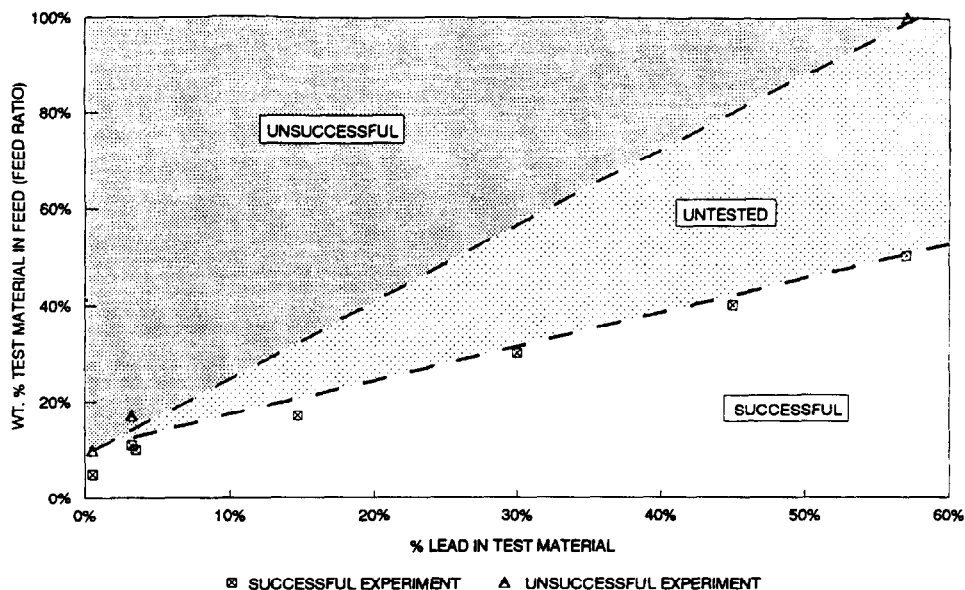


Fig. 2. Percent lead in test material versus feed ratio.

case materials had average Btu-values of over 11,000 Btu per pound. Coke is a typical feed to a blast furnace. Ebonite rubber cases were successfully substituted for a portion of the coke in the blast furnace. Battery cases will not substitute for all of the coke since the large chunks of coke provide structure inside the furnace, which battery cases cannot provide.

Other materials represent substitutes for other furnace feeds. Iron is typically fed to a blast furnace to help separate lead from the slag. The PennDOT bridge blasting material represented a source of iron and calcium in the blast furnace. The material contained so much iron (over 60%) and so little lead in comparison (approximately 3%), that it may be considered an iron source which happens to be contaminated with lead, rather than a lead source to the furnace. In this capacity, it represents a potentially beneficial reuse for a material which most state and municipal authorities have found difficult to dispose. To be used as an iron source, the material would have to be added at a slower rate than during the test run to control the amount of lead lost in the blast slag.

7. Applicability of lead recovery in secondary smelters

Broadly speaking, lead reclamation in secondary smelters is an applicable technology whenever sufficient lead exists in a form which can be economically retrieved from the Superfund material. However, there are certain materials, such as materials

containing large amounts of soils, in which the lead may not be easily reclaimed using the technology. This section describes the procedures to be used to determine applicability and the range of applicability determined by the experiments.

Generally, to determine if a material can be processed through a secondary lead smelter, a two step procedure is required: material characterization followed by a pilot or treatability study at the smelter. Table 4 lists the typical parameters which must be included in a material characterization. Note that the smelter operators are not interested in the TCLP leachability of the metals in the waste, but the total metal content. The leachability only determines the regulatory status (hazardous, non-hazardous) of the material, and does not affect its properties in a smelter.

The table is intended to provide an approximate gauge of the materials that can be processed through the smelter. Because there is such a wide range of lead-bearing

Table 4
Required characterization parameters

Constituent	Lower limit (if applicable)	Upper limit (if applicable)	What does parameter affect?
Total lead	1%	100%	Economics (based on lead recovery), feed rates
Total antimony	NA	NA	Needed to determine refining requirements
Total arsenic	NA	2%	Lead quality, refining
Total copper	NA	2%	Lead quality, refining
Total halogens	NA	< 1%	Damage flue gas system, permits
Total tin	NA	2%	Lead quality
Total iron	NA	None	Feed rates (iron is a furnace feed)
TCLP-metals	NA	NA	Overall need to process
Physical state	No liquids or gases	No liquids or gases	Conveyance, furnace performance, permits
Total sulfur	NA	10%	CaSO ₄ sludge production, sulfur emissions
Total silicate	None	20%	Furnace performance
Total soil content	None	25%	Furnace performance, economics, slag production
Fuel value (Btu/lb)	None	NA	Economics
Total calcium	None	10%	Furnace performance, feed ratios
Total aluminum	None	1%	May cause explosions in the furnaces
Particle size	5 μm	1 m	Loading, conveyance
Oil and grease	None	< 2%	Permits, feed system, material handling
Moisture	None	15%	Heat requirements, may cause steam explosions
Density	None	None	Loading, conveyance, economics
Ash content (excluding lead)	None	70% (est.)	Slag production, furnace performance, economics

materials found in the environment, it is probably necessary to discuss a particular waste feed with a secondary lead smelter before deciding whether the lead is reclaimable. Some wastes may be blended with other materials to make suitable feedstock. A high calcium waste, for example, may be blended with other materials with little or no calcium and fed to the furnace. Of course, this blending may increase the cost of storage and processing significantly. Other materials, metallic aluminum, for example, are prohibited in furnaces.

After characterizing the waste material to determine its suitability in a smelter, a pilot-scale study may be necessary to better determine the effects on the furnaces and the appropriate operating parameters. These will likely have significant bearing on the economics of treating the material. The demolition material tested during this study, for example, had to be shredded and blended relatively slowly with normal furnace feed. This increased the handling and storage requirements by more than 50%. A more detailed cost analysis is presented later in this paper.

8. Reclamation efficiency

In determining whether the process is suitable for Superfund activities, it is important to determine if the secondary lead smelting process actually reclaims lead from the various materials. Unfortunately, there was no way to precisely measure the extent to which the lead from the Superfund materials is reclaimed after these materials are mixed with regular furnace feeds. Therefore, a methodology was developed to estimate the *minimum* reclamation efficiency based on conservative assumptions regarding the partitioning of lead inside the furnaces.

Generally, lead inputs to the smelter include feeds to the reverberatory and blast furnaces. During normal smelting operations, outputs from the smelter include [29]: lead production from both furnaces (usually between 99.5% and 99.7% of the lead feed); (i) blast furnace slag (which contains 0.3–0.5% of the lead feed); (ii) calcium sulfate sludge from the emissions control system (which contains approximately 0.004% of the lead feed); and (iii) fugitive and stack air emissions (which contain less than 10^{-5} % of the lead feed).

The furnaces reclaim over 99% of the lead fed to them. The only significant outlet for lead besides lead product is the slag, which must be landfilled. For the purposes of estimating reclamation efficiency, the slag is estimated to contain 1.5% lead, which the literature suggests can be maintained over a variety of operating conditions [30].

The minimum reclamation efficiency can be estimated noting that the lead partitions between the lead product, which is essentially pure lead, and slag, which contains 1.5% (by weight) lead. The percentage of any feed material partitioning to the slag is approximately equal to the concentration of non-lead, non-combustible materials in the feed (which is approximately equal to the ash content minus the lead concentration in the feed). Thus, for test material with a measured ash content of 50% and 30% lead, it is reasonable to assume that the remaining 20% of the feedstock will become part of the slag. If we further assume that the slag produced by Superfund materials is indistinguishable from that produced by normal feeds operating under the same

furnace conditions, and therefore will contain the same weight fraction of lead as the slag normally contains (1.5%), then we can estimate the amount of lead from the Superfund material lost with the slag. This can be compared with the original amount of lead in the Superfund material to determine a reclamation efficiency:

$$\varepsilon = 1 - 0.015 ([A] - [\text{Pb}])/[\text{Pb}],$$

where ε is the minimum reclamation efficiency; $[A]$ is the ash content of the test material (as a weight fraction) and $[\text{Pb}]$ is the weight fraction of lead in the feed. Based on this estimate, the minimum reclamation efficiencies for the various feedstocks used during the experimental program ranged from a high of 99.5% for the Pedricktown material with 45% lead and 60% ash content, to a low of 70% for the PennDOT material, with an ash content of 70% and a lead content of approximately 3%. The results show that significant reclamation always occurs, even when minimum reclamation conditions are assumed.

9. Lead reclamation economics

The cost of using secondary lead smelters for the recovery of lead from Superfund sites is determined by the cost of the three basic operations: (i) on-site excavation and pre-processing of the material (C_E) (ii) transportation (C_T); (iii) processing at the smelter (C_P). These costs are discussed in further detail below.

9.1. On-site excavation

Excavation costs for Superfund materials vary depending on the health and safety requirements for given sites, contaminants and contaminant concentration. For battery cases, or lead debris, dross, etc., which are relatively accessible on the site, and require little more than dust control during excavation, the costs range between \$5 and 15 per cubic yard. Excavation costs, denoted as C_E , will increase if additional on-site processing is required.

9.2. Transportation

Transportation costs for hazardous wastes are dependent on the amount of material transported, and the distance transported. Typical costs range between \$0.20 and 0.35 per ton-mile (transport 1 ton 1 mile). For most material, the cost of transportation, C_T , is estimated as:

$$C_T = \$0.3 D/\text{mile},$$

where D is the distance from the site to the smelter in miles. Note that for longer distances (over 300 mile), alternate means of transportation (i.e. tandem trucks, rail shipment, etc.) may be more economical.

The transportation economics shift slightly for some materials, particularly those with specific gravities significantly less than 1. These materials may include whole (i.e.,

uncrushed) battery cases which, because of their structure, have relatively large void volumes and therefore a low density. Unless these materials are crushed on-site, the transportation costs will be based not on their weight, but on their volume. This will necessitate a correction factor Φ on the transportation cost equation which is equal to the inverse of the material bulk density in ton per yd^3 , and a maximum of 1. Thus, the overall transportation cost can be estimated as,

$$C_T = 0.3\Phi D$$

where the dimensionless correction factor Φ is equal to $\max(1/\rho, 1)$, in which ρ is expressed in dimensions of ton per yd^3 .

9.3. Processing at the smelter

Based on the results of the study, processing costs for the materials vary significantly depending on the concentration of lead, the market price for lead, and the percentage of the feed which becomes slag. As the market price for lead or the concentration of lead in the feed material decreases, the cost of processing Superfund materials will increase, because the lead represents a saleable commodity generated during the reclamation. If the material contains a greater fraction of constituents which exit the furnace in the slag fraction, then the cost increases commensurate with the disposal costs of slag. Most of the other parameters (for example, a slight increase in oxygen usage in the furnace) have little overall effect on the cost of processing.

CHMR has developed a model for estimating the costs associated with processing Superfund materials at a smelter. The model breaks the cost into four major categories: a base cost (per ton) to cover a portion of normal smelting costs, additional production costs specific to the material, additional disposal costs, and offsets of the value of the recovered lead and reductions in other feeds (if any) to the furnace. These are described further below.

Base cost C_B

According to the literature [12, 17, 24, 28, 32], the cost of processing material in a smelter is approximately $\$0.10 \pm 0.02$ per pound, or $\$200 \pm 40$ per ton of material processed. (Note that this is not the cost of *producing* a pound of lead, which is typically estimated at between $\$0.12$ and 0.17 per pound, but is the cost of *processing* a pound of feed. The two are related, since furnace feeds [including coke, iron and limestone] contain roughly 55–65% lead.) This cost includes the cost of handling and loading the material, maintaining the smelter, normal furnace inputs (coke, natural gas, oxygen, etc.), labor costs, environmental compliance costs, etc.

Additional production costs C_{apc}

These costs include additional labor and equipment costs associated with handling an atypical feed at the smelter. Included in this category are costs associated with maintaining a staff member on-site during loading to ensure that the proper materials are loaded onto the trucks (estimated at $\$6$ per ton); labor costs associated with inspecting, unloading, and mixing the material at the smelter ($\$10$ per ton); costs for

additional management time and attention for the material (\$3 per ton); additional capital costs at the smelter, including loading equipment, storage areas, and piloting costs (estimated at \$18 per ton); legal and contractual costs associated with handling Superfund materials \$10 per ton); and miscellaneous costs, such as analytical costs (estimated at \$10 per ton). These additional production costs remain relatively fixed independent of the amount or types of materials processed, at $\$60 \pm 10$ per ton.

For light materials, the additional processing costs will be based on their volume, rather than weight. More than likely, however, the smelter will choose to crush or grind them before feeding them to the furnaces, at a cost of between \$10 and \$15 per cubic yard. To denote this, a correction factor $\Psi = \$15$ per ton is applied when the bulk density of the material is below 0.8 ton per yd^3 . If the density is above 0.8 tons per yd^3 , $\Psi = 0$.

Additional disposal costs C_{disp}

Additional disposal costs associated with processing Superfund materials include the disposal of slag and calcium sulfate sludge. Based on measurements taken at the smelter, CHMR determined that typical smelter feeds produce in the range of 200 lbs of slag per ton of feed (10% slag in the feed), and 60 lbs of sludge per ton of feed (based on 3% sulfur in the feed). This material is typically disposed of at a cost of \$150 per ton. The cost to dispose of 200 lbs of slag and 60 lbs of sludge is included above as part of the overall cost to process the material. However, some Superfund and waste materials may contain significantly higher percentage of compounds which will end up in the slag, or sulfur which will produce sludge. Therefore, the overall processing cost must be adjusted to include the cost to dispose of the waste materials produced by the feed. This adjustment is calculated as:

$$C_{\text{disp}} = \$150([N] - 0.1) + \$100([S] - 0.03),$$

where $[N]$ represents the percentage of non-combustible, non-lead, and non-volatile material in the Superfund material, and $[S]$ is the sulfur content of the feed. $[N]$ can then be calculated by:

$$[N] = [A] - 1.1[\text{Pb}],$$

where $[A]$ is the ash content of the waste material, measured at or above 1500 °F, and $[\text{Pb}]$ is the percentage lead in the material. The correction factor to the lead concentration corrects for the appearance of lead oxides in the lead. The overall disposal cost differential is therefore,

$$C_{\text{disp}} = 150[A] - 165[\text{Pb}] + 100[S] - 18.$$

Offsets for the value of lead and reduction of other furnace feeds

The value of the recovered lead in a waste material is given by:

$$C_{\text{Pb}} = -\epsilon_r P [\text{Pb}],$$

where ϵ_r is the reclamation efficiency for the feed in question (assumed to be approximately 1), P is the market price for lead in dollars per ton and $[\text{Pb}]$ is the weight

fraction of lead in the material. The negative sign on the cost indicates that this is not a cost per se, but in reality a credit for the lead content to the smelter. The January 1994 market price for lead was approximately \$700 per ton. This is down from over \$750 per ton in 1991, but up from \$450 per ton in 1992. The volatility in the price of lead is due to large sales of lead from the former Soviet Union and the price is anticipated to stabilize during 1994 [31].

A second benefit from Superfund materials is decreased coke usage. For materials such as battery cases, which can be essentially a supply of coke to the furnace, the change in required coke is related to the heat value of the Superfund materials (which in this discussion will be denoted by [Btu] and given in units of Btu per pound). If coke were used only as a fuel source inside a furnace, and if the battery case materials burn similarly to coke, then the reduction in coke usage based on addition of a Superfund materials would be equal to the ratio of the Btu value of the Superfund material to that of coke (i.e., if you feed 1 Btu of energy to the furnace from the Superfund material, you would save 1 Btu's worth of coke in the furnace). However, coke is not used only as a fuel source, but also to provide structure to the materials inside the furnace. In addition, battery cases, with different sizes and shapes, do not burn at the same relatively homogenous rate as coke input to a furnace. Therefore, a one-to-one reduction in energy supply between Superfund materials and coke is not possible. Based on the reduction in coke requirements for the Tonolli feed, in which a 10% feed of a material with a heating value of 12,000 Btu per pound allowed for a reduction of 30% in the coke usage, CHMR estimates that approximately 25% of the heat-value of a Superfund waste can be applied to offset the blast furnace requirements for coke. Based on this, the Btu-value of coke (13,000 Btu per pound) and the market price for the coke used in the furnace (approximately \$150 per ton), the cost savings from the Btu-value of the Superfund material can be estimated as:

$$C_{\text{coke}} = -0.007([\text{Btu}] - 2000),$$

where C_{coke} is in terms of dollars per ton of feed material. The cost savings include savings from not having to add the coke as part of the base feedstock to the furnace. The 2000 Btu per pound differential in the equation is included because below a minimum level, the material probably provides no realizable benefit to the furnace, and may even increase fuel requirements because of its thermal capacity.

Likewise, the iron content of a Superfund material may provide significant benefit to the furnace. The extent of reduction allowed by the addition of Superfund materials containing iron could not be estimated from the experiments conducted, because the smelter fed the material at a rate significantly higher than they usually feed iron. However, assuming a 75% tradeoff from metallic iron input to the furnace, and based on the market price of scrap iron (\$130 per ton), the potential cost avoidance savings are:

$$C_{\text{Fe}} = -360 \max([\text{Fe}] - 0.1, 0)$$

where [Fe] is the weight fraction iron in the feed. Note that the equation predicts that there is no benefit if the iron fraction is below 0.1. The formula includes a correction to avoid double counting the iron which needs to be disposed.

Thus, overall cost benefits and avoidance C_A based on the lead in the Superfund material and reductions of coke and iron usage is:

$$C_A = -P[\text{Pb}] - 0.007([\text{Btu}] - 2000) - 360 \max([\text{Fe}] - 0.1, 0),$$

with $[\text{Btu}]$ in Btu per pound and $[\text{Fe}]$ as weight percentage metallic iron in the feed, and the lead reclamation efficiency assumed to be 1.

Smelter processing cost

The net cost to process the waste materials in a secondary lead smelter, is therefore:

$$C_P = C_B + C_{\text{apc}} + C_{\text{disp}} + C_A,$$

$$C_P = 256 + 150[A] - (165 + P)[\text{Pb}] + 100[S] \\ - 0.007[\text{Btu}] - 360 \max([\text{Fe}] - 0.1, 0),$$

where C_P is in units of dollars per ton of material.

9.4. Overall process economics

The overall process economics can be determined by combining the various components (excavation, transportation, and processing the materials):

$$C_{\text{Tot}} = C_E + C_T + C_P$$

where C_{Tot} is the overall cost of processing in dollars per ton. Fixing the cost of excavation and required pre-treatment at \$15 per ton, inserting a function of distance (D) from the smelter (in miles) for transportation costs, and combining the processing cost for the material, C_{Tot} becomes:

$$C_{\text{Tot}} = 271 + 0.3\Phi D + \Psi + 150[A] + 100[S] - (165 + P)[\text{Pb}] \\ - 0.007[\text{Btu}] - 360 \max([\text{Fe}] - 0.1, 0),$$

with C_{Tot} in dollars per ton of material.

Correction factors Φ and Ψ are functions of the bulk density of the material (in ton per yd^3), where $\Phi = \max[1/\rho, 1]$ and $\Phi = 0$ if $\rho > 0.8$ ton per yd^3 and \$15 per ton if $\rho \leq 0.8$ ton per yd^3 . Neither correction factor will likely apply if the material is crushed on-site to increase its density and decrease handling costs before being shipped to the smelter, but, of course, the cost of this crushing must then be added to pre-processing and excavation costs.

Based on this cost model, the overall cost of processing the materials from the sites studied during this research, have been calculated, and are presented in Table 5. The table includes two costs, the first based on a conservative market price for lead (\$650 per ton) and the second based on a more plausible long-term cost for lead (\$750 per ton). Note that the overall cost of using secondary lead smelters as a treatment technology for Superfund sites is dependent on the lead content and market price for lead and total ash content (i.e., slag generation potential) of the material.

Table 5
Cost of remediating sites

Site	$P = \$650/t$ cost/ton	$P = \$750/t$ cost/ton	Distance D (miles)	Ash (%) [A]	Lead (%) [Pb]
Tonolli	\$228	\$224	40	20	3.5
Hebelka	\$174	\$160	75	30	14.7
Demolition material	\$374	\$373	100	4	1
NL Industries	\$80	\$35	300	65	45
PennDOT	\$231	\$228	250	70	3.2

Table 6
Comparison of smelting and other technologies

Technology	Media	Price range/ton	Comments
Stabilize/capping	Soils	\$30–100	Limited application
	Battery cases	\$50–150	
Stabilize/disposal	Soils	\$50–200	Process + dispose
Physical separation	Soils	\$60–200	
Extractive washing	Battery cases	\$60–250	Metal recovery
	Soils	\$60–250	
Secondary lead smelting	Battery cases	\$75–300	Metal recovery
	Debris	\$100–250	
	Other materials	\$60–200	
		\$100–300	

10. Prognosis for lead reclamation as a remedial approach

Table 6 provides a comparison of the use of secondary lead smelting to other remediation technologies described in the paper for a variety of feeds. The table includes all costs associated with processing each feed in the technology indicated. The table shows that secondary smelting is the most economical alternative for lead debris, and competitive for battery cases.

Secondary lead smelting has other advantages over the alternative technologies, including:

- *It is a permanent solution* – The lead is reclaimed and put back to its original use. The long term effects of other technologies, such as landfilling or stabilization, are still uncertain.

- *It reduces liability* – Once the material is processed in the smelter, it is no longer a waste, but a product, permanently ending the long term CERCLA liability of disposing the waste.

- *It uses existing technology* – This eliminates the need to develop mix ratios for solidification or stabilization.

– *Smelter receptivity* – In an informal survey, CHMR found that virtually all secondary lead smelters are permitted to accept lead-containing hazardous wastes, and that approximately half were amenable to doing so.

CHMR estimates that the total amount of battery case material and other debris which could be processed annually in the US secondary smelters is approximately 300,000 ton. This is based on 25 ton per day per furnace, and 280 production days per year. It appears at this point that several US smelters are currently planning to accept Superfund materials.

11. Conclusions

The following conclusions may be drawn from the study of reclamation of lead from Superfund sites using secondary lead smelters.

– Lead is a common contaminant at Superfund sites, present at between 30 and 50% of the sites.

– Lead was successfully reclaimed in a secondary lead smelter from materials found at three Superfund sites as well as two additional sets of materials.

– Secondary lead smelters can reclaim lead from spent iron-shot paint abrasive blasting materials and demolition wastes containing lead paint.

– Secondary lead smelters can reclaim lead from a variety of Superfund materials containing a minimum of 1% lead.

– Wastes which cannot be processed in secondary lead smelters include wastes with over 25% soil, liquid or gaseous wastes, and materials with high halogen content.

– The economics of reclaiming lead from Superfund sites are dependent on lead concentration, the market price for lead, distance from the smelter, the amount of materials which become incorporated into slag from the process, iron content, Btu-value of the wastes, and to a lesser extent, sulfur concentration.

– The cost for recovering lead from the five sites selected for this project, based on the January 1994 price for lead (\$700/ton), ranged between \$80 and \$374 per ton of materials.

– Factors in selecting reclamation using secondary lead smelters for the materials found at Superfund sites include: lead concentration; material type (dross, debris, slag, soil, etc.); density of the material; sulfur, calcium, iron, antimony, soil, aluminum, and silica concentrations; moisture content (smelters cannot accept wet materials); presence of organic wastes (which typically are prohibited in smelters); and, Btu-value.

Overall, CHMR concludes that secondary lead smelters provide a viable alternative to stabilization and disposal for the treatment of wastes found at battery breaker and secondary lead smelter Superfund sites, as well as for other commonly found lead-containing waste streams.

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