Chapter 3. Lead and Lead Compounds

Five Chemicals Alternatives Assessment Study

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3.1 Lead Overview

3.1.1 Characteristics of Lead

Lead is a natural, bluish-gray metal. The chemical formula for lead is Pb, and its atomic weight is 207.2 g/mol. The Chemical Abstract Series number for lead is 7439-92-1. (National Institute for Occupational Safety and Health 2004) The following table provides a summary for key chemical and physical characteristics for lead.

Table 3.1.1 Lead Summary Table

Chemical and Physical Characteristics of Lead (*2*)	
Melting/Boiling Point	327.4° C / 1,740° C
Vapor Pressure	1.77 mm Hg at 1,000° C
Octanol/Water Partition Coefficient	No data for Log Kow
Density	11.34 g/cm^3
Solubility in Water	Pure lead is insoluble, lead compounds may vary from insoluble to soluble
Soil Sorption Coefficient	No data for Log Koc
Solubility in Organic Solvents	Insoluble
Henry's Law Coefficient	No data

Manufacturers use lead in the form of a metal for many different products. Lead possesses the general physical properties of other metals as a conductor of electricity and heat. Lead has low melting temperature (327° C) and extreme malleability, which enables the easy casting, shaping, and joining of lead products. Lead is relatively abundant in the earth, and has a fairly low price when compared with other non-ferrous metals. Lead can be recycled as a secondary raw material from lead-acid batteries and other lead products (Thornton, et al. 2001).

The high density of lead is desirable for several product categories including weighting applications, and shielding against sound, vibration, and radiation. However, lead has very low tensile strength which precludes its use for applications that require even moderate strength. Creep is the slow plastic deformation of materials under a constant stress. Lead is subject to creep at normal temperatures because its melting temperature is relatively low (Thornton, et al. 2001).

Lead is commonly used in various alloys which offer physical properties different than elemental lead. For example, the strength and creep resistance for lead can be improved with the small additions of other metals (e.g. copper) to form alloys with more desirable mechanical properties.

Lead compounds have different physical properties than elemental lead, and are used for various products. The NLM HSDB lists over 120 lead compounds. The major lead compounds used in commerce are lead oxide (PbO), lead tetraoxide (Pb_3O_4), basic lead carbonate (white lead), tribasic lead sulfate, and dibasic lead phthalate. For example, the reactions of lead oxide in dilute sulfuric acid are fundamental to the operation of a lead-acid battery.

3.1.2 Potential Health and Environmental Impacts of Lead

Summary

Lead is used in the manufacture of batteries, metal products, cables, ceramic glazes, and other various products. Exposure to lead can occur from breathing contaminated workplace air or house dust or ingesting lead-based paint chips or contaminated dirt. Lead is a very toxic element, causing a variety of effects at low dose levels. Brain damage, kidney damage, and gastrointestinal distress are seen from acute (short-term) exposure to high levels of lead in humans. Chronic (long-term) exposure to lead in humans results in effects on the blood, central nervous system (CNS), blood pressure, kidneys, and Vitamin D metabolism. Children are particularly sensitive to the chronic effects of lead, with slowed cognitive development, reduced growth and other effects reported. Reproductive effects, such as decreased sperm count and spontaneous abortions, have been associated with high lead exposure. The developing fetus is at particular risk from maternal lead exposure, with low birth weight and slowed postnatal neurobehavioral development noted. Human studies are inconclusive regarding lead exposure and cancer.

Hazards

Human exposure to lead occurs through a combination of inhalation and oral exposure, while dermal absorption of inorganic lead compounds is reported to be much less significant than absorption by inhalation or oral routes. Inhalation generally contributes a greater proportion of the dose for occupationally exposed groups, and the oral route generally contributes a greater proportion of the dose for the general population. The effects of lead are the same regardless of the route of exposure (inhalation or oral) and are correlated with internal exposure, as blood lead levels. For this reason, this report will not discuss the exposure in terms of route but will present it in terms of blood lead levels.

Acute (Short-Term) Health Effects

Death from lead poisoning is likely to occur in children who have blood lead levels greater than 125 μg/dL and brain and kidney damage have been reported at blood lead levels of approximately 100 μg/dL in adults and 80 μg/dL in children. Gastrointestinal symptoms, such as colic, have also been noted in acute exposures at blood lead levels of approximately 60 μg/dL in adults and children. Short-term (acute) animal tests in rats have shown lead to have moderate to high acute toxicity. (Agency for Toxics Substances and Disease registry (ATSDR) 1999). Effects on glomeral filtration, neurodevelopment, and blood pressure are evident are blood lead levels below 10 μg/dL. The most sensitive targets for the toxic effects of lead are the kidneys and the hematological, cardiovascular, and nervous systems. Because of the multi-modes of action of lead in biological systems, lead could potentially affect any system or organ in the body (ATSDR 2005).

Chronic (Long-Term) Health Effects

Non-cancer Effects

Chronic exposure to lead in humans can affect the blood. Anemia has been reported in adults at blood lead levels of 50 to 80 μg/dL, and in children at blood lead levels of 40 to 70 μg/dL. Lead also affects the nervous system. Neurological symptoms have been reported in workers with blood lead levels of 40 to 60 μg/dL, and slowed nerve conduction in peripheral nerves in adults occurs at blood lead levels of 30 to 40 μg/dL. Children are particularly sensitive to the neurotoxic effects of lead. There is evidence that blood lead levels of 10 to 30 μg/dL, or lower, may affect the hearing threshold and growth and development in children (ATSDR 1999). Meta-analyses conducted on cross-sectional and prospective studies suggest and IQ decline of 1 – 5 points is associated with an increase in lead blood level of 10 μg/dL. No threshold for the effects of lead on IQ has been identified.

Other effects from chronic lead exposure in humans include effects on blood pressure and kidney function, and interference with vitamin D metabolism. Animal studies have reported effects similar to those found in humans, with effects on the blood, kidneys, and nervous, immune, and cardiovascular systems noted.

The U.S. Environmental Protection Agency (EPA) has not established a Reference Concentration (RfC) or a Reference Dose (RfD) for elemental lead or inorganic lead compounds. EPA has established a Reference Dose for tetraethyl lead (an organometallic form of lead) of 1×10^{-7} milligrams per kilogram body weight per day (mg/kg/d) based on effects in the liver and thymus of rats.

Cancer Risk

Human studies are inconclusive regarding lead exposure and an increased cancer risk. Four major human studies of workers exposed to lead have been carried out; two studies did not find an association between lead exposure and cancer, one study found an increased incidence of respiratory tract and kidney cancers, and the fourth study found excesses for lung and stomach cancers. However, all of these studies are limited in usefulness because the route(s) of exposure and levels of lead to which the workers were exposed were not reported. In addition, exposure to other chemicals probably occurred. Animal studies have reported kidney tumors in rats and mice exposed to lead via the oral route. EPA considers lead to be a Group B2, probable human carcinogen. International Agency for Research on Cancer (IARC) considers inorganic lead compounds to be probably carcinogenic to humans (Group 2A), and organic lead compounds to be not classifiable as to their carcinogenicity to humans (Group 3).

Reproductive/Developmental Effects

Studies on male lead workers have reported severe depression of sperm count and decreased function of the prostate and/or seminal vesicles at blood lead levels of 40 to 50 μg/dL. These effects may be seen from acute as well as chronic exposures. Occupational exposure to high levels of lead has been associated with a high likelihood of spontaneous abortion in pregnant women. However, the lowest blood lead levels at which this occurs has not been established. These effects may also be seen from acute as well as chronic exposures. Exposure to lead during pregnancy produces toxic effects on the human fetus, including increased risk of preterm delivery, low birthweight, and impaired mental development. These effects have been noted at maternal blood lead levels of 10 to 15 μg/dL, and possibly lower. Decreased IQ scores have been noted in children at blood lead levels of approximately 10 to 50 μg/dL (ATSDR 1999).

Human studies are inconclusive regarding the association between lead exposure and other birth defects, while animal studies have shown a relationship between high lead exposure and birth defects.

Environmental Hazards

Lead is a naturally occurring, bluish-gray metal that is found in small quantities in the earth's crust. Lead is present in a variety of compounds such as lead acetate, lead chloride, lead chromate, lead nitrate, and lead oxide. Lead readily tarnishes in the atmosphere but it is one of the most stable fabricated metals because of its corrosive resistance to air, water, and soil. Pure lead is insoluble in water; however, the lead compounds vary in solubility from insoluble to water soluble. The vapor pressure for lead is 1.00 mm Hg at 980° C (National Institute for Occupational Safety and Health 2004).

Lead particles are removed from the atmosphere by wet and dry deposition. The average residence time in the atmosphere is ten days, during which long distance transport up to thousands of kilometers may take place. Lead is extremely persistent in both water and soil. The presence of lead in these media varies widely depending on such factors as temperature, pH, and the presence of humic materials.

Although combustion of leaded gasoline was one the primary source of anthropogenic atmospheric releases of lead, industrial releases from smelters, battery plants, chemical plants, and disturbance of older structures containing lead based paints are now major contributors to total lead releases.

Biologists have studied the effects of lead sinkers and jigs on waterbirds, such as loons and swans, since the 1970s. A single fishing sinker swallowed with food or taken up as grit could be fatal to waterbirds. Lead adversely affects the function and structure of the kidney, central nervous system, bones, and production and development of blood cells in waterbirds. Exposure to lead, such as through ingestion of fishing sinkers, can cause lead poisoning in waterbirds, producing convulsions, coma, and death (USEPA 1994).

Exposure Routes

Worker Health

The primary use of lead in the U.S. is in the manufacture of batteries. Lead is also used in the production of metal products, such as sheet lead, solder (but no longer in food cans), and pipes, and in ceramic glazes, paint, ammunition, cable covering, and other products.

Potentially high levels of lead occur in the following industries: primary and secondary lead smelting and refining industries, steel welding or cutting operations, battery manufacturing plants, construction, rubber products and plastics industries, printing industries, firing ranges, radiator repair shops, and other industries requiring flame soldering of lead solder. In these work areas, the major routes of lead exposure are inhalation and ingestion of lead-bearing dusts. In the smelting and refining of lead, mean concentrations of lead in air can reach 4,470 $\mu g/m^3$; in the manufacture of storage batteries mean airborne concentrations of lead from 50 to 5,400 $\mu g/m^3$ have been recorded. (ATSDR 1999) The following bullets include various occupational threshold limits:

- The NIOSH REL for an 8 – 10 hour time-weighted-average exposure is 0.10 mg/m^3 (IARC 2004).
- The NIOSH IDLH is 100 mg/m^3 ((IARC 2004).
- The OSHA PEL for an 8 hour work day is 0.5 mg/m^3 (Smith 2003).
- The ACGIH TLV is 0.5 mg/m3 over an 8 hour workshift (Smith 2003).

Public Health

This section lists the major exposures of lead to the public, but is not intended to be an exhaustive listing of all potential exposures. The largest source of lead in the atmosphere has been from leaded gasoline combustion, but with the phase out of lead in automotive gasoline, air lead levels have decreased considerably. Other airborne sources include combustion of solid waste, coal, and oils, emissions from iron and steel production and lead smelters, general aviation aircraft, racing vehicle, marine fuels, and tobacco smoke.

Exposure of the general population to lead is most likely to occur through the ingestion of contaminated food and drinking water, and by the inhalation of lead particulates in ambient air. Fruits, vegetables, and grains may contain levels of lead in excess of background levels as a result of plant uptake of lead from soils and direct deposition of lead onto plant surfaces. Common source of exposure for children is lead-based paint that has deteriorated into paint chips and lead dusts, and common sources of lead exposure for adults include occupational and non-occupational such as do-it-yourself paint scraping, renovations, and castings. For example, using heat guns or dry scraping of old lead containing paint during home reconstruction and remodeling can result in lead exposure.

Exposure to lead can also occur from food and soil. Children are at particular risk to lead exposure since they commonly put hands, toys, and other items in their mouths, which may come in contact with lead-containing dust and dirt. Lead-based paints were commonly used until 1978 and flaking paint, paint chips, and weathered paint powder may be a major source of lead exposure, particularly for children. Children are also exposed by handling lead-stabilized PVC plastics and lead alloy jewelry and toys. Lead in drinking water is due primarily to the presence of lead in certain pipes, solder, and fixtures (i.e. brass fixtures).

Lead exposure to the general public can also occur during the use of inadequately glazed or heavily worn earthenware vessels for food storage and cooking, as well as by engaging in certain hobbies such as using recreational shooting ranges, stained glass making, or using molten lead in casting ammunition, fishing weights, or toy figurines.

Lead has been listed as a pollutant of concern to EPA's Great Waters Program due to its persistence in the environment, potential to bioaccumulate, and toxicity to humans and the environment. The National Ambient Air Quality Standard (NAAQS) are set by the U.S. EPA for pollutants that are considered to be harmful to public health and the environment. The NAAQS for lead is 1.5 $\mu g/m^3$, which is the maximum arithmetic mean averaged over a calendar quarter (New Jersey Department of Health and Senior Services 2001).

3.1.3 Use and Functionality

The various physical properties of lead were outlined in Section 5.1.1. Lead may be used in the form of metal, alloyed with other metals, or as chemical compounds. The commercial importance of lead is based on its ease of casting, high density, low melting point, low strength, ease of fabrication, acid resistance, electrochemical reaction with sulfuric acid, and chemical stability in air, water, and soil. Many of the physical properties of lead are desirable for various product categories such as storage batteries, ammunition, casting materials, and sheet lead. The total global consumption of lead in 2003 was estimated to be 15.1 billion pounds, and the U.S. consumption of lead in 2003 was estimated to be 3.06 billion pounds. The greatest use of lead is in lead-acid batteries, however lead-acid batteries are not manufactured in Massachusetts (USEPA 1999).

3.2 Lead Use Identification and Prioritization

3.2.1 Use Identification

Lead has many desirable material properties and has a variety of uses. A summary of the major uses is provided below. (Please see Appendix B for a more detailed description of the various uses of lead).

- Batteries
- Ammunition
- Glass
- Heat Stabilizer in Plastics & Resins
- Metal Finishing
- Electronics (solder, board surface finish, components)
- Sheet Lead (sound barriers, roof flashing, radiation shielding)
- Bulk Metal (castings, weighting applications, ammunition)
- Pigments

In order to determine which uses were a priority for assessment in Massachusetts, the following criteria were evaluated:

1. Importance to the Commonwealth of Massachusetts:
    - Use in manufacturing: Total quantity of chemical used in manufacturing operations in Massachusetts
    - Use in consumer products: Total quantity of chemical used in products sold in Massachusetts.
2. Potential availability of alternatives.
3. Exposure potential (environmental, occupational, and public health).
4. Potential value to Massachusetts businesses and citizens of the alternatives assessment results. Specifically, the preferences of the pertinent stakeholders for each chemical were given priority. This stakeholder input was provided during a stakeholder meeting held during October 2006, and from a stakeholder input survey.

Uses in Products

The following table illustrates the uses of lead in various products:

Table 3.2 A: Uses of Lead

Use	U.S. Consumption in 2003 (Pounds)	Percentage of Total U.S. Consumption
Storage batteries	2,578,680,000	84.2%
Ammunition	107,555,200	3.5%
Miscellaneous Uses	93,890,400	3.1%
Oxides	78,682,800	2.6%

Table 3.2 A: Uses of Lead		
Use	**U.S. Consumption in 2003 (Pounds)**	**Percentage of Total U.S. Consumption**
Casting metals	69,866,800	2.3%
Sheet lead	53,336,800	1.7%
Other metal products	50,251,200	1.6%
Solder	13,907,240	0.5%
Proprietary corporate data	6,620,816	0.2%
Billets, ingots	6,193,240	0.2%
Extruded products	3,680,680	0.1%
Bearing metals	894,824	0.0%
Totals:	3,063,560,000	100.0%
Source: USGS		

Use in Massachusetts Manufacturing/Operations

The following table illustrates the uses of lead in various manufacturing and operations in Massachusetts. This table includes lead use as reported by Massachusetts facilities covered by the Toxics Use Reduction Act (TURA). This is not an exhaustive list because it does not include facilities with less than ten employees, facilities with SIC codes not covered by TURA, and facilities using less than TURA defined threshold amounts.

Table 3.2 B: Use of Lead in Massachusetts			
Major Use Category	**TURA Total Use (2003)**	**Pounds**	**Number of Filers**
PVC/Rubber	42.4%	3,955,938	39
Waste Combustors	28.3%	2,642,987	4
Waste Management	14.9%	1,395,219	4
Pigments	2.3%	211,596	4
Metal Finishing	2.2%	201,130	14
Casting/Extrusion	2.0%	190,223	17
Electronics	2.0%	186,434	59
Glass	1.7%	162,137	10
Sheet Lead	1.7%	157,197	3
Power Generation	1.3%	122,861	7
Ceramics	0.6%	58,212	3

Table 3.2 B: Use of Lead in Massachusetts			
Major Use Category	**TURA Total Use (2003)**	**Pounds**	**Number of Filers**
Miscellaneous	0.3%	28,490	40
Ammunition	0.1%	13,782	1
Concrete/Stone	0.1%	10,564	19
Batteries	0.0%	0	0
Totals:	100.0%	9,336,770	224

Source: TURA Data, 2003

Lead Releases in Massachusetts

The following table illustrates the releases of lead in Massachusetts. This table is not an exhaustive listing of releases because it is limited to the generators covered under the U.S. EPA Toxics Release Inventory program.

Table 3.2 C: Lead Released in Massachusetts			
Major Use Category	**TRI Releases in MA (2003)**	**Pounds**	**Number of Filers**
Waste Management	49.4%	140,468	2
PVC/Rubber	25.4%	72,025	21
Glass	7.8%	22,033	9
Power Generation	7.8%	22,289	6
Ammunition	4.0%	11,414	1
Miscellaneous	1.5%	4,236	36
Electronics	1.3%	3,733	39
Casting/Extrusion	1.0%	2,854	10
Metal Finishing	0.9%	2,426	10
Concrete/Stone	0.5%	1,282	5
Ceramics	0.3%	825	3
Pigments	0.2%	495	3
Sheet Lead	0.0%	5	1
Batteries	0.0%	0	0
Waste Combustors	0.0%	0	0
Totals:	100.1%	284,085	146
Source: U.S. EPA TRI Data, 2003			

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Summary of Stakeholder Input

Stakeholder participation at the October 2005 and November 2005 stakeholder meetings included Massachusetts representatives from industry, government, and environmental organizations. The following considerations were evaluated during the prioritization process for the major uses of lead.

Batteries:

- Highest level of lead use accounting for approximately 84% of all lead use in the United States.
- In general, there is a good infrastructure in place for recycling lead in batteries at product end of life.
- Many available battery alternatives contain nickel, cadmium, or other toxic materials.
- Most safer battery alternative technologies are still emerging.

Electronics

- Broad use in Massachusetts by approximately 59 facilities in the electronics industry. However, only a small quantity of lead is incorporated into the product.
- The European Union's directive called Restriction of the use of certain Hazardous Substances (RoHS) restricts the use of lead in many electronics applications. This directive has initiated a movement toward lead-free electronics for affected electronics companies in Massachusetts.
- The electronics industry has already moved toward a standard alternative for lead solder. This alternative is an alloy consisting of tin, copper, and silver (SAC alloy). The Institute has been involved with the electronics industry researching, testing, and evaluating this lead-free alloy for electronics assembly for the past five years.
- The U.S. EPA Design for Environment project has recently completed a comprehensive life cycle analysis for lead and lead-free solders. Therefore, by undertaking an alternatives assessment for lead solder we wouldn't be adding much value to decision making by companies.

Sheet Lead

- Sheet lead is used mostly for roof flashing and radiation shielding applications.
- Lead works well for radiation shielding. For this use, the lead is often isolated from exposure during use and the lead is also easily recyclable.
- There are many commercially available alternatives for lead roof flashing.
- There were health concerns for construction workers and home owners using lead roof flashing.
- Lead use in roof flashing was considered to be added to the priority list if additional time and resources were made available in 2006.

Heat Stabilizers in PVC and Elastomers

- The largest use in Massachusetts manufacturing, accounting for 42% of lead use. Thirty-nine manufacturing facilities in Massachusetts reported a total of approximately 4 million pounds in 2003.
- Many lead-free heat stabilizers are commercially available, and companies are adopting alternative heat stabilizers.

- The U.S. EPA Design for Environment project is underway to evaluate three specific wire/cable applications. In the longer term, this effort will provide life cycle assessment information for several heat stabilizer alternatives.
- There is little or no recycling at end of life for PVC products containing lead.
- An overview of the current market situation for lead-free heat stabilizers would provide high value to Massachusetts manufacturers. There is value to understanding in the short term the various alternatives available before substitutions are made. Wire and cable is an excellent example of lead heat stabilizers used in PVC products.

Weight Applications: Wheel Weights

- Wheel weights commonly become detached from automobile wheels and end up in the environment.
- Several alternatives are in use and are commercially available.
- The Ecology Center of Ann Arbor, Michigan has already gathered some wheel weight information that will be valuable for conducting an alternatives assessment.
- Worker exposure is a concern during installation of wheel weights for new automobiles as well as during after market installation.
- Wheel weights are a good example of lead used in weighting applications. Conducting an alternatives assessment in this area will provide high value to address worker exposure and environmental concerns.

Weight Applications: Fishing Sinkers

- Several states in the Northeast have banned the use of certain lead sinkers. Massachusetts still allows the use of lead fishing sinkers except for use in the Quabbin and Wachusett Reservoirs.
- Several lead-free alternatives are in use and are commercially available.
- Fishing sinkers of all types are lost during use. These fishing sinkers end up in the environment and some of these lead sinkers are ingested by waterfowl.
- Thousands of anglers in the U.S. produce their own lead fishing sinkers.
- Fishing sinkers are a good example of lead used in weighting applications. Conducting an alternatives assessment in this area will provide high value to address wildlife and environmental concerns, as well as health concerns during production and use of lead sinkers by individual anglers.

Ammunition for Shooting Ranges

- Second highest use of lead, accounting for approximately 4% of lead use in the United States.
- For outdoor shooting ranges in Massachusetts, the lead in ammunition usually ends up in the environment and often leads to soil and/or sediment contamination and potentially surface water and groundwater contamination. .
- For indoor shooting ranges, there is high worker and shooter exposure to lead.

- Several alternatives are in use and are commercially available.
- There is a Massachusetts manufacturer of firearms that uses lead ammunition for testing purposes.
- Conducting an alternatives assessment in this area will provide high value to shooting range workers, shooting enthusiasts and public safety personnel.

Pigments

- Most uses of lead pigments have been phased out.
- Lead pigments are primarily used for traffic paint in Massachusetts.
- The single Massachusetts manufacturer of traffic paint is transitioning to a lead-free alternative.
- Lead use in pigments was considered to be added to the priority list if additional time and resources were available.

Castings/Extrusion (jewelry, ornamental, etc.)

- There are 17 TURA filers in Massachusetts that used approximately 190,000 pounds of lead in 2003.
- There is a potentially high consumer exposure during use, especially in children's jewelry.
- Most children's jewelry is now imported, so there is limited control on material selection for foreign manufacturers.
- There are some alternatives commercially available.

In addition to the stakeholder meeting, a survey was provided to stakeholders to solicit their input to prioritize the various uses of lead. Four stakeholders completed and returned this survey. In general, the stakeholder input for the various uses of lead fell into one of the following three categories outlined in the following table:

Table 3.2 D: Stakeholder Input

Stakeholder Input	Lead Use
One or more stakeholders considered this use a low priority	Batteries, Glass, Metal Finishing, Electronics
Stakeholders either did not rank this use or considered it a medium priority	Sheet lead
Stakeholders indicated this use was either a medium or high priority (with at least two stakeholders considered this a high priority)	Heat stabilizers, weight applications, ammunition, pigments

3.2.2 Use Prioritization

Based upon applying the criteria discussed above, the following three applications were selected as priority lead uses for this alternatives assessment project: In summary, these applications were chosen based on stakeholder input, importance to Massachusetts industry and consumers, and likely availability of alternatives. Ammunition when used at indoor and outdoor firing ranges was thought to be a significant source of lead contamination in the Commonwealth. Wheel weights and fishing to be a significant source of lead contamination in the Commonwealth. Wheel weights and fishing sinkers were chosen to be representative of a large number of lead uses that rely on its high density. Wire and cable heat stabilization is the category with the largest use of lead among Massachusetts manufacturers. The priority uses of lead that will be studied are:

- Ammunition for shooting ranges;
- Weighting applications (wheel weights and fishing sinkers);
- Heat stabilizers used in PVC wire and cable coatings.

3.3 Lead Alternatives Identification and Prioritization

Since there are so many alternatives for the various uses of lead, the Institute was not able to fully evaluate them all in the short time span allowed for this project. Therefore, the Institute conducted an evaluation to determine those alternatives that are most feasible based upon the following criteria:

- ***Performance***: Known performance of alternative compared to that of the hazardous chemical. Consider the potential for future performance enhancements (e.g. research funds available for further product development).
- ***Availability***: Number of suppliers/manufacturers that commercially provide the alternative.
- ***Manufacturing Location***: Is the product manufactured in Massachusetts or outside of Massachusetts.
- ***Cost***: Current costs associated with the alternative compared to that of the hazardous chemical. Consider the potential for future cost reductions (*e.g.,* economies of scale due to higher volume production).
- ***Environmental, Health, and Safety***: Known environmental, health and safety risks compared to that of the hazardous chemical.
- ***Global Market Effect***: Information about pending or existing global restrictions that might materially affect the ability of an industry to market its products internationally.
- ***Stakeholder Value***: Stakeholders placing a high priority on a particular alternative so as to inform their decisions.

3.3.1 Alternatives Associated with Ammunition for Shooting Ranges

Available Alternatives

Alternatives based on the following substances were identified:

- Bismuth
- Copper
- Iron
- Tungsten
- Zinc
- Brass
- Bronze
- Ceramic
- Plastic/polymeric
- Steel
- Tin
- Beryllium

Alternatives Screening

Beryllium and beryllium compounds: The U.S. Department of Health and Human Services and the International Agency for Research on Cancer have determined that beryllium and beryllium compounds are human carcinogens. EPA has determined that beryllium is a probable human carcinogen.

Alternatives Prioritization

A law passed in 1986 makes it unlawful to manufacture or import armor-piercing ammunition, which eliminates the possibility of producing handgun ammunition using tungsten alloys, steel, iron, brass, bronze, beryllium copper, or depleted uranium, unless the projectiles are frangible (break apart into small pieces on contact with any hard surface) and are intended for target shooting applications.

Bismuth

Bismuth is similar to lead in density and softness and therefore has the advantage of having ballistic performance which is similar to lead. At least one major ammunition manufacturer produces bismuth handgun bullets. Bismuth is used to produce frangible bullets by plating a cast bismuth core with a copper jacket, or by mixing bismuth with other materials including polyethylene or zinc. Preliminary research indicates that bismuth is a less toxic alternative to lead for use in handgun ammunition used at indoor firing ranges. In January of 1997, bismuth-tin shotgun shot was granted full approval by the U.S. Fish and Wildlife Service as an alternative to lead shotgun shot for hunting migratory waterfowl.

Copper

Copper is widely used as a jacket material for both lead and lead-free bullets. Copper powder is also used to produce frangible bullets, typically in a mixture with other powdered metals including tin, iron, or tungsten. Copper has a density of 8.9 g/cm^3 which is 22% less than lead and will result in either lighter bullets or increased bullet size.

Several major ammunition manufacturers use copper and/or copper powder to produce lead-free handgun ammunition. The cost of copper is roughly 3.5 times the cost of lead. Frangible handgun ammunition made with sintered (heated without melting to form a coherent mass) copper powder is significantly more expensive than lead ammunition but it is competitive with other types of frangible ammunition or reduced hazard ammunition.

Iron

Iron powder has successfully been used to produce frangible handgun bullets. Iron has a density of approximately 7.6 g/cm^3 which is 32% less than lead and will result in either lighter bullets or increased bullet size. Iron handgun bullets, excluding frangible bullets, are banned because they are considered to be armor piercing ammunition. Frangible handgun ammunition made with iron powder is significantly more expensive than lead ammunition but it is competitive with other types of frangible ammunition or reduced hazard ammunition. Iron has the advantage of being magnetic which could facilitate recovery for recycling.

Tungsten

Tungsten has a density of 19.25 g/cm^3 which is 1.7 times the density of lead. Tungsten ammunition can be produced to provide similar ballistic performance to lead ammunition. Several major ammunition manufacturers produce lead-free frangible ammunition using tungsten. Tungsten alloy handgun bullets, excluding frangible bullets, are banned because they are considered to be armor piercing ammunition.

Frangible handgun ammunition made with tungsten is significantly more expensive than lead ammunition but it is competitive with other types of frangible ammunition or reduced hazard ammunition. In January of 1997, several types of tungsten shotgun shot were granted full approval by the U.S. Fish and Wildlife Service as alternatives to lead shotgun shot for hunting migratory waterfowl.

Zinc

Zinc has a density of 7.05 g/cm^3 which is 62% of the density of lead will result in either lighter bullets or increased bullet size. Zinc can be used to produce frangible bullets either by forming the bullets out of zinc powder or zinc wire. Considering commodity prices of metals, zinc is one of the least expensive alternatives to lead. It is approximately twice the cost of lead.

Based on the previously listed criteria, alternatives based on the following materials were given a lower priority for assessment

1. Brass: Brass handgun bullets, excluding frangible bullets, are banned because they are considered to be armor piercing ammunition. Based on internet searches of ammunition manufacturers' and dealers' websites, brass frangible handgun bullets do not appear to be available in the commercial marketplace.
2. Bronze: Bronze handgun bullets, excluding frangible bullets, are banned because they are considered to be armor piercing ammunition. Based on internet searches of ammunition manufacturers' and dealers' websites, bronze frangible handgun bullets do not appear to be available in the commercial marketplace.
3. Ceramic: Ceramic bullets are significantly lighter than lead bullets which results in differences in ballistic performance. Ceramic bullets are used in some training applications where frangible bullets are required but, according to Richard Patterson (SAAMI), ceramic bullets are not widely accepted as a substitute for lead handgun bullets because the low density of ceramic negatively impacts performance.
4. Plastic: Molded plastic bullets are available for limited target practice. These reusable lightweight handgun bullets use primer power alone (no powder load) and therefore have velocities of only 300-400 feet per second and a range of only 25 feet. Since they do not utilize a powder load there is no recoil and the ballistic performance is significantly different from lead bullets.
5. Steel: Steel handgun bullets are banned because they are considered to be armor piercing ammunition. Based on internet searches of ammunition manufacturers' and dealers' websites, steel frangible handgun bullets do not appear to be available in the commercial marketplace.
6. Tin: Tin is used as a minor component in several types of bullets including lead, tungsten, and copper bullets. One major manufacturer produces ammunition with a tin core and copper jacket. Several of the alternatives that contain tin are included in the assessment but are included under the primary materials such as copper and tungsten.

High Priority Ammunition for Shooting Ranges Alternatives

The following alternative ammunitions were selected for assessment:

- Bismuth
- Copper
- Iron
- Tungsten
- Zinc

3.3.2 Alternatives Associated with Wheel Weights

Available Alternatives

The following were identified as potential alternatives to lead wheel weights:

- Zinc and ZAMAC (an alloy of zinc, aluminum and copper)
- Steel
- Plastic
- Copper
- Steel
- Tin
- Tungsten
- Iron
- Internal balancing systems, including plastic beads or other material inserted into the tire

Several European and Japanese automobile manufacturers have already switched to zinc or steel wheel weights. While auto manufacturers are making some progress to switch to lead-free wheel weights, the Institute noted that 80% of wheel weights are used by aftermarket businesses such as tire retailers and service stations and very few of these businesses use lead-free wheel weights.

Alternatives Prioritization

Alternatives that appeared likely to meet the following performance criteria were given a higher priority for assessment:

- Should meet automotive industry standards and specifications established for lead wheel weights
- Should be made of a dense material to minimize size
- Should be corrosion resistant
- Should be resistant to high temperatures
- Should be recyclable

Copper

Copper has several properties that match the requirements of wheel weight applications. It is relatively dense (8.9 g/cm^3), it is ductile and it is corrosion resistant. One manufacturer states that copper is ideal for high quality adhesive weights where small size, appearance and balance accuracy are important. One major UK manufacturer produces copper adhesive weights; copper wheel weights are not manufactured in Massachusetts.

Steel

Steel weights are susceptible to corrosion and therefore must be coated. One manufacturer uses a sacrificial zinc corrosion protection plus a plastic coating. Steel is not ductile and therefore it is more suited for adhesive weights than clip-on weights. Steel wheel weights are currently manufactured in Tennessee, Japan, UK, and Austria. Steel is a relatively inexpensive metal and it is possible that steel weights would cost less than lead weights. Steel is currently used for a wide range of products including automobile wheels and other automotive components.

Tin

One wheel weight manufacturer states that tin offers a high quality appearance with a good color match to alloy wheels and does not require corrosion protection. Tin wheel weights are currently manufactured by companies in India and the UK. No tin wheel weight manufacturers are located in Massachusetts. Based on the higher cost of tin, it is expected that tin wheel weights would cost more than lead weights.

Zinc and zinc alloy (ZAMAC – $ZnAl_4Cu_1$)

Zinc has a density of 7.05 g/cm^3 which is 62% of the density of lead and therefore zinc wheel weights will have the disadvantage of being larger than lead weights. Zinc is successfully being used for both clip-on and adhesive type wheel weights.

Zinc and/or zinc alloy wheel weights are manufactured by companies in Tennessee, Austria, Germany, Thailand, and the UK. No zinc wheel weight manufacturers are located in Massachusetts. Zinc clip-on weights are typically more expensive than uncoated lead clip-on weights but zinc weights are likely to be comparable in price to higher quality coated lead weights. Unless zinc weights are clearly marked or labeled, they are not easily distinguishable from lead weights and therefore will likely cause contamination problems for lead smelters during the recycling of lead wheel weights.

Based on the previously listed criteria, alternatives based on the following materials were given a lower priority for assessment

1. Tungsten: Tungsten has the advantage of being more dense than lead and could be used as a pure metal, as an alloy with other metals, or as a filler for plastic weights. A study by Okopol Institute for Ecology and Political Affairs concluded that tungsten was not a realistic alternative for lead wheel weights due to the high price of tungsten, which could be 100 times the price of lead. The study also stated that world-wide production of tungsten is only 31,500 tons per year while demand for wheel weights is 12,000 tons per year.
2. Iron: Iron was not found to be used for wheel weights, most likely because iron is not corrosion resistant.
3. Plastic (Polypropylene): A European study on the use of heavy metals in vehicles (Lohse, 2001) identified talc filled polypropylene as an alternative material for wheel weights but additional information on the use of polypropylene was not located. Polypropylene has the disadvantages of being a low density materiel and having a low melting point. The European study indicated

that talc filled wheel weights have a density of less than 5.2 g/cm^3, which is less than half the density of lead, and that they would fail at temperatures above 120° C.

4. Internal Balancing Systems: Internal balancing systems incorporate the weights, such as plastic beads, inside the tire. One advantage of internal balancing systems is that the weights will not fall off of the wheel since they are contained within the tire. These systems are also likely to be dynamic balancing systems, providing balancing even as the tire wears. A major barrier to adopting internal balancing systems is that they are not drop-in replacements to lead wheel weights. They are likely to require changes to tire balancing equipment and/or tire designs.

High Priority Alternatives for Lead Wheel Weights

The following alternative materials were selected for assessment:

- Copper
- Steel
- Tin
- Zinc and Zinc Alloy (ZAMAC)

3.3.3 Alternatives Associated with Fishing Sinkers

Available Alternatives

The following were identified as potential alternatives to lead fishing sinkers:

- Bismuth and bismuth/tin
- Brass
- Tin
- Copper
- Iron
- Ceramic
- Zinc
- Steel
- Tungsten, tungsten/nickel alloy and tungsten/polymer composite

Alternatives Prioritization

Alternatives that appeared likely to meet the following performance criteria were given a higher priority for assessment

- Adequate density to minimize size
- Smooth finish to reduce line wear
- Corrosion resistance
- Durability
- Scent absorption (some applications)
- Coloring (some applications)

Bismuth

Bismuth has successfully been used as a replacement for lead for some fishing sinker applications. One manufacturer of bismuth fishing sinkers is located in Minnesota.

Bismuth worm weights were found to be 3 to 6 times the cost of the equivalent lead weights. Preliminary research indicates that bismuth is a less toxic alternative to lead for use in fishing sinkers. The EPA stated that it did not discover any information on the toxicity of bismuth to avian or aquatic species (USEPA 1994).

Ceramic

Ceramic has successfully been used as a replacement for lead for some fishing sinker applications. Ceramic is less dense than lead and therefore ceramic weights are larger than lead weights. The larger size of ceramic weights could be a disadvantage in some applications but one manufacturer states that the larger size and lower density of ceramic weights decreases snags and the likelihood of getting caught on rocks. The color and noise created when using ceramic sinkers is also said to attract fish. Ceramic weights are currently produced by at least one manufacturer in Pennsylvania, but ceramic sinkers are not available at some of the major online fishing equipment retailers. Ceramic sinkers are likely to cost more than equivalent lead sinkers.

Steel

Steel has successfully been used as a replacement for lead for some fishing sinker applications. Steel is less dense than lead and therefore steel weights are larger than lead weights. In order to prevent corrosion, the steel weights must be coated or be made from a stainless steel. Steel fishing sinkers are produced by several companies in the U.S. and Canada. Steel sinkers can be cost competitive with lead sinkers. For some sizes, the price of steel egg sinkers was only 75% of the price of equivalent lead sinkers.

The EPA stated that it did not discover any information on the toxicity of steel to mammalian or aquatic species. EPA believes that steel would have low potential toxicity to those species. No adverse toxicological effects from steel have been indicated as a result of a research program conducted by the Fish and Wildlife Service to replace lead shot with steel shot, which examined toxicity to ducks of five proposed substitute shot metals (USEPA 1994).

Tin

Tin is widely used as a substitute for lead split-shot fishing weights because its ductility meets the requirements of this application. At 7.35 g/cm^3, tin is not as dense as lead and therefore the tin weights would be larger but it is not clear that this is either an advantage or disadvantage. Tin fishing sinkers are produced by several companies in the U.S. and Canada. At one major fishing equipment retailer, tin reusable split-shot sinkers are 1.5 to 2.5 times the price of the equivalent lead sinkers, depending on size and quantity.

EPA states that tin, in the inorganic form, is generally much less toxic to aquatic organisms than lead because of its low solubility, poor absorption, low uptake rate, and rapid excretion. It appears that tin is much less toxic to waterbirds and mammals than lead. (United States Environmental Protection Agency (USEPA 1994).

Tungsten

Tungsten has successfully been used as a replacement for lead for some fishing sinker applications. Manufacturers state that tungsten fishing sinkers have the advantage of being smaller and harder than lead sinkers and therefore are less likely to get hung-up on rocks. They also claim that fish are attracted to the noise created by tungsten sinkers.

Tungsten fishing sinkers are manufactured by several companies in the U.S. and Canada, including at least one company in Massachusetts. Tungsten worm weights were found to be 7 to 11 times the cost of the equivalent lead weights.

The EPA stated that it did not discover any information on the toxicity of tungsten to avian species. Tungsten was found to have low toxicity to aquatic organisms (crustaceans and algae). The toxicity of tungsten to aquatic organisms (daphnids and algae), and mammals (rats) is less than lead based on laboratory studies (USEPA 1994).

Based on the previously listed criteria, alternatives based on the following materials were given a lower priority for assessment

1. Brass: Brass is an alloy of zinc, copper, and lead. The lead in brass may be either intentionally added or exist as an impurity. EPA stated that even though the toxicity of brass to waterbirds has not been tested, based on the toxicity of lead and zinc, brass with and without lead would also be very toxic to waterbirds.
2. Copper: EPA states that laboratory studies indicate that copper is more toxic to aquatic organisms and algae than lead. However, EPA believes that environmental conditions in freshwaters would mitigate the toxicity of copper metal to aquatic organisms. The toxicity of copper to avian species is less than that of lead.
3. Iron: Iron was not found to be used for fishing sinkers, most likely because iron is not corrosion resistant.
4. Zinc: EPA found that zinc is more toxic to aquatic organisms than lead, that it may be bioconcentrated by invertebrates and algae, and it may be more bioavailable to aquatic organisms. EPA believes that environmental conditions could mitigate the toxicity of zinc to a certain extent in freshwaters to aquatic organisms because it is more soluble than lead. Zinc is toxic to mammals and avian species (USEPA 1994).

High Priority Alternatives

The following alternative materials were selected for assessment for fishing sinkers:

- Bismuth
- Ceramic
- Steel
- Tin
- Tungsten

3.3.4 Alternatives Associated with Heat Stabilizers for PVC Wire & Cable Coatings

Available Alternatives

The following were identified as potential alternatives to lead-based heat stabilizers for PVC in wire and cable:

- Mixed metal stabilizers based on:

  - Calcium-zinc
  - Barium-zinc
  - Magnesium-zinc
  - Magnesium aluminum hydroxide carbonate hydrate
  - Magnesium zinc aluminum hydroxide carbonate
  - Barium-calcium-zinc
  - Barium-cadmium-zinc
- Ester thiol
- Organotins

Alternatives Screening

The only alternative that was screened out was the barium-cadmium-zinc alternative based on the carcinogenicity criterion. The U.S. EPA has classified cadmium as a Group B1 carcinogen, a probable human carcinogen. IARC has classified cadmium as a Group 2A, probable human carcinogen.

Alternatives Prioritization

Stakeholders provided input on performance criteria, including:

- Heat stabilizer requirements for PVC processing at temperatures between 160 to 210 degrees Celsius. Also, the stabilizers elevate the resistance of PVC products during use against moisture, visible light, ultraviolet rays, and heat.
- Basic properties of lead that make it desirable for use as a heat stabilizer in PVC wire and cable applications
- Alternatives identified to date, including various mixed metal and organotin technologies.

There were many alternatives to lead available for use as a heat stabilizer for PVC wire and cable applications. Since there are so many alternatives for this use of lead, the Institute was not able to fully evaluate them all in the short time span allowed for this project. Therefore, we conducted an evaluation to determine those alternatives that are most feasible, and/or those alternatives that were representative of a class of alternatives, based upon the criteria listed earlier in this section. Based upon applying the criteria, the following five alternatives for using lead as a heat stabilizer were selected as high priorities for assessment:

1. Calcium-zinc
2. Barium-zinc
3. Magnesium-zinc
4. Magnesium aluminum hydroxide carbonate hydrate
5. Magnesium zinc aluminum hydroxide carbonate

All of the five alternatives can be categorized as mixed metal stabilizers. This family of stabilizers has achieved growing market acceptance as a non-lead heat stabilizer for PVC wire and cable applications. Each of the five alternatives is manufactured by at least one major heat stabilizer manufacturer.

Based on the previously listed criteria, alternatives based on the following materials were given a lower priority for assessment

The ester thiols and organotin alternatives were available for use as a heat stabilizer for flexible PVC applications. However, commercially available products were not found for specific use in PVC wire and cable applications.

High Priority Alternatives

The following alternative materials were selected for assessment for PVC heat stabilizers in wire and cable:

- Calcium-zinc
- Barium-zinc
- Magnesium-zinc
- Magnesium aluminum hydroxide carbonate hydrate
- Magnesium zinc aluminum hydroxide carbonate

3.4 Lead Alternatives Assessment

3.4.1 Alternatives Assessment for Ammunition for Shooting Ranges

Technical Assessment

The focus of this assessment is on alternatives to lead bullets used in handgun training ammunition for use at indoor firing ranges. Ammunition marketed for training applications is designed to be inexpensive and is not designed to meet the performance criteria required for service or duty ammunition. Ammunition designed for competitions, hunting or for use by law enforcement is typically more costly than training ammunition because it is designed for increased accuracy or has features, such as a hollow point, which improve performance for the intended application.

It should be noted that conventional handgun ammunition contains lead in both the projectile (bullet) and the primer. However, the scope of this assessment is limited to alternatives to the lead used for the projectile.

Lead-free or reduced lead ammunition is available in the following configurations:
Totally Lead-Free: Lead-free bullets and lead-free primer.
Lead-Free Primer: Lead bullets with lead-free primer. Ammunition with lead-free primer and a lead bullet with a copper jacket that has a totally enclosed base is referred to as firing line safe ammunition because these features reduce the lead vapor generated during firing.
Lead-free Bullets: Lead-free bullets with conventional primer, which contains lead and other heavy metals.
Frangible Lead-Free Bullets: Lead-free bullets that break up into small fragments upon impact with a hard target. Frangible ammunition may utilize either conventional or lead-free primer.

Longevity/Life in Service

The shelf-life of conventional handgun ammunition can be virtually indefinite if it is stored in a cool, dry environment, free of contaminants (Patterson 2006b). It is the primer that typically limits the shelf-life because it is most susceptible to degradation from elements such as excess heat, moisture, and contaminants. The bullet material does not affect the shelf-life of ammunition and several ammunition manufacturers state that their ammunition with lead-free bullets and conventional lead primer has the same shelf-life as conventional lead ammunition.

Key Standards for Component/End-product

U.S. standards for firearms and ammunition are developed and promulgated by the Sporting Arms and Ammunitions Manufacturers' Institute, Inc. (SAAMI), an accredited standards developer for ANSI. SAAMI was established to standardize case and chamber specifications so any ammunition of a given caliber and type will fit and function safely in any firearm designed for that caliber and type of ammunition. SAAMI standards define the safe range of internal ballistic pressures for a given firearm/ammunition combination and provide specifications required to achieve the safe pressures. (Sporting Arms and Ammunitions Manufacturers Institute, Inc. (SAAMI) 2006) Gun manufacturers recommend the use of ammunition with internal ballistic pressures that meet SAAMI specifications.

The Bureau of Alcohol, Tobacco and Firearms (BATF) has banned handgun ammunition made from the following materials because it may be considered armor piercing: tungsten alloys, steel, iron, brass, bronze, beryllium copper and depleted uranium. These materials can be used if the projectiles are frangible and are intended for target shooting applications. The ammunition considered in this study used frangible projectiles (bullets) with the exception of the solid copper bullets and the jacketed stranded zinc bullets and this ammunition was intended for target shooting. Therefore, none of the alternatives were classified by BATF as armor piercing (Bureau of Alcohol, Tobacco, Firearms and Explosives (BATF)).

Key Physical Characteristics and Key Performance Requirements

Density:

The relatively high density of lead (11.34 g/cm^3) is one of the properties that make it the primary material used for bullets. With a density of 19.3 g/cm^3, tungsten has the highest density of the alternatives in this assessment, followed by bismuth (9.8 g/cm^3), copper (8.9 g/cm^3), iron (7.8 g/cm^3), and zinc (7.10 g/cm^3) (Automation Creations).

Hardness and Malleability:

Lead is a soft malleable metal. These characteristics help to limit internal pressures generated when a firearm is fired. It is critical that internal pressures are limited to avoid damage to the firearm and potentially dangerous conditions. The malleability of the bullet is one of several factors that affect internal pressures. When the propellant is ignited and first starts to push the bullet into the rifling, internal pressures rise dramatically. The softness and malleability of lead and the traditional construction of jacketed lead bullets provide cushioning and serve to reduce the initial peak pressure.

The base metals used for the lead-free alternatives are harder than lead as can be seen in Table 3.4.1A. However, information on the actual hardness and malleability of the alternatives was not available because the alternatives are composed of alloys or mixtures of metal powder and other materials such as plastic. If the softness and malleability of the alternatives is not sufficient to limit internal pressures, the manufacturer can limit peak pressures by making other design changes such as reduced power loading, changing the propellant formulation, using softer jacket material or making dimensional changes.

Table 3.4.1 A: Hardness of Ammunition Base Metals

Material	Hardness		
	Brinell Scale	Mohr's Scale	Vickers Scale
Lead	4.2	1.5	5
Zinc		2.5	30
Copper		3	50
Steel (carbon)	170	5-6	
Tungsten	294	7	

Bullet weight:

The mass of a bullet affects the ballistic performance of ammunition and, for many applications, a higher bullet mass is desirable. The mass of a bullet is a function of the size of the bullet and the density of the bullet material. However, the size of the bullet is dictated by gun dimensions and therefore the bullet weight is driven primarily by the density of the bullet material.

Lead bullets are often available in two or three weights for a given caliber while lead-free bullets are generally available in only one weight for a given caliber. A lead-free bullet typically has a mass that is equal to, or less than, the smallest lead bullet available in that caliber. For example, lead 9 mm ammunition is available in 115, 124 and 147 grain (15.43 grains = 1 gram) bullet weights while 9 mm ammunition with lead-free bullets typically has a bullet weight of 115 grains or less.

According to a manufacturer of bismuth ammunition, Bismuth Cartridge Co., since bismuth is nearly as dense as lead it is possible to manufacture bismuth frangible bullets that match the weight of many lead bullets. For example, the company produces 9 mm frangible bismuth ammunition in 115 grain and 124 grain bullet weights.

The lower density of copper results in bullets that have less mass than equivalent lead bullets. For example, frangible 9 mm ammunition composed of 90% powdered copper and 10% powdered tin is available from several manufacturers (Federal, International and Winchester) with bullet weights ranging from 90 to 100 grains. Ammunition composed of copper powder and a polymer was produced by PMC in the 9 mm caliber with a bullet weight of 77 grains. Solid copper 9 mm bullets are available from one manufacturer in a 115 grain bullet weight (Barnes Bullets).

Frangible 9 mm ammunition composed of powdered iron is available from at least one manufacturer with a 105 grain bullet weight (Remington Arms Company, Inc.). One ammunition manufacturer produced tungsten/nylon frangible 9 mm ammunition with a 115 grain bullet weight, but this product was discontinued (Nowak 2006). Stranded zinc 9 mm ammunition is available from at least one manufacturer with a 100 grain bullet weight (Federal Cartridge Company).

Recoil:

When training with a handgun, it is desirable to use training ammunition that provides the same "feel" as duty ammunition. One factor that affects the "feel" of firing a handgun is the amount of recoil and one of the factors that affect recoil is the weight of the bullet. Recoil is of particular concern for lead-free training ammunition, since lead-free bullets often have a lower bullet weight than lead duty ammunition.

Bismuth Cartridge Co. states that it can produce frangible bismuth ammunition for training that matches the recoil of duty load (lead ammunition) used by law enforcement agencies. (Bismuth Cartridge Company)In its law enforcement ammunition catalog, Federal Cartridge Co. states that the felt recoil of its BallistiClean stranded zinc core ammunition is comparable to service ammunition (Federal Cartridge Company).

A study conducted by the New Jersey Division of Criminal Justice found that several types of lead-free ammunition provided sufficient recoil to meet the "equivalent load" standard. In the 9 mm caliber, the following ammunition received a passing grade for felt recoil (Zamrok 2004):

- Bismuth Cartridge Co. No-Tox, 115 grain (bismuth with copper jacket)
- Federal CQT, 100 grain (stranded zinc with copper jacket)
- International Greenline, 75+P and 100 grain (powdered copper/tin)
- Speer Lawman RHT, 100 grain (copper)
- Winchester SF LE, 100+P grain (powdered copper/tin)
- Winchester SuperClean NT, 105 grain (tin core with copper jacket)

The following ammunition received a failing grade for felt recoil:

- Remington Disintegrator, 105 grain (iron powder with copper jacket)
- Delta 115 grain (copper)
- Winchester Ranger, 85 grain (tungsten/nylon)

Ammunition manufacturers usually provide information about the ballistics of their ammunition products, including bullet velocity, energy and trajectory. Bullet velocity and energy are typically measured at the muzzle of the gun (muzzle velocity and muzzle energy) as well as at certain distances, such as 50 and 100 yards. The values for bullet velocity and energy used in this assessment were those measured at the muzzle of the gun because these values were the most readily available. Data were gathered on the muzzle velocity and muzzle energy of 9 mm lead and lead-free handgun bullets.

There are a number of factors that affect bullet velocity and energy, including bullet weight and the amount of gunpowder in the cartridge. With all other factors equal, a lead-free bullet must have the same weight as a lead bullet to achieve the same bullet velocity and energy. Bullet velocity affects bullet energy and some manufacturers increase velocity for the lighter lead-free bullets to reach the target bullet energy. Due to the number of factors that affect bullet velocity and energy, this assessment did not attempt to compare the performance of lead-free bullets with lead bullets in this area.

Table 3.1.4 B lists examples of the bullet muzzle velocity and muzzle energy for both lead and lead-free ammunition.

Table 3.4.1 B: Muzzle Velocity and Muzzle Energy Comparison

Bullet Material	Manufacturer	Bullet Description Caliber Weight	Muzzle Velocity (ft/s)	Muzzle Energy (ft-lb)
Bismuth	Bismuth Cartridge	Frangible, copper jacket 9 mm 115 grain	1150	338
Copper/tin	International Cartridge	Frangible 9 mm 100 grain	1250	375
Iron	Remington	Frangible 9 mm 115 grain	1220	350
Lead	Remington	Copper jacket 9 mm 115 grain	1135	329
	Federal Cartridge	Copper jacket 9 mm 115 grain	1160	345
	Winchester	Copper jacket 9 mm 115 grain	1190	362
Tungsten/ nylon	Winchester (discontinued product)	Frangible 9 mm 85 grain	1450	335
Zinc	Federal Cartridge	Stranded zinc core with copper jacket 9 mm 100 grain	1230	335

Source: Information compiled from manufacturer websites and performance data sheets.

Terminal Ballistics

Many of the lead-free bullets reviewed in this assessment are frangible, which means they fragment into small particles upon impact with a target. Frangible lead-free bullets are typically viewed as being safer than lead bullets for use at indoor firing ranges because they reduce or eliminate the dangers associated with ricocheting bullet fragments. This is of particular concern when firing at steel targets at close range. Frangible bullets can also limit damage to steel targets. Frangible lead bullets are not currently available.

Frangible bullets made of bismuth, iron, tungsten/nylon or powdered copper fragment into dust when shot into steel targets, reducing the potential for ricochet. The Remington frangible iron ammunition is reduced to dust with fragments of copper from the plated jacket. Remington test data show that 64.5% of the particles hit the floor within 5 ft and 97.2% within 10 ft.

The core of the stranded zinc ammunition consists of zinc cables arranged in a spiral fashion. The cables break apart upon entering a target (Federal Cartridge Company). It is not clear whether stranded zinc ammunition ricochets more or less than lead bullets.

Solid copper bullets are not frangible and may ricochet more than lead bullets because copper is stiffer than lead (Jones 2001).

Barrel Fouling and Barrel Wear

When a bullet is fired, the ignition of the gunpowder generates both heat and pressure. The pressure forces the bullet down the barrel of the gun, where the rifling is engraved into the bullet. This rifling in the barrel causes the bullet to spin. Depending on the bullet composition and design, the combination of pressure, friction and heat can cause the bullet material to smear on the bore of the barrel. If the bullet material smears, it will leave a build-up of bullet material on the barrel. This residual bullet material, combined with residue from the primer and gunpowder, causes barrel fouling. Barrels must be cleaned and cared for to limit barrel fouling, since this build-up of residue can affect accuracy and performance and excessive build-up of material on the bore can increase pressure to a dangerous level. There are a number of factors that affect the amount of barrel fouling, including the bullet material or, if the bullet is jacketed, the jacket material. Guilding metal, which has copper as a main ingredient, is commonly used to jacket conventional lead bullets. Lead-free bullets may use a softer copper jacket to help reduce peak pressures if the alternative material lacks malleability (Patterson 2006b).

Barrel wear is the erosion of barrel material by the bullets and the heat and pressure generated by the burning propellant (Patterson 2006b). There are a number of factors that affect barrel wear including the hardness of the bullet or bullet jacket, malleability of the bullet material, the construction of the bullet, and the hardness of the gun barrel.

Bismuth Cartridge Co. states that use of its bismuth ammunition will not cause more barrel-fouling than conventional lead ammunition and that use of its bismuth ammunition will not cause more barrel wear than conventional lead ammunition (Flaherty 2006).

According to one manufacturer, the copper used for solid copper bullets is softer than the copper alloy commonly used for jacketing of lead bullets. This manufacturer (Barnes) reduces barrel fouling by heat treating the bullets and by adding grooves to the bullet shank, which reduces fouling by providing a relief area for displaced copper. Barnes states that any copper barrel fouling can be cleaned using ammonia-based cleaners (Barnes Bullets).

Remington states that the copper plating on its Disintegrator iron core bullets provides a smooth, ductile jacket that enhances feed and function in all auto-loading pistols, minimizes barrel fouling, and virtually eliminates barrel erosion (Remington Arms Company, Inc.).

In its law enforcement ammunition catalog, Federal Cartridge Co. states that the heavy metal-free primer and lead-free bullets of its BallistiClean stranded zinc core ammunition help to reduce barrel fouling. The stranded zinc ammunition is plated with a copper jacket and therefore barrel wear is expected to be similar to other copper jacketed ammunition (International Cartridge Corp).

Financial Assessment

Initial Purchase Price for Chemical/Alternative

Lead is significantly less expensive than any of the alternatives in this assessment, with the exception of iron. The Platts Metals Week North American producer price for lead was $0.65 per pound in December 2005. The dealer prices for bismuth fluctuated from an average of $3.55 per pound in the first quarter of 2005 to an average of $4.57 per pound in the fourth quarter of 2005. The 2005 fourth quarter price represented a 33% increase over the 2004 fourth quarter price. The December 2005 price for copper (U.S. producer cathode) was $2.23 per pound. Iron is not traded on an exchange (e.g. London Metals Market) but the price for hot rolled steel plate, which was $0.29 per pound in December 2005, suggests that the price of iron is competitive with lead. (Metals

Consulting International (MCI))Tungsten prices fluctuated from approximately $2.72 per pound in January 2005 to approximately $9.98 per pound in May 2005. (DesLauriers 2005) The Platts Metals Week (North American Special High Grade) price for zinc was $0.88 per pound in December 2005.

Initial Purchase Cost for End-product/Component
Ammunition with lead-free bullets or lead-free frangible bullets is marketed primarily to law enforcement agencies and the military and therefore consumer prices for lead-free handgun ammunition were not readily available.

A study conducted by the New Jersey Division of Criminal Justice found the following regarding the purchase price for reduced lead and lead-free ammunition(Zamrok 2004):

- Lead training ammunition was approximately half the cost of lead service ammunition
- Firing line safe training ammunition with lead-free primer and totally encapsulated lead core projectiles cost an additional $2 to $20 per 1000 rounds over lead training ammunition, depending on caliber and manufacturer
- Lead-free training ammunition (lead-free primer and projectile) cost $30 to $40 more than lead service ammunition per 1,000 rounds
- Frangible lead-free training ammunition cost $100 more than lead service ammunition per 1,000 rounds (9mm caliber)

A search of online ammunition retailers found that the cost of lead training ammunition for indoor shooting ranges (9mm, 115 grain, full metal jacket) varied from $0.14 to $0.20 per round. The cost of lead-free training ammunition (copper, copper/tin, iron, and tin/copper) was at least double that of lead training ammunition. The prices found for lead-free 9mm training ammunition ranged from $0.30 to $0.70 per round. In comparison, firing line safe training ammunition with lead-free primer and totally encapsulated lead core projectiles could be purchased for a 10-20% premium over lead training ammunition.

Winchester produces frangible handgun training ammunition (Ranger SF) that is composed of 90% powdered copper and 10% powdered tin with a non-toxic primer. The price of this product (9 mm caliber) is approximately 2.3 times the price of conventional lead training ammunition. Winchester also produces lead-free training ammunition (Super Clean NT) that is composed of a solid tin core with a copper jacket. This ammunition is not frangible. The price of this product for a 9 mm handgun is about two times the price of conventional lead training ammunition (Nowak 2006).

Pricing for bismuth and tungsten ammunition was not available because they are sold only to law enforcement agencies.

Availability of Chemical/Alternative
Bismuth, and tungsten are relatively scarce metals with a limited reserve base, while copper, iron (steel) and zinc are more abundant than lead (European Commission Enterprise Directorate-General 2004).

All primary bismuth consumed in the U.S. is imported and less than 5% is obtained by recycling old scrap. Most bismuth is produced from mines in Mexico, China, Peru and Bolivia. It is a byproduct of processing lead ores, and in China, it is a byproduct of tungsten ore processing. Reported bismuth consumption was 2,120 metric tons in 2003 in the U.S. Worldwide demand is growing at about 5% per year, driven in part by its use as a replacement for lead but a global shortage is not expected. However, the supply could be constrained by low prices (Carlin, James F. Jr.).

In 2005, the worldwide mine production of copper was 16.4 million tons but strong growth in China and India resulted in a global production deficit. In 2006, increased capacity is expected to result in a modest production surplus (Edelstein 2006).

In 2004, worldwide trade in iron ore was approximately 670 million metric tons (Iron and Steel Statistics Bureau (ISSB)).

U.S. consumption of tungsten in 2005 was 11,600 metric tons. World tungsten supply is dominated by Chinese production and exports. The Chinese government regulates tungsten production and the total volume of tungsten exports, and the government has gradually shifted the balance of export quotas towards value-added downstream tungsten materials and products. In 2005, inadequate supplies of tungsten concentrates within China combined with increased demand for tungsten materials in China and elsewhere resulted in steep increases in the prices of tungsten concentrates. In response to this price increase, the sole Canadian tungsten mine restarted operations and action was taken to develop tungsten deposits or reopen inactive tungsten mines in Australia, China, Peru, Russia, the United States, and Vietnam (Shedd 2006).

Worldwide, there was a 200,000 ton production deficit of zinc in 2005. In 2005, U.S. mine production of zinc was 837,800 tons, which accounted for less than one-third of the quantity consumed domestically. Canada and Mexico are leading sources of imported zinc (Gabby 2006).

Availability of Component/End-product

Lead-free handgun ammunition is produced by each of the leading ammunition manufacturers and a few smaller ammunition manufacturers specialize in the production of lead-free ammunition. Currently, the primary market for lead-free handgun ammunition is for law enforcement and military training applications. A few manufacturers also produce lead-free duty rounds. Lead-free ammunition is available in both solid bullet and frangible bullet designs. The bullets made with hard metals (iron and tungsten) must be frangible or they would be classified as armor-piercing bullets.

Handgun ammunition with frangible bismuth bullets is available from at least one manufacturer, Bismuth Cartridge Co. This manufacturer currently only markets its Bismuth Reduced Hazard Ammunition to law enforcement agencies. It is available with conventional, lead-free, or heavy metal free primers. The company manufactures round nose training ammunition and is in the final stages of research and development of a hollow-point duty bullet (Flaherty 2006).

The Bismuth Cartridge Co. website lists the following frangible bismuth ammunition products: 9 mm 115 grain round nose; .40 S&W 135 grain flat point; and .45 Auto 185 grain flat point. A company spokesperson said that it can provide custom bismuth training ammunition that duplicates the trajectories and recoil of an agency's duty load (Flaherty 2006). It also produces bismuth frangible duty rounds for applications where ricochet poses a hazard.

Several ammunition manufacturers produce handgun ammunition using bullets composed of a mixture of powdered copper and powdered tin, which is sintered to produce a frangible bullet. Copper is used by at least one manufacturer to produce solid copper bullets. Solid copper bullets are not frangible and are used for duty rounds, personal defense or hunting applications. Copper is also used as a jacketing material for many types of ammunition, including handgun ammunition with lead, bismuth, iron, and tin cores.

At least one ammunition manufacturer produces lead-free frangible handgun ammunition produced with iron powder. The projectile in Remington's Disintegrator Lead-Free Frangible ammunition is composed of powdered iron with an electroplated copper jacket. Remington markets its

Disintegrator product line to law enforcement agencies. Disintegrator ammunition is available in 9 mm, .40 S&W, and .45 ACP calibers.

Tungsten has been used recently for lead-free handgun ammunition but it could not be confirmed that it is currently produced by ammunition manufacturers. Winchester had produced handgun training ammunition with a tungsten/nylon bullet (Ranger DF) but this product was replaced by ammunition that uses a 90% copper/10% tin bullet (Ranger SF), which Winchester says is a better product. (Nowak 2006)Tungsten/nylon ammunition was used at the Massachusetts Military Reservation firing range at Camp Edwards from 1999 until February 2006, when its use was halted over concerns that tungsten was migrating into Cape Cod's groundwater (Lehmert 2006).

Zinc is used by Federal Cartridge Co. in its BallistiClean handgun ammunition, which is marketed to law enforcement for training. The bullet used in BallistiClean ammunition has a stranded zinc core and a copper jacket (Federal Cartridge Company).

Table 3.4.1 C lists the ammunition manufacturers known to produce handgun training ammunition with lead-free bullets:

Table 3.4.1 C: Ammunition Manufacturers

Manufacturer	Website	Description
Bismuth Cartridge Co.	www.bismuth-notox.com	Frangible bismuth core with copper jacket
CCI/Speer	http://le.atk.com	Frangible copper powder bullet
Federal Cartridge Co.	www.federalcartridge.com	Frangible copper/tin bullet
		Stranded zinc core with copper jacket
International Cartridge Co.	www.internationalcartridge.com	Frangible copper/tin bullet
Remington Arms and Ammunition	www.remingtonle.com	Frangible iron powder bullet with copper jacket
Winchester Ammunition	www.winchester.com	Frangible copper/tin bullet
		Tin core with copper jacket

Capital Costs

The lead bullet production process is significantly different from the production process used to produce frangible lead-free bullets. Production of lead bullets involves extruding a lead billet into wire, cutting the wire into slugs, and then pressing the slugs into the shape of a bullet. For jacketed bullets, a copper jacket is applied (National Research Council (NRC) 2004).

Frangible bullets made from powdered copper/tin or iron require a significantly different production process due to the fact that they are made from powdered metals. Bismuth frangible bullets are cast, swaged and then plated with a copper jacket (Bismuth Cartridge Company).

Due to the differences in production processes, it is likely that switching a lead bullet manufacturing process to a lead-free manufacturing process would require significant capital investment. It should be noted however, that most of the major ammunition manufacturers already market ammunition with lead-free bullets, which means that they have either already invested in lead-free bullet production or they purchase lead-free bullets from a supplier. An expansion of the market beyond current production capacity would likely require significant additional capital expense.

Key Operating Costs During Use of End-product

Use of lead ammunition increases a firing range's operating costs since air monitoring and blood level testing of range officers must be conducted according to OSHA and EPA standards. Use of lead ammunition may also increase costs associated with maintenance of containment and filtration systems, purchase of replacement filters, range cleaning and hazardous waste disposal. By switching to lead-free ammunition, firing ranges can reduce or eliminate costs in these areas (Jones 2001; Massachusetts Division of Occupational Safety 2004).

Frangible bullets, including those made from bismuth, copper, iron and tungsten, fragment into dust when shot at mild steel targets, which reduces wear and damage to the targets, bullet traps and backstops at firing ranges.

Key End-of-Product Life Costs

Lead bullets and bullet fragments collected at indoor firing ranges are typically sold to lead recyclers and therefore may represent a source of revenue for firing ranges. At ranges where both lead and lead-free ammunition is used, certain types of lead-free bullets, such as zinc bullets, may contaminate the lead, making it unsuitable for recycling. (Vargas, 2004) Lead bullets may also be contaminated with other materials, such as materials used for bullet traps, which can decrease the recycling value or eliminate the possibility of recycling. Lead smelters separate the copper jacketing material from the lead and recycle it. Any lead that is not recycled must be disposed of as hazardous waste.

Bismuth, copper, iron, tungsten, and zinc bullets and bullet fragments collected at indoor firing ranges can be disposed of as non-hazardous material. These lead-free materials can also be collected for recycling. Information about the value of reclaimed bullets or bullet fragments made of these lead-free materials was not available but it should be noted that, with the exception of iron, the raw material prices for these alternatives are significantly higher than lead, which indicates the potential of higher values for the reclaimed materials.

A Department of Defense study estimated that the clean-up cost for a closed outdoor lead ammunition firing range can be up to $2.5 million, while the average cost to clean-up an indoor lead ammunition firing range is about $150,000 (Anonymous 2001).

The following tables provide additional financial data for lead ammunition alternatives.

Table 3.4.1 D: Ammunition for Shooting Ranges – Bismuth

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Initial purchase price for chemical/alternative	In 2005, bismuth dealer prices fluctuated from an average of $3.55 per pound in the first quarter to an average of $4.57 per pound in the fourth quarter. The fourth quarter 2005 price represented a 33% increase over the fourth quarter 2004 price. Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	Carlin, 2006a Gabby, 2006a
	Initial purchase cost for end-product/component	Pricing for bismuth ammunition was not available because it is sold only to law enforcement agencies.	

Table 3.4.1 D: Ammunition for Shooting Ranges – Bismuth

	Financial Parameter	Measure/Metric	Source of Information
	Availability of chemical/alternative	Bismuth consumption in the U.S. in 2005 was estimated at 2,280 metric tons. Worldwide demand is growing at about 5% per year, driven in part by its use as a replacement for lead but a global shortage is not expected. Low prices could constrain bismuth supply to the market.	Carlin, 2006a
	Availability of component/end-product	Bismuth frangible ammunition is available from at least one manufacturer, Bismuth Cartridge Co. This manufacturer currently only markets its Bismuth Reduced Hazard Ammunition to law enforcement agencies.	Flaherty, 2006 Bismuth, 2006
	Key end-of-product life costs	The bismuth core fragments into dust when shot into mild steel targets. The bullet particles can be swept up and disposed of as non-hazardous material.	
	Capital costs	Bismuth frangible bullets are cast, swaged and then plated with a copper jacket. (Bismuth, 2006) This manufacturing process differs from the lead bullet manufacturing process, and therefore, it is likely that switching to bismuth bullet manufacturing would require significant capital investment.	Bismuth, 2006

Table 3.4.1 E: Ammunition for Shooting Ranges – Copper

	Financial Parameter	Measure/Metric	Source of Information
Required Data			
	Initial purchase price for chemical/alternative	Copper raw material price: $2.23 per pound, U.S. producer cathode, December 2005 Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	Edelstein, 2006 Gabby, 2006a
	Initial purchase cost for end-product/component	Winchester produces frangible handgun training ammunition (Ranger SF) that is composed of 90% powdered copper and 10% powdered tin with a non-toxic primer. The cost of this product for a 9 mm handgun is about 2.3 times more than conventional lead training ammunition. Winchester also produces lead-free training ammunition (Super Clean NT) that is composed of a solid tin core with a copper jacket. This ammunition is not frangible. The cost of this product for a 9 mm handgun is about two times more than conventional lead training ammunition.	Nowak, 2006
	Availability of chemical/alternative	In 2005, the worldwide mine production of copper was 16.4 million tons but strong growth in China and India resulted in a global production deficit. In 2006, increased capacity is expected to result in a modest production surplus. (USGS)	Edelstein, 2006

Table 3.4.1 E: Ammunition for Shooting Ranges – Copper

	Financial Parameter	Measure/Metric	Source of Information
	Availability of component/end-product	Several ammunition manufacturers produce frangible handgun ammunition using bullets produced by Sinterfire, which are composed of a mixture of powdered copper and powdered tin. Copper is also used as a jacketing material for many types of ammunition, including handgun ammunition with lead, bismuth, iron, and tin cores. At least one ammunition manufacturer produces handgun ammunition with a solid copper bullet. Solid copper bullets are not frangible and are used for duty rounds, personal defense or hunting applications.	
	Capital costs	Frangible bullets made from powdered copper require a significantly different production process due to the fact that they are made from powdered metals. Therefore, it is likely that switching a lead bullet manufacturing process to a powdered copper bullet manufacturing process would require significant capital investment.	
Additional Data if Available			
	Key end-of-product life costs	Frangible copper bullets fragment into dust when shot into mild steel targets. The bullet particles can be swept up and disposed of as non-hazardous material.	

Table 3.4.1 F: Ammunition for Shooting Ranges – Iron

	Financial Parameter	Measure/Metric	Source of Information
Required Data			
	Initial purchase price for chemical/alternative	Iron and iron powder are not traded on an exchange such as the London Metal Exchange and therefore pricing was not readily available.	
	Initial purchase cost for end-product/component	Remington's Disintegrator Lead-Free Frangible ammunition is available at several online ammunition retailers. Prices for 9mm, 100 grain ammunition ranged from \$0.35 to \$0.53 per round.	
	Availability of chemical/alternative	In 2004, worldwide trade in iron ore was approximately 670 million metric tons.	ISSB, 2006
	Availability of component/end-product	At least one ammunition manufacturer produces lead-free frangible handgun ammunition produced with iron powder. The projectile in Remington's Disintegrator Lead-Free Frangible ammunition is composed of powdered iron with an electroplated copper jacket. Remington markets its Disintegrator product line to law enforcement agencies. Disintegrator ammunition is available in 9 mm, .40 S&W, and .45 ACP calibers.	Remington, 2005

Table 3.4.1 F: Ammunition for Shooting Ranges – Iron

	Financial Parameter	Measure/Metric	Source of Information
	Capital costs	Frangible bullets made from powdered iron require a significantly different production process due to the fact that they are made from powdered metals. Therefore, it is likely that switching a lead bullet manufacturing process to an iron bullet manufacturing process would require significant capital investment.	
Additional Data if Available			
	<u>Key</u> end-of-product life costs	Frangible iron bullets reduce wear and damage to bullet traps and backstops at firing ranges.	Remington, 2005

Table 3.4.1 G: Ammunition for Shooting Ranges – Tungsten

	Financial Parameter	Measure/Metric	Source of Information
Required Data			
	Initial purchase price for chemical/alternative	In 2005, tungsten prices fluctuated from approximately $2.72 per pound in January to approximately $9.98 per pound in May. Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	DesLauriers, 2005 Gabby, 2006a
	Initial purchase cost for end-product/component	A study conducted by the New Jersey Division of Criminal Justice stated that the cost for Winchester's Ranger Frangible ammunition, which had a projectile made of tungsten/copper/nylon, was $428 per 1000 rounds or $.43 per round. This is two to three times the price of Winchester's USA training ammunition with a lead projectile and full metal jacket when purchased from online ammunition retailers. Winchester discontinued this tungsten product four years ago.	Zamrok, 2004
	Availability of chemical/alternative	U.S. consumption of tungsten in 2005 was 11,600 metric tons. In 2005, inadequate supplies of tungsten concentrates within China combined with increased demand for tungsten materials in China and elsewhere resulted in steep increases in the prices of tungsten concentrates.	Gabby, 2006a
	Capital costs	The process used to manufacture tungsten bullets is different than the lead bullet manufacturing process and therefore a switch from lead to tungsten bullets would require significant capital investment.	

Table 3.4.1 H: Ammunition for Shooting Ranges – Zinc

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Initial purchase price for chemical/alternative	Zinc raw material price: $0.88 per pound, Platts Metals Week North American Special High Grade, December 2005 Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	Gabby, 2006b Gabby, 2006a
	Initial purchase cost for end-product/component	Not available.	
	Availability of chemical/alternative	U.S. mine production in 2005 was 837,800 tons. Domestic zinc metal production capacity accounts for less than one-third of quantity consumed domestically. Canada and Mexico are leading sources of zinc. In 2005, there was a 200,000 ton production deficit worldwide. (USGS)	Gabby, 2006b
	Availability of component/end-product	Federal produces ammunition with a bullet that has a stranded zinc core and a copper jacket.	Federal, 2006
	Capital costs	The process used to manufacture bullets with a stranded zinc core is different than the lead bullet manufacturing process and therefore a switch from lead to zinc bullets would require significant capital investment.	
		Additional Data if Available	
	Key end-of-product life costs	When zinc ammunition is used at a firing range where lead ammunition is also used, the zinc contaminates the lead making it unsuitable for recycling. The recovered mix of zinc and lead bullets must be disposed of as hazardous waste.	Vargas, 2004

Environmental Health and Safety

Numerous studies indicate that lead exposure can occur at shooting ranges where lead ammunition is used, particularly for range masters and instructors. The primary source of lead exposure is from the airborne lead particles and lead fumes released from the bullet during firing. When lead ammunition is used where the lead core is exposed at the base of the bullet, approximately 80% of the airborne lead comes from the bullet and the remaining 20% comes from lead styphnate in the primer and lead dust generated when the bullet hits the target (Noll, Clark 1997; Simpson 1993; Fischbein 1980).

Results from evaluations of exposures to lead in indoor law enforcement firing ranges by NIOSH showed that shooters had a mean lead exposure of 110 $\mu g/m^3$ (8-hour, TWA) when firing lead bullets. Eighty nine percent exceeded the OSHA PEL for occupational exposure to lead (50 $\mu g/m^3$, 8-hour, TWA) (Centers for Disease Control (CDC) 1983).

The National Association of Shooting Ranges (NASR) lists fifty-five handgun shooting ranges in Massachusetts, most of them with indoor shooting ranges. The handgun ammunition used at these ranges is almost exclusively ammunition with bullets made of lead and primer that contains lead and other heavy metals. A spokesperson from the Sporting Arms and Ammunition Manufacturers Institute (SAAMI) said that, to his knowledge, Massachusetts does not have any lead-free indoor firing ranges with the possible exception of those used by law enforcement and the military (Patterson 2006a).

Environmental Assessment

Drinking Water Standards

The National Primary Drinking Water Regulations are legally enforceable standards, set by EPA, that apply to public water systems. In these standards, the Maximum Concentration Level (MCL) for lead in drinking water is 15 µg/L and the Maximum Concentration Level Goal (MCLG) is zero. Copper is the only alternative ammunition material in this assessment for which EPA has set an MCL. Copper has an MCL of 1300 µg/L.

EPA has also established National Secondary Drinking Water Standards, which are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The following list shows the alternative ammunition materials included in these secondary standards:

- Copper: 1000 µg/L
- Iron: 300 µg/L
- Zinc: 5000 µg/L

Affinity for Water: Water Solubility

Lead, bismuth, copper, and iron are insoluble in water. Tungsten dissolves in water reaching concentrations up to 475 – 500 mg/L (Strigul, Nicolay et al. 2005). Zinc is soluble in water but the solubility is dependent on the properties of the water, such as acidity, temperature, chlorine concentration and hardness. It should be noted that certain compounds of these metals may be soluble.

Density

The density of lead is 11.34 g/cm^3. With a density of 19.3 g/cm^3, tungsten has the highest density of the alternatives in this assessment, followed by bismuth (9.8 g/cm^3), copper (8.9 g/cm^3), iron (7.8 g/cm^3), and zinc (7.10 g/cm^3) (Automation Creations).

Bioaccumulation

According to the International Chemical Safety Cards (ICSCs), bioaccumulation of lead may occur in plants and mammals and it is strongly advised that lead does not enter the environment. Specific information on the bioaccumulation of copper, tungsten, zinc, bismuth and iron were not available. As discussed in earlier in this report, EPA is in the process of developing a framework that will address the issue of bioaccumulation of metals, as well as related issues such as bioavailability.

Aquatic toxicity

National Recommended Water Quality Criteria was used as a source for data on aquatic toxicity of lead and lead-free alternatives. Water Quality Criteria includes the following two aquatic life criteria for both freshwater and saltwater:

- Criteria Maximum Concentration (CMC) – An estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect.

- Criteria Continuous Concentration (CCC) – An estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

Lead, copper and zinc are listed as Priority Toxic Pollutants and iron is listed as a Non Priority Pollutant. Bismuth and tungsten were not included in the Water Quality Criteria list. The following table shows the Water Quality Criteria for lead, copper, iron and zinc.

Table 3.4.1 I: Water Quality Criteria Comparison

Priority Pollutant	**Freshwater**		**Saltwater**	
	CMC (µg/L)	**CCC (µg/L)**	**CMC (µg/L)**	**CCC (µg/L)**
Lead	65	2.5	210	8.1
Copper	13	9.0	4.8	3.1
Iron	-	1000	-	-
Zinc	120	120	90	81

The Water Quality Criteria values indicate that lead, copper and zinc are toxic to aquatic organisms, even at relatively low concentrations.

In 1994, EPA addressed the aquatic toxicity of alternatives to lead fishing sinkers in its response to citizens' petition and proposed ban for lead fishing sinkers. In its assessment of aquatic toxicity of lead alternatives, EPA made the following statements about copper and zinc: "Laboratory studies indicate that copper is more toxic to aquatic organisms, such as fish, crustaceans, worms, and algae than lead." (United States Environmental Protection Agency (USEPA) 1994). However, EPA believes that environmental conditions in freshwaters would mitigate the toxicity of copper to aquatic organisms. Zinc is more toxic to aquatic organisms (fish and crustaceans) than lead and it may be more bioavailable to aquatic organisms than lead. "Tungsten was found to have low toxicity to aquatic organisms (crustaceans and algae)" (United States Environmental Protection Agency (USEPA 1994). EPA stated that it did not find any information to indicate that bismuth or iron is toxic to aquatic species.

Human Health Assessment

Acute Human Effects: Occupational Exposure Limits

Lead exposure can occur at indoor shooting ranges from airborne lead particles and lead fumes released during firing. In general, the lead-free ammunition alternatives have less stringent occupational exposure limits than lead.

- *IDLH*

  The Immediately Dangerous to Life or Health Concentrations (IDLH) for lead is 100 mg/m^3. The IDLH for copper is also 100 mg/m^3. There are no data on IDLH for bismuth, tungsten and zinc. For iron, the IDLH is 2,500 mg Fe/m^3; 1-2 grams may cause death but 2-10 is usually ingested in fatal cases.

- *PEL*

The Permissible Exposure Level (PEL) for lead is 0.050 mg/m^3 (8-hour TWA). The PEL (TWA) for copper is 1 mg/m^3. The PEL for iron oxide is 10 mg Fe/m^3. PELs have not been established for bismuth, steel, tungsten and zinc; however, PELs have been set for zinc chloride (1 mg/m^3) and zinc oxide (5 mg/m^3).

- *REL*

The Recommended Exposure Level (REL) for lead is 0.050 mg/m^3 (TWA). The REL (TWA) for copper is 1 mg/m^3; for steel (iron) is 5 mg Fe/m^3; and for tungsten is 5 mg/m^3. An REL has not been established for bismuth or zinc.

- *TLV*

The ACGIH TLV for tungsten is 5 mg/m^3, for copper is 1 mg/m^3, for iron oxide is 5 mg Fe/m^3 (respirable fraction) and for zinc oxide is 2 mg/m^3 (respirable fraction). ACGIH has posted a Notice of Intended Change for copper,; the new proposed TLV is 0.1 mg.m^3 (inhalable fraction).

Acute Human Effects: Irritation

- *Dermal*

Lead and bismuth do not cause dermal irritation. Skin exposure to copper, iron, tungsten and zinc may cause dermal irritation.

- *Ocular*

Dusts of lead and all of the lead-free alternatives can cause ocular irritation, with the exception of zinc.

- *Respiratory*

Dusts of lead and zinc were not identified as respiratory irritants, while bismuth, copper, iron and tungsten can cause respiratory irritation.

Chronic Human Effects: Mutagenicity and Carcinogenicity
Lead is classified as both a mutagen and probable human carcinogen (IARC 2B). The lead-free alternatives in this assessment (bismuth, copper, iron, tungsten and zinc) are not classified as either mutagens or carcinogens.

Chronic Human Effects: Reproductive and Developmental Toxicity

Lead has been identified as a developmental toxicant in humans. Children are particularly sensitive to the chronic effects, which include slowed cognitive development and reduced growth. High lead exposure is also associated with reproductive effects, such as decreased sperm count in men, spontaneous abortions in women and low birthweight (United States Environmental Protection Agency (USEPA)

The lead-free alternatives in this assessment (bismuth, copper, iron, tungsten and zinc) have not been identified as reproductive or developmental toxicants.

Assessment Summary

Table 3.4.1 J summarizes the alternatives assessment information for lead ammunition.

Table 3.4.1 J: Assessment Summary – Alternatives for Lead Ammunition/ Shooting Ranges

Assessment Criteria		Lead (Reference)	Comparison Relative to Lead				
			Bismuth	Copper	Iron	Tungsten	Zinc
Technical/ Performance Criteria	Density	11.34 g/cm^3	-	-	-	+	-
	Frangibility	No	+	+	+	+	?
	Barrel Wear	Good	=	=	=	?	=
Environmental Criteria	Primary Drinking Water Standards (MCL Action Level)	15 µg/L	?	+	+	?	?
	Aquatic Toxicity: Water Quality Criteria (CMC)						
	Freshwater	65 µg/L	?	-	+	?	+
	Saltwater	210 µg/L	?	-	+	?	-
Human Health Criteria	Occupational Exposure: REL (8-hour TWA)	0.050 mg/m^3	?	+	+	+	+
	Carcinogenicity	EPA B2 IARC 2B	+	+	+	+	+
	Developmental Toxicity	Yes (Prop 65)	+	+	+	+	+
Cost	Cost/9mm round	\$0.14-\$0.20	-	-	-	-	-
	Operating Costs	High	+	+	+	+	+

Comparison Key + Better = Similar - Worse ? Unknown

3.4.2 Alternatives Assessment for Wheel Weights

Technical Assessment

Longevity/Life in Service

Wheel weights are installed on a vehicle's wheels during the tire balancing process and they typically remain in service until the tire is rebalanced or replaced, or until the wheel or vehicle is retired from use. Wheel weights are not typically reused so their life in service is determined by the frequency of tire rebalancing, the life of the tire and the life of the vehicle.

Wheel weights do not typically wear out but they can "fly off" when a vehicle is jarred or during sudden velocity changes. Factors such as improper installation and damage from contact with curbs or other objects can also cause weights to fall off. It is estimated that the annual loss rate is 10%. (Root 2000)

None of the reports and studies reviewed suggested that the material used for the weights affected the life of the weights or was a factor in the rate that the weights fall off the wheels.

Key Standards for Component/End-product

Wheel weights must meet the vehicle manufacturers' specifications before they can be used for Original Equipment Manufacturer (OEM) applications. OEM specifications can include the following: (Gearhart 2006b)

Corrosion protection: Corrosion protection is a focus of OEM specs. The OEMs typically require specs such as salt corrosion testing, cyclic corrosion testing, and UV testing for fading.

Physical dimensions: OEM specs limit maximum clearance dimensions (thickness, length, and width) to eliminate interference with other vehicle components and to prevent out-of-balance problems.

Shape: Some OEM specs specify shape properties such as curvatures or labeling surfaces.

Clip design: While the clip design is typically under producer control, the clip/weight assembly must meet specs such as clip gap and curl.

Material: OEMs did not specify the weight material in the past but they are beginning to specify lead-free weights.

Labeling: OEMs typically require labeling on wheel weights often including identification of the mass and material of the weight.

Aftermarket wheel weights are typically not required to meet OEM specifications.

Key Physical Characteristics & Performance Requirements

Density and Mass:

There are two common methods for attaching weights to wheels; clipping the weight to the rim of the wheel, and affixing the weight to the wheel using adhesive. For both wheel weight applications, a small weight size is desirable to prevent interference with other vehicle components, such as the brakes. Large weights are more visible and therefore less desirable, particularly for use on the outer rim of the wheel. Because density of the weight material directly influences the size of the wheel weight, it is a key physical characteristic.

All of the materials considered in this assessment are less dense than lead, which has a density of 11.34 g/cm^3. With a density of 8.96 g/cm^3, copper has the highest density of the alternatives in this assessment, followed by steel (7.87 g/cm^3), tin (7.34 g/cm^3), and zinc (7.10 g/cm^3). (Automation Creations) The density of a zinc alloy (ZAMAC) used for wheel weights is 6.76 g/cm^3. (Umicore)

The size (volume) of wheel weights made from copper, steel, tin and zinc must be larger than equivalent lead weights by 27%, 44%, 54%, and 60% respectively. Since the allowable thickness and width of wheel weights is limited, this increase in size is typically achieved by increasing the length of the weights. The mass of wheel weights used for passenger car applications typically ranges from 5 grams to 60 grams. (Hennessey Industries) Weights in this range are small enough that the increase in size (length) required for the alternative materials typically does not present problems. (Lohse, Sander & Wirts 2001)

Hardness:

Both clip-on weights and adhesive weights are mounted to curved surfaces of the wheel. Given the wide variety of wheel sizes and designs, it is desirable for wheel weights to be relatively soft and malleable so the curvature of the weight can be adjusted during installation to match the curvature of the wheel. (Lohse, Sander & Wirts 2001)Lead is a soft, malleable metal so it is relatively easy to make adjustments to the curvature of lead weights during installation with the use of a wheel weight hammer.

Lead has a hardness of 4.2 on the Brinell scale and a hardness of 1.5 on the Mohr's scale, which makes it softer than all of the alternative materials except pure tin. Pure tin has a Brinell hardness of 3.9 but some tin alloys are harder than lead (ASTM B 23 has a Brinell hardness of 17). The following table lists the wheel weight materials in order of increasing hardness: (Automation Creations)

Table 3.4.2 A: Hardness of Wheel Weight Materials

Material	Hardness		
	Brinell Scale	Mohr's Scale	Vickers Scale
Tin (pure)	3.9		
Lead	4.2	1.5	5
Tin (alloy)	17		
Zinc		2.5	30
Copper		3	50
ZAMAC (zinc alloy)	91		102
Steel (carbon)	170	5-6	

Malleability:

Copper, and tin are relatively malleable and the curvature of wheel weights made of these materials can be modified, to some degree, during installation. Zinc and zinc alloy are significantly harder and less malleable than lead so it may be difficult to adjust the curvature of the weights during installation. In addition to being relatively hard, steel has limited malleability and therefore forming of weights during installation to match the wheel diameter is typically not possible. The use of steel and zinc weights may require the number of standard wheel weight shapes to be increased. (Lohse, Sander & Wirts 2001)

Melting Point:

Heat generated during braking can result in brake disc temperatures of up to 1300 degrees F. The maximum temperature at the wheel rim where clip-on weights are installed is approximately 250 degrees F, while the maximum temperature at the wheel where adhesive weights are installed is typically well below 400 degrees F. (Lohse, Sander & Wirts 2001) The melting points for copper (1980 deg. F), steel (2732 deg. F), tin (450 deg. F) and zinc (787 deg. F) are higher than the maximum temperatures wheel weights are exposed to. The melting point of lead is 622 degrees F. (Automation Creations)

Corrosion Resistance:

Wheel weights must be corrosion resistant due to the harsh environment which includes exposure to moisture, high temperatures and road salt. The wheel weights must not undergo galvanic corrosion when affixed to steel or aluminum wheels. All lead weights used for OEM applications have a coating to prevent corrosion but many of the aftermarket lead weights are not coated. (Gearhart 2006a) Uncoated lead weights will leave black marks when applied to aluminum wheels.

Copper, steel and zinc wheel weights require a coating in order to prevent corrosion. Copper has good resistance to atmospheric corrosion but it develops a protective coating that over time thickens to give a green patina, which would be unacceptable for wheel weight applications. Steel weights will rust if they are not coated and zinc weights must be coated to prevent galvanic corrosion when mounted on aluminum wheels. A manufacturer of tin adhesive wheel weights states that no corrosion protection is required for tin wheel weights and that they will retain a good surface appearance. (Trax JH Ltd.)

Shape and Configuration:

It is advantageous for wheel weights to be malleable so they can be shaped during installation to match different wheel diameters. Using non-malleable materials for clip-on weights would result in the need to increase the number of shapes/styles/sizes to match the wide variety of wheel designs and sizes. The design of adhesive weights can be modified to account for the limited malleability of the materials like steel. Adhesive weights made of soft malleable materials can be in the form of a bar, while weights made of harder, less malleable materials are constructed of separate small weights attached to a strip of adhesive tape. Partitioning the weight into segments allows for application to the curved diameter of the wheel. (Lohse, Sander & Wirts 2001)

Recyclability:

Lead weights are collected for recycling after they are removed from wheels during the rebalancing of tires. The tire dealers and auto service stations that balance tires typically collect lead weights and send them to secondary smelters for recycling. EPA estimates that 16 million pounds of wheel weights are sent to secondary smelters. (USEPA 2005)

EPA estimates that an additional 8 million pounds may be processed in automobile recycling. During the recycling of automobiles, lead weights must be removed from the wheels to avoid contamination of recycled materials and auto shredder residue (ASR). (Ecology Center 2005a)

Lead from used wheel weights is also used by individuals who make their own lead fishing sinkers and ammunition, who collect the used weights from tire dealers and service stations. EPA estimates that 0.8 to 1.6 million anglers make their own fishing sinkers. This activity has the potential to expose individuals and family members to airborne lead particles or vapors released during the pouring of molten lead into the fishing sinker molds. (United States Environmental Protection Agency (USEPA) 1994)

All of the alternative materials considered in this assessment can also be recycled. Copper can be recycled without any loss of quality and the value of copper provides an economic incentive for recycling. The unique color and appearance of copper weights would facilitate material separation.

Copper recovered from refined or re-melted scrap composed 30% of the total U.S. copper supply. (Edelstein 2006)

Steel is easily recycled and material separation may be easier with steel weights since they can be identified and sorted with the use of magnets. The clips for clip-on weights are also made of steel and therefore could be recycled along with the weight, eliminating the need for separation. Steel weights do not need to be removed from steel wheels during automobile recycling.

Tin and zinc weights resemble lead weights and are more difficult to sort and separate. The high cost of tin provides an economic incentive to recover weights for recycling. A German study estimated that, when vehicles are dismantled for recycling, tin weights would be removed from the vehicles' wheels at a rate approaching 100% because the high price of tin would justify this procedure. (Lohse, Sander & Wirts 2001)

There is the potential that the challenge of separating lead-free weights from lead weights will result in a decline in the recycling of all wheel weights. (Ecology Center 2005b)

The following tables provide additional technical performance data for each of the alternatives.

Table 3.4.2 B: Wheel Weights – Copper

	Technical/ Performance Parameter	Measure/Metric	Source of Information
		Component/End-product	
	Key physical characteristics	Density: The density of copper is 8.96 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given weight size (mass), a copper weight will be 27% larger volume than a lead weight. (MatWeb) Melting Point: At 1980° F, the melting point of copper is significantly higher than the 622° F melting point of lead and well above the maximum operating temperatures required for wheel weights. (MatWeb) Corrosion resistance: Copper has good resistance to atmospheric corrosion. However, it develops a protective coating that over time thickens to give a green patina, which would be unacceptable for wheel weight applications. Therefore, copper weights require a protective coating. (Corrosion Doctors) A manufacturer of copper adhesive wheel weights states that its copper weights are coated to meet OE standards. (Trax) Malleability: Like lead, copper is very malleable. Hardness: Annealed Copper, Vickers: 50 Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb) Recyclability – Copper can be recycled without any loss of quality. Copper recovered from refined or remelted scrap composes 30% of the total U.S. copper supply.	MatWeb, 2006 Corrosion Doctors, 2006. Trax, 2006 Edelstein, 2006.

Table 3.4.2 C: Wheel Weights – Steel

	Technical/ Performance Parameter	Measure/Metric	Source of Information
		Component/End-product	
	<u>Key</u> physical characteristics	Density: The density of steel is approximately 7.87 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given weight size (mass), a steel weight will be 44% larger volume than a lead weight. Melting Point: At 2732° F, the melting point of steel is significantly higher than the 621° F melting point of lead and well above the maximum operating temperatures required for wheel weights. Corrosion resistance: Steel weights are subject to rusting and therefore must be coated for all wheel weight applications to prevent corrosion. Hardness: Carbon steel, Brinell: 170 Lead, Brinell: 4.2 Lead, Vickers: 5 Malleability: Steel has limited malleability and therefore forming of the weights during installation to match the wheel diameter is not possible.	MatWeb, 2006

Table 3.4.2 D: Wheel Weights – Tin

	Technical/ Performance Parameter	Measure/Metric	Source of Information
		Component/End-product	
	<u>Key</u> physical characteristics	Density: The density of tin is 7.34 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given weight size (mass), a tin weight will be 54% larger volume than a lead weight. (MatWeb) Melting Point: At 450° F, the melting point of tin is lower than the 622° F melting point of lead but it is above the maximum operating temperatures required for wheel weights. (MatWeb) Corrosion resistance: A manufacturer of tin adhesive wheel weights states that no corrosion protection is required for tin wheel weights and that they will retain a good surface appearance. (Trax) Hardness: 100% tin, Brinell: 3.9 tin alloy, ASTM B 23, Brinell: 17 Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb)	MatWeb, 2006 Trax, 2006 Sander, 2000

Table 3.4.2 D: Wheel Weights – Tin

	Technical/ Performance Parameter	Measure/Metric	Source of Information
		Malleability: The malleability of tin is similar to lead. (Sander)	

Table 3.4.2 D: Wheel Weights – Zinc

	Technical/ Performance Parameter	Measure/Metric	Source of Information
Component/End-product			
	<u>Key</u> physical characteristics	Density: The density of zinc is 7.10 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given weight size (mass), a zinc weight will be 60% larger volume than a lead weight. (MatWeb) The density of zinc alloy ZAMAC ZL5 is 6.76 g/cm^3. (Umicore) Melting Point: At 787° F, the melting point of zinc is significantly higher than the 622° F melting point of lead and well above the maximum operating temperatures for wheel weights. (MatWeb) Corrosion resistance: While zinc has good corrosion resistance, zinc wheel weights must be coated to prevent galvanic corrosion when mounted on aluminum wheels. (Umicore) Malleability: Zinc is malleable but is brittle at standard temperatures. Hardness: Zinc, Vickers: 30 ZAMAC ZL5, Brinell: 91 (Umicore) ZAMAC ZL5, Vickers: 102 (Umicore) Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb)	MatWeb, 2006. Umicore, 2006.

Financial Assessment

Initial Purchase Price for Chemical/Alternative

Lead is significantly less expensive than any of the alternatives in this assessment, with the exception of steel. In December 2005, the Platts Metals Week North American producer price for lead was $0.65 per pound. The December 2005 price for copper (U.S. producer cathode) was $2.23 per pound. For tin (Metals Week composite), the price was $4.43 per pound, and for zinc (Platts Metals Week North American Special High Grade), the price was $0.88 per pound. Steel is not traded on an exchange (e.g. London Metals Market) but the price for hot rolled steel plate, which was $0.29 per pound in December 2005, suggests that the price of steel is competitive with lead. (Metals Consulting International (MCI))

Initial Purchase Cost for End-product/Component

There are a variety of factors that affect the price of wheel weights including: material, weight, type, quantity in package, order size, vendor, and whether the weight is uncoated or coated. Wheel weights for passenger cars are available in a variety of weights, typically ranging from 0.18 oz. to 2.1 oz.

Clip-on wheel weights are available in a variety of different styles, where each style is designed to fit a specific wheel rim design. Wheel rim designs can vary by the vehicle year, make and model and wheel weight manufacturers often provide tire dealers with a chart that matches the wheel weight style to the vehicle.. The wheel weight styles are designated by letter codes such as AW, EN, FN, LH, and MC. "P" type weights are generic weights for passenger cars and "T" type weights are for trucks. (Hennessey Industries)

For lead weights, the most significant price factor appears to be the coating. A coated lead weight can cost 2-3 times more than the uncoated equivalent. This can be illustrated using prices from an online auto parts retailer, Patchboy.com. The price for an uncoated 0.25 oz. AW type lead weight was $0.05, while the price for the coated version of the same weight was $0.16. The price for an uncoated 2 oz. AW type lead weight was $0.19, while the coated version of the same weight was $0.38. By contrast, the difference in price between the various types of weights is minimal. For example, for 0.25 ounce coated lead weights, there is a $0.01 difference between the AW type and the MC type. For the 2 ounce size, the prices for these two types are the same.

In a 2005 study, the Ecology Center of Ann Arbor, Michigan collected wheel weight price information from three retailers and three manufacturers located in North America, Europe and Japan. Price information was collected on clip-on lead weights (coated and uncoated) and clip-on coated steel and zinc weights. The Ecology Center made comparisons using the average price of weights from 0.25 – 2 oz. in size for each manufacturer and found that steel and zinc coated weights were comparable in price to lead coated weights. In some cases, lead-free weights could be purchased at a lower cost than high quality, coated lead weights. (Ecology Center 2005b)

The following table contains a cost comparison for lead, steel and zinc clip-on weights collected by the Ecology Center in 2005:

Table 3.4.2 E: Wheel Weight Cost Comparison

Average Cost per Weight (for weight sizes 0.25 – 2 ounce)

Source: Ecology Center, 2005b

Wheel Weight Description	Source	Approximate Average Weight Cost
Lead, uncoated, P style	Retailer "B"	$0.09
Steel, coated, P style	Manufacturer "E", Japan	$0.15
Lead, uncoated, MC style	Retailer "A"	$0.18
Zinc, coated, P style	Manufacturer "D", N. America	$0.24
Lead, coated, MC style	Retailer "B"	$0.25
Zinc, coated, MC style	Manufacturer "D", N. America	$0.26
Lead, coated, MC style	Retailer "C"	$0.29
Zinc, coated, MC style	Manufacturer "F", Europe	$0.32
Zinc, coated, MC style	Manufacturer "E", N. America	$0.38
Lead, coated, MC style	Retailer "A"	$0.43

Copper weights are high quality coated weights and appear to be marketed to high end autos including Aston Martin. (Trax JH Ltd.) Although pricing was not available, it is expected that copper weights are significantly more expensive than lead weights based on raw material costs.

Pricing for tin weights was not available. It is expected that tin weights are significantly more expensive than lead weights based on raw material costs.

Availability of Chemical/Alternative

The Ecology Center of Ann Arbor, Michigan has estimated that 70,000 tons of lead is used each year to manufacture wheel weights worldwide. However, the quantity of lead used for this application is decreasing as auto manufacturers are switching to steel and zinc weights.

In 2005, the worldwide mine production of copper was 16.4 million tons but strong demand in China and India resulted in a global production deficit. In 2006, increased capacity is expected to result in a modest production surplus. (Edelstein 2006)

Global crude steel output in 2005 was 1,129 million metric tons. (Iron and Steel Statistics Bureau (ISSB)) Increased production of steel wheel weights is not expected to affect supply or price of steel.

In 2005, the U.S. consumption of tin was 51,480 tons. Tin has not been mined in the United States since 1993. During the period of 2001-2004, the primary sources of imported tin were Peru (44%), China (14%), Bolivia (14%), and Indonesia (11%). World tin reserves appear to be adequate to meet foreseeable demand. Domestic demand for primary tin is expected to grow slowly in the next few years, at a rate of about 1% per year. That rate, however, could double in a few years if new applications, especially those in which tin is substituted for toxic materials, such as lead-free solders, find acceptance in the marketplace. (Carlin, James F. Jr 2006)

In 2005, there was a 200,000 ton production deficit of zinc worldwide. U.S. mine production in 2005 was 837,800 tons. Domestic zinc metal production capacity accounts for less than one-third of the quantity consumed domestically. Canada and Mexico are leading sources of zinc. (Gabby 2006)

Availability of Component/End-product

European and Japanese automobile manufacturers have switched to lead-free wheel weights and U.S. automobile manufacturers are currently in the process of making the switch. Most wheel weight manufacturers are now producing lead-free wheel weights to meet this demand. However, the aftermarket, which accounts for 80% of total wheel weight usage in the U.S., continues to use lead weights almost exclusively. (Gearhart 2006a)The following table lists the manufacturers known to produce lead-free wheel weights.

Table 3.4.2 F: Manufacturers of Lead-free Wheel Weights

Manufacturer	Country	Website	Type of Weight
Azuma	Japan	http://home1.catvmics.ne.jp/~azuma/	Steel
Banner GmbH	Austria	www.bannerbatterien.com	Steel, zinc
Dionys-Hoffman	Germany	www.dionys-hofmann.de	Zinc
Hennessy Industries, Inc. (Bada)	United States	www.ammcoats.com	Steel
Perfect Equipment	United States	www.perfectequipment.com	Steel, zinc
PCP Products	Thailand	www.pcproductsinter.com	Zinc
Plombco	Canada	www.plombco.com	Zinc
Trax JH Ltd.	United Kingdom	www.traxjh.com	Copper, steel, tin, zinc

Copper adhesive weights are available from at least one major wheel weight manufacturer but copper clip-on weights are not available. Copper is not currently being used in the U.S. for wheel weights by either the auto manufacturers or the aftermarket.

Steel wheel weights are available in both clip-on and adhesive styles. Steel is less dense than lead and therefore steel weights are larger than lead weights. As a result, size restrictions limit the availability of some steel weights. Steel weights are available for passenger vehicles which typically use .25 - 2 ounce weights. Trucks often require larger weights which may not be available in steel.

General Motors and Ford are in the process of converting to steel weights and it is expected that this conversion will be complete in 2006 and 2007 respectively. Asian auto manufacturers are currently equipping most of their vehicles with steel weights. (Gearhart 2006b)

The availability of tin wheel weights is very limited. Only one manufacturer (Trax) was identified as a producer of tin wheel weights and only in the adhesive style.

Many of the leading manufacturers of wheel weights, including at least two in North America, produce both adhesive and clip-on zinc weights. Zinc weights are available in a variety of sizes and types but the zinc product offerings are typically not as extensive as the lead product offerings. Zinc weights are used extensively in Europe. U.S. auto manufacturers are equipping new vehicles exported to Europe with zinc weights. (Ecology Center 2005a)

Capital Costs

A significant investment in production equipment is required to start-up production of lead-free wheel weights. Many of the major wheel weight manufacturers have already added lead-free wheel weight production capacity to meet the demand for lead-free weights from the auto manufacturers. However, manufacturers that supply the U.S. aftermarket must still produce lead weights to meet the ongoing demand for inexpensive weights. A shift by the aftermarket to lead-free weights would likely require manufacturers to make additional investments in capital equipment.

It is not known what the current production capacity is for lead-free weights or the capital costs required to convert lead weight production to lead-free weight production. It is also not clear whether one type of lead-free weight production process is more capital intensive than another.

Key Operating Costs During Use of End-product

Operating costs for lead-free wheel weights are expected to be the same as for the equivalent lead weights. Whether the lead-free weights are clip-on or adhesive weights, they are installed in the same manner as the equivalent lead weights.

Replacement Rate

The replacement rate of wheel weights is dependent on a number of factors, including the rate at which weights are lost, and the frequency of tire replacement. It is estimated that 10% of installed wheel weights are lost on an annual basis and the average lifespan of a tire is three years or 44,000 miles. (Ecology Center 2005b)

Key End-of-Product Life Costs

Lead wheel weights that are removed from wheels during tire balancing are subject to state and federal hazardous waste rules unless they are recycled. The lead waste is typically recycled at secondary lead smelters. The lead weights must be transported by licensed haulers, usually those that transport lead acid batteries. The removal and storage of lead weights for recycling may require special containers and recordkeeping. (Minnesota Pollution Control Agency (MPCA) 1998)

If lead weights are not removed from automobiles prior to automobile recycling and shredding, lead can contaminate other recyclable materials and the auto shredder residue (ASR). ASR contaminated with lead may be classified as hazardous waste. (Ecology Center 2005a)

Used copper, steel, tin and zinc wheel weights are not subject to state and federal hazardous waste rules and therefore waste management and recycling costs may be reduced. Steel, copper and zinc are widely used in automobiles so weights made from these materials are not likely to become contaminants in the automobile recycling process since they are recovered during the recycling process. The high value of scrap copper and tin provides an economic incentive for recovery and recycling.

The following tables provide additional financial data for each of the alternatives.

Table 3.4.2 G: Wheel Weights – Copper

	Financial Parameter	Measure/Metric	Source of Information
Required Data			
	Initial purchase price for chemical/alternative	Copper raw material price: $2.23 per pound, U.S. producer cathode, December 2005 Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	Edelstein, 2006 Gabby, 2006a
	Initial purchase cost for end-product/component	Copper weights are high quality weights with small size and appear to be marketed to high end autos including Aston Martin and although pricing was not available, it is expected that copper weights are significantly more expensive than lead weights.	Trax, 2006
	Availability of chemical/alternative	In 2005, the worldwide mine production of copper was 16.4 million tons but strong growth in China and India resulted in a global production deficit. In 2006, increased capacity is expected to result in a modest production surplus. It is estimated that 70,000 tons of lead are used per year to manufacture wheel weights worldwide.	Edelstein, 2006 Ecology Center, 2006
	Availability of component/end-product	Copper adhesive weights are available from at least one major wheel weight manufacturer. Copper is not currently being used in the U.S. for wheel weights by either the auto manufacturers or the aftermarket. The aftermarket, which accounts for 80% of wheel weight usage in the U.S., continues to use lead weights almost exclusively.	Trax, 2006 Gearhart, 2006a
Additional Data if Available			
	Key operating costs during use of end-product	Operation costs for copper weights are expected to be the same as for other adhesive weights. Copper adhesive weights are installed in the same manor as other adhesive weights.	
	Key end-of-product life costs	Copper can be recycled without any loss of quality and 30% of U.S. demand is met by recycled copper. The price of copper provides an economic incentive to recycle scrap copper and it is expected that businesses that balance tires would recycle many of the copper weights removed from wheels. Identification of copper weights is not expected to be an issue since the weights are typically labeled and their copper color is unique.	Edelstein, 2006

Table 3.4.2 H: Wheel Weights – Steel

	Financial Parameter	Measure/Metric	Source of Information
	Required Data		
	Initial purchase price for chemical/alternative	The price for hot rolled steel plate in Dec 2005 was approximately $0.29/lb. Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	steelonthenet, 2006 Gabby, 2006a
	Initial purchase cost for end-product/component	All steel wheel weights are coated. Steel clip-on weights are comparable in price to coated lead clip-on weights and in some cases they are lower in price. The average price for P style steel weights (0.25 – 2 oz.) from a Japanese manufacturer was $0.15.	Ecology Center, 2005b
	Availability of chemical/alternative	Global crude steel output in 2005 was 1,129 million metric ton. Increased production of steel wheel weights will not affect supply or price of steel. It is estimated that 70,000 tons of lead are used per year to manufacture wheel weights worldwide.	ISSB, 2006 Ecology Center, 2006
	Availability of component/end-product	Steel wheel weights are available in both clip-on and adhesive styles. Steel is less dense than lead and therefore steel weights are larger than lead weights. As a result, size restrictions limit the availability of some steel weights. Steel weights are available for passenger vehicles which typically use .25 - 2 ounce weights. Trucks often require larger weights which may not be available in steel. General Motors and Ford are in the process of converting to steel weights and it is expected that this conversion will be complete in 2006 and 2007 respectively. Asian auto manufacturers are currently equipping most of their vehicles with steel weights. In the U.S., the aftermarket, which accounts for 80% of wheel weight usage, continues to use lead weights almost exclusively.	Gearhart, 2006a
	Additional Data if Available		
	Key operating costs during use of end-product	Operation costs for steel weights are expected to be the same as for the equivalent lead weights since steel weights are installed in the same manor as lead weights.	
	Key end-of-product life costs	Used steel wheel weights are not subject to state and federal hazardous waste rules and therefore waste management and recycling costs may be reduced. Steel is widely used in automobiles so weights made from this material is not likely to become a contaminant in the automobile recycling process since it is recovered during the recycling process.	

Table 3.4.2 I: Wheel Weights – Tin

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Initial purchase price for chemical/alternative	Tin raw material price: $4.43 per pound, Metals Week composite, December 2005 Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	Carlin, 2006b Gabby, 2006a
	Initial purchase cost for end-product/component	Pricing for tin weights was not available. It is expected that tin weights are significantly more expensive than lead weights.	
	Availability of chemical/alternative	In 2005, the U.S. consumption of tin was 51,480 tons. Tin has not been mined in the United States since 1993. World tin reserves appear to be adequate to meet foreseeable demand. Domestic demand for primary tin is expected to grow slowly in the next few years, at a rate of about 1% per year. That rate, however, could double in a few years if new applications—especially those in which tin is substituted for toxic materials, such as lead-free solders - find acceptance in the marketplace. Recycling: About 9,000 tons of tin from old and new scrap was recycled in 2005. Of this, about 5,000 tons was recovered from old scrap at 2 detinning plants and 91 secondary nonferrous metal processing plants. Import Sources (2001-04): Peru, 44%; China, 14%; Bolivia, 14%; Indonesia, 11%; and other, 17%. It is estimated that 70,000 tons of lead are used per year to manufacture wheel weights worldwide.	Carlin, 2006b Ecology Center, 2006
	Availability of component/end-product	Availability of tin wheel weights was very limited. In the U.S., the aftermarket, which accounts for 80% of wheel weight usage, continues to use lead weights almost exclusively.	Gearhart, 2006a
		Additional Data if Available	
	Key operating costs during use of end-product	Operation costs for tin weights are expected to be the same as for the equivalent lead weights since tin weights are installed in the same manor as lead weights.	
	Key end-of-product life costs	Used tin wheel weights are not subject to state and federal hazardous waste rules and therefore waste management and recycling costs may be reduced. The high value of scrap tin provides an economic incentive for recovery and recycling.	

Table 3.4.2 J: Wheel Weights – Zinc			
	Financial Parameter	**Measure/Metric**	**Source of Information**
	Required Data		
	Initial purchase price for chemical/alternative	Zinc raw material price: $0.88 per pound, Platts Metals Week North American Special High Grade, December 2005 Lead raw material price: $0.65 per pound, Platts Metals Week North American producer price, December 2005	Gabby, 2006b Gabby, 2006a
	Initial purchase cost for end-product/component	Coated zinc clip-on weights are comparable in price to coated lead clip-on weights. The average price for zinc weights (0.25 – 2 oz.) from a N. American manufacturer was approximately $0.24 for P style weights and $0.26 for MC style weights.	Ecology Center, 2005b
	Availability of chemical/alternative	U.S. mine production in 2005 was 837,800 tons. Domestic zinc metal production capacity accounts for less than one-third of quantity consumed domestically. Canada and Mexico are leading sources of zinc. In 2005, there was a 200,000 ton production deficit worldwide. It is estimated that 70,000 tons of lead are used per year to manufacture wheel weights worldwide.	Gabby, 2006b Ecology Center, 2006
	Availability of component/end-product	Many of the leading manufacturers of wheel weights, including at least two in N. America, produce zinc weights. Zinc weights are available in a variety of sizes and types but the manufacturers zinc product offerings are typically not as extensive as their lead product offerings. Zinc weights are used extensively in Europe. U.S. auto manufacturers are equipping new vehicles exported to Europe with zinc weights. In the U.S., the aftermarket, which accounts for 80% of wheel weight usage, continues to use lead weights almost exclusively.	Ecology, 2006 Gearhart, 2006a
	Additional Data if Available		
	Key operating costs during use of end-product	Operation costs for zinc weights are expected to be the same as for the equivalent lead weights since zinc weights are installed in the same manor as lead weights.	
	Key end-of-product life costs	Used zinc wheel weights are not subject to state and federal hazardous waste rules and therefore waste management and recycling costs may be reduced. Zinc is widely used in automobiles so weights made from this material is not likely to	

Table 3.4.2 J: Wheel Weights – Zinc			
	Financial Parameter	**Measure/Metric**	**Source of Information**
		become a contaminant in the automobile recycling process since it is recovered during the recycling process.	

Environmental Assessment

EPA estimates that 50 to 60 million pounds of lead are used each year to produce wheel weights in the United States. (United States Environmental Protection Agency (USEPA) 2005) In a 2003 study of the stocks and flows of lead wheel weights in the U.S., the U.S. Geological Survey (USGS) reported that approximately 56 million pounds of lead were used to produce wheel weights and approximately 130 million pounds of lead weights were in use on registered vehicles (Bleiwas, 2006). This USGS study estimated that 4 million pounds of lead wheel weights were lost on U.S. roadways in 2003 and an additional 8 million pounds were unaccounted for. The study also estimated that 75 percent (28 million pounds) of lead weights removed from vehicles by tire retailers, repair shops and dealerships were recycled and 6 million pounds of lead wheel weights were recycled by automotive scrap dealers in 2003.

A study published in 2000 estimated that the fleet of cars and light trucks currently in operation in the U.S. contain 55 million pounds of lead wheel weights. (Root 2000)Root estimated that 10% of these weights (5.5 million pounds) fall off the vehicles each year with 3.3 million pounds being deposited on urban streets where much of it is ground into dust by automobile traffic. The study claimed that the residual lead dust can then be washed into waterways or sewers, migrate into nearby residential properties, or become airborne particulates. Wheel weights are also collected during street cleaning operations and then disposed of in municipal landfills.

Drinking Water Standards

The fate of wheel weights that fall off during use is not fully understood but the potential for wheel weight materials to contaminate groundwater, including drinking water supplies, exists. Some of the wheel weights that are deposited on streets and highways are collected by street cleaning operations and disposed of in municipal landfills. The acidic conditions in the municipal landfills can solubolize lead from the wheel weights, resulting in lead contamination of groundwater. (United States Environmental Protection Agency (USEPA)

The National Primary Drinking Water Regulations are legally enforceable standards, set by EPA, that apply to public water systems. In these standards, the Maximum Concentration Level (MCL) for lead in drinking water is 15 μg/L and the Maximum Concentration Level Goal (MCLG) is zero. Copper is the only alternative wheel weight material in this assessment for which EPA has set an MCL. Copper has an MCL of 1300 μg/L.

EPA has also established National Secondary Drinking Water Standards, which are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The following list shows the alternative wheel weight materials included in these secondary standards (aluminum is used in the zinc alloy ZAMAC):

- Copper: 1000 μg/l
- Iron: 300 μg/l

- Zinc: 5000 μg/l
- Aluminum: 20-500 μg/l

Florida and Minnesota have established maximum concentration levels for tin in drinking water (4200 μg/l and 4000 μg/l respectively). Arizona set the maximum concentration level for copper at 1300 μg/l.

Affinity for Water: Water Solubility

Lead, copper, steel and tin are insoluble in water. Zinc is soluble in water but the solubility is dependent on the properties of the water, such as acidity, temperature, chlorine concentration and hardness. It should be noted that certain compounds of these metals may be soluble.

Density

All of the materials considered in this assessment are less dense than lead, which has a density of 11.34 g/cm^3. With a density of 8.96 g/cm^3, copper has the highest density of the alternatives in this assessment, followed by steel (7.87 g/cm^3), tin (7.34 g/cm^3), and zinc (7.10 g/cm^3). (Automation Creations)The density of a zinc alloy (ZAMAC) used for wheel weights is 6.76 g/cm^3. (Umicore)

Bioaccumulation

According to the International Chemical Safety Cards (ICSCs), bioaccumulation of lead may occur in plants and mammals and it is strongly advised that lead does not enter the environment. Specific information on the bioaccumulation of copper, steel, tin, and zinc were not available. As discussed earlier in this report, EPA is in the process of developing a framework that will address the issue of bioaccumulation of metals, as well as related issues such as bioavailability.

Aquatic toxicity

National Recommended Water Quality Criteria was used as a source for data on aquatic toxicity of lead and lead-free alternatives. Water Quality Criteria includes the following two aquatic life criteria for both freshwater and saltwater:

- Criteria Maximum Concentration (CMC) – An estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect.
- Criteria Continuous Concentration (CCC) – An estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

Lead, copper and zinc are listed as Priority Toxic Pollutants and iron is listed as a Non Priority Pollutant. Tin was not included in the Water Quality Criteria list. The following table shows the Water Quality Criteria for lead, copper, iron and zinc.

Table 3.4.2 K: Water Quality Criteria

	Freshwater		Saltwater	
Priority Pollutant	**CMC (µg/L)**	**CCC (µg/L)**	**CMC (µg/L)**	**CCC (µg/L)**
Lead	65	2.5	210	8.1
Copper	13	9.0	4.8	3.1
Iron	-	1000	-	-
Zinc	120	120	90	81

The Water Quality Criteria values indicate that lead, copper and zinc are toxic to aquatic organisms, even at relatively low concentrations. Of the wheel weight materials considered in this assessment, tin and steel appear to be the least toxic to aquatic organisms.

In 1994, EPA addressed the aquatic toxicity of alternatives to lead fishing sinkers in its response to citizens' petition and proposed ban for lead fishing sinkers. In its assessment of aquatic toxicity of lead alternatives, EPA made the following statements about copper, tin and zinc: "Laboratory studies indicate that copper is more toxic to aquatic organisms, such as fish, crustaceans, worms, and algae than lead." (United States Environmental Protection Agency (USEPA) 1994) However, EPA believes that environmental conditions in freshwaters would mitigate the toxicity of copper to aquatic organisms. "Tin, in the inorganic form, is generally much less toxic to aquatic organisms (crustaceans and fish) than lead because of its low solubility, poor absorption, low uptake rate, and rapid excretion." Zinc is more toxic to aquatic organisms (fish and crustaceans) than lead and it may be more bioavailable to aquatic organisms than lead. Information about the aquatic toxicity of steel was not found.

Human Health Assessment

Acute Human Effects

Occupational Exposure Limits

IDLH

The Immediately Dangerous to Life or Health Concentrations (IDLH) for lead is 100 mg/m^3. The IDLH for copper and tin is also 100 mg/m^3. Data on the IDLH for steel and zinc were not located. For iron, 1-2 grams may cause death but 2-10 is usually ingested in fatal cases.

PEL

The Permissible Exposure Level (PEL) for lead is 0.050 mg/m^3 (8-hour TWA). The PEL (TWA) for copper is 1 mg/m^3; for tin it is 2 mg/m^3; and for aluminum (in zinc alloy ZAMAC) it is 15 mg/m^3. PELs have not been established for steel and zinc; however, PELs have been set for zinc chloride (1 mg/m^3) and zinc oxide (5 mg/m^3).

REL

The Recommended Exposure Level (REL) for lead is 0.050 mg/m^3 (TWA). The REL (TWA) for copper is 1 mg/m^3; for steel (iron) it is 1 mg/m^3; for tin it is 2 mg/m^3; and for aluminum (in zinc alloy ZAMAC) it is 10 mg/m^3 (total). An REL has not been established for zinc.

Irritation

Dermal

Lead does not cause dermal irritation. Skin exposure to copper, steel (iron), tin and zinc may cause dermal irritation.

Ocular

Dusts of lead and all of the lead-free alternatives can cause ocular irritation, with the exception of zinc.

Respiratory

Dusts of lead and zinc were not identified as respiratory irritants, while copper, steel (iron) and tin can cause respiratory irritation.

Chronic Human Effects

Mutagenicity and Carcinogenicity

Lead is classified as both a mutagen and probable human carcinogen (IARC 2B). The lead-free alternatives in this assessment (copper, steel, tin and zinc) are not classified as either mutagens or carcinogens.

Reproductive and Developmental Toxicity

Lead has been identified as a developmental toxicant in humans. Children are particularly sensitive to the chronic effects, which include slowed cognitive development and reduced growth. High lead exposure is also associated with reproductive effects, such as decreased sperm count in men, spontaneous abortions in women and low birth weight (USEPA).

The lead-free alternatives in this assessment (copper, steel, tin and zinc) have not been identified as reproductive or developmental toxicants.

Assessment Summary

The following is a summary of the alternatives assessment data for lead wheel weights.

Table 3.4.2 L: Assessment Summary Alternatives for Lead Wheel Weights

Assessment Criteria		Lead (Reference)	Comparison Relative to Lead			
			Copper	Steel	Tin	Zinc
Technical/ Performance Criteria	Density	11.34 g/cm^3	-	-	-	-
	Malleability	Good	=	-	=	-
	Corrosion Resistance (with coating)	Good	=	=	+ (coating not required)	=
Environmental Criteria	Primary Drinking Water Standards (MCL Action Level)	15 □g/l	+	+ (iron)	+ (FL & MN)	?
	Aquatic Toxicity: Water Quality Criteria (CMC) Freshwater Saltwater	65 □g/L 210 □g/L	- -	+ (iron) ?	? ?	+ -
Human Health Criteria	Carcinogenicity	EPA B2 IARC 2B	+	+	+	+
	Developmental Toxicity	Yes (Prop 65)	+	+	+	+
	Occupational Exposure: REL (8-hour TWA)	0.050 mg/m^3	+	+	+	+
Cost	Price per weight (coated, ¼ – 2 oz)	$0.25 - $0.43	-	= / +	-	=
	Available in clip-on & adhesive styles	Yes	-	=	-	=
	End-of-Life Cost (Auto Shredder)	Average	+	+	+	+

Comparison Key + Better = Similar - Worse ? Unknown

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3.4.3 Alternatives Assessment for Fishing Sinkers

Technical Assessment

Longevity/Life in Service

The primary factor affecting the life in service of fishing sinkers is the frequency that they are lost during use. Fishing sinkers of all types are lost during use, such as when the sinker becomes caught on weeds, rocks or other objects. Fishing sinkers can also come loose during casting if they are not properly secured.

Fishing sinkers do not typically wear out. A review of literature on fishing sinkers in the environment, as well as fishing sinker manufacturers' and retailers' websites and brochures, did not identify any data about the service life of fishing sinkers or the effect that the materials of construction have on the service life.

Key Standards for Component/End-product

In efforts to protect water birds from lead poisoning from fishing sinkers, the following northeastern states have enacted legislation restricting the use and/or sale of certain lead fishing sinkers (Minnesota Office of Environmental Assistance (MOEA)):

- Massachusetts - In June 2000, the Massachusetts Fisheries & Wildlife Board voted to prohibit the use of all lead sinkers for the taking of fish in Quabbin and Wachusett Reservoirs, the two bodies of water that support the core of that state's loon population.
- Maine - Passed legislation in 2001 (effective January 1, 2002) to ban the sale of lead sinkers weighing ½ oz or less.
- New Hampshire - Legislation passed in 1998 (effective in 2000) prohibits the use of lead sinkers up to 1 oz and lead jigs up to 1 in. in length in the state’s lakes and ponds. N.H. later expanded the legislation to include all waters of the state. Starting January 1, 2006, the sale of lead sinkers weighing 1 oz or less and lead jigs less than 1 in. long along their longest axis are prohibited in New Hampshire.
- New York - Passed legislation in 2002 (effective May 2004) that bans the sale of lead sinkers ½ oz or less to the end user.
- Vermont - Passed legislation in 2004 banning the sale of lead sinkers weighing ½ oz or less (effective January 2006), and the use of those lead sinkers (effective January 2007) in the state.

The U.S. Fish and Wildlife Service banned lead sinkers in two national wildlife refuges and Yellowstone National Park. It is currently discussing restrictions on the use of lead sinkers and jigs at other national wildlife refuges where loons and trumpeter swans breed. Great Britain banned the use of lead sinkers in 1987. In Canada, it is illegal to use lead fishing sinkers and jigs in national parks and national wildlife areas (United States Fish & Wildlife Service (USFWS); New Hampshire Fish and Game Department).

Key Physical Characteristics and Key Performance Requirements

Fishing sinkers are available in a wide variety of styles, sizes, and configurations where each type is designed to meet the requirements of the application or the preference of the user. The ideal physical characteristics for fishing sinker materials depend, to a large degree, on the intended application of the sinker. A review of manufacturers’ and retailers’ literature and websites and online product reviews indicates that key physical characteristics of fishing sinker materials include: density, malleability, brittleness, corrosion resistance, and hardness. It is estimated that 0.8 – 1.6 million anglers in the U.S. produce their own lead sinkers (United States Environmental Protection Agency (USEPA) 1994)for these individuals who mold their own fishing sinkers, the melting point of the material is also important.

It should be noted that optimal characteristics for fishing sinker materials vary according to application and user preference. For example, malleability and softness are desirable characteristics for split-shot sinkers while hardness is a desirable characteristic for other types of sinkers, since hard materials make noise that is said to attract fish.

Split-shot sinkers are one of the most common types of fishing sinkers. They come in sizes ranging from BB size (0.44 cm in diameter) to about the size of a raisin. The “split” refers to the groove where the fishing line is inserted. The sinker is secured to the line by crimping which closes the groove onto the line. Removable split-shot sinkers feature wings, that when squeezed, open the groove releasing the fishing line. A description of other fishing sinker types can be found in an article by Tim Allard, “An Introduction to Fishing Sinkers” (Allard).

Density and Mass:

Fishing sinkers have two primary purposes: 1) to provide mass to the fishing line to achieve improved casting distance and accuracy and; 2) to provide mass to the fishing line so the bait stays in the desired location (USEPA 1994; McMahon 2006a). The sinker must be made of a material that provides sufficient mass to achieve these results. For some applications, smaller sinkers are desirable because they are less likely to get hung up on obstacles and less likely to be seen by the fish. For other applications, an increase in the sinker size can reduce snags because larger sinkers slide over cracks that smaller sinkers could get caught in (McMahon 2006b).

Ceramic is the least dense material considered in this assessment. With a density of 2.6 g/cm^3 (Du-Co, 2006), a ceramic sinker must be more than three times the volume of a lead sinker in order to achieve a given mass. While a larger sinker may be desirable for some applications, the low density of ceramic is a drawback for use in other applications.

The densities of tin (7.34 g/cm^3), steel (7.87 g/cm^3), and bismuth (9.8 g/cm^3) are all less than that of lead (11.34 g/cm^3) (MatWeb 2006). For bismuth sinkers, a relatively small increase in volume (16%) will achieve the same mass as a lead sinker. Steel and tin sinkers must be 44% and 54% larger in volume respectively than lead sinkers for a given mass. For many applications, these differences in sizes are not significant enough to affect performance.

The density of tungsten (19.3 g/cm^3) is significantly higher than lead and therefore, for a given mass, tungsten sinkers are 41% smaller in volume than lead sinkers for a given mass, which is desirable for applications that benefit from small sinker size (Automation Creations).

Hardness:

The hardness of a sinker can affect performance in several ways. Sinkers made from hard materials are less likely to deform when they hit rocks or other hard objects. Hard sinkers also make more noise when they contact rocks or other hard objects, which is desirable because the noise can attract fish. Some manufacturers and anglers claim that sinkers made of hard materials provide anglers with a better feel for the lake or river bottom than sinkers made of softer materials like lead. Hard sinkers may be more snag-resistant in some cases since they tend to bounce off a snag. (Ellis)

Lead has a hardness of 4.2 on the Brinell scale and a hardness of 1.5 on the Mohr's scale, which makes it softer than all of the alternative materials except pure tin. Pure tin has a Brinell hardness of 3.9 but some tin alloys are harder than lead (ASTM B 23 has a Brinell hardness of 17). Bismuth and tin alloy are somewhat harder than lead while ceramic, steel and tungsten sinkers are significantly harder than lead. Table 3.4.3A lists the fishing sinker materials in order of increasing hardness (Automation Creations):

Table 3.4.3 A: Relative hardness of candidate sinker materials.

Material	Hardness	
	Brinell Scale	Mohr's Scale
Tin (pure)	3.9	
Lead	4.2	1.5
Bismuth	7	
Tin (alloy)	17	
Steel (stainless)	123	5-6
Tungsten	294	7
Ceramic		7.5

Malleability

An advantage of using soft, malleable materials for fishing sinkers is that they can be used for fishing sinker applications where the sinker is crimped onto the fishing line, such as the commonly used split-shot sinkers. Lead is a soft, malleable metal, which makes it ideal for these types of fishing sinkers.

Bismuth is malleable but it is relatively brittle and therefore would be likely to crack if used for split-shot sinkers or other types that utilize crimping (Automation Creations). Ceramic is not malleable and is relatively brittle so it is not a candidate for sinkers that are crimped. Steel and tungsten are not used for split-shot sinkers due to their limited malleability. Tin is malleable like lead and frequently used for split-shot applications. However, tin is more brittle than lead and in a review of lead-free sinkers, it was noted that this brittleness can cause tin split-shot sinkers to fail, particularly if the sinkers are reused (Ellis).

Corrosion Resistance*:*

Corrosion resistance is a key physical characteristic of fishing sinkers due to their exposure to harsh elements such as seawater. Lead, bismuth, ceramic, stainless steel, tin, and tungsten are corrosion resistant materials and are successfully used for fishing sinkers without corrosion preventive coatings or special treatment. Carbon steel sinkers will rust unless they are coated (Ellis).

Melting Point:

The relatively low melting point of lead (622° F) makes it possible for individuals to mold their own lead sinkers at home. The molds and melting pots used for home production of lead sinkers are available through retailers that sell fishing supplies (Brooks, 2005). The low melting points for both bismuth (520° F) and tin (450° F) make home production of fishing sinkers a possibility. The high melting point of steel (2732° F) and tungsten (6100° F) prohibit home molding of sinkers with these materials. The production of ceramic products requires firing at temperatures exceeding 1400° F, so home production of ceramic sinkers would not be feasible.

Shape and Configuration:

There are a wide variety of shapes, sizes and styles of sinkers, each of which are designed to meet specific requirements. Fishing sinker requirements are dependent on a wide variety of factors including: type of fish, type of bait, water conditions, fishing technique, and user preference. To meet these requirements, the sinkers must be available in a variety of shapes and weights. For example, sinkers with rounded or tapered shapes (*e.g.,* bullet or egg sinkers) are designed to resist snags and slip through weeds. Sinkers with flat edges (*e.g.,* pyramid sinkers) are designed to dig into soft bottoms or stay in place in fast currents (Allard).

Fishing sinkers are attached to the fishing line using a variety of techniques including crimping on the line, tying to a loop on the sinker, or, for slip-sinkers, threading the line through the hole in the center of the sinker. Sinkers that are crimped onto the line must be made from a malleable material which does not break when crimped. The sinker must not cut into or abrade the fishing line.

Bismuth sinkers may be manufactured using a molding process similar to lead sinkers; however, bismuth expands as it solidifies and therefore may require the use of high-quality milled molds (Scheuhammer, Norris 1995). The physical properties may limit the variety of bismuth sinker shapes and configurations. Bismuth is relatively brittle and cannot be used for split-shot sinkers or other sinkers where crimping is required because its brittleness results in breakage when it is crimped onto the fishing line.

Ceramic sinkers are currently only available in limited configurations and sizes (i.e. slip sinkers) (Big Ten Tackle). It is not clear whether this is a function of market demand or a limitation of the manufacturing process and/or material properties. The hardness and brittleness of ceramic eliminate the possibility of ceramic being used for split-shot sinkers or other sinkers where crimping is required.

Most steel sinkers are manufactured using a machining process rather than a molding process and therefore the available shapes and configurations are more limited than lead sinkers. Steel can be machined into the symmetrical shape of egg sinkers and bullet or worm weights but machining steel into pyramid or other flat sided weights is probably not feasible. The hardness and limited malleability of steel eliminate the possibility of steel being used for split-shot sinkers or other sinkers where crimping is required.

Like lead, tin sinkers can be produced using a molding process and tin is widely used as a substitute for lead for split-shot sinkers.

Pure tungsten can be forged or extruded; however, impure tungsten is brittle and is difficult to work (ChinaTungsten Online Manufacturing & Sales Corporation). Tungsten is also a very hard metal. These factors may limit the shapes and configurations for tungsten sinkers. Tungsten can be used in a composite material, such as tungsten powder in a polymer base, which could increase the options available.

Appearance*:*

Unnatural appearance, such as having a shiny surface, can be a negative, particularly in clear water situations (Ellis). A shiny, bright surface can be a positive in some applications. Steel and tungsten sinkers can be produced with shiny, bright surfaces. Steel sinkers can be painted a variety of colors to attract fish and paint adheres to steel better than lead. Steel sinkers can also be impregnated with a long-lasting scent designed to attract fish or mask undesirable human odors (Duke).

Ceramic sinkers have the advantage of blending in with a river or lake bottom (Big Ten Tackle). Tin split-shot sinkers are shinier than lead, which could be a negative factor in clear-water situations (Ellis).

Tables 3.4.3 B-F provide additional technical performance data for each of the alternatives.

Table 3.4.3 B: Fishing Sinkers – Bismuth			
	Technical/ Performance Parameter	**Measure/Metric**	**Source of Information**
Component/End-product			
	Key physical characteristics	Density: The density of bismuth is approximately 9.8 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given sinker size (mass), a bismuth sinker will be 16% larger volume than a lead sinker. (MatWeb) Melting Point: At 520° F, the melting point of bismuth is lower than the 622° F melting point of lead. (MatWeb) Malleability: Bismuth alloys are relatively malleable, similar to lead. (MII) Brittleness: Bismuth is relatively brittle for a metal. (MII) Corrosion resistance: Bismuth does not corrode in the atmosphere unless attacked by strong acids. (MII) Hardness: Bismuth, Brinell: 7 Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb)	MatWeb, 2006 MII, 2006

Table 3.4.3 C: Fishing Sinkers – Ceramic			
	Technical/ Performance Parameter	**Measure/Metric**	**Source of Information**
Component/End-product			
	Key physical characteristics	Density: The density of ceramic is 2.6 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given weight size (mass), a ceramic sinker will be more than 3.3 times larger volume than a lead sinker. Hardness: Ceramic, Mohr's Scale: 7.5 (Du-Co) Lead, Mohr's Scale: 1.5 Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb)	Du-Co

Table 3.4.3 D: Fishing Sinkers – Steel			
	Technical/ Performance Parameter	**Measure/Metric**	**Source of Information**
Component/End-product			
	Key physical characteristics	Density: The density of steel is approximately 7.87 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given	Ellis, 2006

Table 3.4.3 D: Fishing Sinkers – Steel			
	Technical/ Performance Parameter	**Measure/Metric**	**Source of Information**
		weight size (mass), a steel sinker will be 44% larger volume than a lead sinker. (MatWeb) Melting Point: At 2732 °F, the melting point of steel is significantly higher than the 621 °F melting point of lead. (MatWeb) Corrosion resistance: Sinkers made from carbon steel are subject to rusting and therefore must be coated to prevent corrosion. Stainless steel is corrosion resistant and would not require coating. (Ellis) Malleability: Steel has limited malleability. Hardness: Stainless Steel (304), Brinell: 123 Stainless Steel (304), Vickers: 129 Steel, Mohr's Scale: 5 Lead, Mohr's Scale: 1.5 Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb)	MatWeb, 2006

Table 3.4.3 E: Fishing Sinkers – Tin			
	Technical/ Performance Parameter	**Measure/Metric**	**Source of Information**
Component/End-product			
	Key physical characteristics	Density: The density of tin is 7.34 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given weight size (mass), a tin weight will be 54% larger volume than a lead weight. (MatWeb) Melting Point: At 450° F, the melting point of tin is lower than the 622° F melting point of lead. (MatWeb) Corrosion resistance: Tin is corrosion resistant and because of this property it is commonly used to coat steel to produce tinplate, which is used for food packaging applications. Malleability: The malleability of tin is similar to lead. (Sander) Brittleness: In a review of lead-free sinkers, one angler stated that the brittleness of tin can result in split-shot splitting apart, particularly if the tin split-shot is reused. (Ellis) Hardness:	MatWeb, 2006 Ellis, 2006 Sander, 2000

Table 3.4.3 E: Fishing Sinkers – Tin			
	Technical/ Performance Parameter	**Measure/Metric**	**Source of Information**
		Component/End-product	
		100% tin, Brinell: 3.9 Tin alloy, ASTM B 23, Brinell: 17 Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb)	

Table 3.4.3 F: Fishing Sinkers – Tungsten			
	Technical/ Performance Parameter	**Measure/Metric**	**Source of Information**
		Component/End-product	
	Key physical characteristics	Density: The density of tungsten is 19.3 g/cm^3 vs. 11.34 g/cm^3 for lead, which means that, for a given weight size (mass), a tungsten weight will be 41% smaller volume than a lead weight. (MatWeb) Melting Point: At 6100° F, the melting point of tungsten is significantly higher than the 622° F melting point of lead. (MatWeb) The high melting point of tungsten eliminates the possibility of anglers molding their own sinkers. The high temperatures result in higher energy costs during manufacturing. The high temperatures can also cause production delays when material or mold changes are made since the molds can take up to two days to cool. Corrosion resistance: Lead and tungsten are corrosion resistant materials and are successfully used for fishing sinkers without corrosion preventive coatings or special treatment. Malleability: Tungsten is very hard (Brinell hardness of 294) and has limited malleability (MatWeb). Hardness: 100% tungsten, Brinell: 294 100% tungsten, Vickers: 310 Tungsten, Mohr’s Scale: 7 Lead, Mohr’s Scale: 1.5 Lead, Brinell: 4.2 Lead, Vickers: 5 (MatWeb)	MatWeb, 2006

Financial Assessment

Initial Purchase Price for Chemical/Alternative

Lead has the advantage of being a relatively inexpensive metal. A major U.S. fishing sinker manufacturer (Water Gremlin) said that its cost to purchase lead was $0.30/lb in 2003. In 2003, the Platts Metals Week average North American Producer price was $0.4/lb. In December 2005, the Platts Metals Week North American producer price was $0.65/lb.

In 2005, the dealer prices for bismuth fluctuated from an average of $3.55/lb in the first quarter to an average of $4.57/lb in the fourth quarter. The 2005 fourth quarter price represented a 33% increase over the 2004 fourth quarter price. Ceramic sinkers cost 33% more per pound than lead according to a manufacturer of ceramic sinkers (Big Ten Tackle). Steel is not traded on an exchange (e.g. London Metals Market) but the price for hot rolled steel plate, which was $0.29/lb in December 2005, suggests that the price of steel is competitive with lead. The Platts Metals Week average composite price for tin in December 2005 was $4.43/lb, which was 7% higher than the November price and 20% less than the December 2004 price. Tungsten prices fluctuated from approximately $2.72/lb in January 2005 to approximately $9.98/lb in May 2005 (DesLauriers 2005).

Initial Purchase Cost for End-product/Component

Results of an economic analysis conducted by EPA in 1994 indicated that a federal ban on the manufacture and distribution of lead and zinc fishing sinkers (1 in. or less in any dimension) would increase the average costs to individual anglers by only $1.50 -3.50/y (USEPA 1994). A study conducted in 1991 found that anglers in Canada spent approximately $500/y on their sport (Filion et al. 1991). While these studies were conducted more than a decade ago, they suggest that fishing sinker purchases represent less than 1% of total expenditures by anglers on their sport.

Fishing sinker cost data for this assessment was collected from three online retailers (Cabela's, Bass Pro Shops, FishUSA.com) and a retail store (Wal-Mart) that carry fishing supplies. Cost data were limited to common types of fishing sinkers used for freshwater fishing, including egg and slip sinkers, split-shot, worm and bullet weights. The cost data were limited to sinkers 1-1/2 oz and less. Wherever possible, price comparisons were made between lead and lead-free sinkers available at the same retailer.

Bismuth egg sinker prices are approximately 5 to 6 times the price of lead egg sinkers, while bismuth worm weights are approximately 4 to 6 times the price of lead worm weights. Ceramic slip sinker prices are approximately 2 to3 times the price of lead slip sinkers. Tin removable split shot sinker prices are approximately 1.5 to 4 times the price of lead removable split shot sinkers. Tungsten bullet and worm weight prices are approximately 7 to 12 times the price of lead bullet weights. Tungsten drop shot weight prices are approximately 3 to 7 times the price of lead drop shot weights.

Steel fishing sinkers appear to be the most competitively priced lead-free alternative. Steel bullet weight prices are approximately 1 to 2 times the price of lead bullet weight sinkers and steel egg sinkers are 0.7 to 2 times the price of lead egg sinkers.

The lead-free fishing sinkers were typically sold in packages with smaller quantities of sinkers than the equivalent lead sinkers, which may affect a per unit price comparison.

Availability of Chemical/Alternative

It is estimated that 2,450 metric tons of lead are used each year in the United States to produce approximately 477 million fishing sinkers (USEPA 1994)

Bismuth, tin, and tungsten are relatively scarce metals with a limited reserve base, while iron (steel) is more abundant than lead (European Commission Enterprise Directorate-General 2004).

All primary bismuth consumed in the U.S. is imported and less than 5% is obtained by recycling old scrap. Most bismuth is produced from mines in Mexico, China, Peru and Bolivia. It is a byproduct of processing lead ores, and in China, it is a byproduct of tungsten ore processing. Reported bismuth consumption was 2,120 metric tons in 2003 in the U.S. Worldwide demand is growing at about 5% per year, driven in part by its use as a replacement for lead but a global shortage is not expected. However, the supply could be constrained by low prices (Carlin, James F. Jr.).

Availability of steatite ceramic would not be affected by increased production of ceramic sinkers. Talc, including the steatite used to produce this ceramic, is mined in many countries including the U.S. and is used in a wide variety of products, including paper, talcum powder, paint filler, and ceramic products such as electrical insulators. U.S. mines produced around 1 million metric tons of crude talc ore per year during the 1990's (United States Geological Survey (USGS) 2000).

Global crude steel output in 2005 was 1,129 million metric tons (Iron and Steel Statistics Bureau (ISSB)). Given the availability and wide use of steel, increased production of steel fishing sinkers are not likely to affect the supply or price of steel.

In 2005, the U.S. consumption of tin was 51,480 tons. Tin has not been mined in the United States since 1993. During the period of 2001-2004, the primary sources of imported tin were Peru (44%), China (14%), Bolivia (14%), and Indonesia (11%). World tin reserves appear to be adequate to meet foreseeable demand. Domestic demand for primary tin is expected to grow slowly in the next few years, at a rate of about 1% per year. That rate, however, could double in a few years if new applications, especially those in which tin is substituted for toxic materials, such as lead-free solders, find acceptance in the marketplace (Carlin, James F. Jr 2006).

U.S. consumption of tungsten in 2005 was 11,600 metric tons. World tungsten supply is dominated by Chinese production and exports. The Chinese government regulates tungsten production and the total volume of tungsten exports, and the government has gradually shifted the balance of export quotas towards value-added downstream tungsten materials and products. In 2005, inadequate supplies of tungsten concentrates within China combined with increased demand for tungsten materials in China and elsewhere resulted in steep increases in the prices of tungsten concentrates. In response to this price increase, the sole Canadian tungsten mine restarted operations and action was taken to develop tungsten deposits or reopen inactive tungsten mines in Australia, China, Peru, Russia, the United States, and Vietnam (Shedd 2006).

Availability of Component/End-product

The availability of lead-free sinkers was assessed by determining the products carried by three major online retailers (Cabela’s, Bass Pro Shops & FishUSA.com) and Wal-Mart stores.

Lead split-shot sinkers account for almost half of the total lead sinker market and 68% of lead sinkers 1 in. in size or less (USEPA 1994). Tin is the only readily available lead-free material used for split-shot sinkers, since most other materials are too hard and/or brittle for this application.

Bismuth sinkers are available in egg sinker and worm weight styles. Ceramic sinkers were not available at three major online retailers (Cabela’s, Bass Pro Shops & FishUSA.com) or at Wal-Mart stores. An internet search located only one company selling ceramic sinkers and the selection was limited to two sizes of slip sinkers. Steel bullet weights and egg sinkers were available at two major online retailers (Cabela’s & Bass Pro Shops). A Wal-Mart store did not carry steel sinkers.

Capital Costs and Key Manufacturing Costs for Component/End-product

It is possible to switch existing lead sinker production equipment to manufacture sinkers out of materials that have similar properties (melting point, malleability, hardness), such as bismuth and tin. Bismuth and tin sinkers can be produced using the molding process that is typically used to produce lead sinkers although different molds may be required. The manufacture of tin split-shot may require greater precision than the manufacture of lead split-shot in order to prevent damage to the fishing line from the hard edges on tin sinkers. Bismuth expands as it solidifies and therefore may require the use of high-quality milled molds. (Scheuhammer, Norris 1995)The lower melting point of bismuth and tin may result in lower energy costs than those for equivalent lead sinker production. Bismuth and tin sinkers can be manufactured by individuals at home using lead sinker molds (USEPA 1994).

Manufacturers switching from lead to steel would be required to make significant investments in capital equipment. The high melting point and hardness of steel make it impractical to manufacture steel sinkers using a molding operation. Steel sinkers can be produced using machining operations. (Ellis) An alternative to investing in steel machining equipment would be to outsource the production of the steel sinkers to a supplier with steel machining capabilities.

Ceramic sinkers are produced in a mold and then fired in a high temperature furnace. A manufacturer of ceramic sinkers, Big Ten Tackle, avoided the investment in production equipment by outsourcing the production of the ceramic components to a company that specializes in the production of ceramic parts.

While tungsten sinkers can be produced using a molding operation, the 6100° F melting point of tungsten eliminates the possibility of switching lead sinker molding equipment to tungsten sinker production. Therefore a switch from lead to tungsten would require significant capital investment unless the tungsten sinkers were produced by a supplier. The high melting point results in high production costs because of the energy costs and the long cooling times (Duke).

Replacement Rate

Fishing sinkers do not typically wear out but are lost during use such as when fishing tackle becomes caught on weeds, rocks or other objects. EPA estimated that 477 million lead, zinc, and brass sinkers are sold each year in the United States for freshwater fishing but it is not clear how many of these sinkers are purchased to replace lost or discarded sinkers.

Key End-of-Product Life Costs

Fishing sinkers are typically lost during use, discarded by anglers in terrestrial habitats or disposed of in household trash. These end-of-life disposal methods bear no cost for the user, manufacturer or retailer. Several state agencies encourage the proper disposal of lead fishing sinkers at municipal household hazardous waste collection events where they would be recycled or disposed of as hazardous waste at a cost to the municipality.

Bismuth, ceramic, steel, tin and tungsten fishing sinkers are not considered to be hazardous and can be disposed of in household trash.

Tables 3.4.3G-K provide additional financial data for each of the alternatives.

Table 3.4.3 G: Fishing Sinkers – Bismuth

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Initial purchase price for chemical/alternative	In 2005, bismuth dealer prices fluctuated from an average of \$3.55/lb in the first quarter to an average of \$4.57/lb in the fourth quarter. The fourth quarter 2005 price represented a 33% increase over the fourth quarter 2004 price. Lead raw material price: \$0.65/lb, Platts Metals Week North American producer price, December 2005 A major U.S. fishing sinker manufacturer (Water Gremlin) said that its cost to purchase lead was \$0.30/lb in 2003.	Carlin, 2006a Gabby, 2006a Myers, 2003
	Initial purchase cost for end-product/component	Egg Sinkers: Prices range from \$0.33 for a 1/8 oz sinker to \$1.00 for a 3/4 oz sinker. Prices are approximately 5 to 6 times the price of lead egg sinkers (Cabela's, 2006). Worm Weights: Prices range from \$0.24 for a 1/16 oz weight to \$0.45 for a 1/4 oz weight. Prices are approximately 4 to 6 times the price of lead worm weights (Bass Pro, 2006) (FishUSA, 2006). Note: The bismuth sinkers were typically sold in packages with smaller quantities of sinkers than the equivalent lead sinkers, which may affect a per unit price comparison.	Cabela's, 2006 Bass Pro, 2006 FishUSA, 2006
	Availability of chemical/alternative	All primary bismuth consumed in the U.S. is imported and less than 5% is obtained by recycling old scrap. Belgium was the leading supplier to the U.S., followed by China, Mexico, and the U.K. Bismuth is a byproduct of processing lead ores, and in China, it is a byproduct of tungsten ore processing. Bismuth consumption in the U.S. in 2005 was estimated at 2,280 metric tons. Worldwide demand is growing at about 5% per year, driven in part by its use as a replacement for lead but a global shortage is not expected. Low prices could constrain bismuth supply to the market.	Carlin, 2006a
	Availability of component/end-product	The following types of fishing sinkers are available from major retailers that sell fishing sinkers online: - Egg sinkers - Worm weights Bismuth split shot sinkers were not carried by several major online retailers.	Bass Pro, 2006 Big Ten, 2006 Cabela's, 2006 FishUSA, 2006 Wal-Mart retail store, Bellingham, MA, March 2006.
	Capital costs	Bismuth sinkers may be produced using a molding process that is similar to the process used to produce lead sinkers although different molds may be required. Bismuth expands as it solidifies and therefore may require the use of high-quality milled molds. The lower melting point of bismuth may result in lower energy costs than those for equivalent lead sinker production. Bismuth sinkers can be manufactured by individuals at home using lead sinker molds.	USEPA, 1994 Scheuhammer, 1995

Table 3.4.3 H: Fishing Sinkers – Ceramic

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Initial purchase price for chemical/alternative	According to a manufacturer of ceramic sinkers, ceramic sinkers cost 33% more per pound than lead. Lead raw material price: \$0.65/lb, Platts Metals Week North American producer price, December 2005. A major U.S. fishing sinker manufacturer, Water Gremlin, said that its cost to purchase lead was \$0.30/lb in 2003.	McMahon, 2006b Gabby, 2006a Myers, 2003
	Initial purchase cost for end-product/component	Slip Sinkers: Prices range from \$0.33 for a 1/2 oz sinker purchased in a package of 24 to \$0.42 for a 1/2 oz sinker purchased in a package of 12. Prices are approximately 2 to3 times the price of lead slip sinkers. Note: The ceramic sinkers were sold in packages with smaller quantities of sinkers than the equivalent lead sinkers, which may affect a per unit price comparison.	Big Ten, 2006 FishUSA, 2006
	Availability of chemical/alternative	Availability of steatite ceramic would not be affected by increased production of ceramic sinkers. Talc, including steatite, is mined in many countries including the U.S. and is used in a wide variety of products, including paper, talcum powder, paint filler, and ceramic products such as electrical insulators. U.S. mines produced around 1 million metric tons of crude talc ore per year during the 1990's.	USGS, 2000
	Availability of component/end-product	Ceramic sinkers were not available at three major online retailers (Cabela's, Bass Pro Shops & FishUSA.com) or at Wal-Mart stores. An internet search located only one company selling ceramic weights (Big Ten, 2006).	Bass Pro, 2006 Big Ten, 2006 Cabela's, 2006 FishUSA, 2006 Wal-Mart retail store, Bellingham, MA, March 2006.
	Capital costs	Ceramic sinkers are produced in a mold and then fired in a high temperature furnace. This manufacturing process is significantly different than the molding process used to produce lead sinkers and therefore a significant capital investment would be required to switch from lead sinker production to ceramic sinker production. A manufacturer of ceramic sinkers, Big Ten Tackle, avoided the investment in production equipment by outsourcing the production of the ceramic components to a company that specializes in the production of ceramic parts.	McMahon, 2006b

Table 3.4.3 I: Fishing Sinkers – Steel

	Financial Parameter	Measure/Metric	Source of Information
Required Data			
	Initial purchase price for chemical/alternative	The price for hot rolled steel plate in Dec 2005 was approximately $0.29/lb (steelonthenet, 2006). Lead raw material price: $0.65/lb, Platts Metals Week North American producer price, December 2005. A major U.S. fishing sinker manufacturer, Water Gremlin, said that its cost to purchase lead was $0.30/lb in 2003.	steelonthenet, 2006 Gabby, 2006a Myers, 2003
	Initial purchase cost for end-product/component	Bullet Weights: Prices range from $0.07 for a 1/16 oz weight to $0.19 for a 3/4 oz weight. Prices are approximately 1 to 2 times the price of lead bullet weights. Egg Sinkers: Prices range from $0.12 for a 1/4 oz sinker to $0.37 for a 1 oz sinker. Prices are approximately .7 to 2 times the price of lead egg sinkers. Note: The steel sinkers were typically sold in packages with smaller quantities of sinkers than the equivalent lead sinkers, which may affect a per unit price comparison.	Bass Pro, 2006 Cabela's, 2006
	Availability of chemical/alternative	Global crude steel output in 2005 was 1,129 million metric ton. Increased production of steel fishing sinkers will not affect supply or price of steel.	ISSB, 2006
	Availability of component/end-product	Steel bullet weights and egg sinkers were available at two major online retailers (Cabela's & Bass Pro). A Wal-Mart store did not carry steel sinkers. Steel split shot sinkers were not available at several major retailers (store and online).	Bass Pro, 2006 Cabela's, 2006 FishUSA, 2006 Wal-Mart retail store, Bellingham, MA, March 2006.
	Capital costs	Manufacturers switching from lead to steel would be required to make significant investments in capital equipment. The high melting point and hardness of steel make it impractical to manufacture steel sinkers using a molding operation. Steel sinkers can be produced using machining operations (Ellis, 2006). An alternative to investing in steel machining equipment would be to outsource the production of the steel weights to a supplier with steel machining capabilities.	Ellis, 2006

Table 3.4.3 J: Fishing Sinkers – Tin

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Initial purchase price for chemical/alternative	Tin raw material price: The Platts Metals Week average composite price for tin in December 2005 was $4.43/lb, which was 7% higher than the November price and 20% less than the December 2004 price. Lead raw material price: $0.65/lb, Platts Metals Week North American producer price, December 2005. A major U.S. fishing sinker manufacturer, Water Gremlin, said that its cost to purchase lead was $0.30 per pound in 2003. Its cost for tin was $3.00/lb.	Carlin, 2006b Gabby, 2006a Myers, 2003
	Initial purchase cost for end-product/component	Removable Split Shot Sinkers: Prices range from $0.02 for a BB size sinker to $0.19 for a #1 size sinker. Prices are approximately 1.5 to 4 times the price of lead removable split shot sinkers. Note: The tin sinkers were typically sold in packages with smaller quantities of sinkers than the equivalent lead sinkers, which may affect a per unit price comparison.	Bass Pro, 2006 Cabela's, 2006 Wal-Mart retail store, Bellingham, MA, March 2006.
	Availability of chemical/alternative	Tin has not been mined in the United States since 1993. World tin reserves appear to be adequate to meet foreseeable demand. Domestic demand for primary tin is expected to grow slowly in the next few years, at a rate of about 1% per year. That rate, however, could double in a few years if new applications - especially those in which tin is substituted for toxic materials, such as lead-free solders - find acceptance in the marketplace. Recycling: About 9,000 tons of tin from old and new scrap was recycled in 2005. Of this, about 5,000 tons was recovered from old scrap at 2 detinning plants and 91 secondary nonferrous metal processing plants. Import Sources (2001-04): Peru, 44%; China, 14%; Bolivia, 14%; Indonesia, 11%; and other, 17%.	Carlin, 2006b
	Availability of component/end-product	Tin split shot sinkers were available at two major online retailers (Cabela's & Bass Pro) and at Wal-Mart stores. Other types of tin fishing sinkers were not available at these major retailers. However, one company, Warrior Sporting Goods, offers a line of tin sinkers including egg, cannon ball, walking, and split shot sinkers.	Bass Pro, 2006 Cabela's, 2006 FishUSA, 2006 Wal-Mart retail store, Bellingham, MA, March 2006. Warrior, 2006

Table 3.4.3 J: Fishing Sinkers – Tin

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Capital costs	Tin sinkers can be produced using the molding process that is typically used to produce lead sinkers although the different molds may be required. The manufacture of tin split-shot may require greater precision than the manufacture of lead split-shot in order to prevent damage to the fishing line from the hard edges on tin sinkers. The lower melting point of tin may result in lower energy costs than those for equivalent lead sinker production. Tin sinkers can be manufactured by individuals at home using lead sinker molds (USEPA, 1994) According to a manufacturer of tin weights, Warrior Sporting Goods, tin weights can be manufactured using the same molds used to manufacture lead weights (Myers, 2003).	USEPA, 1994 Myers, 2003

Table 3.4.3 K: Fishing Sinkers – Tungsten

	Financial Parameter	Measure/Metric	Source of Information
		Required Data	
	Initial purchase price for chemical/alternative	In 2005, tungsten prices fluctuated from approximately $2.72/lb in January to approximately $9.98/lb in May. Lead raw material price: $0.65/lb, Platts Metals Week North American producer price, December 2005. A major U.S. fishing sinker manufacturer, Water Gremlin, said that its cost to purchase lead was $0.30/lb in 2003.	DesLauriers, 2005 Gabby, 2006a Myers, 2003
	Initial purchase cost for end-product/component	Bullet Weights: Prices range from $0.54 for a 1/8 oz weight to $2.15 for a 1 oz weight. Prices are approximately 9 to 12 times the price of lead bullet weights (Bass Pro & Cabela's). Drop Shot Weights: Prices range from $0.75 for a 1/8 oz weight to $3.00 for a 1/2 oz weight. Prices are approximately 3 to 7 times the price of lead drop shot weights (Bass Pro & Cabela's). Worm Weights: Prices range from $0.56 for a 1/8 oz sinker to $2.25 for a 1-1/2 oz sinker. Prices are approximately 7 to 12 times the price of lead worm weights (Bass Pro & FishUSA). Note: The tungsten sinkers were typically sold in packages with smaller quantities of sinkers than the equivalent lead sinkers, which may affect a per unit price comparison.	Bass Pro, 2006 Cabela's, 2006 FishUSA, 2006

Table 3.4.3 K: Fishing Sinkers – Tungsten

	Financial Parameter	Measure/Metric	Source of Information
	Required Data		
	Availability of chemical/alternative	U.S. consumption of tungsten materials in 2005 was 11,600 metric tons (Shedd, 2006). World tungsten supply is dominated by Chinese production and exports. The Chinese government regulates tungsten production and the total volume of tungsten exports, and the Government has gradually shifted the balance of export quotas towards value-added downstream tungsten materials and products. In 2005, inadequate supplies of tungsten concentrates within China combined with increased demand for tungsten materials in China and elsewhere resulted in steep increases in the prices of tungsten concentrates. The sole Canadian tungsten mine restarted operations. Various companies worked towards developing tungsten deposits or reopening inactive tungsten mines in Australia, China, Peru, Russia, the United States, and Vietnam. Recycling: In 2005, the tungsten contained in scrap consumed by processors and end users represented approximately 40% of apparent consumption of tungsten in all forms.	Shedd, 2006
	Availability of component/end-product	Tungsten bullet weights, drop shot weights and worm weights were available at two major online retailers (Cabela's & Bass Pro Shops). A Wal-Mart store did not carry tungsten sinkers. Tungsten split shot sinkers are not available.	Bass Pro, 2006 Cabela's, 2006 FishUSA, 2006 Wal-Mart retail store, Bellingham, MA, March 2006.
	Capital costs	While tungsten sinkers can be produced using a molding operation, the 6100° F melting point of tungsten eliminates the possibility of switching lead sinker molding equipment to tungsten sinker production. Therefore a switch from lead to tungsten would require significant capital investment unless the tungsten weights were produced by a supplier. The high melting results in high production costs because of the energy costs and the long cooling times (Duke, 2006).	Duke, 2006

Environmental Health and Safety

It is estimated that 2,450 metric tons of lead are used each year in the United States to produce approximately 477 million fishing sinkers (USEPA 1994). While the fate of lead fishing sinkers is not known, studies indicate that sinkers are commonly lost during use, either in bodies of water used by anglers or on the shores of these bodies of water. In a study conducted by the University of Arizona, interviews with over 850 anglers revealed that anglers lost, on average, one sinker every six hours of fishing (Duerr, DeStefano 1999). Another survey conducted in 1986 estimated that four to six split-shot sinkers might be spilled and lost for every one used (Lichvar 1994).

Biologists have studied the effects of lead sinkers and jigs on waterbirds, such as loons and swans, since the 1970s. Their ongoing research has documented that, in the northeast United States and Canada where loons breed, lead sinkers or jigs can account for 10 -50% of dead adult loons found by researchers (New Hampshire Fish and Game Department). The U.S. Fish and Wildlife Service identified lead poisoning resulting from the ingestion of lead fishing sinkers as a significant cause of mortality of the Common Loon in the United States and Eastern Canada (Evers, 2004). A study of mortalities of common loons in New England found that the most common cause of death in adult breeding loons was lead toxicity from ingested fishing sinkers) (Pokras, Chafel 1992).

A single fishing sinker swallowed with food or taken up as grit could be fatal to waterbirds. Lead adversely affects the function and structure of the kidney, central nervous system, bones, and production and development of blood cells in waterbirds. Exposure to lead, such as through ingestion of fishing sinkers, can cause lead poisoning in waterbirds, producing convulsions, coma, and death (USEPA 1994).

In a 1994 study, EPA stated that it did not find any information to indicate that bismuth or tungsten are toxic to avian species. Results of a research program on lead-free alternatives to lead shot conducted by the Fish and Wildlife Service indicated that steel and tin are less toxic than lead to ducks when ingested (USEPA 1994).

In the same 1994 study, EPA estimated that 0.8 – 1.6 million anglers in the U.S. produce their own lead sinkers at home. This activity has the potential to expose individuals and family members to airborne lead particles or vapors released during the pouring of molten lead into the fishing sinker molds.

Environmental Assessment

Drinking Water Standards

The National Primary Drinking Water Regulations are legally enforceable standards, set by EPA, that apply to public water systems. In these standards, the Maximum Concentration Level (MCL) for lead in drinking water is 15 μg/L and the Maximum Concentration Level Goal (MCLG) is zero. EPA had not set MCLs for any of the fishing sinker alternatives considered in this assessment.

EPA has also established National Secondary Drinking Water Standards, which are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. Steel (iron) is the only alternative fishing sinker material included in this assessment where a secondary standard applies; iron has a secondary standard level of 300 μg/L.

Florida and Minnesota have established maximum concentration levels for tin in drinking water (4200 μg/L and 4000 μg/L respectively).

Affinity for Water: Water Solubility
Lead, bismuth, ceramic, steel, and tin are insoluble in water. It should be noted that certain compounds of these metals may be soluble. Tungsten dissolves in water reaching concentrations up to 475 – 500 mg/L (Strigul, Nicolay, et al. 2005).

Density

Lead has a density of 11.34 g/cm^3, which makes it more dense than all of the alternative materials considered in this assessment, with the exception of tungsten (19.3 g/cm^3). Ceramic (2.6 g/cm^3) is the least dense alternative followed by tin (7.34 g/cm^3), steel (7.87 g/cm^3), and bismuth (9.8 g/cm^3) (Automation Creations).

Bioaccumulation

According to the International Chemical Safety Cards (ICSCs), bioaccumulation of lead may occur in plants and mammals and it is strongly advised that lead does not enter the environment. Specific information on the bioaccumulation of bismuth, ceramic, steel, tin, and tungsten were not available. As discussed earlier in this report, EPA is in the process of developing a framework that will address the issue of bioaccumulation of metals, as well as related issues such as bioavailability.

Aquatic toxicity

National Recommended Water Quality Criteria was used as a source for data on aquatic toxicity of lead and lead-free alternatives. Water Quality Criteria includes the following two aquatic life criteria for both freshwater and saltwater:

- Criteria Maximum Concentration (CMC) – An estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect.
- Criteria Continuous Concentration (CCC) – An estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

Lead is listed as a Priority Toxic Pollutant and iron is listed as a Non Priority Pollutant. Bismuth, ceramic, tin and tungsten were not included in the Water Quality Criteria list. **Table 3.4.3 L** shows the Water Quality Criteria for lead and iron.

Table 3.4.3 L: Water quality criteria for lead and iron.

	Freshwater		**Saltwater**	
Priority Pollutant	**CMC (μg/L)**	**CCC (μg/L)**	**CMC (μg/L)**	**CCC (μg/L)**
Lead	65	2.5	210	8.1
Iron	-	1000	-	-

The Water Quality Criteria values indicate that lead is toxic to aquatic organisms, even at relatively low concentrations.

In 1994, EPA addressed the aquatic toxicity of alternatives to lead fishing sinkers in its response to citizens' petition and proposed ban for lead fishing sinkers. In its assessment of aquatic toxicity of lead alternatives, EPA made the following statements about tin: "Tin, in the inorganic form, is generally much less toxic to aquatic organisms (crustaceans and fish) than lead because of its low solubility, poor absorption, low uptake rate, and rapid excretion" (USEPA 1994).

Tungsten was found to have low toxicity to aquatic organisms (crustaceans and algae). EPA stated that it did not find any information to indicate that bismuth or steel are toxic to aquatic species.

Human Health Assessment

Acute Human Effects

Occupational Exposure Limits

IDLH

The Immediately Dangerous to Life or Health Concentrations (IDLH) for lead is 100 mg/m^3. The IDLH for tin is also 100 mg/m^3. Data on the IDLH for bismuth, steel and tungsten were not located. For iron, 1-2 grams may cause death but 2-10 is usually ingested in fatal cases. The steatite ceramic used for fishing sinkers may have 0-3% quartz. The IDLH for quartz (crystalline silica as respirable dust) is 50 mg/m^3. Steatite ceramic may also have magnesium oxide, which has an IDLH of 750 mg/m^3.

PEL

The Permissible Exposure Level (PEL) for lead is 0.050 mg/m^3 (8-hour TWA). The PEL (TWA) for tin is 2 mg/m^3. PELs have not been established for bismuth, steel and tungsten. The steatite ceramic used for fishing sinkers may have 0-3% quartz as a contaminant. The PEL for quartz (crystalline silica as respirable dust) is either 250 million parts per cubic foot (mppcf) divided by the value "%SiO2 + 5" or 10 mg/ m^3 divided by the value "%SiO2 + 2." Steatite ceramic may also have magnesium oxide, which has a PEL of 15 mg/m^3.

REL

The Recommended Exposure Level (REL) for lead is 0.050 mg/m^3 (TWA). The REL (TWA) for steel (iron) is 1 mg/m^3; for tin it is 2 mg/m^3; and for tungsten it is 5 mg/m^3. An REL has not been established for bismuth. The steatite ceramic used for fishing sinkers may contain 0-3% quartz. The REL for quartz (crystalline silica as respirable dust) is 0.05 mg/m^3. Steatite ceramic may also contain magnesium oxide, but an REL has not been established for magnesium oxide.

Irritation

Dermal

Lead and bismuth do not cause dermal irritation. Skin exposure to iron, tin, tungsten and the quartz and magnesium oxide in ceramic may cause dermal irritation.

Ocular

Dust from lead and all of the lead-free alternatives can cause ocular irritation.

Respiratory

Dust from lead was not identified as a respiratory irritant, while bismuth, ceramic, steel (iron), tin and tungsten can cause respiratory irritation.

Chronic Human Effects

Mutagenicity and Carcinogenicity

Lead is classified as both a mutagen and probable human carcinogen (IARC 2B). The lead-free alternatives in this assessment (bismuth, ceramic, steel, tin and tungsten) are not classified as either mutagens or carcinogens. If the ceramic used for fishing sinkers contains quartz, crystalline silica may be present during production. Crystalline silica (respirable size) is a known human carcinogen (IARC 1A).

Reproductive and Developmental Toxicity

Lead has been identified as a developmental toxicant in humans. Children are particularly sensitive to the chronic effects, which include slowed cognitive development and reduced growth. High lead exposure is also associated with reproductive effects, such as decreased sperm count in men, spontaneous abortions in women and low birthweight (USEPA).

The lead-free alternatives in this assessment (bismuth, ceramic, steel, tin and tungsten) have not been identified as reproductive or developmental toxicants.

Assessment Summary

The following table summarizes the alternatives assessment for lead fishing sinkers.

Table 3.4.3 M: Assessment Summary of Alternatives for Lead Fishing Sinkers

Assessment Criteria		**Lead (Reference)**	**Comparison Relative to Lead**				
			Bismuth	**Ceramic**	**Steel**	**Tin**	**Tungsten**
Technical and Performance Criteria	Density	11.34 g/cm^3	-	-	-	-	+
	Hardness (desirable for “feel” and noise)	Soft Mohrs: 1.5	+	+	+	= (pure) + (alloy)	+
	Malleability (split-shot application)	Yes	-	-	-	=	-
	Low Melting Point (for home production)	622 °F	+	-	-	+	-
	Corrosion Resistant	Yes	=	=	-	=	=
Environmental Criteria	Highly toxic to waterfowl	Yes	+	?	+	+	+
	Toxic to Aquatic Species	Yes	+	?	+	+	+
	Primary Drinking Water Standards (MCL Action Level)	15 μg/L	?	?	+ (iron)	+ (FL & MN)	?

Assessment Criteria		Lead (Reference)	Comparison Relative to Lead				
			Bismuth	**Ceramic**	**Steel**	**Tin**	**Tungsten**
Human Health Criteria	Carcinogenicity	EPA B2 IARC 2B	+	+	+	+	+
	Developmental Toxicity	Yes (Prop 65)	+	+	+	+	+
	Occupational Exposure: REL (8-hour TWA)	0.050 mg/m^3	?	+	+	+	+
Cost	Retail Price	Low	-	-	- / = / +	-	-
	Availability of End-product	Excellent	-	-	-	-	-

Comparison Key + Better = Similar - Worse ? Unknown

3.4.4 Alternatives Assessment for Heat Stabilizers for PVC Wire and Cable Coatings

Technical Assessment

Introduction

Lead and non-lead heat stabilizers are used extensively in various PVC wire and cable applications. There are thousands of different PVC formulations commercially available to meet the varying requirements of different wire and cable applications. The U.S. EPA is undertaking a detailed life cycle assessment for three specific wire and cable applications. The U.S. EPA effort will examine various heat stabilizer technologies for these products including lead, calcium/zinc, and barium zinc. The U.S. EPA effort will also examine various alternative resins used in these product types including: polyvinyl chloride (PVC), polyethylene (PE), fluorinated ethylene propylene (FEP), and possibly, high density polyethylene (HDPE), and ethylene vinyl acetate (EVA). Given the U.S. EPA's ongoing efforts in this area, this report will provide an overview of the current state of the use of non-lead heat stabilizers for PVC wire and cable applications, instead of a detailed alternatives assessment for alternative materials. The major elements of this overview will include:

- Materials used in wire and cable applications
- Lead and non-lead chemicals used for heat stabilizers
- Considerations for selecting heat stabilizers: performance requirements, financial impact, environmental and health issues, drivers for change, and synergistic materials
- Introduction of other on-going initiatives addressing heat stabilizer usage

Wire and Cable Materials

Wire and cable applications are increasing with the growing use of computers, the Internet, cable television, and the increase in electrical power service worldwide. Wire and cable constructions range from the simple – such as building wire, to the complex – such as power cable and fiber optics. There are numerous coated wire and cable manufacturers in Massachusetts that have reported under the Toxics Use Reduction Act in Massachusetts. In general, Massachusetts companies in the wire and cable industry provide higher value products for niche applications such as fiber optic, transportation, industrial, and communications. Massachusetts has the largest number of coated wire and cable manufacturers of any U.S. state. With sales of over $800 million and more than 3,400 employees (based on 1997 U.S. Census and 2002 U.S. EPA Toxics Release Inventory data), the industry is an important part of the Commonwealth's industrial manufacturing base.

Each type of wire and cable, has several common elements including the core (typically copper or fiber optic), insulation, and jacketing. The core is a key component that is used to transfer electrical energy or light from point to point. A fiber optic cable transmits a signal using a wave of light, while copper wires transmit a signal using an electric current. Another of the key components of a wire is its insulation. Its selection is determined by a number of factors such as stability and long life, dielectric properties, resistance to high temperature, resistance to moisture, mechanical strength, and flexibility. There is no single insulation that is ideal in every one of these areas. It is necessary to select a cable with the type of insulation, which fully meets the requirements of the application. Jackets cover and protect the enclosed wires or core against damage, chemical attack, fire and other harmful elements that may be present in the operating environment.

There are eight major types of materials used in coated wire and cable.

(1) *resins* (thermoplastic and thermoset compounds) for insulation, jacketing and cross-webs;

(2) *plasticizers* to make the plastic flexible and easy to process (and impart other qualities such as impact resistance and abrasion resistance);

(3) *stabilizers* to provide heat resistance during manufacturing as well as visible light, UV-rays and heat resistance during product use;

(4) *flame retardants* to slow the spread of an accidental fire and reduce the amount of heat and smoke released;

(5) *fillers* to reduce formulation costs and improve insulation resistance;

(6) *lubricants* to improve the ease of processing;

(7) *colorants* to give the desired color, which is crucial for identification purposes; and

(8) *core* includes materials such as copper and aluminum that carry movable charges of electricity, or fiber optic materials that transport light.

Wire and Cable Applications
There are several major types of wire and cable products defined by their end use. The list below describes the major wire and cable applications (Graboski 1998).

- **Building wire** – Used to distribute electrical power to and within residential and non-residential buildings. Products are sold through home center and hardware retail chains, electrical distributors and to industrial customers and OEMs.
- **Telecommunications wire** – Twisted pair conductors that are jacketed with sheathing, waterproofing, foil wraps and metal. Used to connect subscriber premises to the telephone company. Products are sold to telecommunications system operators and through telecommunications distributors.

- **Cords, Cordsets, Appliance Wire, other** – Two or three conductor cable insulated with rubber or plastic with a molded plug on one or both ends to transmit electrical energy to power equipment or electronic devices. Products are distributed through distributors, retailers, and to OEMs.
- **Power Cable** – This is insulated wire and cable used to transmit and distribute electrical energy. Products are generally sold to the public utility sector.
- **Coaxial and antennae cable** – Primary applications of this type of cable are broadcasting, cable television signal distribution and computer networking. Products are sold directly to Community Access Television (CATV) operators and through distributors.
- **Electronic and data wire** – This type represents high-bandwidth twisted pair copper and fiber-optic cable. It is used to wire subscriber premises above ceilings and between floors to interconnect components. Growth has been driven by expansion of local and wide area networks..
- **Magnet Wire** – Typical applications are electronic motors, generators, transformers, televisions, automobiles and small electrical appliances.

Wire and Cable Properties
Wire and cable products are manufactured to meet a set of application specific performance standards. The major performance categories include electrical, thermal, and mechanical properties, and are listed in the table below.

Table 3.4.4 A: Wire and Cable Performance

Property	Unit of Measurement	Test Method
Electrical:		
Volume resistivity	Ohm-cm	ASTM D257
Dielectric constant (at 1, 10 Khz, and 1, 10 Mhz)	Ratio	ASTM D149
Dissipation factor (at 1, 10 Khz, and 1 Mhz)	Ratio	None listed
Thermal:		
Maximum Operating/ Service Temperature	Degrees C, F	UL 1007, UL 1015, UL 1569
Minimum temperature (brittle)	Degrees C, F	D746
Thermal stability	Minutes at 180 degrees C	None listed
Mechanical:		
Tensile strength	MPa	ASTM D412
Specific gravity/density	SG is unitless	ASTM D792
Hardness	Shore durometer scale	ASTM D2240

Table 3.4.4 A: Wire and Cable Performance		
Property	**Unit of Measurement**	**Test Method**
Elongation at break	Percent elongation	ASTM D412
Fire resistance/ Flame rating	V-O, HB	UL 94
Smoke test (Arapaho)	None listed	ASTM D4100
Smoke index	None listed	NES-711
Flame Test	cm	IEC 332-3C
Mold shrink, linear flow	In/in	ASTM D955
Limiting Oxygen Index	Percentage oxygen	ASTM D2863
Relative Temp Index mechanical	Degrees C, F	UL 746
Relative Temp Index electrical	Degrees C, F	UL 746
Comparative tracking index	Performance Level Categories	UL 746
Sunlight Resistance	None listed	UL 720 hour Sunlight Resistance
Hot wire ignition	Performance Level Categories	UL 746
High amp arc ignition	Performance Level Categories	UL 746
Halogen content	Percent halogen materials	None listed
Acid gas	mg	MIL-C-24643
Acidity of gases	pH	IEC-754-2
Conductivity	uS/cm	IEC-754-2
Toxicity index	None listed	NES-713

Source: Numerous Wire and Cable Manufacturer Data Sheets

This table was provided to illustrate the many diverse performance characteristics that should be considered when evaluating new materials for wire and cable products. However, it is beyond the scope of this study to identify which of these various electrical, thermal, and mechanical properties are most important for each of the many wire and cable applications.

Additional consideration for the selection of materials for the various wire and cable designs is the applicability of national, state, and local codes and standards. Numerous organizations provide wire and cable guidance and requirements such as: American Society for Testing and Materials (ASTM), National Fire Protection Association (NFPA), Insulated Cable Engineers Association (ICEA), National Electrical Manufacturers Institute (NEMA), American National Standards Institute (ANSI), and International Electrotechnical Commission (IEC) (AlphaGary). It is beyond the scope of this study to identify and evaluate the various wire and cable national, state, and local codes and standards.

Polyvinyl Chloride Overview

There are numerous resins that are used for wire and cable applications including: polyvinyl chloride (PVC), polyethylene, chlorinated polyethylene, cross linked polyethylene, nylon, polypropylene, fluorinated ethylene-propylene (FEP), Teflon, thermoplastic rubber, silicone, ethylene propylene rubber (EPR), styrene butadiene rubber, ethylene propylene diene elastomer (EPDM), polyolefin, and polyurethane. These materials have various performance characteristics that are desirable for different applications. This report will focus on the PVC resin because it used in many wire and cable applications and because lead is commonly incorporated as an auxiliary material for heat stabilization. Lead stabilizers may also be used in some rubbers and elastomers, but those uses were not assessed in this study. The following table illustrates the resins used for wire and cable products.

Table 3.4.4 B: Volume of US Thermoplastic Resins in Wire and Cable - 2000

Thermoplastic resin	Million lb.	Percent
Polyethylene and copolymers	578	46%
PVC	486	39%
Nylons	74	6%
Fluoropolymers	50	4%
Polypropylene	16	1%
Other	53	4%
Total	1257	100%

Source: BCC, Inc. 2000 P-133R

PVC is produced by the polymerization of vinyl chloride monomer in liquid form. PVC is a versatile thermoplastic that is compounded with plasticizers, flame retardants, stabilizers, fillers, lubricants, and colorants, and extruded onto the wire or cable. This report focuses on the use of lead as a heat stabilizer in flexible PVC for wire and cable applications.

While no data are available on the amount of lead stabilizers used in PVC for wire and cable, in 2002, approximately 544 million pounds of PVC were consumed in North America for various wire and cable products. In the U.S., the distribution of PVC consumption for wire and cable is shown in the following table.

Table 3.4.4 C U.S. Consumption of PVC Resins in Wire and Cable in 2002

(Linak, Yagi 2003)

Wire and Cable Application	Percentage (based on weight)
Building wire and power cables	40%
Communication and signal wire	20%
Flexible cord (for household lamps and extension cords)	15%
Appliance wire	10%
Automotive electric wire and other automotive uses	5%
Other	10%
Total	100%

The general performance characteristics of PVC include mechanical toughness, weather resistance, water resistance, good electrical insulating properties, and inherent resistance to mildew and ultraviolet light. The major drawbacks to using PVC include the need for plasticizers for flexible applications and its relatively low decomposition temperature of 212 degrees F.

The types of materials used in a wire and cable depend largely on the specific resin system (e.g. thermoset polyethylene versus cross-linked polyethylene versus polyvinyl chloride) and the requirements for a particular application (*i.e.,* plenum rise communications wire versus high voltage power cable). PVC resin alone cannot be used for thermoplastic processing unless various additives are used to meet the various requirements for specific wire and cable applications. Since there is a wide variety of raw materials and there are continual developments in PVC compounding technology, there are thousands of formulations available. (Wire Association) Table 3.4.4D presents the basic materials used in PVC wire and cable coatings. This table outlines typical polyvinyl chloride formulations for different applications.

When reviewing the formulations in this table, note that:

- The formulations are presented in phr (parts per hundred resin) – a common way to present wire and cable formulations. To convert to weight percent, divide individual phr by total number of parts. Multiply this factor by 100 to get weight percent.
- The formulations are designed to meet Underwriter Laboratory (UL) test specifications.
- The formulations are generic and would require adjustments for specific applications.
- Some of the ingredients use trade names

Table 3.4.4 D: Various Polyvinyl Chloride Insulation Compositions (Wickson 1993)

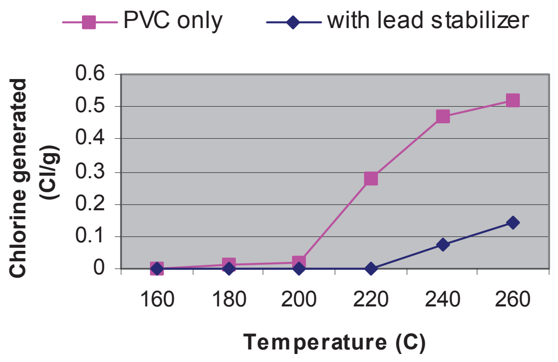
UL Designation	T-TW	THW-THWN	NM-B	THH-THHN	Units
Temperature Rating	**60°C**	**75°C**	**90°C**	**90°C**	**phr**
Polyvinyl Chloride (Resin)	100	100	100	100	phr
DiIsoDecyl Phthalate (Plasticizer)	45	35			phr
Ditridecyl Phthalate (Plasticizer)		15	30	20	phr
Tri Octyl Trimellitate (Plasticizer)			15	35	phr
CaCO3 (Filler)	20	20		15	phr
Clay (Filler)	10	10	7	15	phr
Wax	0.5	0.3	0.5	0.3	phr
Bisphenol A (stabilizer)			0.2	0.3	phr
Sb2O3 (flame retardant)				3	phr
Tribasic lead sulfate (stabilizer)	4	5			phr
Basic lead sulfophthalate (stabilizer)			6	7	phr

Wire and cable extruders purchase either PVC resin to do their own compounding, or purchase the palletized compound.

Heat Stabilizers for PVC Wire and Cable Coatings Overview

PVC resin begins to degrade at temperatures of roughly 160 °C via dehydrochlorination. Since PVC is generally processed at temperatures between 160 °C and 210 °C, stabilizers are necessary to manufacture PVC resin products such as wire and cable. Stabilizers are added to improve heat resistance during manufacturing, and to elevate the resistance of products during use against external impacts such as moisture, visible light, UV-rays and heat. Figure 2 shows the PVC heat degradation relationship between chlorine generation and temperature (Mizuno, et al. 1999).

Figure 2: Heat Degradation of PVC



There are four major categories of primary heat stabilizers used for PVC resins:

- Lead compounds
- Mixed metal salt blends
- Organotin compounds
- Organic compounds

Each of these categories will be described in detail in the next four sections of the report.

Lead compounds

Lead compounds have been the predominant stabilizer in wire and cable worldwide as a result of its cost-effectiveness and excellent electrical insulation properties (*e.g.,* for wet electrical applications). PVC is the only plastic material in which lead is commonly used as a heat stabilizer. Tribasic lead sulfate is thought to be the most widely used PVC stabilizer worldwide. Tribasic lead sulfate is usually used at a level of 4 – 5 parts per hundred resin (phr), although this level may be reduced with optimal resin and plasticizer selection. Tribasic lead sulfate stabilizers are available from several suppliers.

An advantage of lead stabilizers is that the lead chloride produced during the stabilization process does not promote dehydrochlorination. Lead stabilizers also provide excellent wet electrical characteristics for PVC compounds.

There are many different forms of lead compounds that are used as heat stabilizers for various PVC applications. These various lead compounds are listed below (OTA Focus Group June 22, 2004).

- Tribasic lead sulfate CAS 12202-17-4
- Dibasic lead phthalate (Dipthal) CAS 69011-06-9
- Dibasic lead phosphite (Diphos) CAS 1334-40-7
- Tetrabasic lead fumarate CAS 13698-55-0
- Tribasic lead maleate CAS 12275-07-9
- Tetrabasic lead sulfate CAS 52732-72-6
- Monobasic lead sulfate CAS 12036-76-9
- Dibasic lead stearate (co-stabilizer) CAS 12578-12-0
- Normal lead stearate (co-stabilizer) CAS 1072-35-1
- Basic lead carbonate CAS 1319-46-6

Section 3.4 Additional Heat Stabilizer Product Information provides a listing of commercially available lead heat stabilizer products for various wire and cable applications. Information provided in this section includes manufacturer name, model name, chemical(s) used, and key performance attributes.

Mixed Metals

Mixed metals are often used as heat stabilizers in flexible PVC products such as wire and cable. The most common mixed metals used are barium/zinc, calcium/zinc, magnesium/zinc, magnesium/zinc/aluminum, and magnesium/aluminum (hydrotalcite). Barium/cadmium is another mixed metal used as a heat stabilizer, but it has mostly been phased out due to cadmium toxicity concerns. However, it is still commercially available for some applications. Mixed metal stabilizers have extensive use as replacements for lead heat stabilizers in PVC wire and cable applications.

Mixed metal powder stabilizers are mixtures with varying constituents. Powder stabilizers described as lubricating are based on blends of stearates, often barium, calcium or zinc. Moderately lubricating powders are based on laurates rather than stearates. Small amounts of calcium carbonate may be added to aid dispersion, and titanium dioxide may be added for color improvement. Other materials may be added to act as antioxidants and hydrogen chloride (HCl) scavengers. For example, mixed metal heat stabilizers may contain polyols such as pentaerythritol that function as HCl scavengers during processing.

Other important materials in mixed metal stabilizers include zeolite and hydrotalcite. Hydrous zeolite is a complex microporous aluminosilicate that is able to exchange 18 – 20% of its weight for HCl. Hydrotalcite is a platy form of magnesium aluminum hydroxycarbonate. It exchanges carbonate for chloride, thus eliminating carbon dioxide and sequestering HCl (Grossman 2006).

Mixed metal heat stabilizers have been used for years in replacing lead stabilizers in wire insulation and jackets with minimal wet electrical requirements. Initially, barium/zinc stabilizers were used for this application, but it is now common to use calcium/zinc/zeolite or calcium/zinc hyrdrotalcite blends. A standard non-lead formulation for 70 degrees C rated nonmetallic building wire (NM-B) jacket to replace a tribasic lead sulfate stabilizer is illustrated in Table 3.4.4E. This formulation requires approximately the same heat stabilizer loading as a formulation with 4 - 5 phr of tribasic lead sulfate.

Table 3.4.4 E: Formulation for Building Wire (NNM-B) Jacket

Material	Parts per Hundred Resin (PHR)
PVC (electrical grade, medium MW)	100
DIDP (electrical grade)	55 – 60
$CaCO_3$	50
Stearic acid	0.25
Calcium/zinc stabilizer	4 – 5
Epoxidized soybean oil (ESO)	0 - 5

Source: Grossman

NM-B insulation often must meet wet electrical requirements, such as maintaining insulation resistance during 6 months in water at 75 degrees Celsius. For insulation with wet electrical requirements, the calcium/zinc stabilizers should be based on hydrotalcite rather than zeolite. A typical formulation for this application is illustrated in Table 3.4.4F. For wet electrical testing at 90 degrees Celsius, the calcined clay should be silane treated to minimize water pickup, and the plasticizer could be trimellitate (*e.g.,* triisononyl trimellitate, TINTM).

Table 3.4.4 F: Formulation for NM-B Insulation

Material	Parts per Hundred Resin (PHR)
PVC	100
Calcined clay (electrical grade)	10
$CaCO_3$	5 - 10
TINTM plasticizer or equivalent	25
Undecyl dodecyl phthalate (UDP) plasticizer or equivalent	25
Calcium/zinc/hydrotalcite stabilizer	4 - 7

Source: Grossman

Another demanding wire and cable application is the stabilization of PVC jackets for plenum cables and other low smoke flame resistant applications. The challenge is to stabilize the brominated flame retardants as well as the resin, and to counteract the destabilizing activity of various low smoke additives. This requires high stabilizer loading, typically 4 – 6 phr for calcium/zinc/zeolite heat stabilizer. A typical formulation for this application is illustrated in Table 3.4.4G.

Table 3.4.4 G: Formulation for PVC Plenum Cables

Material	Parts per Hundred Resin (PHR)
PVC	100
ATH	60
FR plasticizer	40
Zinc borate	9
AOM	4.5
Antimony oxide	1
Antioxidant	0.2
Stearic acid	0.2
Calcium/zinc/zeolite stabilizer	4 - 6

Source: Grossman

The following table indicates the difficulty and cost for transitioning from lead to non-lead heat stabilizers for various wire and cable applications.

Table 3.4.4 H: Lead to Non-Lead Heat Stabilizer Transition (Source: AlphaGary)

Style	Description	Transition	Cost Effect
SPT – 1, 2, 3	Appliances	Fairly easy	Low
TW, THW	Building wire, outdoor flexible cords	Very difficult	Moderate
THHN, THWN	Industrial/residential building wire	Very difficult	Moderate
ST, SJT	300/600 volt flexible cords	Fairly easy	Low
STW, SJTW	300/600 volt flexible cords (outdoor)	Very difficult	Low
CM, CMR	Communications: tray/riser	More difficult	Low
CMP	Communications: plenum	More difficult	Moderate
UL 758	Fixed appliance wire	Difficult	Moderate
Vinyl TPE	Booster, audio	Difficult	Moderate
SEO, SJEO	Service entrance	Fairly easy	Moderate

Organotin compounds

Organotin chemicals are compounds that contain at least one bond between tin and carbon. The organotins are classified by their alkyl groups (octyl, butyl, and methyl) and their ligands such as thioglycolic acid esters, reverse esters, and carboxylic acids. The major applications for organotins include PVC heat stabilizers, catalysts, glass coatings, biocides, and agrichemicals (Batt). Organotin compounds are used primarily for rigid PVC applications such as pressure pipe, drain/waste/vent pipe, siding, profile extrusion, sheets, roofing, and bottles. Sulfur-containing organotin compounds are currently the most efficient and most universally used heat stabilizer among all organotins. For example, organotin mercaptides are able to react with hydrogen chloride and also help impede autoxidation. The combination of these two functions gives the organotin mercaptides excellent thermostabilizing properties.

Organotins can function as heat stabilizers with levels as low as 0.3 phr. Organotins are used for some flexible PVC applications as well such as flooring topcoats and foamed plastisols. However, organotin heat stabilizers have not yet been commercialized as a replacement for lead in PVC wire and cable applications.

Organic compounds

Organic compounds are a new entry in the market and the subject of intense development by the major heat stabilizer producers. Several types are being evaluated including thiol esters and heterocyclic compounds. In the 1980's, Ciba developed a new class of nonmetallic stabilizers based on the carbon nitrogen six membered ring heterocycle 1,2-dimethyl-4-aminouracil. Research has been conducted for aromatic and aliphatic organic thiol compounds to stabilize PVC compositions. Recently, Professor W.H. Starnes from the College of William and Mary has reported that thiol esters such as 2-ethylhexyl 3-mercaptobenzoate function as efficient stabilizers. Although their usage is still very low, they could become a significant factor in the market in response to the pressures to replace heavy metal heat stabilizers. There is a significant research and development effort underway to develop organic stabilizers as an alternative to mixed metal types (Grossman 2006).

It has been reported that the addition of epoxidized soybean oil (ESO) increases the heat stabilizer effectiveness for the thiol esters mentioned above. This includes enhanced performance for dynamic heat stability and decomposition time. Generally, epoxidized soybean oil is utilized in PVC as a hydrogen chloride (HCl) scavenger. Epoxidized soybean oil can be used at a loading of 3 to 10 parts per hundred resin (phr). (Starnes, William Herbert Jr., Du 2004)

Drivers for Change

There are numerous factors that drive companies in the wire and cable industry to switch to less hazardous materials in their products. These factors can be categorized as regulatory and market drivers. For regulatory drivers, the European Union has enacted several directives over the past several years aimed at restricting the use of certain hazardous materials in vehicles and electrical and electronic equipment. In January 2003, The European Union (EU) published directives on Waste Electrical and Electronic Equipment (WEEE) and the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (RoHS).

The WEEE directive deals with end-of-life management of electrical and electronic equipment (*e.g.,* take-back and recycling of used computers and equipment), whereas the RoHS directive addresses the types of materials that are used in manufacturing electrical and electronic equipment.

RoHS restricts the following six chemicals above certain threshold amounts, with certain exceptions: lead, cadmium, hexavalent chromium, mercury, poly-brominated biphenyls and poly-brominated diphenyl ethers, with an implementation date of July 1, 2006. Companies and suppliers to companies that sell products in the European Union must find safer alternatives for these substances to continue selling into the European marketplace. The regulations also promote re-use and recovery of products, and minimizing the risks associated with recycling and disposing of these products at the end of their useful life.

Japan has its own regulations requiring the recycling of certain electronic products and China has passed a set of its own regulations similar to those of the European Union, with an effective date of March, 2007. In the U.S., drivers include a focus on lead in wire and cable products under California Proposition 65 and the US EPA`s focus on persistent, bioaccumulative and toxic (PBT) substances.

Even in the absence of regulatory requirements, many large companies have taken the initiative to eliminate materials of concern from their products where possible. They are trying to make more environmentally friendly and recyclable products, as well as trying to phase out materials that they believe may be restricted in the future. In particular, many U.S. automotive and electronics companies such as GM, Toyota, Dell and Apple have begun to phase out lead and some halogenated compounds from their products. These requirements move down the supply chain to manufacturers all over the world, who must be able to supply components without these materials or risk loss of business.

Lead and Non-lead Heat Stabilizers for PVC Wire and Cable Coatings: Performance Considerations

The performance of any heat stabilizer depends on the specific application and the formulation used. In general, it was found that the lead-free heat stabilizers can achieve comparable performance properties to the lead heat stabilizers for many applications. The results of some recent performance testing conducted by industry between lead and non-lead heat stabilizers is included to illustrate this point.

Amfine Chemical Corporation is a provider of mixed metal heat stabilizers for use in PVC wire and cable applications. In 2003, Amfine conducted a performance study comparing various electrical and mechanical properties for the following five different PVC formulations.

A: Dibasic lead phthalate and stearic acid
B: Tribasic lead sulphate and dibasic lead stearate
C: Amfine RUP-110GP (Magnesium zinc heat stabilizer)
D: Amfine RUP-110GP (Magnesium zinc heat stabilizer)
E: Amfine RUP-144RT (Magnesium zinc heat stabilizer)

The base formulation for this test is listed in the table below.

Table 3.4.4 I: Base Formulation

Material	PHR
Polyvinyl chloride (PVC)	100
TINTM	25
Diundecyl phthalate (DUP) plasticizer	25
Clay #33	12
Sb_2O_3	4

The results from this performance test are shown in Table 3.4.4 J.

Table 3.4.4 J: Lead and Non-lead Heat Stabilizer Performance Comparison

Material/Performance Property	A	B	C	D	E
Dibasic lead phthalate (phr)	6.0				
Stearic acid (phr)	0.2				
Tribasic lead sulfate (phr)		5.0			
Dibasic lead stearate (phr)		1.0			
RUP-110GP (phr)			6.0	8.0	
RUP-144RT (phr)					6.0
Press plaque, 190 Cx5min (YI)	31.0	24.1	31.5	30.7	29.2
190 Cx30min (YI)	43.7	30.7	36.0	34.1	33.5
Color rating after heat aging 190^0Cx60min (1 for good, 10 for poor)	7.5	7	6.5	6.5	6
Decomposition time at 200 C (min)	90	120~	120	120<	120<
Volume Resistivity (VR) VRx10^{14} Original (Ohm-cm)	0.7	3.8	4.0	3.9	0.9
Immersion Into hot water (90 C)					
VRx10^{14} after 1 week	0.1	0.1	12.7	12.8	16.4
VRx10^{14} after 2 weeks	0.08	0.2	20.8	14.9	23.5
VRx10^{14} after 3 weeks	0.9	2.9	16.1	17.0	39.0
VRx10^{14} after 4 weeks	0.6	0.8	12.8	15..9	22.9
VRx10^{14} after 5 weeks	0.7	1.6	15.4	14.6	16.0
VRx10^{14} after 6 weeks	0.4	4.3	12.1	16.6	12.3
VRx10^{14} after 12 weeks	0.6	2.9	11.3	22.4	10.8
VRx10^{14} after 18 weeks	0.4	3.2	12.4	15.4	15.5
VRx10^{14} after 26 weeks	0.5	2.2	11.5	15.5	14.5
Elongation %	323	336	329	324	324
Tensile strength MPa	31.6	32.0	31.1	30.0	31.6
100% Modulus MPa	19.2	18.6	18.2	18.1	18.6
Weight Loss %	6.0	5.8	5.6	6.3	6.6
Elongation %	271	275	280	265	285
Elongation retention %	84	82	85	82	88
Tensile strength MPa	32.1	32.8	32.5	31.7	33.5
100% Modulus MPa	25.1	25.4	24.8	24.8	24.6

Source: Amfine Datasheet for RUP 144RT

For this testing, the non-lead heat stabilizers had similar or better performance compared to the lead heat stabilizers for mechanical properties such as elongation and tensile strength, and electrical properties such as volume resistivity.

In 2002, Sumitomo Electric Industries published a paper that compared the performance between lead and lead-free heat stabilizers for PVC wire. The lead-free heat stabilizer used for the performance test was a combination of calcium/zinc and hydrotalcite. The outer diameter of the conductor was 0.48 mm, and the thickness of the insulation was 0.5 mm. The results of the performance test are shown in the table below.

Table 3.4.4 K: Lead versus Lead-free Heat Stabilizer Performance Test

Performance Characteristic	Lead-free Stabilizer	Lead Stabilizer
Tensile Strength	19.9 MPa	22.1 MPa
Elongation	117%	109%
Heat Deformation (121 degrees C, 250 g)	60.9	72.8
Flammability (VW-1)	Pass	Pass
Cold Bend (-10 degrees C 1 hour)	No crack	No crack
Volume resistivity (ohms cm)	1.0×10^{14}	2.0×10^{14}

Source: Moriuchi et al.

For this testing, the non-lead heat stabilizers had similar performance compared to the lead heat stabilizers for mechanical properties such as elongation, heat deformation, and tensile strength, as well as electrical properties such as volume resistivity.

Ferro Polymer Additives Division has conducted performance testing to compare their Therm-Chek 7700 heat stabilizer versus a tribasic lead sulfate heat stabilizer. Therm-Chek 7700 is a mixed metal heat stabilizer using aluminum/magnesium/zinc. The testing was done to compare the water absorption and the residual heat stability between the two stabilizer types. The residual heat stability is measured using the Congo Red Test. For this test, the sample is cut into small pieces and then heated. Hydrogen chloride (HCl) released from the sample causes a color change of moist Congo Red. The time duration is measured from the time heat is applied to the sample until the color change occurs. The base formulation for this test is shown in Table 3.4.4L.

Table 3.4.4 L: Base Formulation

Material	Concentration (phr)
PVC	100
DIDP	50
$CaCO_3$	50
Calcinated clay	10
Stabilizer	4

The test conditions were conducted on a 70 g sample weight. The following table indicates the results of the testing.

Table 3.4.4 M: Testing Results

Performance Property	Tribasic Lead Sulfate	Therm-Chek 7700P
Congo Red (200 degrees C)	122	134
Water Absorption (14 days at 70 degrees C)	1.0 %	1.1 %

Source: Ferro, Polymer Additives Division, Therm-Chek 7700P, Technical Datasheet

For this test, the mixed metal stabilizer outperformed the lead stabilizer in the Congo Red test and had comparable water absorption levels with the lead stabilizer.

Synergistic materials

The performance of existing non-lead heat stabilizers may be enhanced through the addition of certain synergistic materials in the PVC resin. Research is underway at the University of Massachusetts Lowell to enhance the performance and practical utility of non-lead heat stabilizers through the addition of a small amount of organically modified clay, to form a layered silicate nano-composite. The objective of this research is to improve the thermal stability, flame retardance, and overall performance of the formulation using the same loadings of commercially available non-lead heat stabilizers. The intent is to take advantage of an effect already demonstrated commercially by nano-composite barrier resins. The dispersed clay platelets improve barrier properties thanks to their high aspect ratio and impermeability, which forces diffusing species to take a highly tortuous path in order to pass through the material.

The addition of clays to such a resin system allows for a number of specific enhancements with respect to what non-lead heat stabilizers already accomplish. First, dispersed clays can increase HCl scavenging efficiency. Second, the cationic surfactants that are ion-exchanged into the inter-layer galleries of the clays can help with dispersing the clay in the polymer (their primary function), but also serving as antioxidants themselves, through inclusion of unsaturated functionalities for instance, further enhancing the thermal stability of these materials. Finally, in addition to the enhanced thermal stability often seen in polymer / clay nanocomposites in general, an additional advantage often seen in these systems is their inherent flame retardance, due to formation of silicate char once burning begins at an exposed surface (Schmidt 2005).

The results reported in United States Patent Number 6872854 indicates that synergistic materials may be used to address the discoloration of the PVC compound when using non-lead heat stabilizers, particularly discoloration in the initial stage of heating. Complexes of metal salts of organic acids in combination with β-diketone compounds, such as calcium benzoate 1,3-diphenylpropane-1,3-dionate (CBDBM), are efficient solid intermediates for halogenated resin stabilizers. When used jointly with other low toxicity intermediates, such as zinc or magnesium intermediates, these stabilizer complexes can replace previously used mixed metal stabilizers containing cadmium, lead and/or other heavy metal compounds (Krainer, et al. 2005).

Financial Assessment

The three major financial impact categories to consider for switching to non-lead heat stabilizer for PVC wire and cable applications are: raw material costs, processing costs, and research/testing/approval costs. The raw material costs are a function of the heat stabilizer raw material price per pound, and the heat stabilizer loading requirements in the PVC formulation. It is challenging to obtain a direct cost comparison between lead and non-lead heat stabilizers. The heat stabilizer prices are typically not published, and actual pricing is negotiated between heat stabilizer vendor and compounder. Further, the heat stabilizer is comprised of numerous constituent materials which may be varied depending on application requirements. Also, PVC heat stabilizers are usually delivered as so-called one packs, which not only contain the heat stabilizers but also lubricants and acrylic processing aids.

Historically, there was a significant price differential between the lead and non-lead heat stabilizers. The premium required for non-lead heat stabilizer was approximately 10 percent approximately four years ago. However, over the past few years the sales volumes of mixed metal heat stabilizers have significantly increased because of greater market acceptance. Consequently, the cost for mixed metal heat stabilizers has decreased. Based upon conversations with heat stabilizer suppliers and compounders, the cost differential between lead and mixed metal heat stabilizers is estimated to now be between cost neutral and a 10% premium for mixed metal heat stabilizers.

The loading requirements for lead and non-lead stabilizers vary depending on the application. In general, the loading requirements between lead and non-lead heat stabilizers are considered to be not significantly different.

From a processing cost standpoint, no new capital equipment is typically required for compounders or wire and cable manufacturers that are transitioning from lead to non-lead heat stabilizers. However, some engineering time is required to make the necessary changes to their process operating profiles.

A significant barrier to switching to new PVC formulations without lead heat stabilizers is the testing and approval costs. Cable manufacturers that change their PVC formulations to eliminate the use of lead as a heat stabilizer must undergo a testing and approval process similar to that required for most formulation changes. Typically, new compounds are initially screened in small scale performance tests to evaluate various mechanical, electrical, thermal, and fire resistance properties. Next, the wire and cable products using the new formulation must be manufactured and evaluated in their finished geometry at third party verification laboratories. The major verification laboratories are Underwriters Laboratories (UL) and ETL Semko. The extent of testing required depends largely on the potential effect the change will have on the critical parameters of the insulation and jacket. It is necessary to check with the testing authority to determine the exact testing required for a given formulation change.

There are up-front research and development efforts required to develop a lead-free substitute for existing compounds using lead stabilizers. This effort has been estimated at approximately 100 man-hours for each new formulation. The testing and approval costs for wire and cable manufacturers are typically between $3,000 to $10,000 per compound per cable. The low end of this range is usually for applications with minimal testing requirements such as a PVC jacket. The high end of this range is typically for applications that require more comprehensive testing such as PVC insulation (AlphaGary Corporation 2002). It may be possible to reduce overall testing costs by obtaining testing and approval for a family of cables at one time, rather than taking a cable by cable approach (Massachusetts Office of Technical Assistance). The following table provides general testing requirements for different applications:

Table 3.4.4 N: Testing Requirements for Various Wire and Cable Applications (OTA)

Application Type	Testing and Approval
Wet-rated wire insulation – *e.g.,* THWN	Standard for Thermoplastic Insulated Wires and Cables – UL 83. The water immersion test at rated temperature takes a minimum of 12 weeks and frequently is completed in 24 weeks.
Power Limited Tray Cable (PLTC)	Cable Tray Flame Test (UL 1685) required and physical testing on samples of the cable jacket, un-aged and after aging in an air oven (typically a seven-day test).
Riser-rated communications cable	Riser Cable Flame Test (UL 1666) and physical testing similar to PLTC cable.
Plenum jacket	NFPA 262 Smoke and Flame Test required. Because of the difficulty in predicting outcomes of this test based on small changes in construction, more testing than for PLTC and CMR constructions may be required.
Flexible Cable –e.g. STP cord	No testing required a priori. Manufacturer responsible for providing assurance that the product meets the UL standard. UL will confirm that the product meets the standard during follow-up testing.
Generically authorized compounds	Substitutions are the responsibility of the cable manufacturer and need not be pre-authorized. UL will confirm that the product meets the standard during follow-up testing.

Environmental, Health, and Safety Assessment

Various lead compounds are used for lead heat stabilizers. Lead compounds have different physical characteristics and chemical properties than lead. Consequently, the environmental and health effects for lead compounds are different than lead. For this study, ten different lead compounds were identified for use in lead heat stabilizers. The most widely used lead compound in lead heat stabilizers is tribasic lead sulfate. The CAS number for tribasic lead sulfate is 12202-17-4, and the chemical formula is $Pb_4O_3(SO_4)H_2O$. Tribasic lead sulfate is comprised of 88 – 90% lead. (Polytrans S.A.) Since there is limited environmental and health data available for tribasic lead sulfate and it is primarily comprised of lead, the environmental, health, and safety properties of lead were used for comparison with lead-free stabilizer alternatives.

The mixed metal heat stabilizer alternatives typically are each comprised of several different chemical compounds. Given the time and resource constraints for this project, the environmental, health, and safety data were collected and reported for five representative mixed metal heat stabilizers. These five heat stabilizers and their constituent chemical compounds are shown in Table 3.4.4 O.

Table 3.4.4 O: Mixed Metal Heat Stabilizers for PVC Wire and Cable Coatings

Manufacturer	Product Name	Chemical Compounds
Amfine Chemical Corp. (Mitsubishi, Asahi Denka)	RUP-103	Magnesium-zinc: Inorganic compounds trade secret (< 80%) Zinc stearate (< 20%) Calcium silicate (< 10%)
Chemtura	Mark EZ 760	Magnesium/aluminum/zinc: Isopropylidenediphenol (< 20%) zinc stearate (< 15%) magnesium aluminum hydroxide carbonate CAS 11097-59-9 (? %)
Chemtura	Mark 6750	Calcium/barium/zinc: Calcium hydroxide (45 – 55%) Barium stearate (20 – 30%) Zinc stearate (10 – 20%) Titanium dioxide (5 – 10%) Trade secret (? %)
Kyowa (Kisuma)	Alcamizer P93	Magnesium/aluminum/zinc: Magnesium zinc aluminum hydroxide carbonate hydrate, CAS 169314-88-9, (95 - 100%) MgO/Al_2O_3 Molar ratio: 3 ZnO/Al_2O_3 Molar ratio: 1
Akrochem Corporation	Zeocros P-321	Magnesium/aluminum: Magnesium aluminum hydroxide carbonate CAS 11097-59-9 (95%) Water (5%)

Sources: (Amfine Chemical Corporation RUP-103 MSDS, 1999, Chemtura Mark 6750 MSDS, 2005, Chemtura Mark EZ 760 MSDS, 2006, Kisuma Alcamizer P93 MSDS, 2005, Akrochem Corporation Zeocros P-321 MSDS, 2005)

In general, the mixed metal alternatives are comprised of chemical compounds that are insoluble or negligibly soluble in water. Consequently, aquatic toxicity for many of these compounds were not identified because of the low water solubility.

From an environmental standpoint, all of the chemical compounds are not considered to be ozone depleting or greenhouse gases. Also, there was no evidence found for these chemicals to be bioaccumulative.

For acute health effects, the following chemicals are considered dermal, ocular, and respiratory irritants: zinc stearate, titanium dioxide, calcium silicate, calcium hydroxide, and isopropylidenephenol. Magnesium zinc aluminum hydroxide carbonate hydrate is considered to be an irritant for dermal and respiratory only. There is no evidence that barium stearate and magnesium aluminum hydroxide carbonate are irritants.

The OSHA-PEL for nuisance dust of 15 mg/m^3 total dust and 5 mg/m^3 for respirable dust is recommended for calcium hydroxide, zinc stearate, calcium silicate, and magnesium aluminum hydroxide carbonate. The oral LD50 (lethal dose) concentrations for rats is shown in the table below for each of the chemicals.

Table 3.4.4 P: LD50 for Various Heat Stabilizer Chemicals

Chemical	LD50 Oral Dose for Rats (mg/kg)
Tribasic lead sulfate	> 2,000
Magnesium aluminum hydroxide carbonate	> 2,000
Isopropylidenephenol	3,250
Barium stearate	3,390
Calcium silicate	3,400 – 5,000
Magnesium zinc aluminum hydroxide carbonate hydrate	> 5,000
Zinc stearate	> 5,000
Calcium hydroxide	7,340
Titanium dioxide	12,000 – 20,000

For chronic health effects, there is no evidence that any of these chemicals cause mutagenicity, reproductive harm, or developmental harm. Except for titanium dioxide, carcinogenicity is not considered an issue for these chemicals. Titanium dioxide is considered by NIOSH to be a potential occupational carcinogen (NIOSH). Also, skin sensitization is not considered an issue for these chemicals with the exception of isopropylidenephenol where skin sensitization is considered possible with repeated exposures.

Significant environmental, health, and safety considerations not previously mentioned in this report for the specific chemicals used in mixed metal stabilizers are listed below.

Zinc stearate: Grossly excessive and chronic inhalation of the dust may cause a progressive chemical pneumonitis, cyanosis, and pulmonary edema. Fine dust dispersed in air in sufficient concentrations, and in the presence of an ignition source is a potential dust explosion hazard (Baker 2004). Thermal oxidative decomposition of this chemical can produce carbon dioxide, carbon monoxide, and zinc oxide fumes.

Calcium silicate: Exposure to this chemical can occur through inhalation, ingestion, or skin contact. No further significant environmental, health, and safety considerations were identified for this chemical.

Isopropylidenephenol: Inhalation and dermal absorption are considered to be major routes of exposure for this chemical. Degradation products for this chemical include carbon dioxide and monoxide.

Magnesium aluminum hydroxide carbonate: Thermal decomposition occurs for this chemical at temperatures greater than 300 degrees Celsius, and acids with pH < 1 should be avoided (Kisuma Chemicals BV 2004).

Calcium hydroxide: Dermal absorption is considered possible for this chemical. Calcium hydroxide can have violent reactions with maleic anhydride, mitroethane, nitromethane, nitroparaffins, nitropropane, and phosphorus. Calcium hydroxide is a gastric irritant, and ingestion may be followed by severe pain, vomiting, diarrhea, and collapse. Calcium hydroxide is corrosive and may cause severe burns and blistering upon dermal contact. For ocular contact, it may induce corneal epithelium and blindness (Baker 2005). This chemical decomposes upon heating to produce calcium oxide.

Barium stearate: The decomposition products for this chemical are oxides of barium and carbon. There are limited environmental and health data available for this chemical.

Titanium dioxide: Long term exposure to titanium dioxide dust may result in mild lung fibrosis. Violent or incandescent reactions may also occur with lithium or other pure metals such as aluminum, magnesium, potassium, sodium, and zinc. (Baker 2003)

Magnesium zinc aluminum hydroxide carbonate hydrate: This chemical may be harmful to aquatic organisms due to the presence of zinc, and may cause long-term adverse effects in the aquatic environment. (Kisuma Chemicals BV 2005)

Other Relevant Wire and Cable Initiatives

U.S. Environmental Protection Agency Design for Environment Project

The U.S. Environmental Protection Agency's (EPA) Design for the Environment (DfE) Program and the Massachusetts Toxics Use Reduction Institute (TURI) have formed a partnership with wire and cable industry stakeholders to conduct a life-cycle assessment (LCA) of the insulation and jacketing used in three different wire and cable products. Project partners include wire and cable manufacturers, compounders (i.e. AlphaGary), additive suppliers (i.e. Albemarle), trade association members, TURI, EPA, and project researchers.

The specific goal of the partnership is to evaluate the environmental impacts of the current standard material formulation and alternative formulations for heat stabilizers, flame retardants, and polymer systems for selected wire and cable products, in order to help companies make environmentally sound product and material choices.

The focus of this project will be on the following three product types:

- Category 6, riser-rated communication cable (CMR)
- Category 6, plenum-rated communication cable (CMP)
- Non-metallic sheathed cable, as used in building wire (NM-B)

These products were chosen by the project partners because together they contain materials common to many wire and cable applications, they typically contain materials for which alternatives are being sought, and they represent a significant share of the wire and cable market. The U.S. EPA effort will examine various heat stabilizer technologies for these products including lead, calcium/zinc, and barium zinc. This project will also examine various resins for these product types including: polyvinyl chloride (PVC), polyethylene (PE), high density polyethylene (HDPE), and ethylene vinyl acetate (EVA).

Using a life-cycle assessment approach, the study will generate data to help manufacturers, users, and suppliers of wire and cable incorporate environmental considerations into their decision-making processes. An LCA examines all of the steps involved in manufacturing, using, and disposing of a product or material, and estimates the environmental impacts from each of the following stages: raw material extraction/processing, manufacture, product use/maintenance, and end-of-life disposition. (USEPA 2006)

Massachusetts Toxics Use Reduction Institute: Wire and Cable Supply Chain Program

In 2001, the Massachusetts Toxics Use Reduction Institute (TURI) initiated a multi-year effort to work with the Wire and Cable industry supply chain. This was in response to emerging regulations and market pressures that will affect the hazardous materials used by the industry, including lead compounds, decabromodiphenyl ether, cadmium, and hexavalent chromium. Making successful, robust changes in a product’s basic materials requires participation of all parts of the product supply chain, including raw material suppliers, compounders, extruders, and original equipment manufacturers. The Institute's objective is to find alternative safer materials to help the industry remain competitive.

This supply chain program benefits from university research on the environmental impact of wire and cable constituents, laboratory evaluation of alternative materials, and meetings that draw companies from throughout the supply chain together to discuss human and environmental impacts, regulatory requirements, new technology developments, and business and technical strategy.

The Institute has provided several workshops over the past five years. Over 100 professionals from over 6o firms have attended semiannual workshops that span the supply chain, topics covered include updates on the latest regulatory changes, speakers from original equipment manufacturers (OEMs) such as Dell, Microsoft and Xerox, and reviews of innovative products and raw materials such as low-smoke halogen free wiring (Judd Wire, Inc.), heavy metal free jacket and insulation materials (AlphaGary), and lead-free heat stabilizers that pass wet electrical requirements (Teknor Apex).

Vinyl 2010

Vinyl 2010 is a voluntary commitment of the European PVC industry to meet the challenge of sustainable development by undertaking important principles and actions to address PVC manufacture, additives, and waste management. The PVC industry is represented by the following European associations: European Council of Vinyl Manufacturers, European Council for Plasticizers and Intermediates, European Stabilizers Producers Association, and European Plastics Converters. Based on 2000 consumption levels, this voluntary commitment includes a plan to reduce the use of lead heat stabilizers by 50% by 2010, and a 100% reduction by 2015. (European Council of Vinyl Manufacturers (ECVM) et al. 2001)

Massachusetts Office of Technical Assistance (OTA) Greener Cable Initiative

The Office of Technical Assistance for Toxics Use Reduction (OTA) is a non-regulatory office within the Executive Office of Environmental Affairs that helps manufacturers and other toxic chemical users reduce or eliminate their use of toxics and generation of hazardous byproducts. In June 2004, OTA conducted a focus group meeting with the wire and cable industry and has subsequently developed a fact sheet titled, "Strategies for Streamlining Testing and Certification: Environmentally Friendly Wire and Cable". The purpose of this fact sheet is to review strategies for streamlining the testing and certification process, thereby facilitating companies adoption of alternative heat stabilizers and other substances. This initiative has included many companies throughout the supply chain including Halstab, AlphaGary, and Polymer Concentrates.

Additional Heat Stabilizer Product Information

The following tables provide information for the various lead and non-lead heat stabilizers that are commercially available.

Table 3.4.4 Q: List of Alternatives for Lead Heat Stabilizers

Manufacturer	Data Source	Model	Chemical (s)	Performance
Addenda	Datasheet	addiStab - TLF	Tetrabasic lead fumarate (CAS 13698-55-0)	Heat stabilizer used for PVC plenum cable jackets and flexible PVC wire insulation. Used with most sensitive plasticizers, and frequently used with dibasic lead phthalate.
Addenda	Data sheet	addiLube - DBLS	Dibasic lead stearate (CAS 12578-12-0)	Co-stabilizer and lubricant for wire insulation and jacketing. Commonly used in conjunction with lead based heat stabilizers. Typical use level is 0.5 to 1.0 PHR.
Addenda	Data sheet	addiStab-TLM	Tribasic lead maleate (CAS 12275-07-9)	Heat stabilizer for wire insulation and jacketing. Used where photosensitivity is not an issue. Frequently used in combination with dibasic lead phthalate.
Addenda	Datasheet	addiThal	Dibasic lead phthalate (CAS 69011-06-9)	Primary heat stabilizer for flexible PVC. Used for high temperature wire insulation and jacketing.
Addenda	Datasheet	addiBase	Tribasic lead sulfate (CAS 12202-17-4)	Primary heat stabilizer for flexible PVC. Used for low and high temperature wire insulation and jacketing.
Addenda	Datasheet	addiBase-Mono	Monobasic lead sulfate (CAS 12036-76-9)	Primary heat stabilizer for flexible PVC. Used for wire insulation and jacketing. Less reactive with plasticizers than tribasic lead sulfate.

Table 3.4.4 Q: List of Alternatives for Lead Heat Stabilizers				
Manufacturer	**Data Source**	**Model**	**Chemical (s)**	**Performance**
Addenda	Datasheet	addiBase-Tetra	Tetrabasic lead sulfate (CAS 52732-72-6)	Primary heat stabilizer for flexible PVC. Used for low temperature wire insulation and jacketing. Used where photosensitivity is not an issue.
Associated Additives		Almstab	Dibasic lead phosphite	
Associated Additives		Almstab	Normal lead stearate (CAS 1072-35-1)	Secondary stabilizer and lubricant
Associated Additives		Almstab	Basic lead carbonate	Can be used as a PVC stabilizer where the processing temperature does not exceed 180 degrees C.

Table 3.4.4 R: List of Mixed Metal Heat Stabilizers:				
Manufacturer	**Data Source**	**Model**	**Chemical (s)**	**Performance**
Akrochem Corp.	Bill Allen Datasheet MSDS	Zeocros P-321	Magnesium aluminum hydroxy carbonate (95%) CAS 11097-59-9 water (<5%) CAS 7732-18-5	Can be used for wire and cable applications, however, not as effective as lead for water resistance. Has the added benefit of releasing water at 300 degrees Celsius and therefore can be used as a flame retardant.
Akcros (part of Akzo Nobel)		Akcrostab BZ-5043, Lankromark LZB 248	Barium-zinc:	
Amfine Chemical Corp. (Mitsubishi, Asahi Denka)	Jay Kolaya Website Datasheet MSDS	RUP-103	Magnesium-zinc: Inorganic compounds trade secret (< 80%) Zinc stearate (< 20%) Calcium cilicate (< 10%)	For automobile PVC wire harness insulation.

Table 3.4.4 R: List of Mixed Metal Heat Stabilizers:

Manufacturer	Data Source	Model	Chemical (s)	Performance
Amfine Chemical Corp. (Mitsubishi, Asahi Denka)	Jay Kolaya Website MSDS	RUP – 110GP	Magnesium-zinc: magnesium compounds trade secret (<80%) Zinc stearate (< 20%) Inorganic compounds trade secret (< 10%) Organic compounds trade secret (<10%)	For automobile PVC wire harness.
Amfine Chemical Corp. (Mitsubishi, Asahi Denka)	Jay Kolaya Datasheet MSDS	RUP – 144 RT	Magnesium-zinc: Inorganic compounds trade secret (< 75%) Zinc stearate (< 25%) Organic compounds trade secret (< 20%)	For automotive PVC wire harnesses and UL building wires (such as THW-2 and THWN-2) requiring long term wet properties.
Arkema (previously Atofina)	Peg Duffy Additives Customer Service	Stavinor	Calcium-zinc	Product no longer manufactured in the U.S., and is only available for purchase in Europe.
Associated Additives	Ingrid Lane Datasheet MSDS	Almstab PCZ4	Zinc stearate and calcium stearate	Can replace liquid cadmium-barium-zinc systems. Typical loading levels are 4 t0 6 phr. Would need to be modified for use with wire and cable applications.
Baerlocher		Baeropan, Baerostab		
Blachford	Howard Gunn	Chemstab	Barium-zinc	Products no longer manufactured.
Chemson	Sent email	Naftomix, Naftosafe	Calcium-zinc, magnesium-aluminum-zinc, organic based stabilizers?	

Table 3.4.4 R: List of Mixed Metal Heat Stabilizers:

Manufacturer	Data Source	Model	Chemical (s)	Performance
Chemtura (GL and Crompton)	Marge Biercevicz MSDS Website	Mark EZ 760	Magnesium/aluminum/zinc: Isopropylidenediphenol (< 20%) zinc stearate (< 15%) magnesium aluminum hydroxide carbonate CAS 11097-59-9 (? %)	Mark EZ 760 is a low zinc containing solid stabilizer specifically developed to meet the general requirements of PVC cable insulation compounds, e.g. heat stability and volume resistance, as well as excellent low water absorption properties. This product is also suitable for flame retarded and transparent formulation.
Chemtura (GL and Crompton)	Marge Biercevicz MSDS Website	Mark 6731	Barium/zinc: Barium stearate (< 50%) Metal oxide trade secret (< 25%) Metal oxide trade secret (< 20%) Zinc stearate (< 12%) Trade secret (< 5%) calcium silicate (< 5%)	When used with Drapex® 6.8, epoxidized soybean oil, Mark 6731 can be used as a replacement for lead and cadmium containing stabilizers in wire and cable jacketing and primary insulation compounds.
Chemtura (GL and Crompton)	Marge Biercevicz MSDS Website	Mark 6750	Calcium/barium/zinc: Calcium hydroxide (45 – 55%) Barium stearate (20 – 30%) Zinc stearate (10 – 20%) Titanium dioxide (5 – 10%) Trade secret (? %)	Used for flexible wire and cable jacket compounds. Mark 6750 is a highly efficient powder stabilizer intended to replace lead stabilizers in UL-62, UL-444, UL-493 and UL-719 jacket compounds. Mark 6750 imparts excellent early color hold and long term dynamic stability. Where solid Barium/Cadmium stabilizers are used, Mark 6750 can be substituted resulting in equivalent color hold and improved long term stability.

Table 3.4.4 R: List of Mixed Metal Heat Stabilizers:				
Manufacturer	**Data Source**	**Model**	**Chemical (s)**	**Performance**
Chemtura (GL and Crompton)	Website	Mark 6736 ACM	Barium/zinc: Barium stearate (< 45%) Metal oxide trade secret (< 20%) Zinc stearate (< 20%) Titanium dioxide (< 15%) Hydrotalcite trade secret (< 10%) Trade secret (< 5%) Calcium silicate (< 5%) Metal oxide trade secret (< 2%) Zinc compound (< 1.5%)	Designed as a replacement for conventional lead heat stabilizers for wire and cable primary insulation compounds. Compared to leads, Mark 6736ACM will improve the early color hold of the insulation compound. In addition long-term heat stability will be better than a previously available barium/zinc stabilizer. Mark 6736ACM imparts electrical properties to insulation compounds only slightly less than that of lead stabilizers.
Chemtura (GL and Crompton)	Website	Mark 6751	Calcium/barium/zinc: Calcium hydroxide (45 – 55%) Barium stearate (20 – 30%) Zinc stearate (10 – 20%) Titanium dioxide (5 – 10%) Trade secret (?%)	Used for flexible wire and cable jacket compounds, and is intended to replace lead stabilizers in UL-62, UL-444, UL-493 and UL-719 jacket compounds. Mark 6751 imparts excellent early color hold and long term dynamic stability. Where solid Barium/Cadmium stabilizers are used, Mark 6751 can be substituted resulting in equivalent color hold and improved long term stability.

Table 3.4.4 R: List of Mixed Metal Heat Stabilizers:				
Manufacturer	**Data Source**	**Model**	**Chemical (s)**	**Performance**
Chemtura (GL and Crompton)	Website	Mark 6767	Calcium/barium/ magnesium/zinc: Calcium hydroxide (<45%) Magnesium oxide (<15%) Titanium dioxide (<15%) Barium carboxylate trade secret (< 12%) Barium carboxylate trade secret (< 12%) Calcium silicate (< 8%) Antioxidant trade secret (< 8%) Trade secret (< 6%) Zinc carboxylate trade secret (< 5%) Zinc carboxylate trade secret (< 4%)	Used for flexible wire and cable PVC compounds, and is intended to replace lead stabilizers in UL-62, UL-493 and UL-719 jacket and insulation compounds. Mark 6767 is cost competitive with lead stabilizers in simple jacket compounds at lower loadings. The pound-volume cost will be virtually the same.
Chemtura (GL and Crompton)		Mark 6796	Calcium-zinc	
Chemtura (GL and Crompton)		Mark 6797	Calcium-zinc	
Chemtura (GL and Crompton)		Mark 6784 ACM	Calcium-zinc	
Durachemicals		Durastab	Calcium-zinc	
Ferro		Therm-chek RC 149, 216, 197, 215, 217	Great article	
Ferro	Datasheet	Therm-chek PD 958 P	Calcium-zinc	Developed as a replacement for lead-based heat stabilizers in wire and cable formulations. Useful in general jacketing applications, that do not require wet electrical properties

Table 3.4.4 R: List of Mixed Metal Heat Stabilizers:

Manufacturer	Data Source	Model	Chemical (s)	Performance
Ferro	SpecialChem	Therm-Chek RC 376P and RC 377P	Calcium-zinc	Designed to replace tribasic lead sulfate on a part for part basis in general purpose wire and cable jacketing applications.
Ferro		Therm-Chek SP1797	Barium/cadmium/zinc	Used for flexible PVC extrusion applications.
Ferro		Therm-Chek MX 125	Barium/cadmium/zinc	Used for flexible PVC extrusion applications.
Ferro	SpecialChem	Them-Chek RC 556P	Calcium-zinc	Replacement for lead-based heat stabilizers in general purpose jacketing and insulation applications that do not require wet electrical properties. Does not require ESO as a co-stabilizer.
Ferro	Jim Keenan Datasheet	Therm Chek 7206	Calcium-zinc	Used for a wide range of cable applications including energy and telecommunications. Used for both primary insulation and sheathing. Designed to have processing characteristics similar to those of lead. The dosage for sheathing and low temperature cables is 3 – 5 phr.
Ferro	SpecialChem	Therm-Chek 7208P	Calcium-zinc	Used for hight temperature cable and automotive wire applications. Suitable for use in 105 degree Celsius rated automotive and UL insulation products.
Ferro	Jim Keenan Datasheet	Therm Chek 7209	Calcium-zinc	Used for a wide range of cable applications including energy and telecommunications. Used for both primary insulation and sheathing. For some applications the level of lubrication may need to be adjusted. The dosage for sheathing and low temperature cables is 3 – 5 phr.
Ferro	Jim Keenan Datasheet	Therm Chek 7700	Aluminum-magnesium-zinc	Used for high temperature cable and automotive wire applications. Designed to have processing characteristics similar to those of lead. Outperforms lead in the Congo Red test. Compounds stabilized with this product exhibit lower levels of water absorption than compounds stabilized with calcium-zinc stabilizers. Recommended dosage is 7 – 12 phr.

Table 3.4.4 R: List of Mixed Metal Heat Stabilizers:

Manufacturer	Data Source	Model	Chemical (s)	Performance
Halstab		Plastistab		
Kyowa (Kisuma)	K. Kakinuma, Robert Groenhagen Datasheet MSDS	Alcamizer P93	Magnesium zinc aluminum hydroxide carbonate hydrate, CAS 169314-88-9, (95 - 100%) MgO/Al_2O_3 Molar ratio: 3 ZnO/Al_2O_3 Molar ratio: 1	No deterioration of the insulating characteristics of PVC.
Kyowa (Kisuma)	K. Kakinuma, Robert Groenhagen Datasheet MSDS	Alcamizer 1	Magnesium aluminum hydroxide carbonate hydrate, CAS 11097-59-9, (95 – 100%) MgO/Al_2O_3 Molar ratio: 4	No deterioration of the insulating characteristics of PVC.

3.4.4.5 Assessment Summary

The following table summarizes the alternatives assessment information for lead heat stabilizers.

Table 3.4.4 S: Assessment Summary of Alternative Heat Stabilizer Constituents for PVC Wire and Cable Coatings

Assessment Criteria		Lead (Reference)	Comparison Relative to Lead				
			Zinc stearate	Barium stearate	MgAlZn	MgAl	Titanium dioxide
Environmental Criteria	Toxic to Aquatic Species	Yes	+	+	+	+	+
Human Health Criteria	Carcinogenicity	EPA B2 IARC 2B	+	+	+	+	=
	Developmental Toxicity	Yes (Prop 65)	+	+	+	+	+
	LD 50 (oral dose rats)	> 2,000 for tribasic lead sulfate	+	+	+	=	+
	Occupational Exposure: PEL/REL (8-hour TWA)	0.050 mg/m^3 (REL)	+	+	?	+	+

Comparison Key + Better = Similar - Worse ? Unknown

3.5. Summary and Conclusions

Manufacturers use lead metal, alloys and compounds for many different products. Lead possesses the general physical properties of other metals, *e.g.,* as a conductor of electricity and heat. Lead has a low melting temperature (327° C) and extreme malleability, which enables the easy casting, shaping, and joining of lead products. The high density of lead is desirable for several product categories including weighting applications, and shielding against sound, vibration, and radiation.

Lead is used in the manufacture of batteries, metal products, cables, ceramic glazes, and various other products. Exposure to lead can occur from breathing contaminated workplace air or house dust or ingesting lead-based paint chips or contaminated dirt. Lead is a very toxic element, causing a variety of effects at low dose levels. Brain damage, kidney damage, and gastrointestinal distress are seen from acute (short-term) exposure to high levels of lead in humans. Chronic (long-term) exposure to lead in humans results in effects on the blood, central nervous system (CNS), blood pressure, kidneys, and Vitamin D metabolism. Children are particularly sensitive to the chronic effects of lead, with slowed cognitive development, reduced growth and other effects reported. Reproductive effects, such as decreased sperm count and spontaneous abortions have been associated with high lead exposure. The developing fetus is at particular risk from maternal lead exposure, with low birth weight and slowed postnatal neurobehavioral development noted. Human studies are inconclusive regarding lead exposure and cancer.

Human exposure to lead occurs through a combination of inhalation and oral exposure, while dermal absorption of inorganic lead compounds is reported to be much less significant than absorption by inhalation or oral routes. Inhalation generally contributes a greater proportion of the dose for occupationally exposed groups, and the oral route generally contributes a greater proportion of the dose for the general population.

We looked at alternatives to the use of lead for ammunition, wheel weights, fishing sinkers, and heat stabilizers for wire and cable applications. These applications were chosen based on stakeholder input, importance to Massachusetts industry and consumers, and likely availability of alternatives. Ammunition used at indoor firing ranges has led to significant worker exposure, and at outdoor firing ranges is a source of lead contamination in the Commonwealth. Wheel weights and fishing sinkers were chosen to be representative of a large number of lead uses that rely on its high density. Wire and cable coating heat stabilization is the category with the largest use of lead among Massachusetts manufacturers.

There are uses of lead that are important to certain stakeholders that did not make the priority list for this assessment because of the time and resource constraints associated with this study. These important uses of lead, such as roof flashing and pigments, could be further investigated given additional time and resources.

Ammunition

Five alternatives were assessed for lead in handgun ammunition used at indoor firing ranges. In general, the alternatives are more desirable from a human health and environmental standpoint, with the exception of aquatic toxicity for copper and zinc. Alternatives are available that closely approximate the ballistic performance of lead ammunition and have the benefit of being frangible, which reduces the risk of injury from ricocheted bullets and reduces wear on targets. The current purchase price for alternatives is significantly higher than lead ammunition but operational costs of firing ranges can be reduced through the use of lead-free ammunition.

Wheel Weights

Four alternatives were assessed for lead use in wheel weights. In general, the alternatives are more desirable from a human health and environmental standpoint, with the exception of aquatic toxicity for copper and zinc. The alternatives meet the performance requirements for use in automobile applications and steel and zinc weights are currently used by auto manufacturers. Steel and zinc weights are competitive in price with the coated lead weights used by auto manufacturers.

Fishing Sinkers

Five alternatives were assessed for lead use in fishing sinkers. In general, the alternatives are more desirable from a human health and environmental standpoint, though there are some data gaps for the ceramic, bismuth, and tungsten alternatives which makes it difficult to make a full comparison. No one alternative meets the technical performance requirements for every sinker type or application but each alternative is successfully being used for one or more types of sinkers. While most alternatives are several times the price of equivalent lead sinkers, steel bullet weights and egg sinkers are competitive in price to the equivalent lead sinkers.

Heat Stabilizers for Wire and Cable

Five alternatives were assessed for lead use in heat stabilizers. In general, the alternatives are more desirable from a human health and environmental standpoint. Alternatives are available that meet the wire and cable technical specifications, and research on new alternatives is ongoing. The cost differential between lead and non-lead heat stabilizers is estimated to be between cost neutral and a 10% premium for mixed metal heat stabilizers. This cost differential is anticipated to diminish as mixed metal heat stabilizers gain further market acceptance and as new materials reach commercialization.

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