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> Antimony in Switzerland

A substance flow analysis

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A substance flow analysis

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> Abstracts

Increasing quantities of antimony are being used in Switzerland for an ever broader range of applications. Antimony is mainly used today in the following types of products: (1) metal products such as batteries and ammunition; (2) non-metal products such as catalysers and stabilisers in plastics, glass and brake linings; and (3) bromided and chlorinated flame-proofing agents. The material flow analysis in this report is primarily based on published data. It describes the products and routes via which antimony was imported into Switzerland, utilised, disposed of and exported, in the course of 2001. The findings permit an assessment of the quantities of this element (which has a toxicological profile similar to that of arsenic) that are released into the environment, and the extent to which pollution of the soil with antimony is increasing.

Keywords:
Antimony
Material flow analysis
Lead batteries
Ammunition
Metals
Plastics
Break linings
Flame-proofing agents

Antimon wird in der Schweiz in steigenden Mengen und für immer mehr Verwendungszwecke eingesetzt. Die heutigen Hauptanwendungsgebiete von Antimon sind (1) Metallprodukte wie Batterien oder Munition, (2) nichtmetallische Produkte wie Katalysatoren oder Stabilisatoren in Kunststoffen, Glas oder Bremsbelägen, und (3) bromierte und chlorierte Flammschutzmittel. Die Stoffflussanalyse beruht hauptsächlich auf Literaturangaben. Sie zeigt für das Jahr 2001, über welche Güter und Wege Antimon in die Schweiz importiert, gebraucht, entsorgt und exportiert wird. Die Ergebnisse geben Aufschluss darüber, in welchen Mengen das Element, das ein mit Arsen vergleichbares toxikologisches Profil zeigt, in die Umwelt gelangt und wie stark die Belastung der Böden mit Antimon zunimmt.

Stichwörter:
Antimon
Stoffflussanalyse
Bleibatterien
Munition
Metalle
Kunststoffe
Bremsbeläge
Flammschutzmittel

L'antimoine est utilisé en quantité croissante et à des fins de plus en plus diverses en Suisse. Les domaines d'application les plus fréquents aujourd'hui sont: 1) les produits métalliques tels que les piles ou les munitions, 2) les produits non métalliques tels que les catalyseurs ou les stabilisateurs dans les matières plastiques, le verre ou les revêtements de frein et 3) les produits ignifuges bromés et chlorés. La présente analyse des flux de matière repose principalement sur des données bibliographiques. Elle démontre par quels canaux et marchandises l'antimoine a été importé en Suisse, utilisé, éliminé et exporté en 2001. Les résultats révèlent en quelles quantités l'élément – dont le profil toxicologique est comparable à celui de l'arsenic – est rejeté dans l'environnement et dans quelles proportions la contamination des sols par l'antimoine augmente.

Mots-clés :
Antimoine
Analyse des flux de matière
Piles au plomb
Munitions
Métaux
Matières plastiques
Revêtements de frein
Agents ignifuges

In Svizzera si sta registrando un aumento dell'impiego di antimonio per un numero sempre maggiore di applicazioni. Attualmente, i principali settori d'impiego di questo elemento sono (1) la fabbricazione di prodotti in metallo come batterie o munizioni, (2) la fabbricazione di prodotti non metallici come catalizzatori o stabilizzatori in materie plastiche, vetro o pastiglie di freni e (3) la produzione di ritardanti di fiamma bromurati e clorurati. L'analisi dei flussi di sostanza, basata principalmente sulle pubblicazioni esistenti in tale ambito, indica, in riferimento al 2001, i beni e le vie attraverso cui l'antimonio viene importato, consumato, smaltito ed esportato. I risultati ottenuti mostrano le quantità di questo elemento, dal profilo tossicologico comparabile a quello dell'arsenico, che giungono nell'ambiente, e indicano inoltre l'entità dell'aumento dei carichi di questa sostanza nel suolo.

Parole chiave:
antimonio
analisi dei flussi di sostanza
batterie al piombo
munizioni
metalli
materie plastiche
pastiglie di freni
ritardanti di fiamma

> Foreword

Antimony is a chemical element that is little known outside of scientific circles. It has been in use for centuries in the area of metals processing, notably for the hardening of lead. Today it is used not only in numerous metal products such as turbines, batteries, ammunition and cables, but also in non-metal products, for example as a catalyser for the polymerisation of plastics and as a flame-proofing agent.

The fact that antimony is being used to an ever increasing extent for the manufacture of new products, is present in large quantities in existing products and has a toxicity profile similar to that of arsenic, prompted the Swiss Federal Office for the Environment to commission a material flow analysis for antimony for 2001. The associated tasks proved to be extremely time-consuming and demanding, and it is thanks to the initiative and untiring efforts on the part of Annette Johnson from EAWAG that this project was brought to a successful conclusion.

The objectives of the material flow analysis were to identify the most important areas of application for antimony, and to determine how, as well as in which quantities and from which products, this element is released into the environment. The usage pattern identified for Switzerland largely corresponds to that identified in other industrialised countries, and is therefore of importance for other states and international organisations (e.g. the OECD) that want to analyse and reduce their level of chemical risk.

This analysis was based on official statistical data, market studies and scientific publications and reports. The Swiss Federal Office for the Environment wishes to express its sincere thanks to everyone who contributed in any way towards the successful conclusion of this study.

Georg Karlaganis
Head of Substances, Soil and Biotechnology Division
Federal Office for the Environment (FOEN)

> Vorwort

Antimon ist ein in der breiten Öffentlichkeit wenig bekanntes chemisches Element. Dabei wird es schon seit Jahrhunderten in der Metallverarbeitung verwendet, namentlich zur Härtung von Blei. Heute wird Antimon nicht nur in zahlreichen Metallprodukten wie Turbinen, Batterien, Munition und Kabeln eingesetzt, sondern auch in nichtmetallischen Produkten, beispielsweise als Katalysator für die Polymeration von Kunststoffen oder als Flammschutzmittel.

Die zunehmende Verwendung von Antimon zur Herstellung neuer Produkte, die hohen Antimonlager in bestehenden Produkten und ein Toxizitätsprofil, das Ähnlichkeiten zu Arsen aufweist, haben das Bundesamt für Umwelt veranlasst, über Antimon eine Stoffflussanalyse für das Jahr 2001 erstellen zu lassen. Die Arbeiten haben sich als sehr aufwändig und anspruchsvoll erwiesen und es ist der Initiative und Ausdauer von Frau Dr. Annette Johnson von der EAWAG zu verdanken, dass das Projekt nun doch erfolgreich abgeschlossen werden konnte.

Ziel dieser Stoffflussanalyse ist es, die wichtigsten Anwendungsgebiete für Antimon zu identifizieren und abzuklären, auf welchen Wegen und in welchen Mengen Antimon aus den verschiedenen Produkten in die Umwelt gelangt. Das Verbrauchsmuster von Antimon, wie es in der Schweiz festgestellt wurde, entspricht im Wesentlichen demjenigen anderer Industriestaaten und ist deshalb auch für andere Länder und internationale Organisationen (z.B. OECD) von Bedeutung, die ihr chemisches Risiko analysieren und reduzieren wollen.

Die vorliegende Analyse beruht auf offiziellen statistischen Daten, auf Marktanalysen und auf wissenschaftlichen Publikationen und Berichten. Das BAFU dankt allen Personen, die zum Gelingen dieser Studie in irgend einer Weise beigetragen haben.

Georg Karlaganis
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> Avant-propos

L’antimoine est peu connu du grand public. Et pourtant, cet élément chimique est utilisé depuis des siècles dans la transformation des métaux, notamment pour durcir le plomb. Aujourd’hui, l’antimoine rentre dans la composition de nombreux produits, tant métalliques – turbines, piles, munitions et câbles – que non métalliques, p. ex. comme catalyseur pour la polymérisation de matières plastiques ou comme agent ignifuge.

En raison de l’utilisation croissante de l’antimoine pour fabriquer de nouveaux produits, des stocks importants d’antimoine dans les produits existants et du profil toxicologique de l’élément – comparable à celui de l’arsenic –, l’Office fédéral de l’environnement a fait effectuer une analyse des flux de matière pour 2001. Les travaux ont été fastidieux et exigeants, et le projet n’aurait pu aboutir sans l’initiative et la persévérance de Mme Annette Johnson de l’EAWAG.

La présente analyse vise à identifier et à clarifier les principaux domaines d’application de l’antimoine, les canaux par lesquels l’élément parvient dans l’environnement et en quelles quantités il est rejeté. Les modes de consommation de l’antimoine en Suisse correspondent pour l’essentiel à ceux des autres pays industriels; ils sont donc également pertinents pour d’autres pays et organisations internationales telles que l’OCDE désireux d’analyser et de réduire leur risque chimique.

L’analyse repose sur des données statistiques officielles, des études de marché ainsi que sur des rapports et publications scientifiques. L’OFEV remercie toutes les personnes qui contribué à cette étude d’une manière ou d’une autre.

Georg Karlaganis
Chef de la division Substances, sol, biotechnologie
Office fédéral de l’environnement (OFEV)

> Premessa

L’antimonio è un elemento chimico che, nonostante sia poco noto all’opinione pubblica, viene già da secoli impiegato per la lavorazione dei metalli, e in particolare per indurire le leghe di piombo. Oggi l’antimonio è utilizzato non solo per la fabbricazione di numerosi prodotti in metallo come turbine, batterie, munizioni e cavi, ma viene impiegato anche per realizzare prodotti non metallici, ad esempio come catalizzatore per la polimerizzazione delle materie plastiche, o come ritardante di fiamma.

Il sempre maggiore impiego dell’antimonio per la fabbricazione di nuovi prodotti, il tenore elevato di tale sostanza nei prodotti già esistenti e un profilo tossicologico per vari aspetti simile a quello dell’arsenico hanno spinto l’Ufficio federale dell’ambiente a commissionare un’analisi dei flussi di questa sostanza in riferimento al 2001. I lavori si sono rivelati particolarmente dispendiosi e complessi, ed è grazie all’iniziativa e alla costanza della dottoressa Annette Johnson dell’Eawag che il progetto ha potuto essere portato a termine con successo.

L’obiettivo della presente analisi dei flussi di sostanza è quello di individuare i principali settori d’impiego dell’antimonio, chiarire attraverso quali vie tale sostanza giunge nell’ambiente e rilevarne le quantità provenienti dai diversi prodotti che lo contengono. Il modello di consumo dell’antimonio definito per la Svizzera corrisponde fondamentalmente a quello di altri Paesi industrializzati ed è quindi importante anche per gli altri Stati e per le organizzazioni internazionali (ad es. l’OCSE) che intendono analizzare e ridurre i rischi legati a questo elemento chimico.

L’analisi si basa su dati statistici ufficiali, su analisi di mercato e su pubblicazioni e rapporti scientifici. L’UFAM ringrazia tutti coloro che hanno in qualche modo contribuito alla riuscita del presente studio.

Georg Karlaganis
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Ufficio federale dell’ambiente (UFAM)

> Summary

Antimony has been used for many centuries, especially to harden lead for many products, such as gas turbines, solder, weights, type-set metal, pewter, shots and in the past decades for lead-acid batteries and cable sheathing. More recently, it has come into use in plastics as a polymerization catalyst and as a flame retardant in association with halogenated hydrocarbons in the form of antimony oxide.

The present study represents a substance flow analysis for the three product groups, metals, nonmetals and flame retardants for the year 2001. The pathway of these products through waste management and to the environment is examined. The study is based on data available from Swiss statistics, market analysis, scientific literature and reports.

Metal products

Antimony is added to lead as a hardening agent. About 880 tons of antimony were imported into Switzerland in 2001, mainly in the form of lead-acid batteries, while around 790 tons were exported as batteries (31 % of total exports) and rolled and extruded products. Approximately 128 tons entered consumption, while 470 tons entered waste management. Antimonial lead is slowly being replaced by other alloys. Almost 100 % of antimonial lead was collected for reuse, 60 % was reused in Switzerland and 40 % was exported as secondary antimonial lead for reuse.

Nonmetal products

Here antimony is mostly used as a catalyst and stabilizer for plastics (PET, polyester, PVC), as a fining agent in cathode ray tube (CRT) glass or in lubricants and brake pads. The last two products made up almost two thirds of the antimony consumed in nonmetal products in 2001. There is virtually no production of antimony-containing nonmetal products in Switzerland. In 2001 114 tons of antimony entered consumption and around 100 tons entered waste management. Most products were incinerated (65 tons or 85 %) and some were reused (8 %) or directly exported for treatment (7 %) The recycling of PET bottles accounted for 5 tons of antimony reintroduced into production in 2001.

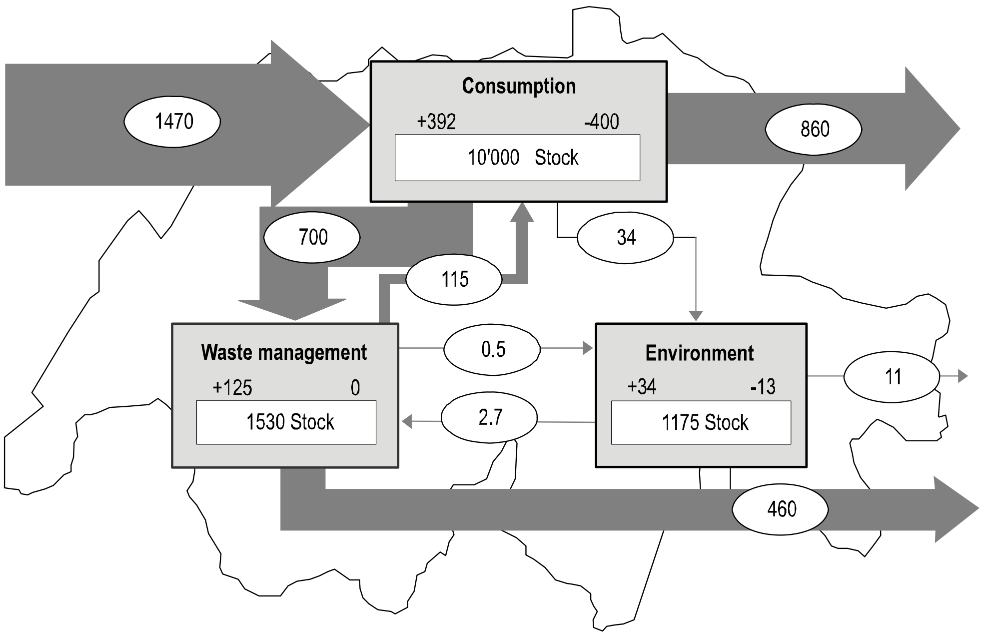
Flame retardants

Brominated and chlorinated flame retardants contain antimony. These are used in plastic products. Antimony in halogenated flame retardants contributes to about two thirds of the overall antimony consumption in Switzerland. About 95 % of antimony is used in brominated flame retardants and 5 % antimony in chlorinated flame retardants. This is lower than the reported European average of 16 %. In 2001 approximately 412 tons of antimony were consumed. Two thirds of the products containing antimony were directly imported. Flame retarded products made the greatest contribution to the increase in stock in Switzerland in 2001 (roughly 280 tons). Roughly 130 tons entered waste management from consumption in 2001. About one third of the collected waste was exported and the rest was incinerated.

Antimony flows through Switzerland

At the end of 2001 about 1500 tons of antimony were imported into Switzerland (Figure I), of which about 8 % were used for production and 92 % in finished products. Some 5 % of total 'trade in products' goods were reused from collected waste, 60 % antimony in imported and produced goods are again exported and 40 % are consumed in Switzerland. Of the consumed goods 3 % antimony in ammunition goes directly into the pedo-/lithosphere of the environment. Overall antimony consumption stock in Switzerland amounts to around 10'000 tons. Most of the stock is allocated to plastics in Flame retardants (FR) products (73 %).

Fig. 1 > Total Sb flows through Switzerland 2001(tons/year).



Of the 700 tons antimony disposed of in 2001, 173 tons were incinerated and 124 tons were landfilled both directly and as incineration residues. Roughly 460 tons of antimony were exported with collected materials and incineration residues. Seepage out of landfills is negligible in comparison to the input so the stock of antimony in the landfills is steadily increasing. In 2001 it was estimated to be 1530 tons. In the year selected, 16.5 tons of antimony entered the pedo-/lithosphere locally at shooting ranges. The stock of antimony at shooting ranges was estimated to be 2440 tons in 2001. The largest diffuse emission of antimony was estimated to be from the wear of brake pads (17 tons). The overall deposition rate of antimony away from major roads was estimated to be 6 tons/a in 2001, which indicates that significant amounts were deposited at roadsides. Approximately 11 tons left Switzerland in river water.

Following conclusions could be made:

> The antimony consumption pattern in Switzerland is similar to other industrialized countries.
> Much of the antimony imported into Switzerland is exported and the remainder is added to the stocks of the system.
> Future trends in the consumption of antimony will be dominated by the demand for flame retardants.
> The demand for antimony for use in other products is dominated by antimonial lead used in lead-acid batteries, lubricants and brake pads. However, the demand for antimony may decrease for certain products in the long-term.
> The largest emissions of antimony to the environment are the result of the use of antimony in brake pads and shooting practice.

> Zusammenfassung

Antimon wird bereits seit vielen Jahrhunderten verwendet. Es dient zur Härtung von Blei für zahlreiche Erzeugnisse wie Gasturbinen, Lötmetall, Gewichte, Letternmetall, Zinnlegierungen, Schrot und in den letzten Jahrzehnten Blei-Säure-Batterien und Kabelumhüllungen. In der jüngeren Vergangenheit wird es in Form von Antimonoxid als Katalysator bei der Polymerisierung von Kunststoffen und zusammen mit halogenierten Kohlenwasserstoffen als Flammschutzmittel eingesetzt.

Die vorliegende Studie präsentiert die Stoffflussanalyse für 2001 für die drei Stoffgruppen Metalle, Nichtmetalle und Flammschutzmittel. Analysiert wurde der Weg dieser Stoffe von der Abfallentsorgung in die Umwelt. Die Studie beruht auf Daten aus der Schweizer Statistik und Marktanalysen, aus der Fachliteratur und wissenschaftlichen Berichten.

Metallprodukte

Antimon dient zur Härtung von Bleilegierungen. 2001 wurden rund 880 Tonnen Antimon vorwiegend in Form von Blei-Säure-Batterien in die Schweiz importiert. Gleichzeitig wurden rund 790 Tonnen als Batterien (31% der Gesamtausfuhr) sowie als Walz- und Presserzeugnisse exportiert. Rund 128 Tonnen wurden verbraucht, 470 Tonnen wurden der Abfallentsorgung zugeführt. Antimon-Blei-Legierungen werden nach und nach durch andere Legierungen ersetzt. Blei-Antimon wurde zu fast 100% gesammelt und wiederverwertet. 60% der Wiederverwertung fand in der Schweiz statt, während 40% als sekundäres Blei-Antimon zur Wiederverwertung exportiert wurde.

Nichtmetall-Produkte

In der Schweiz wird Antimon vorwiegend als Katalysator und Stabilisator für Kunststoffe (PET, Polyester, PVC), zur Vergütung von Bildsschirmröhren oder als Gleitmittel in Bremsbelägen eingesetzt. Die beiden letztgenannten Produkte machten 2001 beinahe zwei Drittel des Antimon-Verbrauchs bei Nichtmetall-Erzeugnissen aus. Antimonhaltige Nichtmetalle werden in der Schweiz praktisch nicht hergestellt. 2001 wurden rund 114 Tonnen Antimon verbraucht und rund 100 Tonnen der Abfallentsorgung zugeführt. Die meisten Produkte wurden verbrannt (65 Tonnen bzw. 85%), manche wiederverwertet (8%) oder direkt zur Aufbereitung exportiert (7%). 2001 flossen durch das Recycling von PET-Flaschen rund 5 Tonnen Antimon in die Produktion zurück.

Flammschutzmittel

Bromierte und chlorierte Flammschutzmittel enthalten ebenfalls Antimon. Sie werden vorwiegen in Kunststoffprodukten eingesetzt. Das in halogenierten Flammschutzmitteln enthaltene Antimon macht rund zwei Drittel des gesamten Antimonverbrauchs der Schweiz aus. Davon werden rund 95% in bromierten und 5% in chlorierten Flammschutzmitteln verwendet. Dies liegt unter den durchschnittlichen 16% in Europa. 2001 wurden rund 412 Tonnen Antimon verbraucht. Zwei Drittel der antimonhaltigen Produkte wurden direkt importiert. 2001 war der Anstieg der Antimonmenge in der Schweiz vorwiegend auf schwer brennbare Produkte zurückzuführen (rund 280 Tonnen). Vom

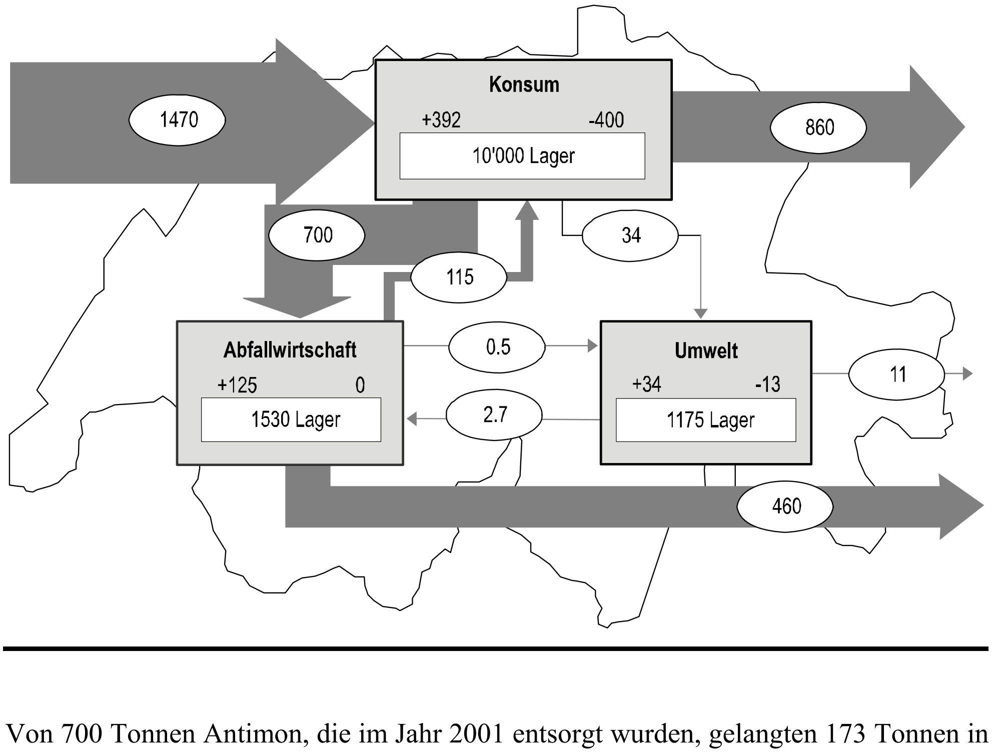
Gesamtverbrauch 2001 wurden rund 130 Tonnen der Abfallentsorgung zugeführt. Rund ein Drittel des gesammelten Abfalls wurde exportiert, der Rest verbrannt..

Antimon-Flüsse durch die Schweiz

Ende 2001 wurden rund 1500 Tonnen Antimon in die Schweiz importiert (Abbildung 1), davon rund 8% zur Herstellung und 92% als Fertigprodukte.

Von der Gesamtmenge der handelbaren Produkte wurden 5% gesammelt und wiederverwertet. 60% des Antimons in importierten Gütern und Fertigerzeugnissen wurden reexportiert und 40% in der Schweiz verbraucht. Vom Gesamtverbrauch gelangen 3% des Antimons durch Munition direkt in die Pedo-/ Lithosphäre der Umwelt. Der Gesamtvorrat an Antimon beträgt in der Schweiz rund 10’000 Tonnen. Das meiste davon (73%) befindet sich als Flammschutzmittel in Kunststoffen.

Abb. 2 > Gesamter Sb-Fluss durch die Schweiz 2001 (Tonnen/Jahr).



Von 700 Tonnen Antimon, die im Jahr 2001 entsorgt wurden, gelangten 173 Tonnen in Müllverbrennungsanlagen und 124 Tonnen entweder direkt oder als Verbrennungsrest in Mülldeponien. Rund 460 Tonnen Antimon wurden als Sammelgut oder Verbrennungsrest exportiert. Da die Auswaschung aus Deponien im Vergleich zum Eintrag nur geringfügig ist, wächst die Menge an Antimon in den Deponien stetig an. 2001 waren es schätzungsweise 1530 Tonnen. Im selben Jahr gelangten an Schiessplätzen 16,5 Tonnen Antimon lokal in die Pedo-/Lithosphäre. Die auf Schiessplätzen abgelagerte Gesamtmenge Antimon wurde für 2001 auf 2440 Tonnen geschätzt. Die grösste diffuse Antimon-Emission stammt vermutlich aus der Abnutzung von Bremsbelägen (17

Tonnen). Durchschnittlich betrug die Antimon-Emissionsrate entlang der Hauptstrassen 2001 schätzungsweise 6 Tonnen/Jahr, was darauf schliessen lässt, dass an den Strassenrändern bereits beträchtliche Mengen abgelagert sind. Rund 11 Tonnen sind über die Flüsse aus der Schweiz geflossen.

Folgende Schlussfolgerungen wurden gezogen

> Das Verbrauchsmuster für Antimon in der Schweiz ist mit anderen Industriestaaten vergleichbar.
> Von dem in die Schweiz importierten Antimon wird ein grosser Anteil wieder exportiert; der Rest kommt zu dem bereits bestehenden Vorrat hinzu.
> Für die zukünftige Entwicklung des Antimon-Verbrauchs wird die Nachfrage nach Flammschutzmitteln ausschlaggebend sein.
> Andere Produkte wie Blei-Säure-Batterien, Gleitmittel und Bremsbeläge enthalten vorwiegend Blei-Antimon. Langfristig dürfte die Nachfrage nach bestimmten Produkten jedoch zurückgehen.
> Die höchsten Antimon-Emissionen entstehen durch die Verwendung von Antimon in Bremsbelägen sowie an Schiessplätzen.

> Résumé

Depuis plusieurs siècles, l'antimoine est notamment utilisé pour durcir le plomb destiné à divers produits tels que les turbines à gaz, le métal de soudure, les poids, le métal de typographie, la poterie d'étain, la grenaille et, ces dernières décennies, les accumulateurs au plomb et les gaines de câbles. Plus récemment, on a commencé à l'utiliser dans le domaine des matières plastiques comme catalyseur de polymérisation et, sous forme d'oxyde d'antimoine, comme agent ignifuge en association avec des hydrocarbures halogénés.

La présente étude constitue une analyse des flux de substances relative aux trois groupes de produits que sont les métaux, les non-métaux et les agents ignifuges pour l'année 2001. On y examine le cheminement de ces produits vers l'environnement via la gestion des déchets. Elle est basée sur des données provenant de Statistique suisse, d'analyses de marchés, de la littérature scientifique et de rapports.

Produits métalliques

L'antimoine est ajouté au plomb comme agent de durcissement. En 2001, environ 880 tonnes d'antimoine ont été importées en Suisse, principalement sous forme d'accumulateurs au plomb, alors qu'environ 790 tonnes ont été exportées en tant qu'accumulateurs (31 % du total des exportations) et sous forme de produits laminés et extrudés. Environ 128 tonnes sont entrées dans le processus de la consommation alors que 470 entraient dans celui de la gestion des déchets. Le plomb antimonié est petit à petit remplacé par d'autres alliages. Presque tout le plomb antimonié a été collecté à des fins de réutilisation: 60 % ont été réutilisés en Suisse et 40 % exportés en tant que plomb antimonié usagé destiné à la réutilisation.

Produits non métalliques

En Suisse, l'antimoine est principalement utilisé comme catalyseur et stabilisateur dans le domaine des matières plastiques (PET, polyesters, PCV), comme agent d'affinage des verres destinés aux tubes cathodiques (CRT, cathode ray tube en anglais), ou de lubrifiants et de plaquettes de freins. En 2001, les deux derniers produits représentaient presque les deux tiers de l'antimoine consommé dans des produits non métalliques. En Suisse, on ne fabrique pratiquement aucun produit non métallique antimonié. Durant l'année examinée, 114 tonnes d'antimoine sont entrées dans le cycle de la consommation et environ 100 tonnes dans celui de la gestion des déchets. La plupart des produits ont été incinérés (65 tonnes ou 85 %) ; quelques-uns ont été réutilisés (8 %) ou directement exportés à des fins de retraitement (7 %). En 2001, le recyclage des bouteilles en PET représentait 5 tonnes d'antimoine réintroduit dans la production.

Agents ignifuges

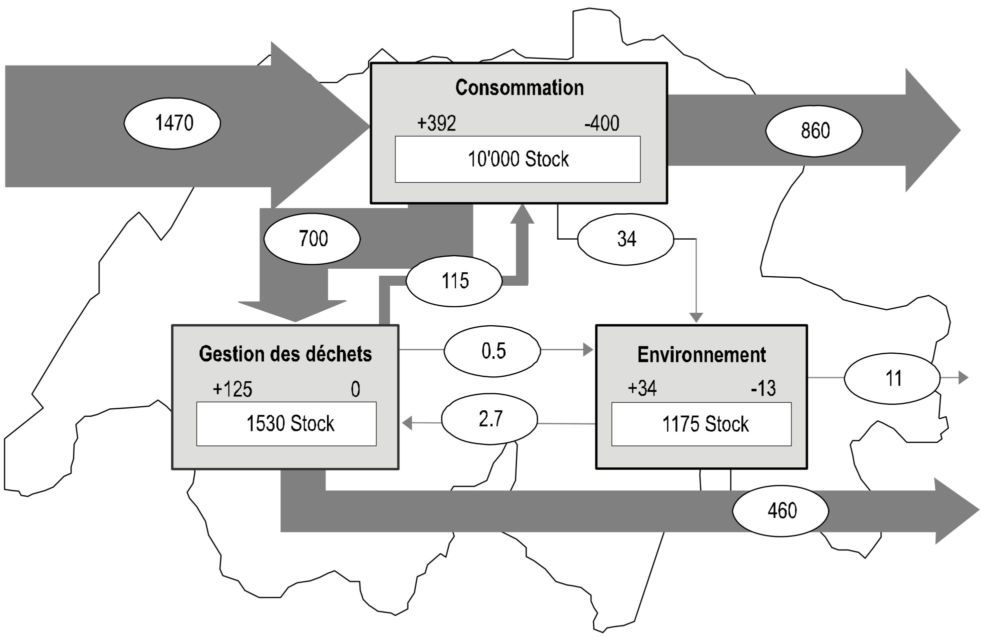
Les agents ignifuges bromés et chlorés contiennent de l'antimoine. Ils sont utilisés dans des produits en matière plastique. L'antimoine présent dans les agents ignifuges halogénés représente environ deux tiers de l'antimoine consommé en Suisse. Environ 95 % de cet antimoine sont utilisés dans des agents ignifuges bromés, 5 % dans des agents chlorés. Ceci est inférieur à la moyenne européenne connue qui est de 16 %. En 2001, environ 412 tonnes d'antimoine ont été consommées. Deux tiers des produits antimo-

niés ont été directement importés. Ce sont les produits ignifuges qui ont le plus contribué à l'accroissement du stock en Suisse durant cette année-là (environ 280 tonnes). Durant la même année, quelque 130 tonnes sont entrées dans la gestion des déchets via la consommation. Environ un tiers des déchets collectés a été exporté, le reste a été incinéré..

Flux d'antimoine en Suisse

En 2001, environ 1500 tonnes d'antimoine ont été importées en Suisse (figure I), 8 % ont été utilisés pour la production et 92 % dans des produits finis. Quelque 5 % du total des biens « commerciaux » ont été réutilisés à partir de déchets collectés, 60 % de l'antimoine contenu dans des biens importés et fabriqués sont à nouveau exportés et 40 % sont consommés en Suisse. Pour ce qui est des biens de consommation, 3 % de l'antimoine des munitions entrent directement dans la pédosphère et éventuellement la lithosphère. L'antimoine total consommé et stocké en Suisse représente environ 10 000 tonnes. La plus grande partie de ce stock concerne les matières plastiques des agents ignifuges (73 %).

Fig. 1 > Flux globaux de Sb en Suisse en 2001(tonnes/an).



Des 700 tonnes d'antimoine utilisées en 2001, 173 ont été incinérées et 124 mises en décharge soit directement soit sous forme de résidus d'incinération. Environ 460 tonnes d'antimoine ont été exportées dans des matériaux collectés et des résidus d'incinération. Les pertes via les eaux de percolation issues des décharges étant considérées comme négligeables, le stock d'antimoine des décharges est en constante augmentation. En 2001, il a été estimé à 1530 tonnes. Durant l'année examinée, 16,5 tonnes d’antimoine sont entrées dans la pédosphère et éventuellement la lithosphère à proximité de stands de tir. En 2001, le stock d’antimoine des stands de tir a été estimé à 2440 tonnes. L’usure des plaquettes de freins est considérée comme la principale source d’émissions diffuses d’antimoine (17 tonnes). Le taux global de dépôts d’antimoine loin des routes principales a été estimé à 6 tonnes/an en 2001, ce qui indique que des quantités significatives sont déposées le long des routes. Environ 11 tonnes ont quitté la Suisse avec l’eau des rivières.

Les conclusions suivantes ont pu être tirées :

> En Suisse, la consommation d’antimoine est similaire à celle d’autres pays industrialisés.
> Une grande partie de l’antimoine importé en Suisse est exportée, le restant est additionné aux stocks du système.
> Selon les pronostics, la consommation d’antimoine sera dominée par la demande en agents ignifuges.
> La demande d’antimoine pour l’utilisation dans d’autres produits est dominée par le plomb antimonié utilisé dans les accumulateurs au plomb, les lubrifiants et les plaquettes de freins. Cependant, pour certains produits, la demande d’antimoine pourrait diminuer à long terme.
> Les émissions d’antimoine dans l’environnement résultent principalement de l’utilisation d’antimoine dans les plaquettes de freins et la pratique du tir.

> Riassunto

L'antimonio è utilizzato da molti secoli, soprattutto per indurire il piombo destinato a vari prodotti, quali le turbine a gas, le leghe per saldature, i pesi, il metallo usato per la composizione tipografica, il peltro, le cartucce a pallini e, negli ultimi decenni, per gli accumulatori al piombo e le guaine dei cavi. Più recentemente si è incominciato a utilizzarlo nel settore delle materie plastiche come catalizzatore di polimerizzazione e, sotto forma di ossido di antimonio, come ritardante di fiamma in associazione con gli idrocarburi alogenati.

Il presente studio costituisce un'analisi dei flussi di sostanza relativa ai tre gruppi di prodotti, vale a dire i metalli, i non metalli e i ritardanti di fiamma per l'anno 2001. Il percorso effettuato da questi prodotti verso l'ambiente è stato esaminato mediante la gestione dei rifiuti. Lo studio è basato su dati provenienti da statistiche svizzere, analisi di mercato, letteratura scientifica e rapporti.

Prodotti metallici

L'antimonio viene aggiunto al piombo come indurente. Nel 2001 sono state importate in Svizzera circa 880 tonnellate di antimonio, principalmente sotto forma di accumulatori al piombo, mentre circa 790 tonnellate sono state esportate come accumulatori (il 31% del totale delle esportazioni) e sotto forma di prodotti laminati ed estrusi. Circa 128 tonnellate sono entrate nel processo di consumo, mentre 470 tonnellate sono entrate nella gestione dei rifiuti. Il piombo all'antimonio viene sostituito a poco a poco da altre leghe. Quasi tutto il piombo all'antimonio è stato raccolto a scopo di riciclaggio, il 60% è stato riusato in Svizzera e il 40% è stato esportato come piombo all'antimonio usato per essere riciclato.

Prodotti non metallici

In Svizzera l'antimonio è utilizzato soprattutto come catalizzatore e stabilizzatore per le materie plastiche (PET, poliesteri, PVC), come chiarificante del vetro usato per i tubi catodici (CRT, cathode ray tube in inglese), nei lubrificanti e nelle guarnizioni dei freni. Nel 2001 gli ultimi due prodotti costituivano quasi i due terzi dell'antimonio consumato nei prodotti non metallici. In Svizzera non viene di fatto fabbricato nessun prodotto non metallico contenente antimonio. Nello stesso anno 114 tonnellate sono entrate nel processo di consumo e circa 100 tonnellate sono entrate nella gestione dei rifiuti. La maggior parte dei prodotti è stata incenerita (65 tonnellate pari all'85%), alcuni sono stati riutilizzati (8%) o esportati direttamente per essere trattati (7%). Nel 2001 il riciclaggio delle bottiglie di PET rappresentava l'equivalente di 5 tonnellate di antimonio reintrodotto nella produzione.

Ritardanti di fiamma

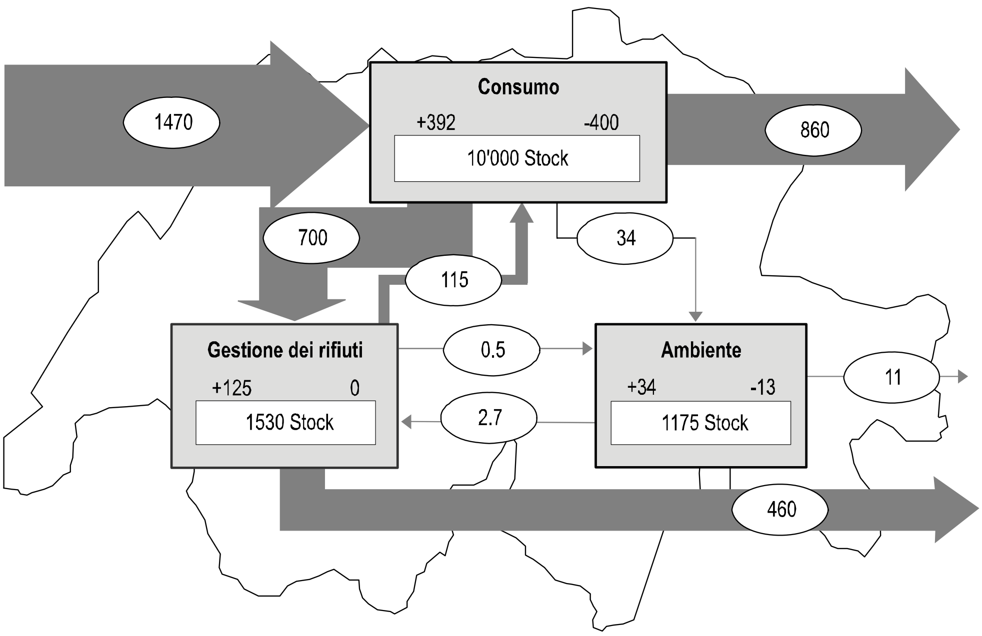
I ritardanti di fiamma bromurati e clorurati contengono antimonio. Essi vengono utilizzati nei prodotti in materia plastica. L'antimonio presente nei ritardanti di fiamma alogenati costituisce i due terzi circa del consumo totale di antimonio in Svizzera. Circa il 95% di questo antimonio è utilizzato nei ritardanti di fiamma bromurati e il 5% nei ritardanti di fiamma clorurati.

Ciò è inferiore alla media europea, che è del 16%. Nel 2001 sono state consumate circa 412 tonnellate di antimonio. Due terzi dei prodotti contenenti antimonio sono stati importati direttamente. I prodotti contenenti ritardanti di fiamma hanno contribuito maggiormente ad aumentare lo stock in Svizzera durante l'anno di riferimento (all'incirca 280 tonnellate). Nello stesso anno circa 130 tonnellate provenienti dal consumo sono entrate nella gestione dei rifiuti. Circa un terzo dei rifiuti raccolti è stato esportato e il resto incenerito..

Flussi di antimonio in Svizzera

Alla fine del 2001 circa 1'500 tonnellate di antimonio sono state importate in Svizzera (figura 1), di cui circa l'8% è stato utilizzato per la produzione e il 92% in prodotti finiti. Circa il 5% del totale dei beni "commerciali" è stato riusato a partire da rifiuti raccolti, il 60% dell'antimonio contenuto nei beni importati e fabbricati è stato riesportato e il 40% è stato consumato in Svizzera. Per quanto riguarda i beni consumati, il 3% dell'antimonio contenuto nelle munizioni entra direttamente nella pedosfera ed eventualmente nella litosfera. L'antimonio totale consumato e stoccato in Svizzera ammonta a circa 10'000 tonnellate. La maggior parte di questo stock concerne le materie plastiche nei prodotti contenenti ritardanti di fiamma (73%)..

Fig. 3 > Flussi totali di Sb in Svizzera nel 2001 (tonnellate/anno).



Delle 700 tonnellate di antimonio smaltite nel 2001, 173 tonnellate sono state incenerite e 124 tonnellate messe in discarica sia direttamente sia come scorie di incenerimento. All'incirca 460 tonnellate di antimonio sono state esportate con i materiali raccolti e le scorie di incenerimento. Se paragonata alla quantità immessa, l'infiltrazione nelle acque a partire dalle discariche è trascurabile, dimodoché lo stock di antimonio nelle discariche è in continuo aumento. Nel 2001 è stato valutato a 1'530 tonnellate. Nell'anno preso in esame, 16,5 tonnellate di antimonio si sono accumulate nella pedosfera ed eventualmente nella litosfera in prossimità dei poligoni di tiro. Nel 2001 lo stock di antimonio in prossimità dei poligoni di tiro è stato valutato a 2'440 tonnellate. L'usura delle guarnizioni dei freni è considerata come la principale fonte di emissioni diffuse di antimonio (17 tonnellate). Nel 2001 il tasso globale di depositi di antimonio lontano dai maggiori assi stradali è stato valutato a 6 tonnellate/anno, e ciò indica che quantità significative di tale sostanza sono depositate sul bordo delle strade. Circa 11 tonnellate hanno lasciato la Svizzera con l'acqua dei fiumi.

Si sono potute trarre le seguenti conclusioni:

- in Svizzera il consumo è simile a quello degli altri Paesi industrializzati;
- una parte consistente dell'antimonio importato in Svizzera è esportato e il rimanente è aggiunto agli stock del sistema;
- in futuro il consumo di antimonio sarà dominato dalla domanda di ritardanti di fiamma;
- la domanda di antimonio per l'utilizzazione in altri prodotti è dominata dal piombo all'antimonio usato negli accumulatori al piombo, nei lubrificanti e nelle guarnizioni dei freni. Tuttavia, a lungo termine la domanda di antimonio per certi prodotti potrebbe diminuire;
- le emissioni di antimonio nell'ambiente derivano principalmente dall'utilizzazione di tale sostanza nelle guarnizioni dei freni e dalla pratica del tiro.

1 > Introduction

Antimony (Sb) was used as early as 4000 BC in metal products, such as containers, mirrors and bells. In addition, stibnite was used in Biblical times as a medicine and as cosmetic for decorating the eyes. Its name is derived from the Greek *anti-monas* meaning a metal seldom found alone. In Latin antimony is called *antimonium.* Pliny the Elder named it *stibium* in Latin and wrote about seven medicinal remedies using stibium (stibnite) or antimony sulfide. Its purpose was to "purge" the body by making people vomit. Later in the Middle Ages its use was called into question. In some countries it was used as a medicine, in others it was classified as a poison.

Today, antimony is coming into use in ever increasing quantities in products (in alloys, as a fining agent in glass and plastics, as a flame retardant in plastics, textiles and brake pads) and waste streams. Worldwide, over 100'000 tons are being mined annually at the present time. According to the statistics of the United States Geological survey (USGS), antimony ranks ninth in the list of metals consumed in the United States of America (USA) after iron, aluminum, copper, lead, zinc, chromium nickel and tin (Buckingham and Carlin, 2002). It is entering the environment through various paths, its toxicity is similar to that of arsenic, yet still very little is known of its effect on human health and its behavior in the environment.

The aim of this report is to assess the major products entering or produced in Switzerland that contain antimony and to determine the pathway of antimony through production, consumption, waste management to the environment. The reference year chosen for this study was 2001.

1.1 Geochemical properties and eco-toxicity of antimony

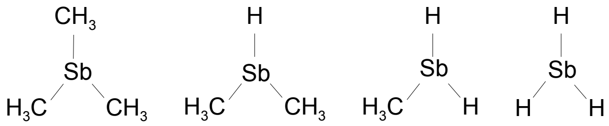
Antimony is rarely found naturally as native metal but normally occurs in nature in the form of sulfide minerals and is obtained from sulfide ore. It usually occurs in combination with sulfur and the heavy metals copper, lead, gold and silver. There are more than 100 antimony minerals, but stibnite (Sb_2S_3) is the main ore mineral (Christie and Braithwaite, 2002). In the periodic table it is located in the same group as arsenic (Group 15) and its biogeochemical properties are thought to be similar (Gebel, 1999a, 1999b).

Tab. 1.1 > Summary of antimony speciation in environmental systems.

Sb (III) is present as $Sb(OH)_3$ (1.1<pH< 11.8) in aqueous solution and has affinity for:

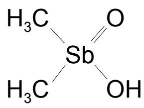
- ⇒ chloride
- ⇒ sulphide
- ⇒ organic acids
- ⇒ organic compounds with thiol groups

Methyl stibines found under highly reducing conditions

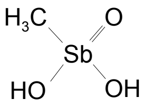


Sb(V) is present as $Sb(OH)_6^-$ (pH> 2.5) in aqueous solution

- ⇒ may form complexes with sulfide
- ⇒ forms organometallic compounds



stibonic acid



stibinic acid

Filella and May, 2003.

Antimony exists in environmental systems in trivalent and pentavalent oxidation states. Table 1.1 summarizes the antimony species that have been determined in environmental systems.

In all oxic systems investigated to date Sb(V), is the predominant redox species (≥ 90 % of total dissolved antimony). Antimony(III) and methylated species make up only a small fraction of total dissolved antimony in aqueous systems. From what little is known of the antimony species it would appear that either Sb(III) is either not stable in aqueous systems as it oxidizes to Sb(V), or that it is less soluble. Antimony is probably released to the environment by the oxidation of Sb(III). In most minerals, including stibnite, antimony is present as Sb(III). Antimony present in metal products would have to be oxidized from its elemental state (Sb(0) to Sb(III) and then to Sb(V). The literature suggests that Fe species play an important role in the solubility of both Sb(III) and Sb(V). Both species sorb to Fe hydroxides and Sb(III) may be co-oxidized by either ferrous or ferric species (Leuz et al., 2006).

Antimony is a non-essential element in plants and animals. It is in the same group of the periodic table (15) as arsenic and it is generally thought that their toxicity is similar. Organisms detoxify the metalloid anions by metabolism. The oxidized species that accumulate in organisms are reduced, conjugated with glutathione and subsequently methylated to less toxic species. The process is not so efficient for antimony, so it is thought that antimony is not as efficiently detoxified as arsenic. The effect of elevated antimony concentrations in aquatic ecosystems is not known. However, aquatic toxicity reference values have been defined by the USEPA in ecological risk assessment. They make use of parameters such as lethal concentration (LC_{50}, the concentration at which 50 % of the population die within a given time) and effects concentrations (EC_{50}) showing reproductive effects for species native to aquatic systems. The values for antimony and arsenic are 160 and 190 µg/L respectively. In comparison, cadmium has a value of 0.66 µg/L (USEPA, 1999) This would indicate that the eco-toxicity of both antimony and arsenic are relatively low for aquatic systems. It should be noted that little distinction is made with regard to speciation of the species.

In soils antimony is mobilized via the same processes as in aquatic systems. However, the soil minerals provide a very large surface area for sorption and studies show (e.g. Blay, 2000) that much of the antimony species are sorbed to iron hydroxides. Plant uptake may be one route into the food chain.

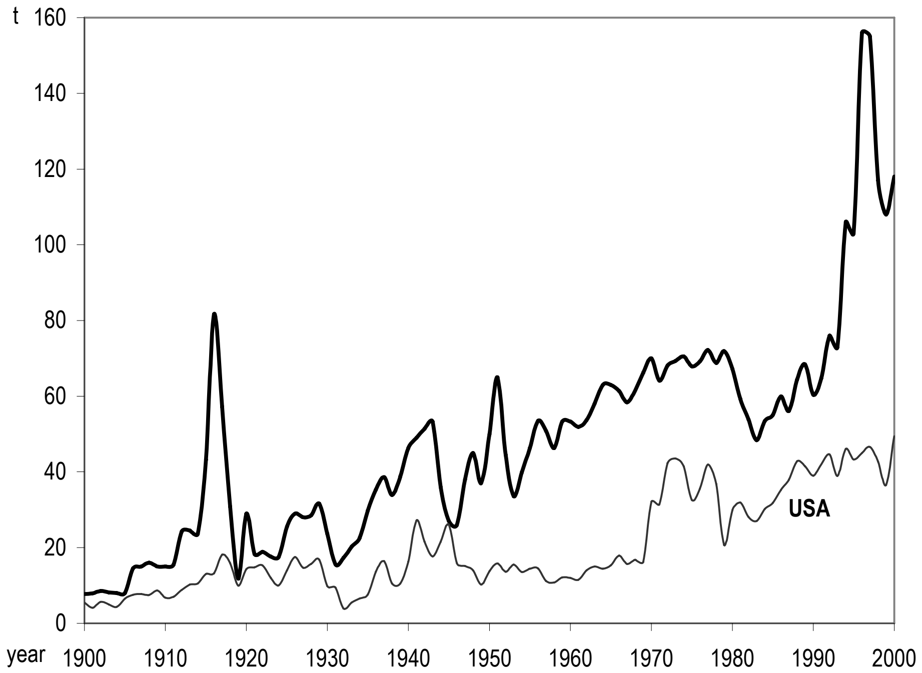
Antimony and its compounds are classified as priority pollutants by the European Union (Council of the European communities, 1976 and 1998) and the Environmental Protection Agency of the United States (USEPA, 1979). Antimony is found on the list of banned hazardous compounds specified in the Basel Convention (United Nations Environment Programme, UNEP 1999). The World Health Organization (WHO, 3rd edition, 2003) published guidelines of standard values and toxicity data for antimony. Table 1.2 specifies guidelines and standards on emissions of and exposures to antimony in Europe and the USA. There is an increasing interest in antimony because of the continuing accumulative anthropogenic entry into the environment (Council of the European communities, 1998; USEPA, 1995, 1998, 1999; UNEP, 1999; WHO, 2003).

Drinking water limits for antimony are based on effect concentrations. It was found that rats exposed to antimony in drinking water at a single dose level of 0.43 mg/kg body weight and day had a decreased longevity and changes in blood glucose and cholestrol levels. Adopting a 250-fold safety margin for potential health effects, the World Health Organisation (WHO) has set a provisional guideline value for drinking water of of 5 µg/L for antimony. The USEPA has set the maximum contaminant level of antimony in drinking water to 6 µg/L. In Japan the recommended maximum drinking water concentrations for antimony is 2 µg/L.

1.2 The production of antimony

The production of antimony has grown by roughly tenfold during the twentieth century (Fig. 1.1), showing a marked increase during the world wars and in the nineties. Worldwide, about 160’000 tons of antimony were mined in 2001.

Fig. 1.1 > World production of antimony in the twentieth century.



Carlin, USGS, 1992–2003.

China is by far the biggest global producer. Its largest antimony reserves are in Guangxi Province, adjacent to Vietnam, where the large producers include the Huan Dong Metal Material Plant. This plant has a capacity to produce 10'000 tons/a of Sb_2O_3. The province's proliferation of small privately-owned mines contributes to the country's huge capacity of around 135'000 tons/a. World antimony reserves are estimated at 2.075 million tons, sufficient, at current mining levels, for a further 20–30 years (Masters, 1999–2003). China has the largest total reserves with about 60 %, followed by Russia (13 %) with smaller reserves in Bolivia, Kyrgystan, South Africa, Tajikistan and the USA (Carlin, USGS, 1992–2003). There is uncertainty in production data due to differences in reported data of Chinese output, and in more recent years, lack of any real statistics from Russia (Masters, Mining Annual Review, 2000).

The abundance of antimony in China is the main factor determining trends in the antimony market during the last years. The Mining Journal (Masters, 2002) reports that, China accounting for about 83 % of world mine production and a similar percentage of recorded exports, this figure would be much higher if unrecorded or illegal exports were included. The price of antimony during the nineties was around 0.8 U.S.$/lb, but factors such as environmental concerns, mining accidents and the buoyancy of the world markets can strongly affect the price. Since 2002 the Chinese government officials have better export controls, leading to a reduction in surplus and an increase in price to 1.3 U.S.$/lb (Carlin, USGS, 2002).

1.3 The global consumption of antimony in 2001

There is some difficulty in estimating global consumption because of the variety of uses to which antimony is put. As well as the considerable disagreement over the exact level of world mine output, the primary and secondary (recycled) consumption of antimony is difficult to estimate. Total antimony consumption in all forms was estimated for the year 2000 to be between around 75'000 t a^{-1} to 90'000 t a^{-1} (USAC, 2001) and around 100'000 t y^{-1} (Crew Development Corp., 2001). The data from USAC is thought to refer to market economy which accounts for around 70 % of total world demand (Roskill, 2001), which would translate into an estimated world demand between of 107'000 t y^{-1} and 129'000 t y^{-1} total antimony consumption. Further, the Mining Annual Review (2002) reported a forecast that world demand for antimony trioxide in the flame retardant market will rise by some 4 % annually from an estimated 83'500 t in 1998 to around 95'000 t in 2003. These figures have been used for extrapolation to estimate world consumption in 2001, where data was only available until 2000 (Tab. 1.2). The primary antimony, referred to in Table 1.3, is produced from mining and smelting and secondary antimony is recycled from lead battery plates and old scrap. The most significant of antimony compounds is antimony oxide, which accounted in 2000 and 2001 for some 70 % of total antimony consumption (Masters, 2000, 2001).

Estimates of the market share held by regions vary significantly. All sources agree that the USA is the largest market for antimony oxides, accounting for some 35 % to 57 % of world consumption. Estimates of the market share held by Europe ranges from.just 8 % to 31 %. Yet, most sources report similar estimates for Europe of 27'400 t y^{-1} (Weber M., Industrial Minerals, 2000), 26'600 t y^{-1} (Masters, 2000), 23'500 t y^{-1} (USAC, 2001), which roughly agree on a world share of 30 %. Only Hillgrove (2000) estimates an 8 % of market share for Europe. This may be partly because Australia, based on its geographical location, is a major supplier to Asia and exports little to Europe. Estimates for Asia (mainly Japanese consumption) range from 19 % to 23 %. The Japanese use 81 % of their antimony oxide for flame retardants and 15 % for glass, which is probably related to their production of electrical and electronic goods (Hillgrove, 2000).

Tab. 1.2 > Estimated global consumption of antimony in 2001.

tons Sb	USA	Europe	Asia	**World**	%
Primary antimony metal	5'400	3'700	1'900	**11'000**[1]	10
Sodium antimonate	1'900	1'000	6'700[5]	**9'600**[2]	9
Antimony oxides	28'200[1]–24'700[6]	4'100[7]–21'900[6]	9'400[1,7]–16'400[8]-	**79'300**[3]	71
Antimonial lead (primary and secondary)	-	-	-	**11'000**[4]	10
Total	-	-	-	**110'900**	100

Source: [1]USAC (2001); [2]Roskill (2001); [3]Masters, Mining Annual Review (2000); [4]ILZSG (2001); [5]Asia/Pacific; [6]Weber, Industrial Minerals (2000); [7]Asia, Japan; [8]Hillgrove (2000).

The low level of primary antimony consumption is due to the high recycling rates for lead-acid batteries. According to Roskill (2001) antimonial lead accounts for about 80 % of secondary antimony, recycled from lead-acid batteries. However, quantitative estimations of primary and secondary antimonial lead, accounting for about 100'000 tons per year, are not very well documented by areas, due to the low level of response to the USGS (Carlin, 2001) and the lack of statistical data for China and Russia (Masters, 2000). The consumption of primary antimony for USA, Europe and Asia in 2001 has been estimated at 50, 33 and 17 % respectively (USAC, 2001). European consumption of antimony products is considered to be about 40 % less than US consumption (Roskill, 2001). Available statistics for the recycling of antimonial lead are shown in Table 1.3.

Tab. 1.3 > Recycling rates of antimonial lead, as percent of total antimonial lead market.

Area	1985 %	1999 %	2010 forecast %
Worldwide[1]	45	53	60
Europe[2]	-	70	-
USA[3]	-	79	-
UK[4]	-	89	-
Switzerland[5]		~100	~100

Source: [1]Doe Run (2000); [2]Roskill (2001); [3]Carlin, USGS (2000); [4]World Bureau of Metal Statistics (2000); [5]Bubendorff, Metallum AG (2004).

Primary antimony

Antimony is extracted by pyrometallurgical, or less commonly, by electrometallurgical methods (Ullmann's Encyclopedia of Industrial Chemistry, 1993). Some hydrometallurgical processes have been developed by Roycefield Resources, Canada and by Hillgrove, Australia involving leaching antimony sulphide to produce antimony chloride, and then using solvent extraction and hydrolysis to produce antimony trioxide.

Antimony metal is most commonly traded in ingots and slabs weighing 20–50lb and with a purity of 99.0–99.85 %. Antimony ore and concentrates are the starting-point for metallurgical and non-metallurgical products. Antimony metal used for the production of antimony trioxide should contain 99.65 % Sb, and for thermoelectric devices and semiconductors a very high purity metal of 99.99–99.999 % Sb is required.

Secondary antimony from antimonial lead

Antimony is alloyed with lead to increase its strength, fatigue resistance and corrosion resistance. During the past 10 to 15 years, recycling activities have been steadily growing and lead alloys from primary sources are being used less and less. In the past decade consumption fell by 40 % in USA, 7 % in Japan and 2 % in GB (Roskill, 2001). Today, antimonial lead is mainly produced in secondary lead smelters from recycled batteries and lead scraps. According to the USGS (Carlin, 2001, 2002), the Mining Annual Review (Masters, 2001, 2002) and Roskill (2001), it is very hard to estimate the amount of secondary antimony recovered globally.

1.4 The use of antimony

The use of antimony falls into 3 main groups *(Carlin, USGS, 1992–2003)* outlined below. The metal market accounts for around 20 % of world consumption, although total consumption of secondary material, such as recycling and reusing of antimonial lead, is assumed to be much higher as estimated by Carlin (USGS, 1998–2002). A significant quantity is used in nonmetal products, mainly as a chemical catalyst.

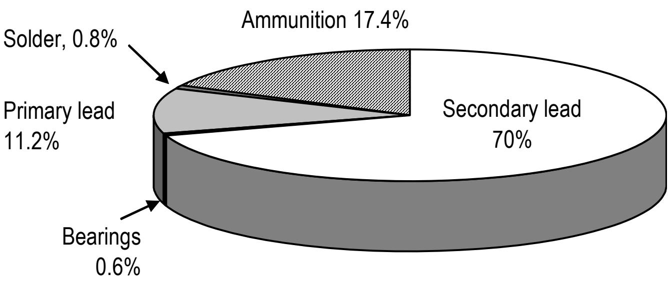
Metal products

Antimony is used to harden lead for lead-acid batteries, ammunition, and rolled and extruded lead products, such as pipes, tank linings, roofing and cable sheaths. Global antimony consumption amounts to about 10–20 %, mainly covered from secondary smelters of antimonial lead scrap (Carlin, USGS, 1998–2002). On a global scale the metallurgical market accounts for batteries, mainly in Latin-America, South-East Asia and in Eastern Europe.

In metallurgical applications, the supply of secondary antimony substantially exceeds that of primary metal. From the available data it can be concluded that, globally, more than 80 % of the antimony alloys are used as antimonial lead (Carlin, 2001, 2002, Masters, 2001, 2002). Of these, 89 % are used in batteries in GB (World Bureau of Metal Statistics, 2000) and 79 % are used in batteries in the USA (Carlin, 2000).

Figure 1.2 shows the distribution of antimony consumption in metal products. Primary and secondary lead provide the largest metallurgical market for antimony, accounting for around 81 % of antimony-containing metal products in 2001 and for about 39 % of total US demand of primary and secondary antimony (Carlin, USGS, 2002).

Fig. 1.2 > Antimony content in metal products as a percentage of the total metal products in USA for 2001.



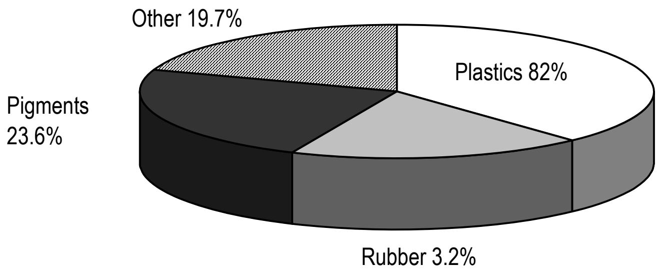
Carlin, USGS, 2002.

Nonmetal products

Nonmetal products account for about 20–25 % of global consumption. On a global scale, about 10 % of total antimony oxide consumption is estimated to be used as catalyst in nonmetal products (Masters, 2000). The main use of antimony is as a polymerization catalyst in plastics manufacture. Antimony is also used as a heat stabilizer in plastics and as a fining agent in CRT glass. Plastics provide the second largest non-metallurgical market for antimony, after flame retardants, accounting for 38 % of US nonmetal consumption in 2001 (Carlin, USGS, 2002). Figure 1.3 shows the distribution of antimony consumption in nonmetal products.

Fig. 1.3 > Antimony content in nonmetal products as % of total nonmetal products in USA for 2001.

"Other" refers to use in fireworks, mordant, rubber products, lubricants, fluid catalytic cracking and fluorescent light bulbs.

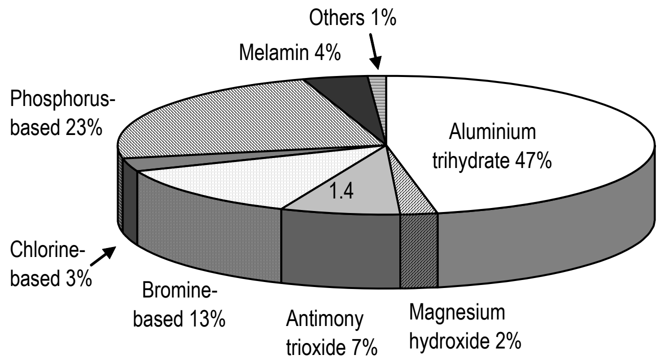


Carlin, USGS, 2002.

Flame retardants

Flame retardants (FR) are by far the largest market for antimony, accounting for about 60–65 % global consumption and some 90 % of global antimony trioxide consumption (Carling, 1998–2002; Masters, 2000–2002). Antimony trioxide is used as a synergist, together with halogenated hydrocarbons in flame-retardant polymer formulations and is widely used in electrical and electronics applications for household appliances, in the car industry and construction.

Fig. 1.4 > Estimated consumption of flame retardants in Europe in 1998.

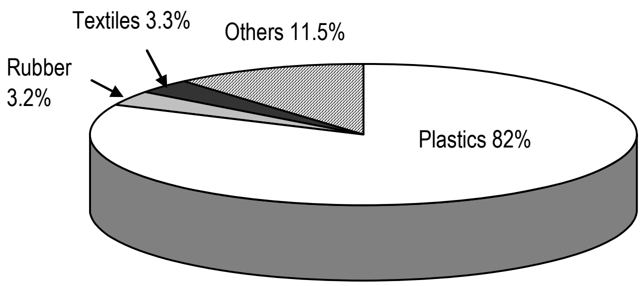


Weber, Industrial minerals, 2000.

Figure 1.4 gives an overview of the total flame retardant market in Europe. The total market was estimated at 340'000 tons in 1998. Aluminum hydroxide is used most frequently and the use of magnesium hydroxide is increasing at present (Weber, 2000). Antimony is always used in combination with bromine-based FR (market share 42'800 t) and chlorine-based FR (market share 10'200 t). In some applications in which polymers already contain halogens Sb_2O_3 is used alone (market share 23.9 t in Europe). According to Weber (2000) the market share of halogenated flame retardants in Europe account only for 16 %. On a global scale, halogenated FR have the largest market share at 47 % (Townsend Tarnell, 1999). The main reason is that revised standards have discouraged the use of halogenated flame retardants in Europe during the past years, but not in USA.

Fig. 1.5 > Antimony content in FR products as % of total FR products in USA for 2001.

"Other" includes paper and pigments.



Carlin, USGS, 2002.

Plastics provide the largest FR market for antimony, accounting for about 47 % of total US primary antimony demand and 82 % of USA FR consumption in 2001, expressed in percent antimony content (Carlin, USGS, 2002). Figure 1.5 shows the distribution of FR consumption by product. The growth forecast for flame retardants for Europe is about 3 % and for North America about 5 %. The market in the rest of the world is still small. Nevertheless, markets in the Far East show a permanent annual increase in double digits (Weber, 2000).

1.5 Summary

The following points sum up the introduction:

i Though antimony is used in such a wide range of products and in large quantities, relatively little is known about its geochemical properties.
ii The ecotoxicology of antimony does not appear to be an issue
iii Antimony is regarded to be a priority pollutant.
iv There is a discrepancy between production (mining) and consumption of antimony. The difference between the amount of antimony that is yearly produced and the amount that is reported to be used as "primary antimony" may be due to an increase in stock i.e. a shift in demand and supply, as a result of the global economical slow-down during 2001.
v The primary use of antimony is for flame retardation (roughly 60–65 %), followed by nonmetal products (20–25 % and metal products (10–20 %).
vi The pathways through the waste management systems after consumption, and emissions to the environment are not known.

2 > Methodical procedures

In the present report, the FOEN guidelines on 'Material Flow Analysis for Switzerland' (FOEN, 1996) were adopted as a basis. As in the report, the flow of substances are first determined in subsystems and then aggregated to form a whole system.

The following individual steps were performed:

> The determination of the processes to be included in the material flow analysis
> The identification and quantification of products and the concentrations of antimony in the products.
> Structuring of the system, based on the FOEN guidelines (FOEN, 1996) and the available data. The FOEN report "Selected polybrominated flame retardants – substance flow analysis" (FOEN, 2002) was used as the basis for the estimation of the use of antimony in flame retarded products.
> Balancing of the subsystems.
> Compilation and combination of the individual systems into a whole system 'Switzerland'.
> Evaluation and interpretation of the results and comparison to existing antimony global and country-based statistics

2.1 Definition of processes and products

The system Switzerland (Figure 2.1) was divided into three separate subsystems (1st aggregation level) comprising the following processes (2nd aggregation level):

The subsystem **trade in products** comprises:

> Production and industry
> Trade
> Consumption and households

The subsystem **waste management** includes the processes:

> Incineration
> Wastewater treatment
> Dumping in landfills
> Collection of recyclables and hazardous waste collection
> Reuse of wasted materials

The subsystem **environment** is composed of the following processes:

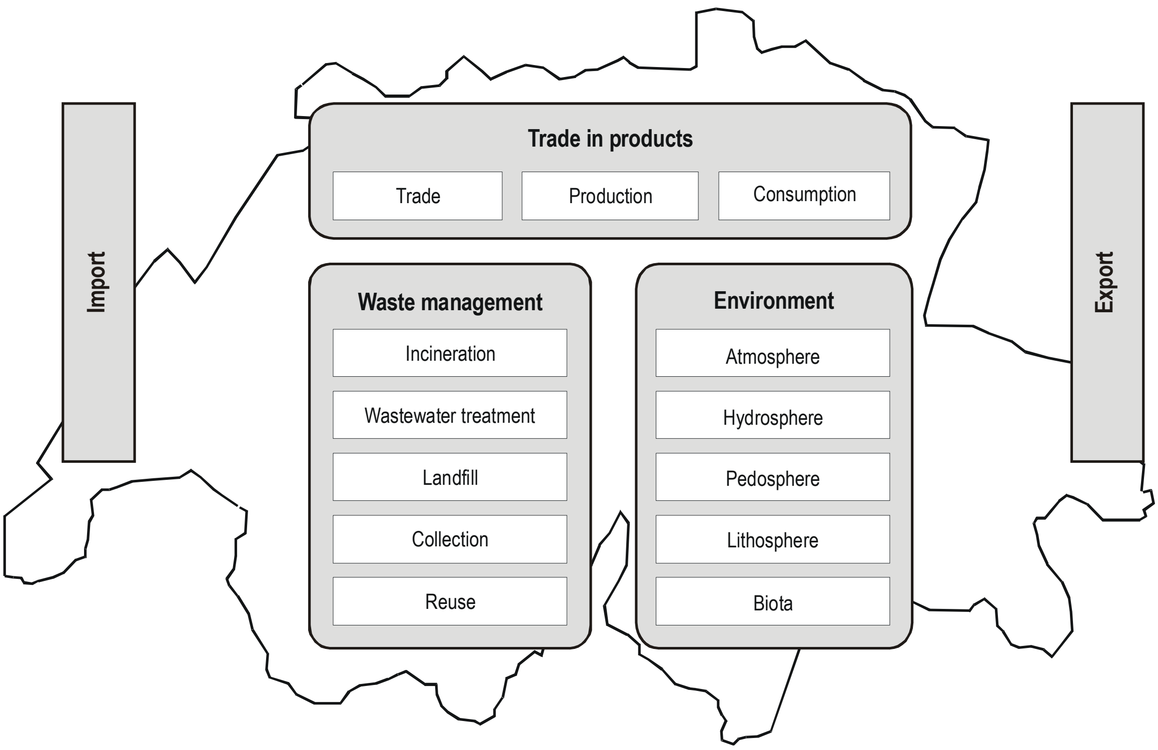
> Atmosphere
> Hydrosphere
> Pedo- and Lithosphere
> Biota

For the exchange of products with other countries further 2 subsystems were defined:

> Import
> Export

The physical boundary of the system is identical to the political border of Switzerland.

Fig. 2.1 > System border and system processes for the material flow analysis of antimony.



2.2 Data sources

The concentration data for antimony within the three subsystems trade products, waste management and environment was determined from national and international literature, market analysis, internet company information and the literature, from Swiss governmental agencies (e.g. BFS, 2003; EZV, 1998–2002; FOEN,1996–2002) and from various industrial Swiss societies and organisations, as well as from analytical data. Detailed information on the sources used are listed and explained in the appendix.

Subsystem 'trade in products'

The study is based on data from the literature. The substance flows were calculated from the flow of goods and the concentrations (percentage of antimony in product based on information from industrial producers). The flow of goods was determined from existing market analysis and data from Switzerland and other countries (e.g. Roskill, 2001, Swiss Federal Statistical Office (BFS, 2003) Swiss Foreign Trade Statistics (EZV, 1998–2002). The estimation of stocks in the process 'trade in products' was based on life cycles of consumer products. The most in-depth information on antimony was supplied by the U.S. Geological Survey of Minerals (Carlin, 1992–2003), the Mining Annual Review (Masters, 2000–2003) and the Roskill's 'Economy of Antimony' (Roskill, 2001).

Subsystem 'waste management'

The prime data input to flows into, in and out of the process 'waste management' in Switzerland was available from the Swiss Agency for Environment, Forests and Landscapes (FOEN). Material flows to and from the different treatment processes, i.e. municipal solid waste, sewage sludge, construction wastes, MSWI bottom ash and so on, were obtained from FOEN (2004). In addition to this product-related treatment, such as auto shredding or recycling, were determined from individual studies or measurements. The antimony concentrations of the materials were obtained from published sources. Auto shredder residues were sampled and analysed by ourselves.

Subsystem 'environment'

For the subsystem 'environment', the antimony content in the pedosphere and the hydrosphere were obtained from scientific studies from research institutes governmental agencies in Switzerland. No information was determined for 'biota'. Also, it was assumed that the antimony concentrations entering Switzerland via the atmosphere were equal to those leaving, in the absence of any detailed information. The assumptions and simplifications are discussed in detail in the next chapter.

2.3 Data basis

Basic data was used for mass balance calculations according to Baccini and Bader (1996) and the FOEN guidelines (1996) or international data was compared and/or extrapolated where data for Switzerland was not available.

Where not otherwise stated, comparison between global nations are based on population figures (Tab. 2.1).

Tab. 2.1 > Population data.

Population 2001	Million inhabitants	Factor for Switzerland
World	6'150.00	0.0012
Industrial countries[1]	1'193.90	0.0061
Europe (incl. Russia)	726.30	0.01
Europe (excl. Russia)	581.60	0.0125
Western Europe	183.40	0.0396
Germany	82.09	0.0884
France	59.50	0.122
Austria	8.08	0.899
Netherlands	15.93	0.456
USA	277.80	0.026
Japan	127.33	0.057
Switzerland	**7.26**	**1**

BFS, 2003, United Nations 2001.
[1]North America, Japan, Western Asia, Europe, Australia, New Zealand.

Tables 2.2 and 2.3 summarize the basic data for the determination of the flows and stocks into the environmental compartments 'waste management' and 'environment'.

Tab. 2.2 > Land areas in Switzerland.

Total area of Switzerland	4'128'400 ha
Total agricultural area 1990	945'760 ha
Settlement area	240'000 ha
Area of lakes and rivers	170'000 ha

FOEN No. 295, 1997.

Tab. 2.3 > Volumes and masses of environmental compartments for Switzerland.

	Sediment upper 2 cm	Soil upper 2 cm	Water average:50m	Air first 500 m	Unit
Area	170'000	945'760	170'000	4'128'400	ha
Volume	34'000'000	189'152'000	85'000'000'000	2.062E+13	m³
Mass	51'000'000	283'728'000	85'000'000'000		t

FOEN No. 338, 2002.

The mass transfer coefficients for mass balance calculations have been determined as described in Chapters 3, 4 and Appendix I.

2.4 Uncertainties and data reliability

The total consumption of antimony in Switzerland can only be roughly estimated. From the data of the Swiss Foreign Trade Statistics (EZV, 1998–2002) less common products could not be extrapolated as they are recorded, in one entry, together with similar items not containing antimony; or based on customer request, data of certain goods are suppressed (not published) by the EZV. Several values had to be extrapolated from literature and from market analyses from other countries. Owing to the structure of available data, it was not possible in all cases to analyze a specific year. This was in particular the case for antimony-containing products that are rare commodities. Instead, for these cases a rough picture was sketched of the situation in Switzerland around 2001 ± 3 years.

For the process 'waste management', the quantities of waste materials were well known due to the great effort made by cantonal and federal authorities over the last years. The antimony content of the waste streams is more uncertain. One of the greatest uncertainties with regard to the process 'environment' is the emission to the atmosphere. The uncertainties are discussed in detail later.

Where necessary, uncertainties and data reliability are documented and explained in detail in Chapters 4 and Appendix I.

3 > Scope of application and occurrence of antimony

Antimony and its compounds are and have been used in a vast variety of products. More than 70 products using antimony have been identified, mostly with concentrations less than 15 %.

In this chapter all products are listed, described and classified according to the end-uses in the following categories:

> compounds
> metallurgical uses
> non-metallurgical uses
> flame retardants

Their economical relevance now, in the past and in the future are described. The flow in trade, production and consumption through Switzerland are quantitatively calculated and recorded. The details are listed in the appendix.

3.1 Antimony compounds

3.1.1 Classification of major products

Table 3.1 lists all major compounds and intermittents of antimony and their end-use. Table 7.1 in Appendix A1-1 lists the corresponding concentrations of antimony in compounds, intermetallics and intermediates.

Antimony oxides

Plastics are the main market for antimony oxides. Outside the flame retardant industry, which accounts for about 90 % of global antimony oxide consumption, antimony oxides are used as a catalyst in the esterification of PET resins and polyester resins production, as heat stabilizer in PVC, as a degasser in the glass and ceramics sector, as an opacifier in porcelain enamels, in pottery glazes and as a brick additive. The main area of growth lies in catalysts for production of PET. According to the USGS in 2001, (Carlin, 2001) the growth in demand for antimony trioxide in this area was forecast at some 10 % per year in the USA for the following few years and 14–15 % per year in the South-East Asian market (Roskill, 2001). Japan's antimony trioxide consumption is higher in glass production compared to average world end-use, being a major global electronics appliances and car manufacturer.

Antimony pentoxide is used as FR in textiles, paper and plastics applications, because it has more stable physical and chemical properties. Future use of antimony pentoxide is said to increase, especially in thermoplastics, because of its superior properties. The colloidal sized particles of Sb_2O_5 are much smaller (Sb_2O_5 particle occupies only 0.2 % of the cross-sectional area of the polymer fiber compared to 7 % for Sb_2O_3) and do not act as crack propagators in plastics, like Sb_2O_3, resulting in a better strength. Sb_2O_5 also enables compounds to retain translucency, and deep and bright colors can be attained at low color loadings (NYACOL, 2003). An example is Sb_2O_5 used as FR in ABS used in computers, telecommunications, office equipment, electronic appliances, furniture and automotive interiors.

Tab. 3.1 > Major world antimony products – Major compound and chemical market.

Compounds and Intermittents	Chemical Abbreviation	Use
Antimony oxides (antimony trioxide, antimony tetraoxide, antimony pentoxide)	Sb_2O_x	FR: Plastics (resin, electrical & electronics, motor vehicles, aircraft & aerospace), textiles, wood & paper, adhesives & sealant, rubber. Catalyst: PET, PVC and polyester resins. Paint and colour fastener. Porcelain, enamelling. Glass (finishing agent/degasser). Fluorescent light bulbs as phosphorescent agent. Chemical intermittent for antimony pentoxide, sodium antimonate, antimony sulfide, antimony trichloride, potassium antimonite, potassium antimony tartrate. Zinc electrowinning to remove Co and Ni impurities.
Sodium antimonate	$NaSbO_3$	Glass (finishing agent/degasser) for color TV bulbs and optical glass. FR same as for antimony oxides. Special colors in industrial applications.
Antimony chlorides (antimony trichloride, antimony pentachloride)	$SbCl_3$ $SbCl_5$	FR same as for antimony oxides. Catalyst in organic chlorination and polymerization. FCC as catalyst. Pigments, stain. Pharmaceutical industry (e.g. Vitamin A reagent).
Antimony sulfides (antimony trisulfide, antimony pentasulfide)	SbS_3 SbS_5	Pyrotechnics: ammunition primer for detonators, basal recess containing SbS_3 for tracer bullets, marine markers, visual signaling, fireworks, explosives, matches. Friction material in break lining to decrease friction and wear. Lubricants to increase stability. Vulcanizing and coloring rubber, pigments – SbS_5.

Source: UAMY (2001); USAC (2003); Chemico Chemicals (2004); Roskill (2001); Ullmann's Encyclopedia of Industrial Chemistry (1993).

Sodium antimonate

$NaSbO_3$ is preferred to Sb_2O_3 in certain industrial applications, because it avoids the risk of incomplete oxidation of the antimony during the melting and eliminates losses caused by premature volatilisation. Umicore in Belgium (2003), the leading supplier of sodium antimonate outside China, reports sales dominantly in the area of CRT glass (94 %), and to a lesser extend of FR combined with chlorine (4 %) and of enamels (2 %).

Antimony chlorides

Antimony trichloride is produced by reacting antimony sulfide ores with calcium chloride. This recovery process is called the chloridization process. Antimony trichloride is a catalyst in organic chlorination and polymerization reactions and is used as flame retardant in PVC. Its major application is as the feed material for catalyzing the formation of FCC. Antimony pentachloride is occasionally used in flame retardant brominated compounds and in the pharmaceutical industry in small quantities.

Antimony sulfides

Antimony trisulfide, also called stibnite, is added to ammunition primer, to fluid lubricants used in brake pads and disk clutches, to fireworks and matches, and in pyrotechnics. Antimony pentasulfide can be used as vulcanizing agent and for different colour pigments in the manufacturing of rubber compounds and for matches and fire works.

3.1.2 Classification of minor products

Table 3.2 lists all minor compounds of antimony and their end-use. Table 7.1 in Appendix A1-1 lists the corresponding concentrations of antimony in compounds, intermetallics and minor intermediates. It should be noted that their economical significance is minimal.

Tab. 3.2 > Minor world antimony products – Minor compound and chemical market.

Compounds	Chemical abbreviation	Use
Antimony (III) bromide		
Antimony fluorides (antimony trifluoride, antimony pentafluoride)		
Intermetallics: Indium antimonide Aluminum antimonide Gallium antimonide	 InSb AlSb GaSb	Semiconductors and electronics.
Antimony glycolite (colloidal) Antimony triacetate	$Sb(gly)_3$ $Sb(C_2H_3OC_2)C_3$	High performance catalysts for PET.
Trimethyl antimony	$(CH_3)_3Sb$	Semiconductor primer. Analytical reagent: standards etc.
Hydrated potassium antimonyl tartar	$K(SbO)C_4H_4O_6 \cdot 5H_2O$	After treatment agent for dyeing textiles. Pharmaceuticals to treat stomach ailments and leishmaniasis (disease transmitted form sandflies). Pesticide (to kill wasps and moths, prevent damage to citrus fruits in wet season.
Antimony aluminite Antimony arsenide Antimony iodide Antimony selenide Antimony sulfiodide Antimony telluride	$SbAl_3$ SbAs SbI_3 $SbSe_3$ SbSI $SbTe_3$	Analytical reagent (microanalysis, standards and reagent). Medicine – SbI_3.

Source: UAMY (2001); USAC (2003); Chemico Chemicals (2004); Roskill (2001); Ullmann's Encyclopedia of Industrial Chemistry (1993).

Antimony bromide

Antimony tribromide's chemistry is similar to that of antimony trichloride in that they readily hydrolyze, form complex halide ions, and form a wide variety of adducts with ethers, aldehydes, mercaptans etc. They are soluble in carbon disulfide, acetone and chloroform (Ullmann's Encyclopedia of Industrial Chemistry, 1993). Antimony tribromide is used as an intermediate in the production of chemical compounds, for ferroelectricity, pyroelectricity, photoconduction and dielectric polarization with respect to their solid-state properties, and for chemical analysis standards. It is occasionally used as mordant in the dying process. Antimony tribromide is produced by Great Western Inorganics, Colorado, USA (GWI, 2004).

Antimony fluoride

Antimony trifluoride is sometimes replaced for antimony trioxide in the production of pottery and ceramics.

The main use of antimony pentafluoride is as a fluorinating agent for some processes.

Intermetallics

Small quantities of very high-purity antimony metal are consumed as dopants in n-type semiconductor materials and in the production of Group II-V intermetallic semiconductor compounds, such as indium antimonide, aluminum antimonide and gallium antimonide. Although, intermetallics are a high-value market, the quantities of antimony metal used in this market are small. The world consumption of intermetallics is estimated at around 21–22 tons in 2001 (Roskill, 2001).

Other minor compounds

All other compounds do not have much industrial significance and are used in trace amounts for laboratory reagents, medicine, pesticides and others, as described in Table 3.2.

3.1.3 Trade

The figures for import and export of compounds were taken from the Swiss Federal Customs Administration (EZV, 2001), were available, otherwise, they were estimated. Table 7.2 in Appendix I gives a detailed list of all assumptions and references on how data for the traded compounds were gathered. In addition it should be noted that antimony ores and antimonial lead listed in Table 3.3 are imported or exported as compounds and are listed separately by the EZV. Furthermore, some secondary antimonal lead, recycled from recycling of lead-acid batteries and scrap, is exported to other countries, such as the USA (Carlin, USGS, 2002). It is assumed that all imported antimony oxides and sodium antimonates are consumed in Switzerland or are exported after being manufactured in nonmetallurgical products (Sections 3.3 and 3.4).

Tab. 3.3 > Flows of goods and substances in imported and exported goods.

Compiled listing of metal products.

Compounds	Imported into Switzerland in 2001 tons/year	Exported from Switzerland in 2001 tons/year	National consumption in 2001 tons/year	Sb consumed in 2001 tons/year
Antimony ore and concentrates	10	-	10	5.3
Antimonial lead	4.1	313.9	–309.8	–33.3
Antimony oxides[1]	681	-	681	538
Sodium antimonate	122	-	122	59
Total	**817**	**314**	**503**	**569**

[1]Averaged estimated value (from Tab. 7.2).

3.1.4 Production

Switzerland does not have any natural resources of antimony ores (Knopf, Mining Annual Review, 2002). Further, no chemical compounds containing antimony are produced in Switzerland. A Swiss company, Alusuisse Martinswerk GmbH, Bergheim, Germany produces flame retardant, however the plant is not physically located in Switzerland and the company has changed hands in 2001 to Albemarle Corp., USA, a leading Chemical Company in oxide (also antimony) manufacturing. Antimony is therefore entirely imported into Switzerland either as compounds or in finished products (IAOIA, 2004; Kompass, 2004).

3.1.5 Consumption

All antimony compounds imported to Switzerland are entirely used in the manufacturing process of metallurgical and nonmetallurgical products with the exception of antimonial lead from recycling (Tab. 3.3). A surplus of antimonial lead has been exported from recycled batteries and scrap from Switzerland. Part of it is reused in the production of extruded lead products and the major part is exported to other countries. The values are regarded to be rough estimates in the absence of detailed information. The values were not used in the material flow analysis. In the following sections product-based antimony consumption data is presented.

3.2 Metal products

3.2.1 Classification of products

Table 3.4 lists all metal products in which antimony is consumed and their end-use. Table 7.3 in Appendix I lists the corresponding concentrations of Antimony in metal products.

Batteries

The main use in the metallurgical lead market is in the battery sector. The lead-acid battery is a secondary cell in which the electrodes are made of lead alloys and the electrolyte is a solution of sulfuric acid (H_2SO_4) in water. Traditionally, grids in lead-acid batteries were made from lead-antimony alloys, with additions of up to 10 % antimony. The two most common alloys used today to harden the grids are antimony and calcium, with small amounts of tin, silver and/or selenium, and arsenic added to improve strength and electrical properties to the lead. Lead-acid batteries are used either as starting (SLI) and/or storage (deep cycle) batteries. These batteries are used in the following categories:

> "Starting, lighting ignition" (SLI) batteries are the most widely used, they account for around 70 % of total sales of lead-acid products. They are commonly used to start and run automobiles, where a very large starting current is needed for a short time. SLI batteries have many very thin plates about 0.4" thick, with a large surface area, designed to be discharged no more than 1 to 5 % from full charge. SLI batteries have an energy range from a few hundred W to over 2 kW.
> Deep cycle batteries are designed to discharge (or deep cycle) as much as 80 % time after time, and have thicker plates (Magnacharge, 2003). They are used where power is needed over a longer period of time. Their energy range is between a few kWh and 100 kWh. Deep cycle batteries are used as traction (also called industrial) batteries for electrical vehicles and as stationary batteries for uninterruptible power supply (UPS) equipment for telecommunication networks, hospitals and PV energy storage.

The two most common types of lead-acid batteries are flooded (also known as wet or liquid electrolyte) cells and valve regulated lead-acid (VRLA) sealed batteries.

> Flooded (wet) cells are divided into maintenance free and low maintenance batteries, based on their plate formulation. Maintenance-free batteries use lead-calcium/calcium plates and low maintenance batteries have lead-antimony/calcium (less than 2 % antimony, with the consequent reduction in hardness offset by the addition of small quantities of arsenic) plates. They are also called hybrid or dual batteries.
> Valve regulated sealed lead-acid (VRLA) batteries are gas-recombinant type of batteries with immobilized electrolyte. They were developed as an alternative to traditional deep cycle flooded design, where the risk of acid spillage had made them less suitable, especially for stationary equipment in telecommunication (Wittemann and Dick, 1998). The VRLA is a cell that is sealed and fitted with a valve which opens to vent the cell whenever the internal pressure to the cell exceeds the pressure external to the cell by a set amount. VRLA's are divided into two groups, gel cells and absorbed glass mat (AGM). Gel cells contain acid that has been "gelled" by the addition of silica gel, but they must be charged at a very slow rate to prevent damage, which limits their use to only few applications. The newer AGM VRLA product, using absorbed glass mats between the plates. These batteries use antimony-free lead-calcium alloys.

Today in Europe, low maintenance dual (or hybrid) batteries are mainly used for cars (SLI), while VRLA batteries without antimony are mostly implemented for UPS applications. The VRLA batteries have plates made of lead-calcium-tin alloys for the negative grid and a low lead-antimony alloy for the positive grid (KCM S.A., 2003; Roskill, 2001).

The major differences between lead-antimony and lead-calcium alloys in batteries are in their performance. The advantage of antimony added to batteries for mechanical properties is because the electrical resistance of the alloy is increased and subsequently, the grid produced from it. Lead-antimony alloy grids are extremely strong, have an increasing hardness, creep resistance and improved castability to mold desired grid shapes. Further, the electrochemical stability of the lead is increased, which is important in batteries subject to wide cycles of charging and discharging. Therefore, lead-antimony batteries can be deep cycled more times than lead-calcium batteries. The disadvantages of lead-antimony alloys are that they are 3–8 % less conductive compared to non-antimony alloys, and suffer in reaching high cranking performance, which is important for SLI batteries. Thin grids (SLI) require alloys of the highest conductivity for optimum performance (Prengaman and Sigmund, 2001).

Because of the low level of calcium (0.03–013 %) added to provide the required mechanical properties for modern battery grids, the conductivity of lead-calcium alloys is nearly the same as pure lead. The addition of small amounts of tin (0.02–1.2 %) reduces the rate of corrosion of lead-calcium tin alloys by 50 % and increases conductivity to facilitate recharge of the battery. Aluminum (0.01–0.03 %) added to the alloy prevents loss of the calcium and trace amounts of silver (100–450 ppm) help to prevent changes in the dimensions of the positive grid in creep, because of grid oxidation at the grain boundaries, during service at high temperatures (Prengaman and Sigmund, 2001). The disadvantages of lead-calcium batteries compared to lead-antimony batteries are higher production cost and poor cycle life, particularly at higher ambient temperatures.

In Europe the hybrid (dual) type containing lead/calcium/tin for the negative grid and low lead-antimony for the positive grid are more common. By the year 2000, most lead-acid SLI batteries produced in the Western world had made the transition from traditional flooded lead-antimony alloy batteries to low maintenance based dual batteries (Prengaman and Sigmund, 2001). In Switzerland, the transition began in the 1990's (Jörg, SwissBat, 2004). SLI batteries are not produced in Switzerland (Bubendorff, Metallum AG, 2004; Jörg, SwissBat, 2004). In addition, VRLA batteries without antimony have almost completely replaced conventional flooded designs in stationary power (UPS) applications in Europe. In USA, the trend lags Europe by about five years, but these batteries are estimated to account for over 50 % of the industrial battery market (Roskill, 2001). Replacement to VLRA UPS batteries started in Switzerland in the second half of the 1980's (Jörg, SwissBat, 2004). Only UPS batteries are produced in Switzerland and they do not contain antimony (Bubendorff, Metallum AG, 2004; Jörg, SwissBat, 2004).

The main area of growth of antimony in batteries lies in SLI batteries produced in the industrializing countries of Latin America, South-East Asia, and Eastern Europe, mainly because of lower production costs and better market suitability. Growth rates of over 5 % per year are forecast for China, India, Korea, Thailand and Turkey (Roskill, 2001).

Tab. 3.4 > Antimony Products – World Metal Market.

Metal products	Sb compound used	Use
Lead alloys: Lead-acid batteries	Pb/Sb	Antimony is used in lead to improve castability, hardness, strength, creep resistance, and electrochemical stability. Three categories of batteries: SLI (starting, lighting, ignition) for motor vehicles. Deep cycle (traction) batteries for industrial and recreational electrical vehicles, such as forklift trucks, airport ground equipment, marine, and mining vehicles. Stationary deep cycle batteries for uninterruptible power supply (UPS) used in hospitals, telecommunication, computer, tools; and for storage, such as photovoltaic cells (PV), telephone exchange and load leveling equipment for electrical utilities.
Lead alloys: Ammunition and shot	Pb/Sb	Antimony is used as a hardening additive in lead for small ammunition. Some mines contain antimony (35 %).
Lead alloys: Bearing metals	Sn/Pb/Cu/Sb Pb/Sn/Sb / (Cu)	Reduction of friction and wear in machinery and help in prevention of failure due to seizure or fatigue, also called Babbitt metal. Tin-based Babbitt is used in low-speed diesel engines, gas turbine bearings, marine gearbox bearings and all large machinery. Lead based Babbitt is cheaper and used for oil-film bearings.
Lead alloys: Rolled and extruded lead sheets and pipes	Pb/Sb	Antimony alloyed with lead improves strength and hardness. *Construction sector* (6–12 % Sb): Lead sheets for flashing, cladding, roofing and damp proofing to provide water proofing and a protective layer on exposure to the atmosphere. *Chemical sector* (4–8 % Sb): Lead sheets and pipes for heating and cooling coils, lining for tank, pumps valves and process vessels in contact with corrosive materials and in the nuclear industry. Lead pipes are used for carriage of corrosive chemicals and lead sheathed cables. *Medical sector* (4 % Sb): Lead sheets for medical radiation shielding.
Lead alloys: Cable sheathing	Pb/Sb	The addition of antimony improves resistance to voltage stress. Were widely used for sheathing medium power cables and high-voltage underground cables.
Lead alloys: Weights	Pb/Sb	Lead weights (3–4 % Sb) for analytical scales, curtain weights, yacht keels and in balancing for vehicle wheels.
Lead alloys: Fusible alloys	Various mixtures of Pb/Bi/Sn/Sb	Alloys with low melting point used in material which would be harmed by excess heat. May be used in specialized solder applications for safety devices in airlines, fire stations, automotive industry. Demand for antimony is low, most fusible alloys contain no antimony.
Lead alloys: Type metal	Pb/Sn/Sb	Used to make printing type (2–28 % Sb). This market has fallen to negligible levels in western countries, being replaced by electronic printing.
Lead alloys: Solders	Pb/Sn/Sb Sn/Sb Cu/Sb	Antimony increases the hardness of tin-lead eutectic alloys. Used for construction and electronic applications. Due to restrictions in lead alloy, consumption of lead alloys containing antimony has been greatly diminished by 2004.
Copper alloys	Cu/Zn/Sb	Addition of antimony (0.05–0.6 % Sb) increases the fatigue and tensile strength of copper alloys. Around 0.3 % antimony can be added to the alloy to inhibit dezincification in brass used in plumbing systems for condenser tubing, valves connectors, pumps and taps, as in some countries water will attack zinc rich alloys.
Pewter	Sn/Sb/Cu	Also called Britannia Metal, with addition of tin (90–98 %), antimony (0.5–8 %) and some copper. Plates, flasks, jewelry and substitute for silverware. Production of Britannia metal, practically ceased after 1920.
Semiconductors	InSb AlSb GaSb	Antimonides, also called intermetallics, used as doping agent for thermoelectric devices, infra-red detectors, light emitting diodes (sensors, video cameras, DVDs, laser LED, photo detectors for fiber optics).
Magnetic steel	Fe/Si/Sb/MnS (MnSe)	Some processes use antimony (0.2 % Sb) together with manganese sulfide or manganese selenide as grain-growth inhibitor. Magnetic strips are used for certain applications – stickers on fridge, closing devices etc.

Source: Amspec (2004); Chemico Chemicals (2004); Roskill (2001).

Ammunition and shot

Lead shot has traditionally been used because of its softness, high density and low cost. Antimony metal is used as a hardening additive in lead alloys for small arms ammunition, mainly for sporting and military ammunition. Lead is highly toxic, however and lead shot has been banned for wildfowling in several countries, such as the USA, Finland and the Netherlands. In Denmark and the UK all shooting with lead shot over wetland areas, has been banned (Roskill, 2001). There is an increasing concern over the use of lead ammunition, outdoors because of the potential for environmental contamination and indoors because of the possibility of dust inhalation.
Data for antimony consumption in lead alloy shot and ammunition are not published. Data for lead consumption show recorded consumption totaled 116'300 tons in 1998, with USA with by far the largest market of 48 % (ILZSG, 2001).
In Switzerland, shot and ammunition containing antimony are used in GP 11, GP 90 and Pist Pat (PP41). Table 7.11 in Appendix I shows the metal composition of the ammunition data respectively and the consumed antimony in ammunition from 1970 to 2003.

Bearing metals

Bearing metals reduce friction and wear in machinery and help prevent failure due to seizure or fatigue. They form a surface over which other metals can slide. Bearing metals can be classified in two groups – one based on tin and the second on lead. Both alloys contain tin and antimony, while thin-based alloys also contain copper.
Tin-based alloys are more widely used than lead-based grades because they have better corrosion resistance and are less likely to exhibit segregation but they cannot be used at temperatures above 130°C. Lead-based alloys are lower in cost and are used for oil-film bearings because they retain good rubbing characteristics under extreme operating conditions such as high load, fatigue or temperature. They are preferred in railway and motor vehicle applications, where their properties are adequate. The strip of bearing alloys on backing material is very thin, ranging from 1–2mm, and rarely over 10mm even in large industrial equipment.
Both primary and secondary antimony from scrap is used in bearings. US demand for antimony in bearing metals fell from 90 tons in 1990 to an average of 40 tons per year. Similarly, Japanese consumption fell by 10 % between 1994 and 2000 (Roskill, 2001). This fall is partly due to improvements in bonding and welding technology, which have reduced the thickness of bearing strips used, and partly to increased competition from aluminium-tin alloys (no antimony in the alloy), which combine high fatigue strength with good surface properties and are used extensively in automotive industry.
Bearing metals are not produced in Switzerland, they are only traded (Kompass, 2004).

Rolled and extruded lead sheets and pipes

The main market for rolled and extruded lead products lies in the use of lead sheet in the construction sector. Both primary and secondary lead is used. The different uses of extruded lead product are listed in Table 7.4 in Appendix I. Areas of growth for lead rolled and extruded products, containing antimony, lie in lead sheet used for roofing (mainly in the UK and USA) and cladding, to deaden sound in hotels and public buildings, and for vibration damping in bridges (Roskill, 2001).
In Switzerland, however this market is small, but one company is still producing lead sheets (Senn, 2004).

Cable sheathing

Lead alloys containing antimony were widely-used for sheathing medium-voltage power cables and high-voltage underground telephone cables, because lead provides

effective protection for the cable insulation material against moisture, weathering and oxidation in a wide range of environmental conditions.
Lead alloys have faced increasing competition from alternative materials, due to technology changes in the cable sheathing market. In the telecommunications sector, lower-cost extruded co-polymers are used, especially for telephone cables which carry no heat and the increased use of optical fiber and co-axial cables have further exacerbated the decline in lead cable sheathing. In high-voltage power cables, laminated aluminum has replaced lead because it is stronger and lighter.
Today, use of lead cable sheathing is largely confined to niche markets, including unjointed submarine power cables up to 100 km in length, and to developing countries in tropical regions where lead sheathing is better able to withstand the climatic conditions than its substitutes. No separate data has been published for antimony in cable sheathing. However, recorded lead consumption during 1994 and 1999 fell by 73 % in Germany, 83 % in USA and 47 % in Japan. In most Asia (China, India and South-East Asia) lead cable sheathing demand rose by 20 % from 1994 to 1998 and is likely to rise further as domestic economies are growing fast in these areas (Roskill, 2001).
There is no lead cable sheathing produced in Switzerland. One trading company in Basel still imports/exports lead cable sheathing, but only based on special request (Kompass, 2004, Meier, Swissmem, 2004).

Weights

Lead alloys containing antimony are most widely used in vehicle balancing weights, and in weights for analytical instruments.
Weights are not produced in Switzerland, they are only traded (Kompass, 2004).

Fusible alloys

Fusible alloys are alloys with a low melting point of 20–176°C and are composed of bismuth, tin, lead and cadmium. The main market lies in safety devices in airlines, fire stations, and oil and gas rigs. Demand for antimony in fusible allows is very low, as antimony is only used in few fusible alloys, such as setting punches in press tools and castings of plastic components, which use trace amount of antimony addition.
In Switzerland the amount of antimony used in fusible alloys is negligible and not included in mass balance calculations.

Type metal

This market has fallen to negligible levels in western countries, because of the switch to electronic printing. In the Swiss printing industry, type metal was gradually replaced by photosetting in the 1970s. From 1985 to 1990, photosetting was in its turn replaced by digital printing technology (Weber, 2004). Therefore, it can be safely assumed that a possible stock was disposed of years ago.

Solders

Solders are mainly used in construction and electronic applications. Traditionally, the most widely used alloys were the tin-lead eutectics (60–63 % tin and 40–37 % lead). For most application these binary alloys are satisfactory however, for applications requiring higher strength, corrosion resistance or resistance to elevated temperatures ternary alloys, such as antimony (hardness), silver (strength) and bismuth and indium (temperature) were added. Due to environmental restrictions in lead alloy and consumption of solder in both the structural and electrical and electronic goods (EE) market, the use of antimony in solder has fallen to negligible amounts. The fall in

demand is primarily due to the replacement of tin-lead solder by lead-free materials. It has been replaced mainly by tin/silver, copper/silver solder.
In the automotive sector lead solder containing antimony has still been used for body fillers, for seams between spot-welded body panels and smooth out blemishes in press-formed panels. However, the ITRI (2000) reported that the automotive industry is also moving towards lead-free solder. In the EE sector, based on more stringent environmental regulations (e.g. WEEE Directive – Waste from Electrical and Electronic Equipment, EU) the use of lead solder in EE equipment is scheduled to be phased out by 2008. Most large EE producers in Japan and USA, however, have replaced lead solder since 2001 (Roskill, 2001). Small quantities of antimony will continue to be produced for high temperature solders for telecommunication cooling solutions, including thermoelectric coolers, utilizing tin-antimony solder melting at elevated temperature of 232°C (Roskill, 2001).
In Switzerland tin/lead solder had been used in the past for the construction of apparatus for chemical plants and to solder batteries. However, in Swiss applications lead-alloy solder containing antimony has never been used (Wirth, Compumet AG, 2004). Since more than two decades, the lead in the solder alloys had been replaced with lead-free materials in Switzerland.

Copper alloys

Small additions of antimony to brass and copper alloys increases fatigue resistance and tensile strength. Antimony may be added to copper pipes to improve corrosion resistance. However, the use of antimony in copper pipes is negligible in Switzerland (Zobrist, 2004).

Pewter

Pewter (or Britannia metal) contains tin (90–98 %), antimony (0.5–8 %) and some copper. Addition of antimony makes the metal harder and improves casting quality, while copper improves its workability. It is used for plates, flasks, jewelry and substitute for silverware. Production of pewter declined in the 20th century and practically ceased after 1920 (Artimport, 2003).

Semiconductors

High-purity antimony metal is used as a dopant in n-type semiconductor materials (thermoelectric devices) and in the production of Group II-V intermetallic compound semiconductor materials, such as indium antimonide, aluminum antimonide and gallium antimonide. For these applications a very-high purity 5N–7N antimony metal (99.999–99.99999 % antimony) is required.
Semiconductors are an expanding and high-value market for antimony metals. However, the quantity of antimony metal consumed is very low. World consumption of antimony metals in semiconductors has been forecast to increase from 19 tons in 1998 to 25 tons in 2005 (Roskill, 2001). Amounts of antimony in semiconductors (0.09 tons as antimony in 2001) have a negligible impact on Switzerland.

Magnetic steel

Magnetic steels are alloy of iron and up to 4 % silicon. Some processes use antimony (0.2 % antimony) together with manganese sulfide or manganese selenide as a grain-growth inhibitor. Others use aluminum nitride and boron instead of antimony. Magnetic steels are a niche market and the amount of antimony used is negligible.

3.2.2 Trade

The figures for import and export of finished metal products (Tab. 3.5) were taken from the Federal Customs Administration (EZV, 2001), were available, otherwise, they were estimated. Section A1-2.1 and Table 7.4 (Appendix I) give a detailed listing of all assumptions and references on how data for the traded metal products were gathered.

Tab. 3.5 > Flows of goods and antimony content in imported and exported goods.
Compiled listing of metal products.

Metal products	Imported into Switzerland in 2001 tons/year	Exported from Switzerland in 2001 tons/year	National consumption from trade in 2001 tons/year	Sb consumed from trade in 2001 tons/year
Lead-acid antimony based batteries: SLI	10'600	147	10'453	198.6
Lead-acid antimony based batteries: Deep-cycle (traction)	3'960	6'078	-2'118	-116.5
Ammunition and shot	104.9	120.8	-15.9	-0.5
Bearing metals	7.2	-	7.2	0.8
Rolled and extruded lead products	9'033.1	8'831.3	201.8	10.1
Weights	135.8	143.3	-7.5	-0.3
Total	**23'841**	**15'320**	**8'521**	**92.2**

3.2.3 Production

All metal products produced in Switzerland are listed in Table 3.6. Table 7.5 in Appendix I gives a detailed list of all assumptions and references on how production data of products were gathered.

Tab. 3.6 > Flows of goods produced in Switzerland – compiled listing of metal products.

Metal products	National production/reuse in 2001 tons/year	Sb consumed from production in 2001 tons/year
Ammunition and shot	(9'436) 320.7	(84.9) 8.7
Rolled and extruded lead products	540	27
Total	**860**	**36**

3.2.4 **Consumption**

Tab. 3.7 > Flows of goods and antimony content of consumed goods – compiled listing of metal products.

Table 3.7 corresponds to Table 7.6 (Section A1-2.3) in Appendix I.

Metal products	Sb consumed from trade in 2001	Sb consumed from production in 2001	National Sb consumption in 2001
	tons/year	tons/year	tons/year
Lead-acid antimony based batteries: SLI	198.6	no production	198.6
Lead-acid antimony based batteries: Deep-cycle (traction)	–116.5	no production	–116.5
Ammunition and shot	–0.5	8.7	8.2
Bearing metals	0.8	no production	0.8
Rolled and extruded lead products	10.1	27	37.1
Cable sheathing	no trade	no production	-
Weights	–0.26	no production	–0.26
Total	**92**	**36**	**128**

3.2.5 **Stock**

Stocks (Tab. 3.8) have been calculated in Appendix I (Section A1-2.4 and Tab. 7.7 to 7.10).

Tab. 3.8 > Stock of metal products and antimony.

Metal products	Average national consumption for 2001 (tons)		Life cycle	Stock
	product	Sb	years	tons Sb
Lead-acid antimony based batteries: SLI	10’186.7	193.5	5	967.7
Lead-acid antimony based batteries: Deep-cycle (traction)	-2’219.7	-122	∅ 6 (5–7)	-732
Ammunition and shot	421.7	16.2	1	16.2
Bearing metals	9.4	1.04	∅ 18.2	18.9
Rolled and extruded lead products	540	27	40	1’080
Cable sheathing	510	4.3	40	172
Weights	46.2	1.6	>40	64
Total	**9’494**	**122**		**1’587**

3.3 Nonmetal products

3.3.1 Classification of major products

Table 3.9 lists the major nonmetal products in which antimony is consumed and its end-use. Antimony is used primarily as a catalyst in plastics, because there is a cross-linking with antimony in plastics to produce a more stable polymer:

Plastics – Polyester

Polyester is a polymer where individual units (monomers) are held together by ester linkages. Their different properties and use depends on the type of monomers from which they are formed. Polyester can be differentiated into two types, namely saturated (thermoplastic) polyesters resins, used for fibers and films, and unsaturated polyesters or thermosetting resins used extensively for laminated and chemically resistant coating. The most common commercial types of unsaturated polyesters are polymer reactions with styrene, or other vinyl unsaturated monomers, and urea-formaldehyde (Packaging Graphics, 2004). Typical applications of the thermosetting resins are found in transportation, appliances, electrical and construction markets, and for decorative products.

The most common commercial types of saturated polyesters are poly(ethylene terephthalate), commonly known as PET, DMT produced with dimethyl terephathate, TPA produced with terephthalic acid; and PBT (polybutylene terephthalate) produced by the reaction with DMT.

> PET (Polyester thermoplastics): One of the most important quantitatively significant polyesters is poly(ethylene terephthalate) made by poly-condensation of ethylene glycol. The everyday name depends on whether it is being used as fiber or as a material for making packaging, such as bottles for soft drinks and film food packaging. When it is being used as a fiber for making textiles it is often just called polyester, or by its brand name Terylene, Trevira, Dacron, Diolen or Mylar. When it is being used to make bottles, for instance, it is usually called PET. PET is also used in automotive, electrical component and signage applications.
> PBT often is used in the construction sector for door and window hardware, automobile luggage racks and headlight components (DuPont, 2004).

In order to achieve polymerization of polyesters a catalyst is required. As catalyst several compounds are suitable, but for economic considerations antimony compounds (in their oxidized form) have been almost exclusively used since the early seventies (Krüger, 1999). Antimony improves the quality of the polyester produced and reduces catalyst costs. Japanese and other East Asian producers use germanium dioxide for high-quality bottles, because antimony trioxide reduces bottle transparency, and for heat-resistant bottles (Roskill, 2001).

Global production of polyester in 2002 amounted to 21 million tons. From 1982 through to 2002 polyester manufacturing grew on average by 7.3 % per year. In the worldwide manufactured fiber production by region the Asian share was up 65 % in 2002 from 30 % in 1982. This compared with a North American and Western Europe combined share of 46% in 1982, down to 27% in 2002. The other significant shift in the twenty-year period was Eastern Europe – moving from 17% to 2% (The Fiber Organon, 2002). PET consumption in the packaging sector rose by 16% per year in Western Europe between 1996 and 1999 (Roskill, 2001). The total polyester consumption in Europe amounted to 3.67 million tons in 2001, of these 3.18 million tons accounted for PET and 0.49 million tons for polyester resins (APME, 2003).

In Switzerland, PET consumption rose by 51.5% from 1995 to 2001, or by 13% per year between 1995 and 2001 (Fig. 7.3 and Tab. 7.33 – 'use and recycling of PET'). PET is not produced in Switzerland (Rischgasser, KVS, 2004) however, it is recycled, melted and reproduced (Association PRS, 2004). Polyester resins are not produced in Switzerland (Rischgasser, KVS, 2004) however, it is recycled.

Poly vinyl chloride (PVC)

PVC belongs to the family of thermoplastics. PVC has a tendency to decompose on heating or prolonged exposure to ultra-violet light. This leads to the generation of chlorine gas, colouration and embrittlement of the plastic and a loss of plastic strength. The incorporation of heat stabilisers into the PVC matrix stabilises the polymer against the degradation process. Five groups of PVC stabilisers are used – lead, barium-zinc, calcium-zinc, organotins and organic compounds – and antimony compounds account for only a small portion of the market. In future, consumption of lead stabiliser will fall and the PVC industry will largely adopt calcium-zinc or tin stabilisers in favour of antimony compounds (Roskill, 2001). Only small quantities of antimony compounds are consumed in PVC stabilization. Japanese demand for PVC totalled 2.46 million tons in 1999, but consumption of antimony trioxide in this market was estimated at below 200 tons (Roskill, 2001).

PVC consumption in Western Europe accounted for 5.704 million tons in 2001 (APME, 2003). PVC is not produced in Switzerland (Rischgasser, KVS, 2004) however, it is recycled.

Lubricants

Antimony trisulfide, available as a black powder or paste, is added to increase the stability of fluid lubricants used in brake pads and disk clutches. Antimony trisulfide is also added to molybdenum disulfide lubricants to decrease friction and wear.

All lubricants are imported and there is no production in Switzerland. Because of car-manufacturing improvements, consumption of brake fluids has decreased by 15% in the past 3 years, although quantity of cars increased by 3.7% during the same time in Switzerland (VSS, 2003).

Brake pads

Information from manufacturers on the composition of brake pads is sparse. Since the use of asbestos in products has been banned, sulfides of antimony, molybdenum and copper have been used in percent concentration ranges to prolong and increase the effectiveness of brake pads (Weckwerth, 2005) Brake pads are mainly produced in Asia and the near East.

Glass and ceramic

The main market for antimony in the glass and ceramics sector is the use of sodium antimonate for the production of cathode ray tubes (CRT). Smaller quantities of antimony trioxide and sodium antimonate are used as opacifiers in porcelain enamels, as pottery glazes and as brick additives. Glass and ceramics together are reported from the USGS to account for 4 % of total US consumption of primary antimony in 2001and 18.7 % of US nonmetal antimony containing products (Carlin, USGS, 2003). These products are only imported to and not produced in Switzerland (VSKI, 2004, Stengele, 2004).

Glass

Antimony compounds are added to specialty glass batches as decolorizing and fining (degassing) agents. The main applications lie in television and computer monitor cathode ray tube (CRT) glass and to some smaller extent in optical glass used for cameras, photocopiers, binoculars and spectacles, as well as in fluorescent light glass tubing.

Fining (degassing) agents are used to remove the gaseous inclusions which appear in the glass batch when it is melted. Antimony compound additions between 0.3 and 0.8 % are used for degassing CRT and optical glasses. Antimony additions of 0.1–0.2 % (Roskill, 2003) are used to decolorize glass with iron and other impurities. The decolorization using antimony compounds has excellent light transmitting properties over the infra-red end of the spectrum. By far the largest market for antimony compounds in the glass and ceramics industry is the use of sodium antimonate (Roskill, 2001).

Industry sources estimate that the Asia/Pacific region accounts for 70 % of world production of CRT glass, with the USA accounting for 20 % and Europe for 10 % (Roskill, 2001). Production of CRT glass has mirrored the shift in CRT manufacture from Western Europe, USA and Japan to South-East Asia. The production in Japan declined by over 40 %, between 1997 and 2000 (Roskill, 2001). In the medium-future, the demand for CRT glass has been forecast to rise by 3 % per year for television and by 7 % per year for computer monitors.

Ceramics

The main application for antimony trioxide and sodium antimonite lies in porcelain enamels. These enamels are used for iron bath tubs and sinks. Antimony compounds have the additional advantage of raising acid resistance. Antimony compounds are only used in lead-free white enamels. In recent years, the development of titania white enamels has partially replaced antimony-based enamels.

Naples yellow, a lead antimonite pigment formed from antimony trioxide and lead, is used as a glaze for pottery. Glazes represent a negligible fraction of antimony consumption.

Antimony trioxide applied to red-burning clays will chemically bleach the clay surface to a buff colour. Bricks represent a negligible fraction of antimony consumption.

No enamel is produced in Switzerland according to the VSKI (2004). Moreover, bathtubs and sinks made of cast iron and enamel are a rare product today, (Sanitas Troesch, 2004).

Tab. 3.9 > Antimony products – Nonmetal market.

Nonmetal products	Sb compound used	Use
Thermoplastics: PVC	Sb_2O_x	Heat stabilizer for PVC used in window frames, pipes, flooring, wallpaper, bottles, cling film, toys, guttering, cable insulation, credit cards, medical products.
Lubricants	SbS_3	Added as black power or paste to increase stability of fluid lubricants in brake pads and disc clutches. Decrease friction and wear of molybdenum disulfide.
Glass	$NaSbO_3$* Sb_2O_x	Fining agent (degasser) in CRT glass (Computers, TV bulbs and optical glass used for cameras, photocopiers, binoculars and spectacles). Heavy plate glass exposed to sun (excellent light transmitting properties near end of spectrum).
Ceramics: Enamels Glazes Bricks	Sb_2O_x $NaSbO_3$ SbF_3	Opacifier in porcelain enamels for led free white enamels for cast iron bath tubs and sinks. Additional advantage of acid resistance. Sodium antimonate and antimony trioxide are used. Opacifier in pottery glazes, used as yellow pigment for body stain. For porcelain and pottery mostly sodium antimonate is used. Antimony trifluoride may be used, too. Antimony trioxide is used to bleach red-burning clay for bricks.
Pigments	Sb_2O_3 SbS_3, SbS_5	Sb_2O_3 produces white pigment in oil-based enamels used as automotive or house paint using antimony oxide. SbS_3 and SbS_5 produce pigments of black, vermillion, yellow and orange for use in rubber. Camouflage paint can contain SbS_3. Electroconductive pigments in in plastics for electronic equipment consisting of tin oxide doped with antimony.

Source: Amspec (2004); Chemico Chemicals (2004); Roskill (2001).

Pigments

Antimony compounds are used for white, black, vermillion, yellow, orange and camouflage pigments, as well as electroconductive pigments.

> White pigments are prepared with antimony trioxide. They have a niche market in exterior oil-enamels used as automotive or house paints, because they control chalking and therefore, improve tint retention.
> Antimony trisulfide and antimony pentasulfide produce black, vermillion, yellow and orange pigments for use in rubber. These pigments are relatively weak, but they have resistance to heat and outdoor weathering, and are compatible with most resins.
> Camouflage paints reflect infra-red radiation to produce the same color as green vegetation. These paints may contain antimony trisulfide.
> Electroconductive pigments consist of tin oxide doped with antimony trioxide to increase electrical conductivity. They can be co-extruded in bright colors since their near white color does not affect base colorants and they are dispersed in polymers. Applications include the protection of electronic equipment from damage due to electrostatic discharge, and priming of plastic components.

Pigments account for 5 % of total US consumption of primary antimony in 2001 and 23.6 % of US nonmetal antimony containing products (Carlin, USGS, 2003). Japanese consumption of antimony trioxide in pigments is around 600 tons per year, which represents 3 % of their total market.

In Switzerland, antimony in pigments is mainly used for fire-protection paints. Trace concentrations of antimony are introduced into mixed phase pigments or spinels, where they are tied in the crystal lattice of the molecule. These pigments are neither soluble in water nor in acid. Other antimony-based pigments are no longer used. Pigments containing antimony are not produced in Switzerland (Kastien, 2004).

3.3.2 Classification of minor products

Table 3.10 lists the minor nonmetal products in which antimony is consumed. Antimony compounds find applications in a wide range of minor end-uses. Combined US consumption of primary antimony in these markets totaled 544 tons in 2001, 4.2 % of total US primary antimony consumption and 19.7 % of US nonmetal antimony containing products (Carlin, USGS, 2003).

Tab. 3.10 > Antimony products – Minor nonmetal market.

Nonmetal products	Sb compound used	Use
Matches, fireworks	SbS_3	Can be used to provide glittering effect in fireworks.
Rubber	SbS_5	Replaces selenium or tellurium as vulcanising agent in red rubber compounds.
Fluorescent light bulbs	Sb_2O_x	Antimony is used as phosphorescent agent.
Mordant	SbF_3 $SbBr_3$ $K(SbO)C_4H_4O_6 \cdot 5H_2O$	Used as a mordant at 2–4 % Sb in the dying process for textiles and leather to improve the wet-fastness properties.

Source: Amspec (2004); Chemico Chemicals (2004); Roskill (2001).

Ammunition primer and explosives

Antimony trisulfide is used as an ammunition primer in detonators, ignition agents and smoking agents. In primary explosives, antimony trisulfide ignites the next element in a series of explosions of increasing mass and decreasing sensitivity.

The US consumption of primary antimony in ammunitions primer totalled 26 tons or 0.16 % of total US consumption in 2000, after that year consumption of ammunition primer has not any more been reported as a separate item in the US (Carlin, USGS, 2001). Ammunition primer and explosives are not produced in Switzerland (RUAG Ammotec, 2004).

Fluid catalytic cracking agents (FCC)

Antimony compounds are used in the refining process of gasoline, gas and coal cracking. The FCC unit is one of the major gasoline producer units in the refinery operation. Antimony compounds are added to the process as water-based metal passivation additives, scavenging nickel form the FCC catalyst, to improve gasoline yields and reduce catalyst attrition. Also, there exist extensive literature on the FCC process, no reports on possible trace concentrations of antimony in gasoline have been published. Moreover, a chemical analysis of antimony in gasoline is, based on the explosive nature of gasoline, not feasible. Therefore, we assume that antimony content in gasoline is negligible. (Environment Australia, 1999)

Matches and fireworks

The crude commercial antimony sulfide can be used directly in the manufacture of matches or Bengal Lights, antimony trisulfide burns brightly when heated and emits dense white smoke. It can be used to provide the glittering effect in fireworks. Some minor amounts of fireworks, though no matches, are manufactured in Switzerland (Kompass, 2004).

Rubber

Antimony is occasionally used to replace selenium or tellurium as vulcanizing agent in the production of red rubber compounds (Roskill, 2001). Rubber products containing antimony are not produced in Switzerland (Kompass, 2004).

Fluorescent light bulbs

Antimony trioxide is used as a fining agent (degasser) in some fluorescent light bulb glass. There is some production of fluorescent light bulbs in Switzerland, however amounts of antimony used here is negligible (Kompass, 2004).

Mordant

Antimony can be used in mordant and textiles for the dying process. It is one of several after-treating agents which can be used in certain acid dyes for nylon textiles and as fixing agent for leather. It is a niche product and the amount of antimony used in this process in Switzerland is negligible. There is no production of mordant in Switzerland (Kompass, 2004).

3.3.3 Trade

The figures for import and export of finished nonmetal products (Tab. 3.11) were taken from the Federal Customs Administration (EZV, 2001), were available, otherwise, they were estimated. Section A1-3.1 and Table 7.13 give a detailed listing of all assumptions and references on how data for the traded nonmetal products were gathered. Table 7.12 lists the corresponding concentrations of antimony in nonmetal products.

Tab. 3.11 > Flows of goods and antimony in imported and exported goods – compiled listing of nonmetal products.

Nonmetal products	Imported into Switzerland in 2001 tons/year	Exported from Switzerland in 2001 tons/year	National consumption from trade in 2001 tons/year	Sb consumed from trade in 2001 tons/year
Thermoplastics: PET (bottles)	6'500	-	6'500	1.3
Thermoplastics: PET (textile fibres, film food packaging)	20'401.4	1'221.4	19'180	3.9
Thermosets: Polyester resins	19'983.7	12'336.7	7'647	1.5
Thermoplastics: PVC	177'973.5	86'800.5	91'173	6.4
Glass	not known	not known	2'258	7.9
Ceramics	not known	not known	3.1	0.2
Pigments	not known	not known	255	10.2
Lubricants	741	16	725	39.9
Brake pads	1200	84.6	1115	29
Minor nonmetal market: Ammunition primer and explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant	not known	not known	n.d.	8.5
Total	**226'800**	**100'459**	**128'856**	**109**

3.3.4

Production

Nonmetal products are not produced in Switzerland. However, plastics are collected, and recycled. Table 7.14 in Appendix I gives a detailed list of all assumptions and references on how production data of products were gathered.

Tab. 3.12 > Flows of goods and substances produced in Switzerland – compiled listing of nonmetal products.

Nonmetal products	National production/reuse in 2001 tons/year	Sb consumed from production in 2001 tons/year
Thermoplastics – PET (bottles)	25'220	5
Thermoplastics: PET	1'330	0.27
Thermosets: Polyester resins	530	0.11
Thermoplastics: PVC	6'323	0.44
Total	**33'403**	**5.8**

3.3.5 Consumption

Tab. 3.13 > Flows of goods and substances of consumed goods – Compiled listing of nonmetal products.

Table 3.13 corresponds to Table 7.15 in Appendix I.

Nonmetal products	Sb consumed from trade in 2001 tons/year	Sb consumed from production in 2001 tons/year	Sb consumed in 2001 tons/year
Thermoplastics: PET (bottles)	1.3	5	6.3
Thermoplastics: PET	3.85	0.27	4.12
Thermopsets: Polyester resins	1.5	0.11	1.64
Thermoplastics: PVC	6.4	0.44	6.84
Glass	7.9	no production	7.9
Ceramics	0.17	no production	0.17
Pigments	10.2	no production	10.2
Lubricants	39.9	no production	39.9
Brake pads	29	no production	29
Minor nonmetal market: Ammunition primer and explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant	8.5	no production	8.5
Total	**109**	**6**	**115**

3.3.6 Stock

Tab. 3.14 > Stock of nonmetal products.

The stocks listed in Table 3.14 have been calculated in Appendix I (Section A1-3.4 and Tables 7.16 to 7.22).

Nonmetal products	Average national consumption for 2001 (tons)		Life cycle	Stock
	product	Sb	years	tons Sb
Thermoplastics – PET (bottles)	29’786	6	1	6
Thermoplastics – PET (textile fibers, packaging, raw material)	21’316	4.3	3	12.9
Thermosets: Polyester resins	7’647	1.5	19.3	29
Thermoplastics: PVC	91’173	6.4	14.4	92.2
Glass	3’885.7	13.6	6.7	91.1
Ceramics	5.3	0.29	40	11.6
Pigments	297.5	11.9	40	476
Lubricants	725	39.9	7	279.3
Brake pads	1115	29	4	87
Minor nonmetal market: Ammunition primer and explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant	n.d.	6.2	3	18.6
Total	**154’836**	**90**		**1’053**

Notes: Brake pads wear down over the 2 years. It is assumed that the average wear on the pads is 50 %. Assumptions are given in Section A1-3.

3.4 Flame retardants

3.4.1 Classification of products

Antimony oxide by itself is not a flame retardant, and halogenated organic compounds (mainly bromine and chlorine) alone have a weaker flame retardant effect. However, when they are combined they become synergistic and are the most effective and widely used flame retardant systems used in plastics.

Two mechanisms exist in the synergistic system. First is the "free radical capture" process that takes place in the vapor phase. On combustion at a temperature of above 300°C, the halogen forms hydrochloric or hydrobromic acid that reacts with the antimony oxide to form antimony trichloride, antimony oxychloride, antimony tribromide, or antimony oxybromide. It is thought that "free radicals propagate" the flame. The antimony trihalides or oxyhalides act as "free radical traps" taking up free radicals and inhibit ignition and pyrolysis in the solid, liquid and vapor phases. A second process occurs in the solid phase and is the "char process". The antimony oxide promotes the formation of "char" (carbon) on the substrate, which reduces volatile gas formation (UAMY, 2001). In essence, the combustion process is deprived of oxygen.

The two main disadvantages of synergistic halogenated flame retardant systems containing antimony are

- smoke generation
- environmental concern.

Breakdown products, from incomplete combustion, lead to an increase in smoke density, when halogenated flame retardants burn. In addition, acids formed during the burning of halogenated flame retardants are toxic and corrosive, and can cause secondary damage to electronic equipment. There has been much debate, prominently in Europe, over the toxicity of halogenated flame retardants, especially for brominated flame retardants. There are concerns over the emission of traces of compounds into the atmosphere during the processing, recycling or incineration of plastics. Antimony trioxide itself has a Class B carcinogen label and is suspected of causing tumors.

Antimony compounds are used in flame retardants for a wide range of plastics and rubbers – halogenated polymers: PVC, unsaturated polyester, PE; non-halogenated polymers: ABS, PP, PS, epoxy resins, rubber, PU; as well as poly-olefins, EDPM, adhesives, paints, paper and textiles. Table 3.15 lists flame retardant products in which antimony trioxide is consumed. Table 7.23 in (Section A1-4) lists corresponding concentrations of Sb in FR products.

Tab. 3.15 > Antimony products – Flame retardant market.

Flame retardant products	Flame retardant addition	End-use
Polyvinyl chloride (PVC)	Unplasticised (rigid) PVC products are flame retarded due to their chlorine content. Plasticised PVC products contain flammable plasticizers and must be flame retarded. Antimony trioxide additions are 1–10 % by weight. If plasticizers are used that reduce the halogen content, it can be increased by phosphate esters or chlorinates waxes.	Wall cladding, siding, injection molding parts. Wire and cable industry.
Polyethylene (PE)	Low-density PE burns rapidly and must be flame retarded with 8–16 % antimony trioxide and 10–30 % of a halogenated paraffin wax or a halogenated aromatic or cycloaliphatic compound.	Cable insulation, flooring, roofing, conveyor belts.
Unsaturated polyester	Halogenated polyester resins are flame retarded with around 5 % antimony trioxide.	Housing and electrical parts, train carriage seating, bath and shower trays, panels, wall claddings, storage crates.
Acrylonitrile-butadiene-styrene (ABS)	As ABS is processed at high temperatures, a stable flame retardant must be used. Up to 25 % of a chlorinated cycloaliphatic compound or an organic brominated compound is used with 5–12 % antimony trioxide.	Home and business electrical and electronic equipment (casing), communications products, car interior trims and panels.
Polypropylene (PP)	As PP is generally processed by injection molding or extrusion at 400–450 °C, a stable flame retardant is used. 5–15 % antimony trioxide and up to 40 % of a brominated chlorinated cycloaliphatic or aromatic compound is used. Higher flame retardant additions are needed for application over 450 °C.	Cable insulation, flooring, roofing, conveyor belts.
Polystyrene (PS)	Crystal PS can be flame retarded with a brominated flame retardant and small quantities of antimony trioxide. High-impact PS contains an elastomer and must be flame retarded with large quantities of a brominated compound and around 10 % antimony trioxide. Expanded PS beads are flame retarded with a brominated compound and an activator such as an organix peroxide.	Electric and electronic casings and component applications, lighting appliances, cable insulation.
Epoxy resins	Epoxy resins are generally flame retarded with a brominated organic compound and a fine particle antimony trioxide.	Circuit boards, laminated casting resins.
Rubber elastomers	Styrene butadiene rubber, ethylene propylene rubber, latex and other elastomers can be flame retarded with halogenated compounds and 5–30 % antimony trioxide.	Cables, injection molded parts, profiles, films, flooring, carpet backing, seat cushions, seals, high voltage insulation.
Rubber	Antimony trioxide and a halogen are used to flame retard.	Hose, belting and carpet backing.
Polyurethane (PU)	Up to 10 % antimony trioxide and a brominated hydrocarbon are used to flame retard PU.	Foams.
Paints	Paints are flame retarded with halogen, usually chlorinated paraffin or rubber, and 10–25 % antimony trioxide.	
Textiles	Antimony trioxide and halogenated flame retardants are used in modacrylic fibres and halogenated polyesters. Chlorinated paraffin and/or polyvinyl chloride latex and around 7 % antimony trioxide are used to flame retard.	Curtains, carpeting, padding, canvas and other textiles.

Roskill, 2001; Weber, Industrial Minerals, 2000.

3.4.1.1 Brominated flame retardants

Compared to alternative flame retardants, brominated hydrocarbons in combination with antimony are the most effective, as lower quantities are required. Consumption of brominated FR in Western Europe accounts for 15 % of worldwide consumption, evaluated to be over 200’000 tons (205’000 to 265’000 tons BSEF (2000); 310’000 tons for 1999 FOEN (2002); 340’000 tons by Weber (2000).

Antimony trioxide is used as a synergist, along with brominated hydrocarbons in flame retardant polymer formulations widely used in electrical and electronics applications. Nearly two thirds (59 %) of the EE industry’s brominated FR consumption is destined for housings, including car interior plastics and textiles; printed circuit boards account for 30 %; connectors and relays for 9 % and wire and cabling for 2 % (BSEF, 2000 and Tab. 3.15). Typical bromine to antimony trioxide ratios range from 2:1 to 5:1 (∅ 3:1) (Roskill, 2001; Nyacol, 2003; Nilsson, 2001). In Europe roughly 42’800 tons of BFR and about 23’900 tons of antimony trioxide are used according to Weber Industrial minerals, 2000 – Fig. 1.4). Around 15’000 tons antimony (at 35 % Sb_2O_3 ratio to BFR) are used with brominated flame retardants and the remainder is used with chlorinated flame retardants (8900 tons antimony trioxide).

3.4.1.2 Chlorinated flame retardants

Chlorinated flame retardants are mainly added to PVC (USAC, 2003; Danish Environmental Protection Agency, 1999; Roskill, 2001). Antimony trioxide additions to PVC are 1–10 % by weight (Roskill, 2001). As a rule four to five parts of chlorinated flame retardant are used to one part of antimony trioxide (∅ 22 % Sb_2O_3) on a weight basis (USAC, 2003). The stoichiometric ratio of chlorine to antimony is 5:1. In addition to its catalytic function, the formation of $SbCl_3$ and SbOCl acts as a dehydrating agent that increases charring in the solid phase of the polymer.

Because of the high chlorine content in PVC, antimony trioxide with small or no addition of an organic halogen (mostly additional chlorine) seems to be an economical and effective flame retardant in high performance PVC applications. Rigid PVC products (unplasticized) are essentially flame retarded and no additional chloride is added, though if plasticizers are used in PVC the halogen content is decreased and additional chloride or other flame retardants are added (USAC; 2003). Both rigid and flexible PVC are mainly used for building materials. Approximately 40 % of rigid PVC is used for pipes and fittings. Sidings, window frames, rain gutters and flooring account for about 20–25 % of PVC use and only little ClFR and antimony are usually added. Flexible (plasticized) PVC is used for the wire and cable industry (30 %). These products require both the addition of ClFR and antimony. The remainder, about 8 %, is used for films and packaging and is usually not flame retarded (McCarthy and Tucci, 2003). Thus roughly a total of 52 % of all PVC products are flame retarded.

Tab. 3.16 > Estimated consumption of chlorinated flame retardants per area.

Area	tons per year	tons Sb_2O_3
USA[1]	19'000	4'180
USA[2]	36'700	8'074
USA[3]	42'730	9'400
Western Europe[1]	29'000	6'380
Western Europe[2,4]	10'200	2'244
Western Europe[5]	8'730	1'920
Western Europe[6]	11'200	2'464
Western Europe[7]	10'110	2'224

Source: [1]SRI International 1995 quoted at Euromin '97 (Roskill, 2001); [2]Alusuisse Martinswerk (1998) quoted in Euromin '99 (Roskill, 2001; [3]3 % forcasted increase in CIFR for 2001(Alusuisse Martinswerk, 1999; [4]Fig. 1.4 (Weber, Industrial minerals, 2000; [5]Frost & Sullivan (1999; [6]5.2 % forecasted increase in CIFR for 2001 (Freedonia, 2001; [7]5 % forcasted increase in CIFR for 2001 (Frost & Sullivan, 1999).

The market share of chlorinated FR in PVC is about 3 % (Tab. 3.16) in Europe and 11 % in USA (Roskill, 2001). According to Weber (Industrial minerals, 2000 – Fig. 1.4) about 10'200 tons of chlorinated FR and about 8900 tons antimony trioxide are used for PVC applications in Western Europe.

Available data on consumption of chlorinated flame retardant are given in Table 3.16 for USA and Western Europe. Globally, the share of halogenated flame retardant consumption fell from 25 % to 16 % in Europe between 1995 –1998, but rose from 20 % to 38 % in the USA (Roskill, 2001). The main reason is that flame retardant standards have discouraged the use of halogenated (brominated and chlorinated) flame retardants in Europe.

Section A1-4.2 explains all assumptions used to calculate flows for chlorinated flame retardants.

3.4.2 Trade

The values in Table 3.17 for import and export of finished brominated flame retardant products were taken from the Federal Customs Administration (EZV, 2001). Table 7.24 and section A1-4.1 in Appendix I give a detailed list of data for the traded brominated flame retardant products. The values in Table 3.18 were based on the assumptions made in A1-4.2.

Tab. 3.17 > Imported and exported products containing brominated flame retardants for Switzerland in 2001.

Brominated flame retardants	Imported into Switzerland in 2001 1000 tons/year	Exported from Switzerland in 2001 1000 tons/year	National consumption in 2001 1000 tons/year
EDP and office electronics	42.7	6.5	36.2
Communications technology	13.6	4	9.6
Household electronics	26.6	5	21.6
Household appliances – small	7.1	9	–1.9
Household appliances – large	101.8	55.4	46.4
Special appliances	2	5	–3
Small EE components	50.5	55.5	–5
Vehicles	616.5	272	344.5
Building materials and textiles	-	-	-
Total	**861**	**412**	**449**

Tab. 3.18 > Imported and exported products containing chlorinated flame retardants for Switzerland in 2001.

Chlorinated flame retardants	Imported into Switzerland in 2001 tons/year	Exported from Switzerland in 2001 tons/year	National consumption in 2001 tons/year
PVC for cables and wire	98400	48000	50400
PVC for building materials	72200	35200	37000
Total	**170600**	**83200**	**87400**

Tab. 3.19 > Amount of brominated FR and antimony consumed in 2001.

Table 3.19 corresponds to Table 7.26 (Appendix I).

Brominated flame retardants	National consumption in 2001 1000 tons/year	Brominated FR consumed in 2001[1] tons/year	Sb_2O_3 consumed from trade in 2001 tons/year	Sb consumed from trade in 2001 tons/year
EDP and office electronics	36.2	445	148	123
Communications technology	9.6	63.7	21.2	17.6
Household electronics	21.6	29.6	9.9	8.2
Household appliances – small	–1.9	–2.4	–0.8	–0.7
Household appliances – large	46.4	37.9	12.6	10.5
Special appliances	–3	–13.4	–4.5	–3.7
Small EE components	–5	–0.9	–0.3	–0.2
Vehicles	345	144	47.8	40
Building materials and textiles	-	-	-	-
Total	**448**	**703**	**234**	**194**

Source: [1]FOEN, No. 338 (2002), extrapolated from Tab. 5–17 and 5–18 therein.

The values in Table 3.19 for the brominated flame retardant products consumed from trade were extrapolated using the transfer coefficient derived from data from the environmental Series no. 338 (FOEN, 2002). Table 7.26 in section A1-4.1 (Appendix I) gives a detailed list of all assumptions and references on how data for the brominated flame retardant products were gathered.

The estimates for chlorinated flame retarded products shown in Table 3.20 have been similarly estimated (see section A1-4.2, Appendix I).

Tab. 3.20 > Amount of chlorinated FR and antimony consumed in 2001.

Chlorinated flame retardants	National consumption in 2001	ClFR consumed in 2001	Sb2O3 consumed in 2001	Sb consumed from trade in 2001
	tons/year	tons/year	tons/year	tons/year
PVC for cables and wires	50’400	55.5	12.2	10.1
PVC for building materials	37’000	42.3	9.3	7.4
Total	**87400**	**97.8**	**21.5**	**17.5**

3.4.3 Production

The figures in Table 3.21 for the brominated flame retardant products produced in Switzerland were extrapolated using the transfer coefficient derived from data from the environmental Series no. 338 (FOEN, 2002). Table 7.27 and section A1-4.1 in Appendix I gives a detailed list of all assumptions and references on how data for the brominated flame retardant products were gathered.

Tab. 3.21 > Production of products containing brominated flame retardants in Switzerland in 2001.

Brominated flame retardants	National production in 2001[1]	BFR consumed from production in 2001[1]	Sb_2O_3 consumed from production in 2001[2]	Sb consumed from production in 2001[2]
	1000 tons	tons/year	tons/year	tons/year
EDP and office electronics	41.3	339	113	94
Communications technology	2.7	14	4.7	3.9
Household electronics	5.0	19.4	6.5	5.4
Small household appliances	11.2	6.9	2.3	1.9
Large household appliances	32.9	27	9.0	7.5
Special appliances	12.6	70	23.3	19.4
Small EE components	173	30	9.9	8.2
Vehicles	4.1	0.8	0.3	0.2
Building materials and textiles	51	215	72	60
Total	**335**	**722**	**240.6**	**200**

Source: FOEN, No. 338 (2002), extrapolated from Tab. 5–15 therein.
Average concentration of antimony in brominated FR based on Tab. 7.1 and 7.23.

Chlorinated flame retardant products are not produced in Switzerland. Based on our findings no PVC products are produced in Switzerland.

3.4.4 Consumption

The figures in Table 3.22 for the consumed brominated flame retardant products correspond to the sum of Table 7.28 in Appendix I. The consumption of antimony used with chlorinated flame retardants shown in Table 3.23.

Tab. 3.22 > Consumed antimony used with brominated flame-retardant products in Switzerland in 2001.

Brominated flame retardants	Sb consumed from trade in 2001 tons/year	Sb consumed from production in 2001 tons/year	Total Sb consumed in 2001 tons/year
EDP and office electronics	123	93.7	217
Communications technology	17.6	3.9	21.5
Household electronics	8.2	5.4	13.6
Household appliances – small	–0.7	1.9	1.2
Household appliances – large	10.5	7.5	18
Special appliances	–3.7	19.4	15.7
Small EE components	–0.2	8.2	8
Vehicles	40	0.2	40.2
Building materials and textiles	-	59.5	59.5
Total	**194**	**200**	**394**

Tab. 3.23 > Consumed antimony used with chlorinated flame-retardant products in Switzerland in 2001.

Chlorinated flame retardants	Sb consumed from trade in 2001 tons/year	Sb consumed from production in 2001 tons/year	Total Sb consumed in 2001 tons/year
PVC for cables and wires	10.1	no production	10.1
PVC for building materials	7.4	no production	7.4
Total	**17.5**	**no production**	**17.5**

The halogenated flame retardant market share in Europe for ClFR is reported to be 16% (Weber (2000), or roughly 5:1. The amount of ClFR consumed in Switzerland in 2001 was estimated to be around 285 tons and the amount of antimony 47 tons, which is approximately 2.5 times larger than the value listed in Table 3.23. This is due to the fact that Switzerland's population is 3.96% of the European population, while PVC consumption is only 1.6%, indicating that Switzerland's consumption of PVC is lower than the European average.

3.4.5 **Stock**

The figures in Tables 3.24 and 3.25 for the stock of brominated and chlorinated flame retardant products respectively were extrapolated using the transfer coefficient derived from data from the environmental Series no. 338 (FOEN, 2002). Table 7.29 and section A1-4.1 in Appendix I gives a detailed list of all assumptions and references on how data for the brominated flame retardant products were gathered. The extrapolated stock is based on the life cycle shown is adopted from Table 9–13 from FOEN, No. 338 (2002).

Tab. 3.24 > Stock of brominated flame retardants and antimony (CH 2001).

Brominated flame retardants	Life cycle[1] years	Stock of goods[2] 1000 tons	Stock of BFR tons	Stock of Sb_2O_3[3] tons	Stock of Sb tons
EDP and office electronics	7.4	574	2452	817	678
Communications technology	7.5	92	618	206	171
Household electronics	14.8	394	2515	838	696
Household appliances – small	7.5	70	88	29	24
Household appliances – large	14.8	1174	957	319	265
Special appliances	13.1	126	562	187	155
Small EE components	23.8	3927	2333	778	646
Vehicles	13	4538	2051	684	567
Building materials and textiles	40	2040	12441	4147	3442
Total		**12934**	**24017**	**8006**	**6645**

Source: FOEN, No. 338 (2002), taken from Tab. 9–13 therein.
FOEN, No. 338 (2002), extrapolated from Tab. 5–22 therein.
Average concentration of antimony in brominated FR based on Tab. 7.23

Tab. 3.25 > Stock of chlorinated flame retardants and antimony (CH 2001).

Chlorinated flame retardants	National Consumption in 2001 tons	Life cycle years	Stock of goods 1000 tons	Stock of Sb tons
PVC for cables and wires	50400	23.8	1200	240
PVC for building materials	37000	40	1480	296
Total	**87400**		**2797.5**	**536**

Note: Tab. 7.14 and 7.26.
Average concentration of antimony in chlorinated FR based on Tab. 7.22 and 7.23 and assumptions in section A1.4.2.

4 > Results

This chapter shows the flow of antimony through Switzerland in “Trade in Products” (Section 4.1) including examples of the most important “Metal”, “Nonmetal” and “Flame retardant” categories; “Waste Management” (Section 4.2) and “Environment” (Section 4.3). The subsystems are integrated in the overall system “Switzerland” in Section 4.4.

Data estimations and assumptions of parameters for the subsystem ‘trade in products’ are described in detail in Chapters 3 and Appendix A1. For some products only consumption values were known (e.g. pigment, ceramics, minor products). To be able to balance the flows, these consumption values where assumed to be 100 % imported.

Data estimations and assumptions of the subsystems ‘waste management’ and ‘environment’ applicable throughout the product flow charts are presented in detail at the end of the chapter in 4.2 and 4.3. Supporting data can be found in Sections A2 and A3. Since some are also required to understand antimony flows associated with specific products, they are outlined below:

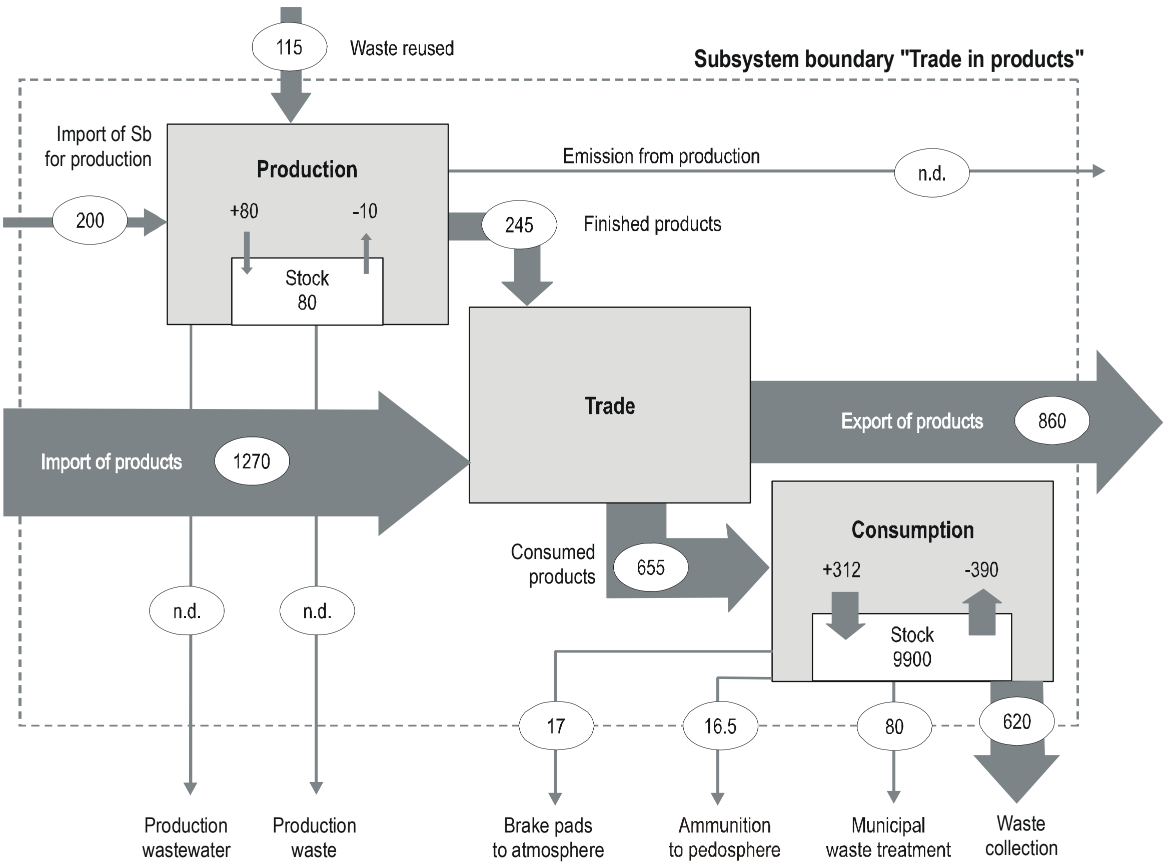
- All products for collection and disposal (incineration and landfill) were treated in the same way. In 2001, 88 % of waste was incinerated and 12 % directly landfilled.
- Antimony flowing from products through incineration was treated the same for all products. It was estimated that 32.23 % was exported with APC residues for landfilling (60 % of APC residues), 67.3 % was landfilled within Switzerland and 0.4 % was dissolved as a result of the washing the filter ash and must be treated by WWT.
- Details of waste treatment pertaining to the different products are given in Tables 7.

4.1 Flux of subsystem ‘trade in products’

Figure 4.1 shows that the import and export of products containing antimony are the largest contributors to the ‘Trade in products’ processes. Only 209 tons of antimony is used in production in Switzerland in comparison to the 1507 tons of antimony in imported products. About 40 % of the products produced in Switzerland use secondary antimony. Of the products imported into Switzerland, about 58 % are exported again and only 42 % are consumed in Switzerland. There is a large stock of antimony of 10’170 tons in consumed products has built up over the past decades. In 2001 the output from the stock was 399 tons, while the input was 350 tons. This is mainly the result of the shift to antimony free lead-acid car batteries over the past two decades.

It should be noted that in the process ‘Trade’ import, export or production data of some non-metal products (Tab. 3.11) were not known, while consumption data was available. In order to balance the process ‘trade’, it was nevertheless assumed that all of these consumed non-metal products were imported.

Fig. 4.1 > Fluxes in the subsystem ‘Trade in products’.



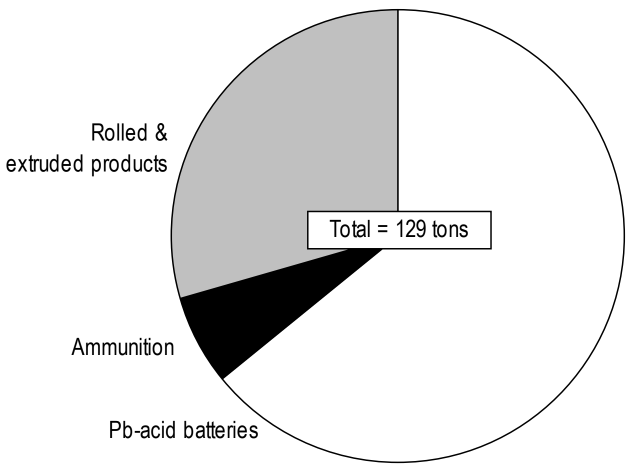
t Sb/a

4.1.1 Flux of metal products

Significant amounts of elemental antimony were consumed in lead-acid batteries (82 tons), rolled and extruded products (37 tons) and ammunition (8.2 tons) in 2001, as shown in Figure 4.2. Other products considered were bearing metals, weights, cable sheathing and semiconductors, though the amount of Sb consumed in these products was around 0.8 tons in 2001.

Fig. 4.2 > Total amounts of Sb consumed in metal products in Switzerland for 2001.

Only significant products are shown. (> 0.5 % of total consumption).

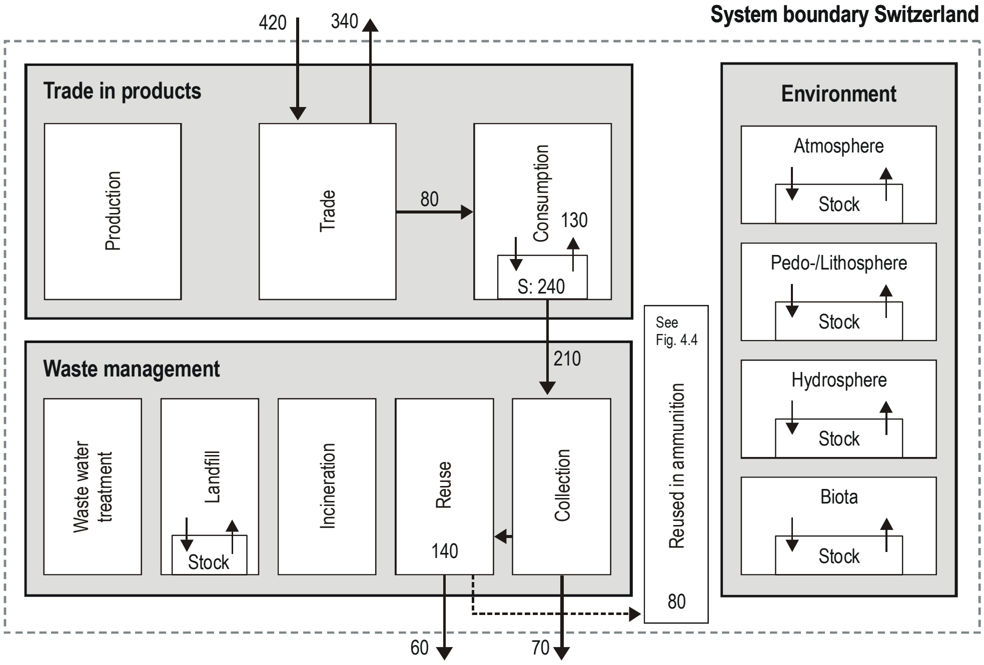


The flow of antimony Pb-acid batteries, rolled and extruded products and in ammunition through the system "Switzerland" is illustrated in detail below. Data, estimations and assumptions on 'Trade in products' parameters are described in Chapter 3.2, Appendix A1-2 and Tables 3.5 to 3.8 and 7.4 to 7.10. Sb concentrations used for calculations are given in Table 7.3 (Appendix I).

All metal products are made from antimonial lead and depending on the product, at different Sb concentrations (Tab. 7.3). In Switzerland all antimonial lead products are collected and recycled by Metallum AG, the only lead scrap and battery recycling company in Switzerland. Metallum AG measures a concentration of 9000 ppm Sb in the melted antimonial lead. From our information 40 % of the remelted antimonial lead is exported and 60 % is used in Switzerland (Bubendorff, 2004). There is no or negligible lead-acid battery production containing antimonial lead in Switzerland (Bubendorff, 2004; Jörg, 2004) (Fig. 4.3). About one quarter is reused in rolled and extruded products (Bubendorff, 2004; Senn, 2004) (Fig. 4.5). We do not have any information as to how the remaining 75 % of remelted antimonial lead is used (Fig. 4.4). We presume that all goes to RUAG. We have information that about 8.7 tons Sb were reused by RUAG in 2001, leaving 76.2 tons of Sb to be used in national production of a product unknown to us.

Fig. 4.3 > Sb-flows in the metal compound in Pb-acid-batteries (tons).

Details are given in Table 8.1 (Appendix II).



Information on ammunition consumption was provided by the Swiss Federal Department of Defence (personal information, Viktor Schärer, 2004). Soil remediation data was provided by Eberhard Recycling AG, Kloten, 2004. The calculation of the stock in the pedo-/lithosphere was estimated from data supplied by the Federal Department of Defense and by RUAG Ammotec. Military activities were registered since 1836 and are taken into account since that time.

Fig. 4.4 > Sb-flows in ammunition 2001 (tons).

Details are given in Table 8.2 (Appendix II).

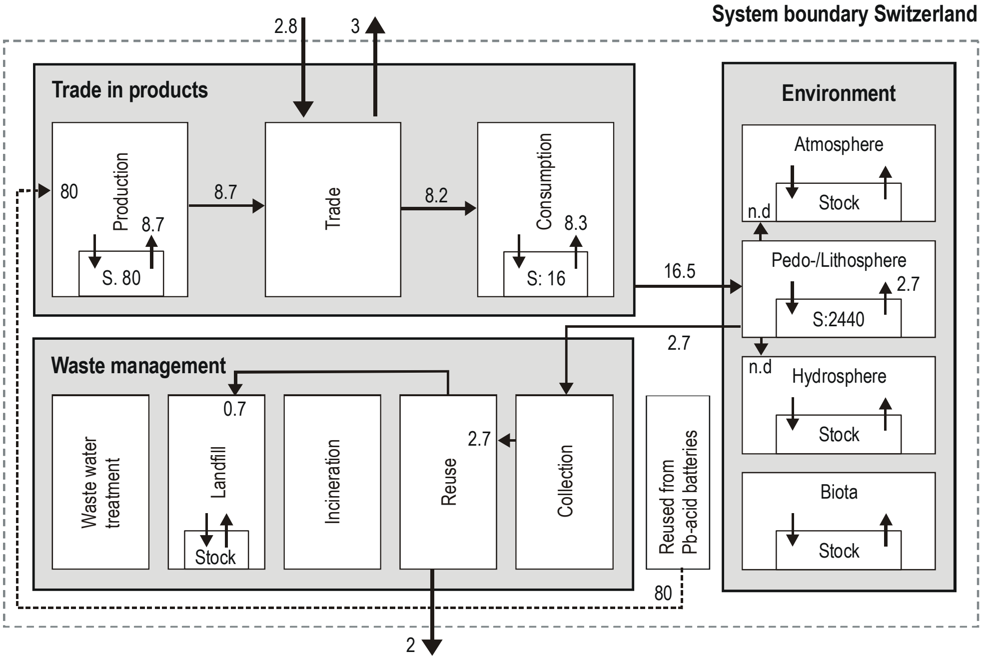
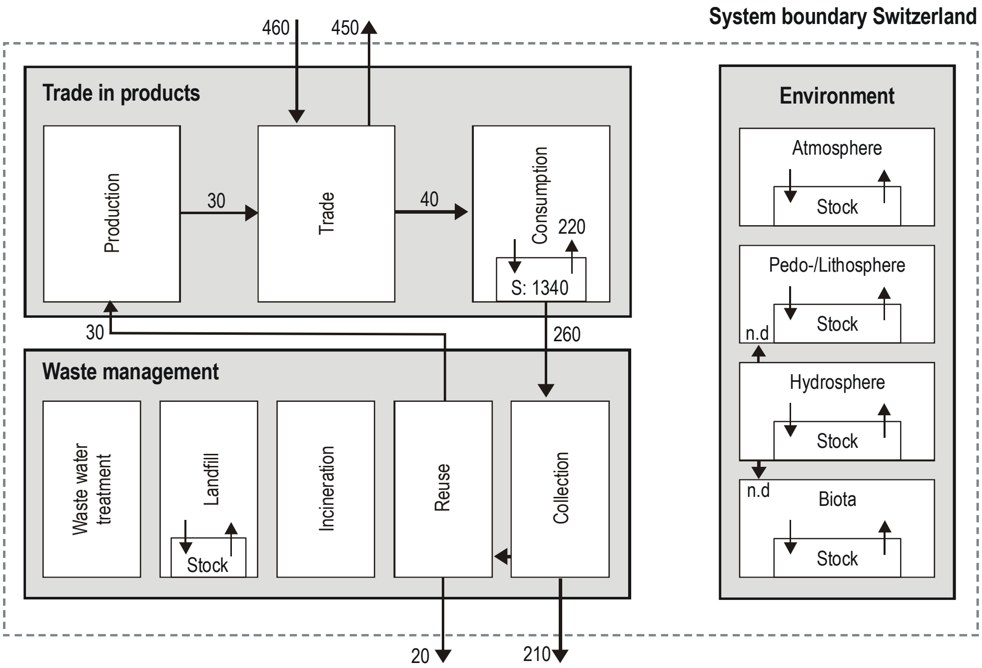


Fig. 4.5 > Sb-flows in rolled and extruded lead products including bearing metals and weights (tons).

Details are given in Table 8.3 (Appendix II).



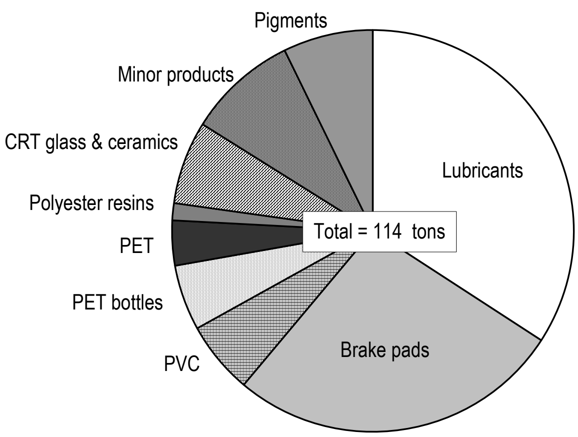
Concentrations of Sb in bearing metals and weights are different from rolled and extruded metal products (Tab. 7.3, Appendix I). However, the contribution of bearing metals and weights to rolled and extruded metal products are only 1.5 %. We therefore used the Sb content of the latter for bearing metals and weights.

4.1.2 Flux of nonmetal products

Antimony is used in a variety of nonmetal products (Fig. 4.6).The total amount of Sb in consumed nonmetal products in Switzerland for 2001 was 117 tons.

With an average Sb content of 5.5 % (Tab. 7.12, Appendix I), lubricants and brake pads contributed a significant amount to the overall Sb consumption in nonmetal products. Antimony in plastics contributed, with 22 %, the 2nd largest amount. While plastics are used in much larger quantities than lubricants, only trace amounts of Sb (0.007–0.02 %) catalyst are required for polymer stabilization. Pigments and glass & ceramics were estimated to contribute about 12 % and 9.4 % to nonmetal Sb consumption respectively. The remaining 10 % were minor products that include ammunition primer & explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, and mordant.

Fig. 4.6 > Total amounts of Sb consumed in nonmetal products in Switzerland for 2001.

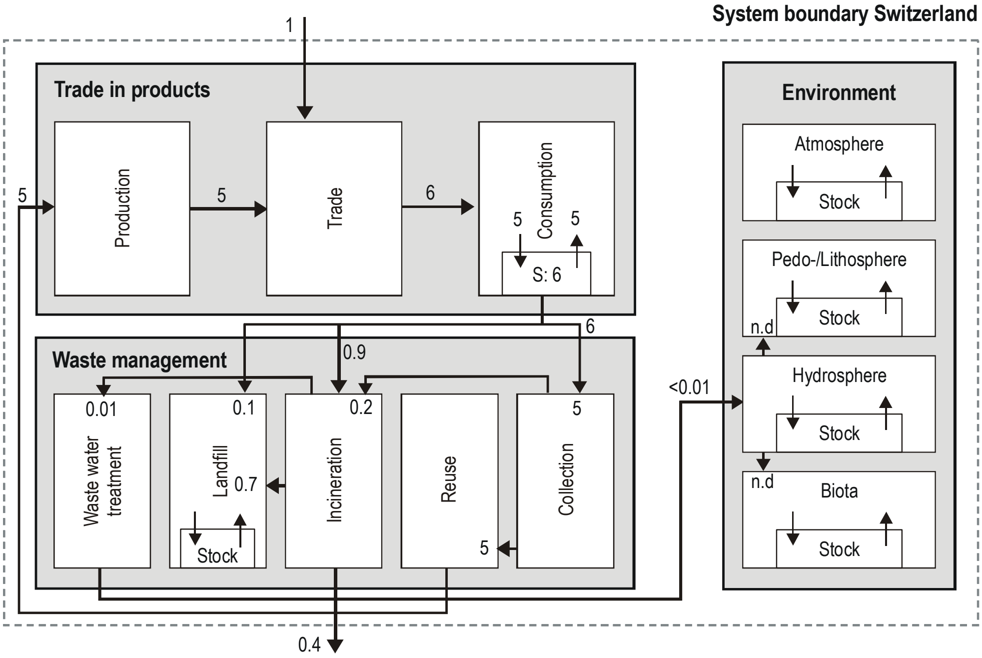


The flow of different nonmetal products through the system "Switzerland" is illustrated in detail below. Data, estimations and assumptions on 'Trade in products' parameters are described in Chapter 3.3 and Appendix A1-3 and Tables 3.11 to 3.14 and 7.13 to 7.22. Sb concentrations used for calculations are given in Table 7.12 (Appendix I).

The information on PET bottles shown in Figures 4.7 was obtained from FOEN (2001) and BFS (2003) (see also Fig. 7.3 and Tab. 7.33, Appendix I). The consumption of PET bottles in Switzerland increased by over 82 % from 1995 to 2001, while during the same time the recycling rate increased by 106 % to about 80 % recycling (Tab. 7.33, Appendix I).

Fig. 4.7 > Sb-flows in PET bottles 2001 (tons).

Details are given in Table 8.4, Appendix II.



For PET, polyester resins and PVC, the collection data for Switzerland was extrapolated from collection data published for Western Europe (APME, 2003). The flows are shown in Figures 4.8 to 4.10. These figures show that the stock of the Sb catalyst used for plastics in Switzerland increased in 2001. This trend reflects European and global plastic consumption (APME, 2003; Roskill 2001). Since Sb is also used as flame retardant in plastics, it is not likely that it will be substituted with other groups of catalysts or stabilizers at present

Around 95 % of consumed plastics were collected in 2001. However, of the collected plastics the major amount (69 %) was incinerated in Switzerland, while only 7 % was reused, the remainder was exported from Switzerland. In total about 71 % of the consumed plastics was incinerated.

Fig. 4.8 > Sb-flows in PET 2001 (tons).

Details are given in Table 8.5, Appendix II.

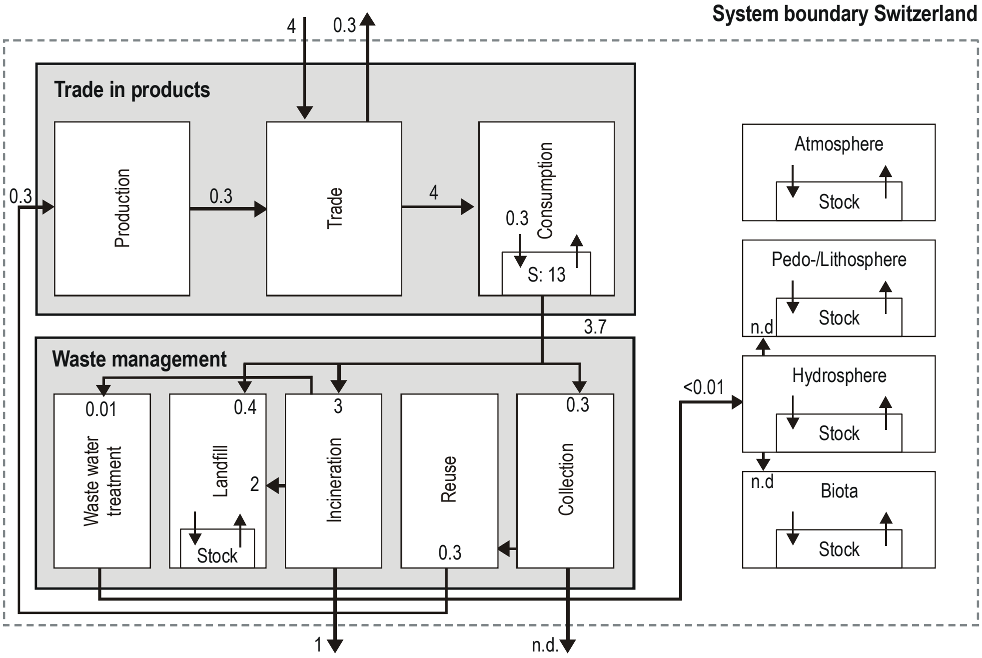


Fig. 4.9 > Sb-flows in polyester resins 2001 (tons).

Details are given in Table 8.6, Appendix II.

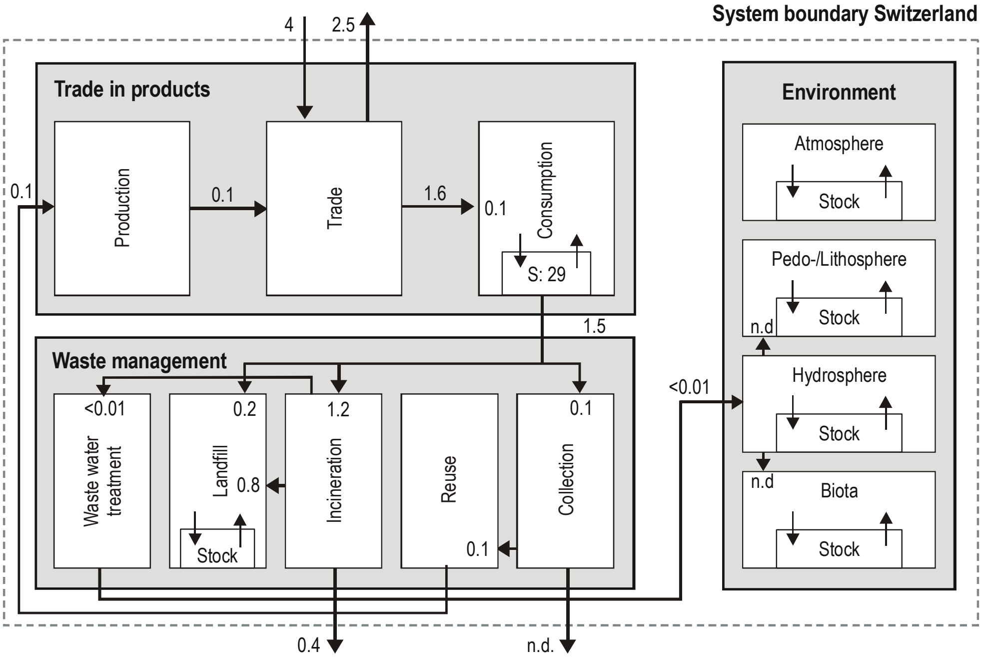


Fig. 4.10 > Sb-flows in PVC 2001 (tons).

Details are given in Table 8.7, Appendix II.

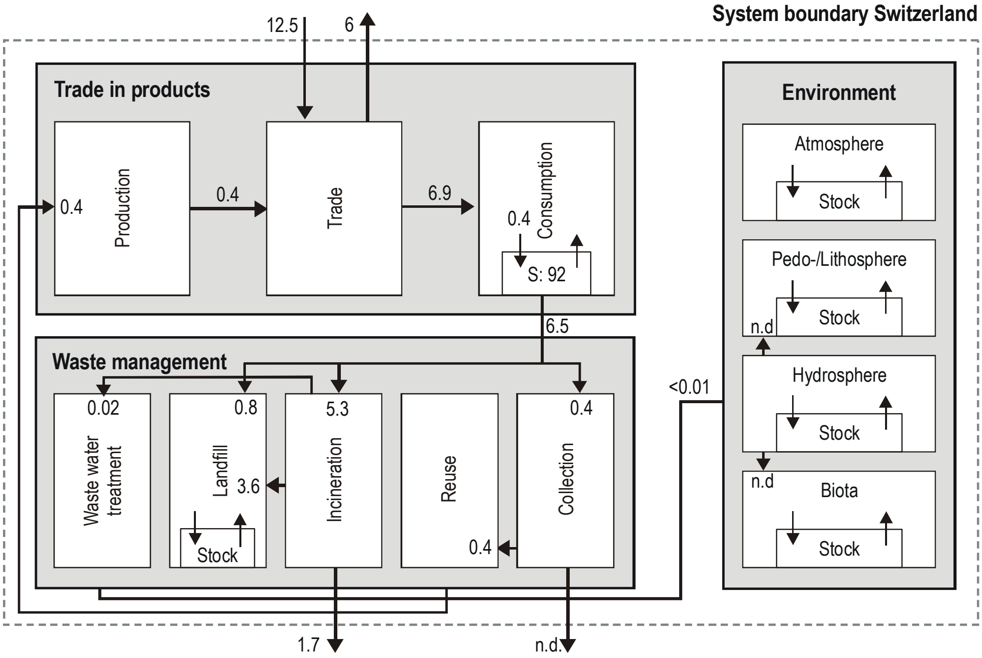
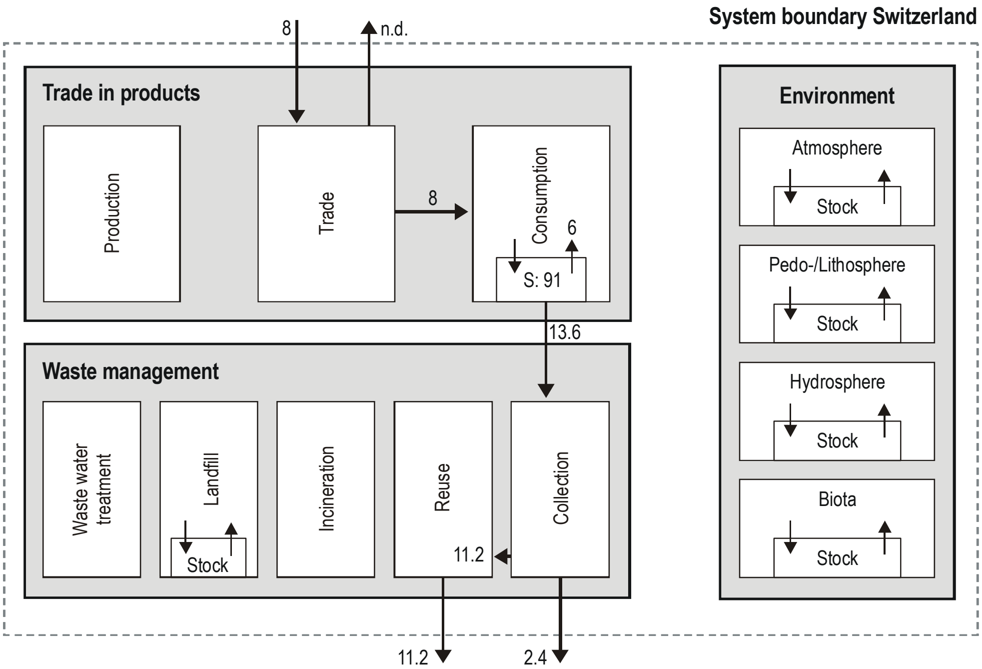


Fig. 4.11 > Sb-flows in CRT-glass 2001 (tons).

Details are given in Table 8.8, Appendix II.



The flows of antimony in CRT glass are shown in Figure 4.11. According to the Swiss Association for Information, Communication and Organisational Technology (SWICO) and the Swiss Foundation for Waste Management (S.EN.S), CRT glass collected in Switzerland was exported directly from Switzerland (Hischier Roland, 2004; personal information from Markus Stengele, IMMARK AG, Regensdorf, 2004). The stock of CRT-glass is depleting in Switzerland (Tab. 7.17, Appendix I), while an overall increase of 10 % demand in CRT-glass is globally forecast, with the main consumers being in Asia (Roskill, 2001). The change in CRT-glass consumption is related to a decrease in conventional monitors to liquid crystal technology. The new technology no longer requires the use of heavy metals to protect users against radiation.

According to VSKI (2004) the ceramic market in Switzerland for ceramics containing antimony is very small (Fig. 4.12) and almost dormant. The stock is depleting by about 1.2 % yearly (Tab. 7.18, Appendix I). The flows in pigments is a little larger (Fig. 4.12) but we have very little information and have assumed that the products that use Sb-based pigments are incinerated after use (Fig. 4.13).

Fig. 4.12 > Sb-flows in Ceramics 2001 (tons).

Details are given in Table 8.9, Appendix II.

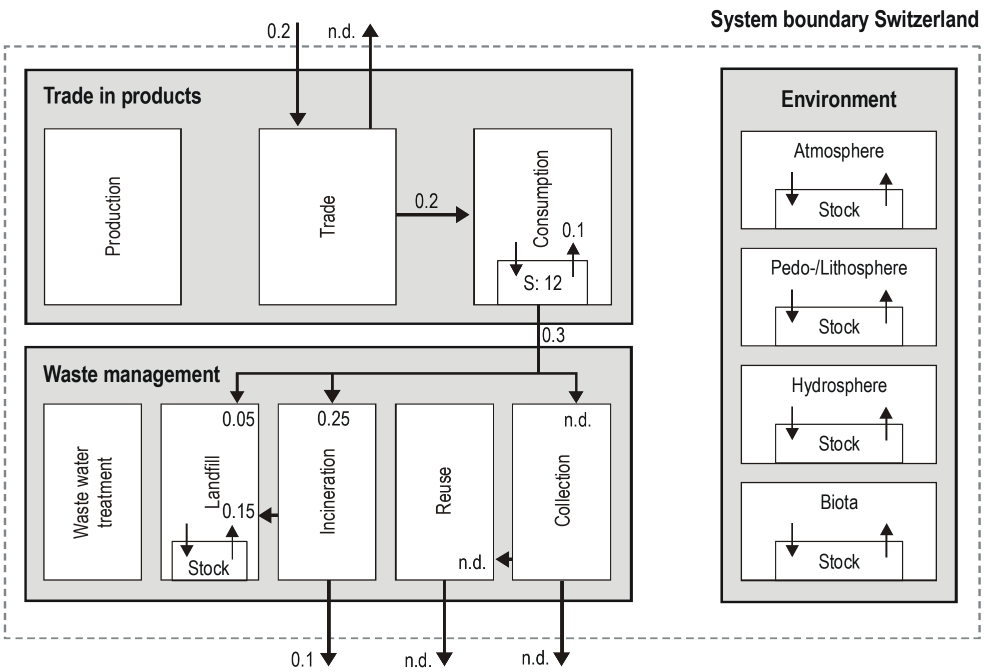


Fig. 4.13 > Sb-flows in pigments 2001 (tons).

Details are given in Table 8.10, Appendix II.

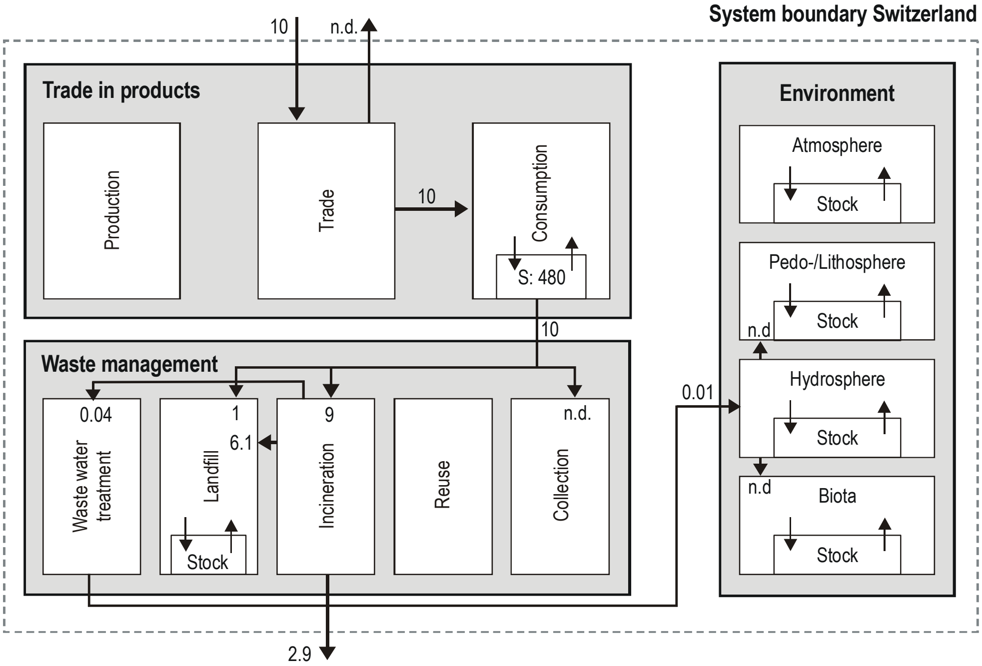
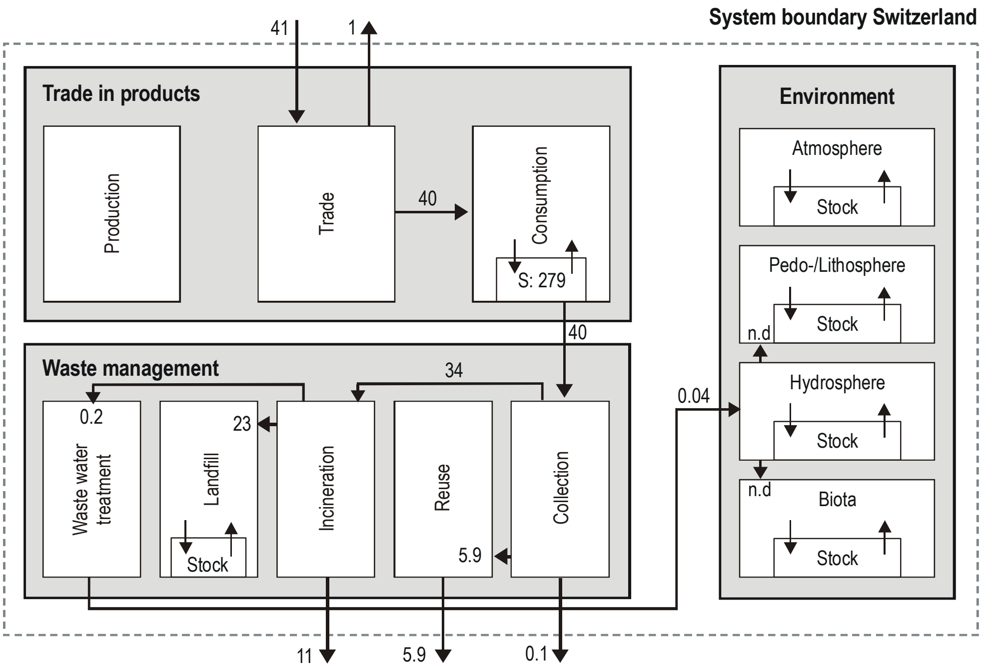


Fig. 4.14 > Sb-flows in lubricants 2001 (tons).

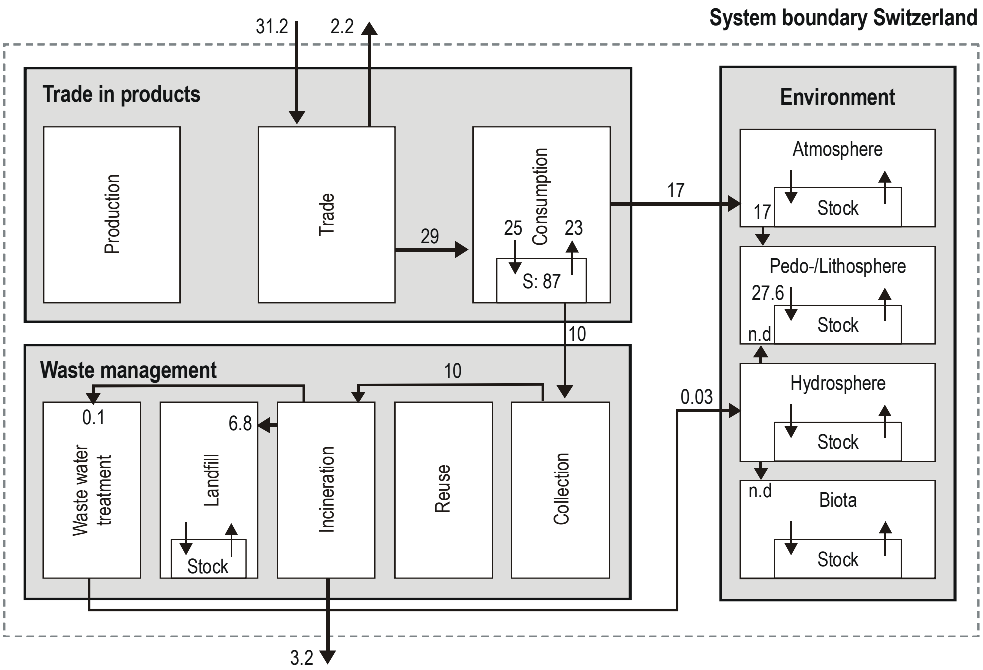
Details are given in Table 8.11, Appendix II.



Lubricants are considered to be hazardous waste. The amounts of antimony associated with the use of lubricants is quite large (Fig. 4.14). In Switzerland burnable hazardous waste is generally incinerated. Lubricants may be recycled or chemically and/or physically treated. In Figure 4.14 these last two sub-processes are shown combined in the process ‘reuse’. Extra stock is exported back to the producer, usually at the end of the year (Reuse–Export). The distribution of the collected lubricants containing Sb was estimated according to the distribution of lubricants in general. According to U. Müller (VSS, 2004) the lubricant market in Switzerland has been stable over the past years, neither increasing nor decreasing.

Fig. 4.15 > Sb-flows in brake pads (tons).

Details are given in Table 8.12, Appendix II.

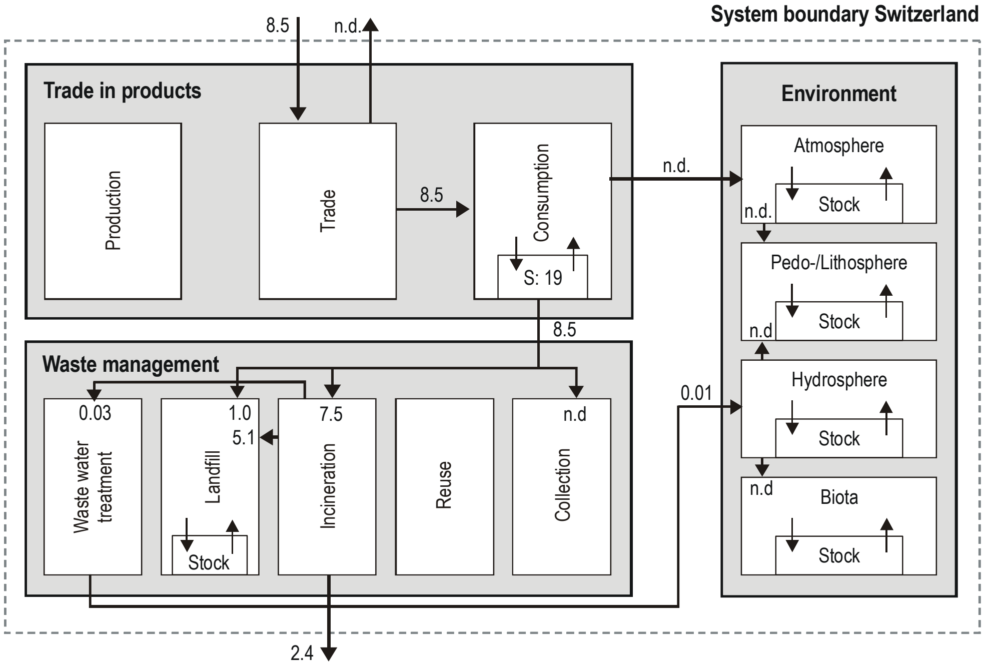


Antimony is used in significant amounts in brake pads. Here it is seen that the amounts entering the environment are quite large (Fig. 4.15). Another major flow is from auto shredder plants to incineration and then landfilling and export.

The minor non-metal products market (Fig. 4.16) is not negligible. Around 8.5 tons were consumed in 2001. Since very little is known, it was assumed that no stock is accumulated and that the products are collected and incinerated.

Fig. 4.16 > Sb-flows in minor non-metal market products 2001 (tons).

Details are given in Table 8.13, Appendix II.



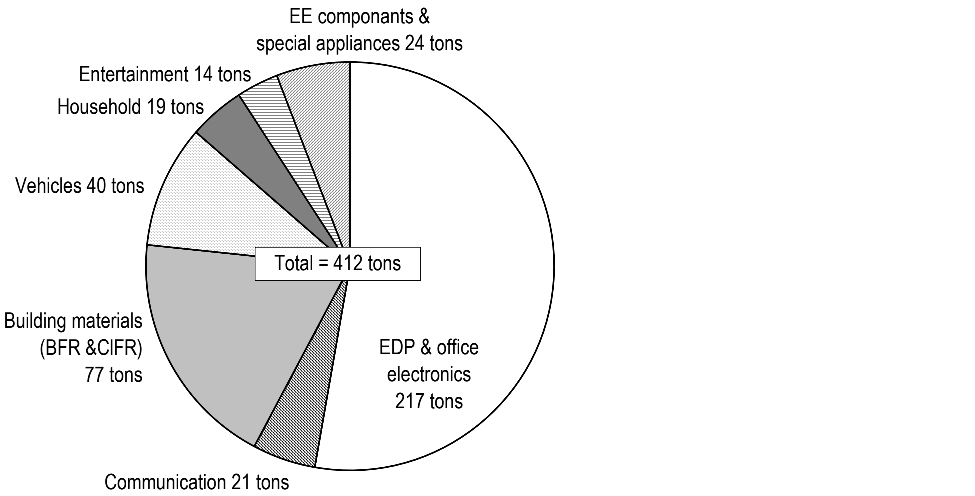
4.1.3 Flux of flame retardants

Significant quantities of Sb are consumed in flame-retarded products. Figure 4.17 shows three groups of products, electrical and electronic appliances (EE) and household goods (household products, entertainment products, EE and special appliances, electronic products), ASR and building materials. The groups have been subdivided according to the waste treatment options in order to be able to determine the flows of Sb in the subsystem "Waste Management". The major use, approximately 327 tons (67 %) of Sb in FR, is in EE and households goods. The proportion of Sb used as flame retardants in vehicles is approximately 9 % (44 tons). Antimony used as a FR in building materials (38 % BFR in insulating foam, plastic sheeting and textiles; and 62 % chlorinated FR in PVC construction materials) amounts to approximately 24 % (117 tons) of total FR consumption in Switzerland.

The flow of flame retarded products through the system "Switzerland" is illustrated in detail in Figure 4.18. Data, estimations and assumptions on 'Trade in products' parameters are described in Chapter 3.4 and Appendix A1.4 and Tables 3.17 to 3.25 and 7.24 to 7.29. Antimony concentrations used for calculations are given in Table 7.12 (Appendix I). The flows are shown in 3 categories:

> electronic electrical goods including household products (Fig. 4.18)
> vehicles (Fig. 4.19)
> construction materials (Fig. 4.20)

Fig. 4.17 > Total amounts of Sb consumed in flame retarded products in Switzerland for 2001.



It should be noted that household goods are included collected and treated in both EE and auto shredder plants (Tab. 7.40, Appendix I). The concentration of antimony in waste EE-material that is treated in EE shredder plants was measured to be 1700 ± 200 mg/kg (FOEN 2004, Schriftenreihe 374). The collection distribution data was given by S.EN.S (2003). The concentration of antimony in nonmetal shredder residues from auto shredder plants is estimated to be 330 mg/kg (Tab. 7.34, Appendix I). The flow diagrams were constructed with information from EZV (2001); FOEN, Department for water protection and fisheries (2001); and the Stiftung Autorecycling Schweiz (2004).

While the import of finished goods containing halogenated hydrocarbons greatly exceeded export from 1998 to 2001 according to the customs statistics of the Federal Government of Switzerland (EZV, 1998–2001), exports increased more (28.9 %) than imports (9.1 %) during this period (Fig. 7.2, Appendix I). (According to the SWISS-MEM (1999–2001) publications, exports in Switzerland grew well above average during this period). Moreover, more FR products were consumed than discarded in 2001 and the stock increased in 2001 (FOEN, 2004). The input into the stock of FR in 2001 was 271.2 tons of Sb, representing an increase of 6.2 %.

Fig. 4.18 > Sb-flows from brominated FR in EE and household goods 2001 (tons).

Details are given in Tables 8.14, 8.15 and 8.16, Appendix II.
Non-metal shredder residues are included in "Waste Management".

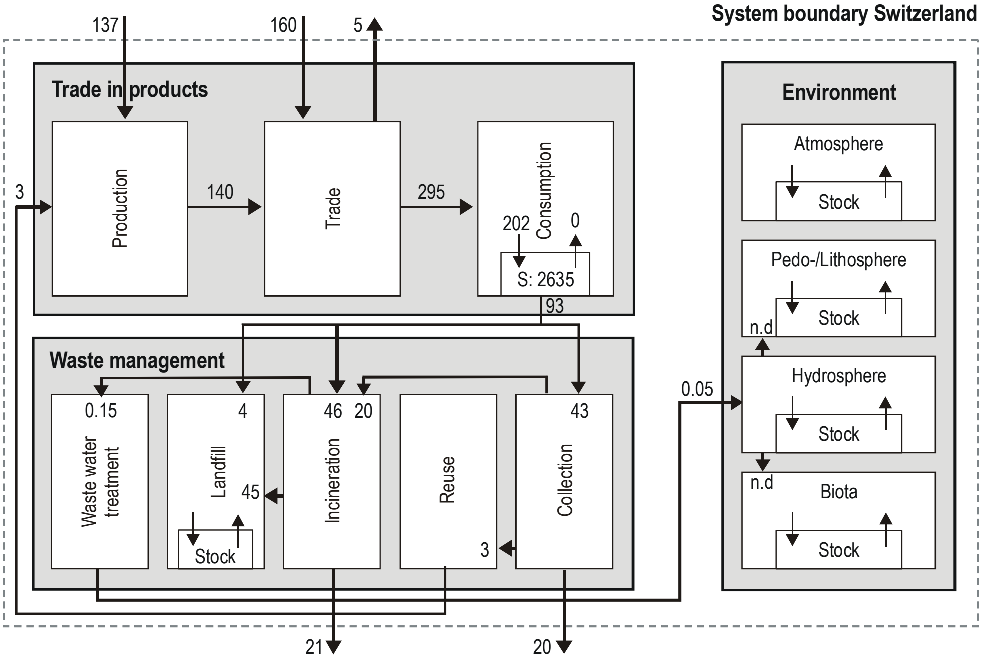
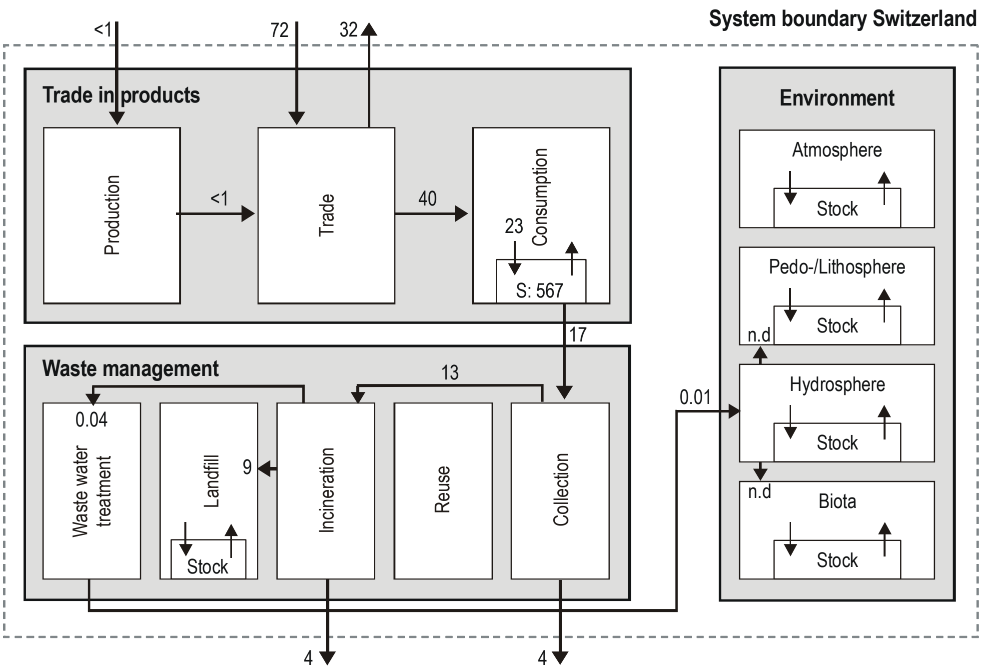


Fig. 4.19 > Sb-flows in vehicles and auto shredder residues 2001 (tons).

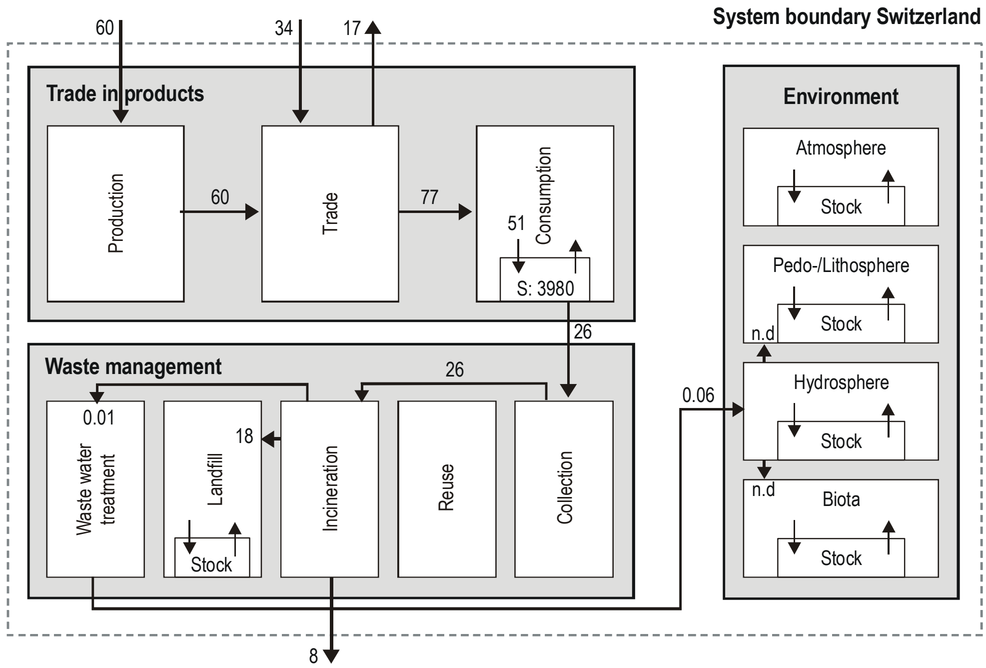
Details are given in Table 8.17, Appendix II.



The source of data for antimony flows in “vehicles” are the detailed statistics of the “Stiftung Autorecycling Schweiz”. The amount of ASR was determined by using 2 tons as the weight of an average car and 0.85 tons as the weight of an end of life (dismantled) car before shreddering. Approximately 26 % (0.22 tons) of the end of life car is burnable ASR (Stiftung Autorecycling Schweiz, 2004). Consumption increased in 2001 and the input to stock was 31.3 tons Sb, an increase of about 8 %. Approximately 54 % of the ASR was exported, the rest was incinerated.

Fig. 4.20 > Sb-flows from ClFR and BFR in building materials 2001 (tons).

Details are given in Table 8.18, Appendix II.



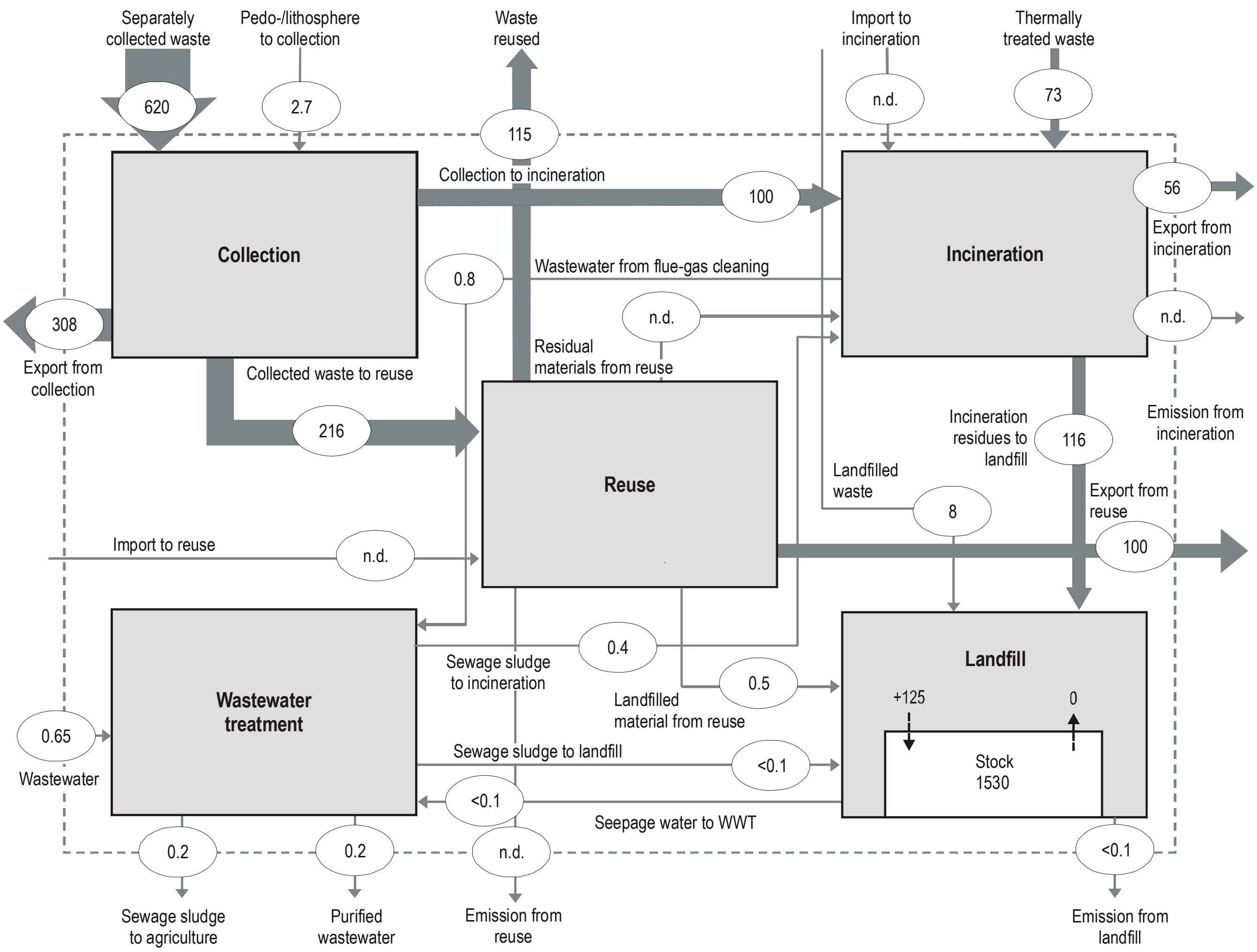
Significant amounts of antimony are used in association with FR in building materials (Fig. 4.20). Assuming that all burnable construction waste (plastics and foams) was incinerated, the amounts of construction materials that were collected and incinerated in 2001, the amount of antimony entering incineration from building materials is of the same order of magnitude as that from EE and household goods.

4.2 Flux of subsystem 'waste management'

The flow of Sb through the subsystem "Waste Management" represents the sum of the flows of all the products through "Collection", "Reuse", "Incineration", "Waste water treatment" and "Landfill". The flows are shown in Figure 4.21. It was assumed that only the process "Landfill" had a stock in the landfilled material. Antimony flows in sewage sludge (Fig. 4.23) were incorporated in Figure 4.21. Sewage sludge was not considered in association with individual products because data were not readily available and because they were too small in value to be significant (all less than 1 ton). Thus, the inputs and outputs in the subsystems "Incineration" and "Wastewater treatment" do not exactly balance because of the addition of sewage sludge data.

Figure 4.21 shows that in 2001 770 tons of antimony entered "Waste Management".

Fig. 4.21 > Fluxes in the subsystem 'Waste management'.



4.2.1 Collection

Waste collection occurs through different channels. Municipal solid waste, construction waste and sewage sludge are collected by regional public or private organizations. These enter the subsystem 'collection'. Some waste streams are not centrally collected but delivered straight to treatment plants. These streams are shown in the individual product diagrams in Section 4.1. Waste volume inputs to 'collection', 'reuse', 'incineration', and 'landfill' were readily available on the FOEN internet site (FOEN, 2004). Data sources and estimates are described below.

All the waste categories considered in 'waste management' are listed in Table 4.1. The estimate of the Sb content of construction wastes to be incinerated arises from balancing the amount of Sb entering 'incineration' and that leaving 'incineration' (Tab. 7.34 and 7.35, Appendix I).

4.2.2 Incineration

In the process 'incineration' the incineration of municipal solid waste (MSW), sewage sludge, imported waste and burnable construction wastes was considered independently of incineration plant, i.e. whether incinerated in a MSW incineration plant, a sewage sludge incinerator or a cement kiln. The products that were incinerated or landfilled are listed in Tables 7.34 and 7.37 (Appendix I) respectively. In 2001 95 % of MSW was incinerated and the rest was landfilled.

Wastes that have been omitted are those that are 'co-processed' in cement kilns for which there is no information on antimony content. These are solvents and distillates, plastics and smaller fractions grouped under 'rest'. The plastics originate from many different sources, namely industrial production wastes, plastic sheeting used in agricultural production, used containers and so on (Stenger, 2005). (Burnable hazardous wastes have not been considered either, because there is no information on antimony content. It should be pointed out, however, that easily identifiable hazardous waste streams, such as air pollution control (APC) residues from waste incineration or lubricants, are included.

Tab. 4.1 > Waste categories, amounts and antimony content considered in the process 'waste management'.

Waste category	Treatment	Amount t	Sb content mg/kg
Municipal solid waste	incineration	2'244'000	48
	landfill	306'000	48
Construction waste	incineration	400'000	*64**
	landfill	1'600'000	0.3
	reuse	9'000'000	0.3
Sewage sludge	incineration	119'800	3.5
	landfill	4'600	3.5
	agriculture	75'600	3.5
Imported wastes	incineration	50'000	48
Rest incineration	incineration	80'000	330
ASR and household goods	incineration	28'690	330
EE products (30 %)	incineration		
Tyres and rubber	incineration	18'000	136
Used oil	incineration	41'000	1

*estimate, see Tab. 7.34 and 7.35 in Appendix I.

The incineration residue distribution was calculated from waste management data for WTP 2000, 2001 and 2002 given by the FOEN (2001). The details are listed in Table 7.35 (Appendix I). According to available information for 2001, all MSWI bottom ash was landfilled in Switzerland. The APC residues fly ash and filter cake were combined, 40 % being treated and landfilled within Switzerland and the remainder exported. The APC residues are washed within the MSWI plants. The wash water contains an average of 0.24 mg/L antimony (Tab. 7.35, Appendix I). With respect to antimony, this results in transfer coefficients of 32.3 % for export, 67.3 % to landfill and 0.4 % to WWT. These coefficients are applied to the antimony flows for all products that enter the process 'incineration'. Since most antimony-containing products are incinerated in MSWI plants, these values were adopted for incineration in cement kilns and hazardous waste treatment plants as well.

The transfer from incineration and reuse to the atmosphere is unknown.

4.2.3 Landfill

According to FOEN (2004), 5 % of wastes that were collected with the MSW waste stream in 2001 were landfilled and 95 % incinerated and then landfilled (Tab. 4.1). In the year 2001, approximately 306’000 t, 4600 t and 1’600’000 t tons of MSW, MSWI bottom ash and construction waste respectively were landfilled.

For the calculation of the leachate from landfill we assumed on average a landfill depth of 15m, 1m of rainfall per year, evaporation of 70 % and leachate of 30 %, assuming grass coverage (Belevi and Baccini, 1988). The densities of the bottom ash and the MSW were assumed to be 0.6 t/m³ and 1.6 t/m³ respectively (Christensen et al., 1994; Johnson et al, 1999). The concentration of Sb in the leachate water in MSWI bottom ash was given by Johnson et at. (1999) to be 30 µg/L. The concentration of leachate water in MSW was not available for Sb. In absence of any information it was assumed that Sb would behave in a similar fashion to arsenic, since they are in the same group (15) of the periodic table. An average concentration of 15 µg/L was adopted (ATV, 1988; Christensen et al., 1994).

The landfill stock was estimated using information from FOEN (2001). Waste landfilled between 1932 and 2001 was considered. Between 1932 and 1969 a Sb concentration of 8.6 mg/kg was adopted for both waste categories. Between 1969 and the present day a linear increase to present-day concentrations (Tab. 7.37, Appendix I) was used for calculations.

4.2.4 Reuse

Reuse is treated with individual product flows. Metal products, PET bottles, CRT glass, lubricants and flame-retarded plastics all enter ‘reuse’ to varying degrees.

4.2.5 Wastewater treatment

The amount of waste water in Switzerland per year (2’000’000’000 tons) was taken from Maurer (2004).

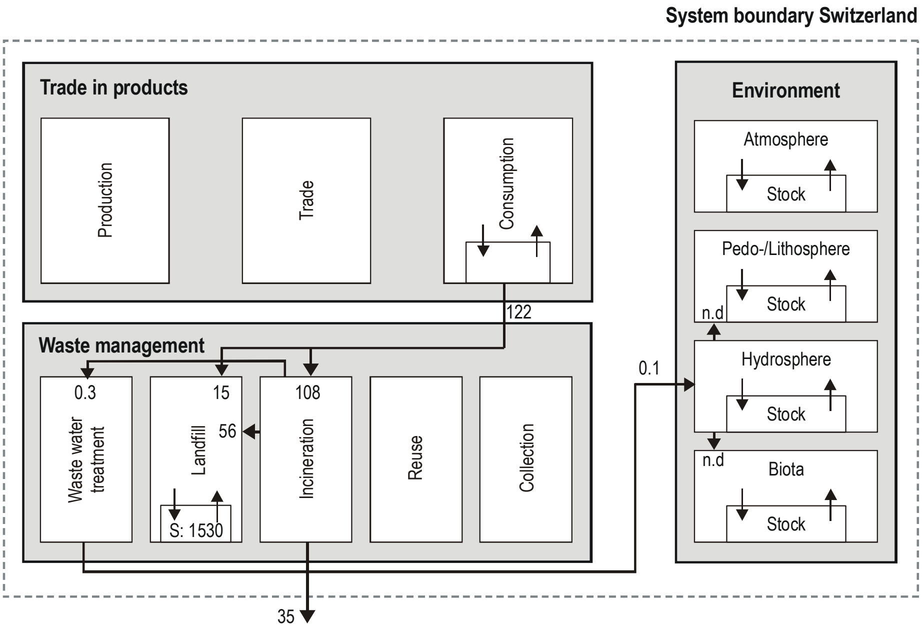
The concentration of Sb in waste water was assumed to be 1 µg/l, the concentration of Sb in purified waste water to be 0.5 µg/l. This is a bit higher than the concentration in the river Rhine (0.37 µg/l), that we measured ourselves due to the dilution in the river. In this way approximately 1 ton Sb finds it’s way into sewage sludge and the same amount into the hydrosphere. This estimate represents roughly 10 % of the total Sb leaving Switzerland via the river Rhine. This rough estimate is probably in the right order of magnitude.

4.2.6 ### Important waste streams

Important waste streams, namely municipal solid waste (Fig. 4.22), sewage sludge (Fig. 4.23) and construction waste (Fig. 4.24) have been investigated individually. No attempt has been made to address hazardous waste streams collectively, because other than air pollution control residues from municipal waste incineration, our knowledge of Sb concentrations is poor.

Fig. 4.22 > Sb-flows in municipal solid waste 2001 (tons).

Details are given in Table 8.19, Appendix II.



The flow of Sb from consumption into the MSW stream that is treated in the subsystem 'waste management' is shown in Figure 4.22. Data used is tabulated in Table 8.19 (Appendix II). Antimony in MSW is derived to a significant degree from flame-retarded products.

The Sb-concentration in sewage sludge is given in Table 7.36 (Appendix I) at 3.5 mg/kg based on Kupper (2002). Antimony concentrations are small in all streams.

The concentration of Sb in construction material is estimated to be 4 mg/kg on average. The value was based on the average concentration of Sb in cement and concrete of 3.9 mg/kg (Achternbosch et al., 2003), the average top-soil concentration is 8.6 mg/kg (Tab. 7.42) and the average earth's crust content is 0.3 mg/kg. No attempt has been made to consider the proportions of cement, soil and stones. It should be noted that construction waste was not included in the material flow analyses diagrams for Switzerland (Fig. I and 4.26). It was excluded because a full analysis of construction materials was not carried out. It should be noted that a significant amount of construction and demolition wastes are directly reused (amounting to around 18.8 tons of antimony). The sheer volume of construction leads to a large stock of 8370 tons.

Fig. 4.23 > Sb-flows in waste water treatment and sludge 2001 (tons).

Details are given in Table 8.20, Appendix II.

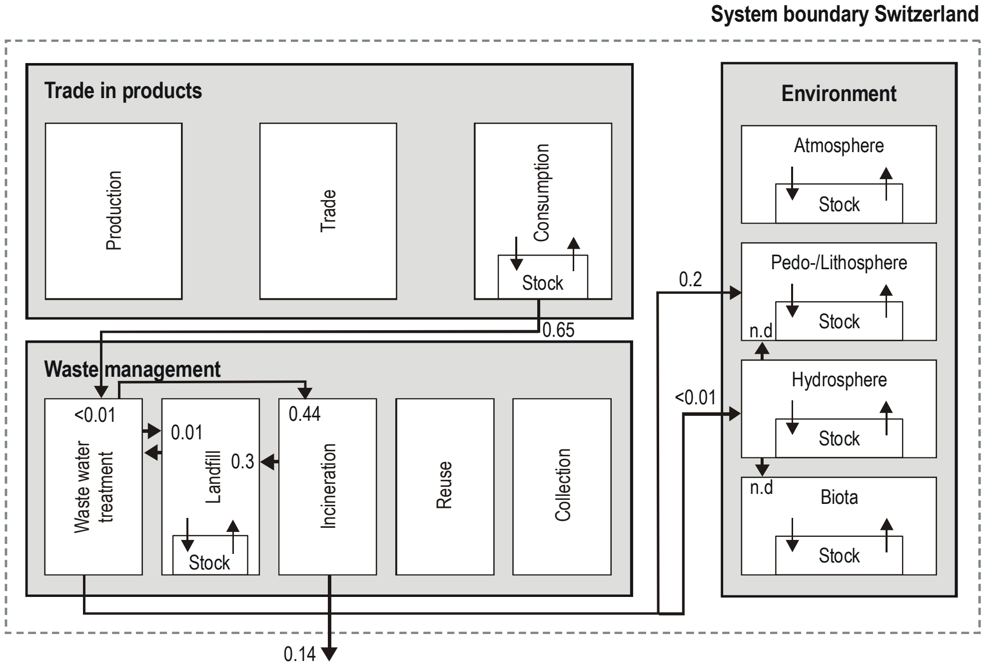
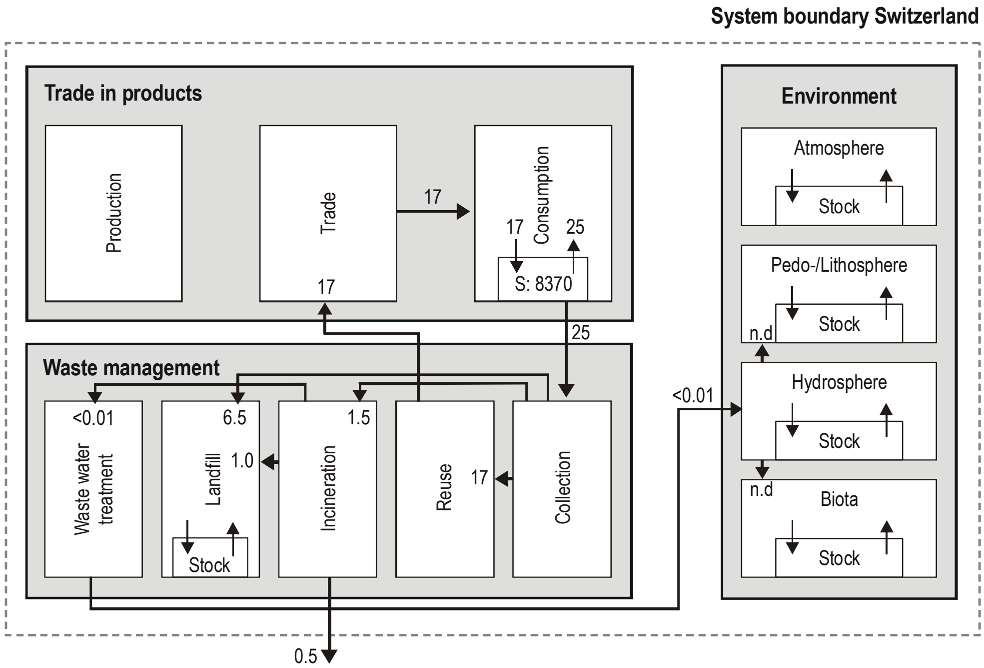


Fig. 4.24 > Sb-flows in construction waste 2001 (tons).

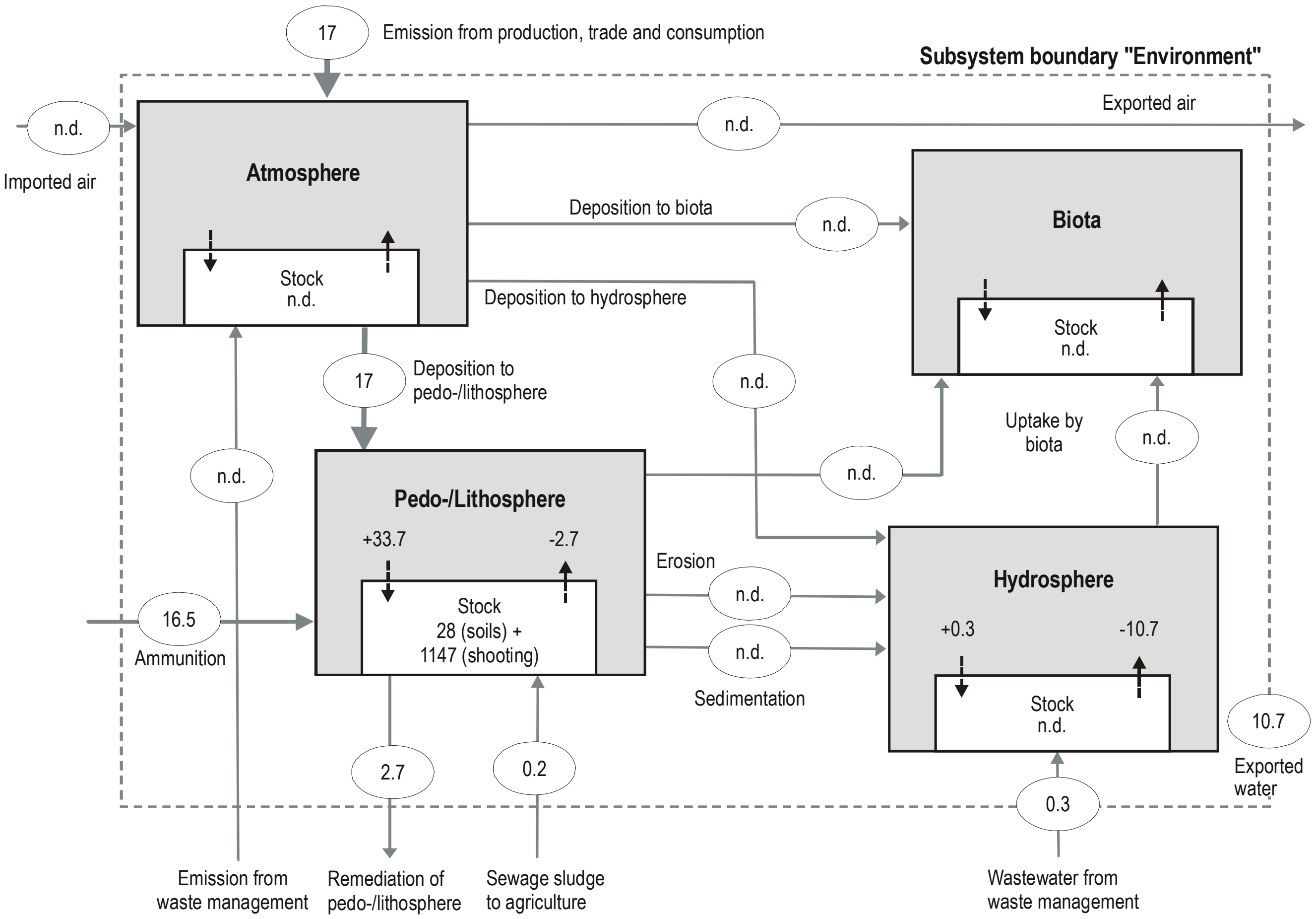
Details are given in Tables 8.21, Appendix II.



4.3 Flux of subsystem ‘environment’

Calculations in the subsystem were made using the values in Tab. 3.6, 3.7, 7.41, 7.42 and 7.43.

Fig. 4.25 > Fluxes in the subsystem ‘Environment’.



4.3.1 Atmosphere

The data was not sufficient for detailed analysis. There is very little data on gaseous Sb emissions from industrial plants or incinerators or vehicles so it is not possible to determine the source of Sb deposition. Urban air affected by traffic can have Sb concentrations up to approximately 100 times higher in comparison to cleaner air in the countryside (Tab. 7.43). This observation indicates that vehicles are a source of Sb, possibly from corrosion products, brake fluids or petrol. Estimates of brake pad erosion, yield an emission of 27.6 tons in 2001 for cars alone. Given that the estimates are approximate, it is plausible that the deposition of antimony is greater at roadsides.

A relatively reliable deposition rate of 6.1 t/a, or roughly 0.15 mg/m².a was estimated (Tab. 7.44) for sites not directly at roadsides. The deposition rate was determined in two different ways, firstly by sampling with a Bergerhoff sampler that samples both wet and dry deposition, and secondly by analysis of peat concentrations, an alternative way of determining total deposition. The results are quite close (Tab. 7.44), which lends veracity to the values.

Measured Sb atmospheric concentrations (Tab. 7.43) of 1 to about 20 ng/m³, yield an insignificant potential atmospheric stock ranging from 0.02 to maximal 0.4 tons. Exports and imports via the atmosphere were neglected and it was assumed that the air import equalled the air export concentration.

4.3.2 Hydrosphere

The reported antimony concentrations in river water originate from a number of sources. Filella et al. (2002) reviewed the literature for dissolved Sb concentrations in surface waters. The found values range from 0.07 to 0.8 µg/L. Bart and Von Gunten (1976) show that total (dissolved and particulate) concentrations of antimony in the River Aare increased from 0.066 µg/L at Thun, to 0.124 µg/L at Bern and 0.138 µg/L at Hagneck. Own measurements of the total concentrations of antimony of the River Rhine sampled in 3 samples taken on 11.8.04 at Basel yielded an average value of 0.37 µg/L. Thus an average value of 0.2 µg/L was adopted.

The influx of Sb into Switzerland via the hydrosphere is negligible, the Sb-discharge using the average concentration and a water discharge of 1296 m³/s or 5.33 x 10^{10} m³ a^{-1} according to Zobrist et al. (2004).

Sedimentation and erosion were not determined and it was assumed that the amount of sedimented material equals the amount of material washed out of Switzerland via rivers.

4.3.3 Pedosphere / Lithosphere

There was substantial data available from the Swiss National Soil Observation Network (NABO), Keller and Desaules (2001). Over 500 soil samples (0–20 cm) have been measured for antimony. The average concentration is 8.6 mg/kg. However, contaminated soils were also sampled. The median concentration was 0.1 mg/kg. The latter value is roughly a third of the average earth's crust concentrations. It is possible that antimony is leached from soils, resulting in values lower than the earth's crust.

At present deposition rates (Tab. 7.44), it would take only 5 years to double soil concentrations. The reservoir in the top 2 cm of agricultural soil is estimated from NABO concentrations to be 28 t.

One of the most significant input to the pedosphere is caused by shooting activities (16.5 tons in 2001) at shooting ranges. The Sb input from sewage sludge was roughly 0.4 tons in 2001. Another is from the erosion of brake pads in cars, which is estimated to be 17 tons.

The Sb deposition for Switzerland from the atmosphere was around 6 tons. Brake pad erosion could make a significant contribution to this diffuse input to soils. The average antimony concentration in agribultural soils (59 samples) in Japan are reported to be 0,7 mg/kg (Nakamura et al., 2006).

4.3.4 Biota

The fluxes to and from biota were not easy to estimate. It was difficult to find data concerning the Sb-transfer to and from biota. Therefore the fluxes are not determined.

4.4 Flux of substances in the complete system

By far the largest quantity of Sb consumed in Switzerland is through flame retardant products (488 tons), which contribute 66 % of the total antimony consumption in 2001. The metal products and the nonmetal products contribute almost equally at 128 and 117 tons respectively. The total consumption was 733 tons in 2001.

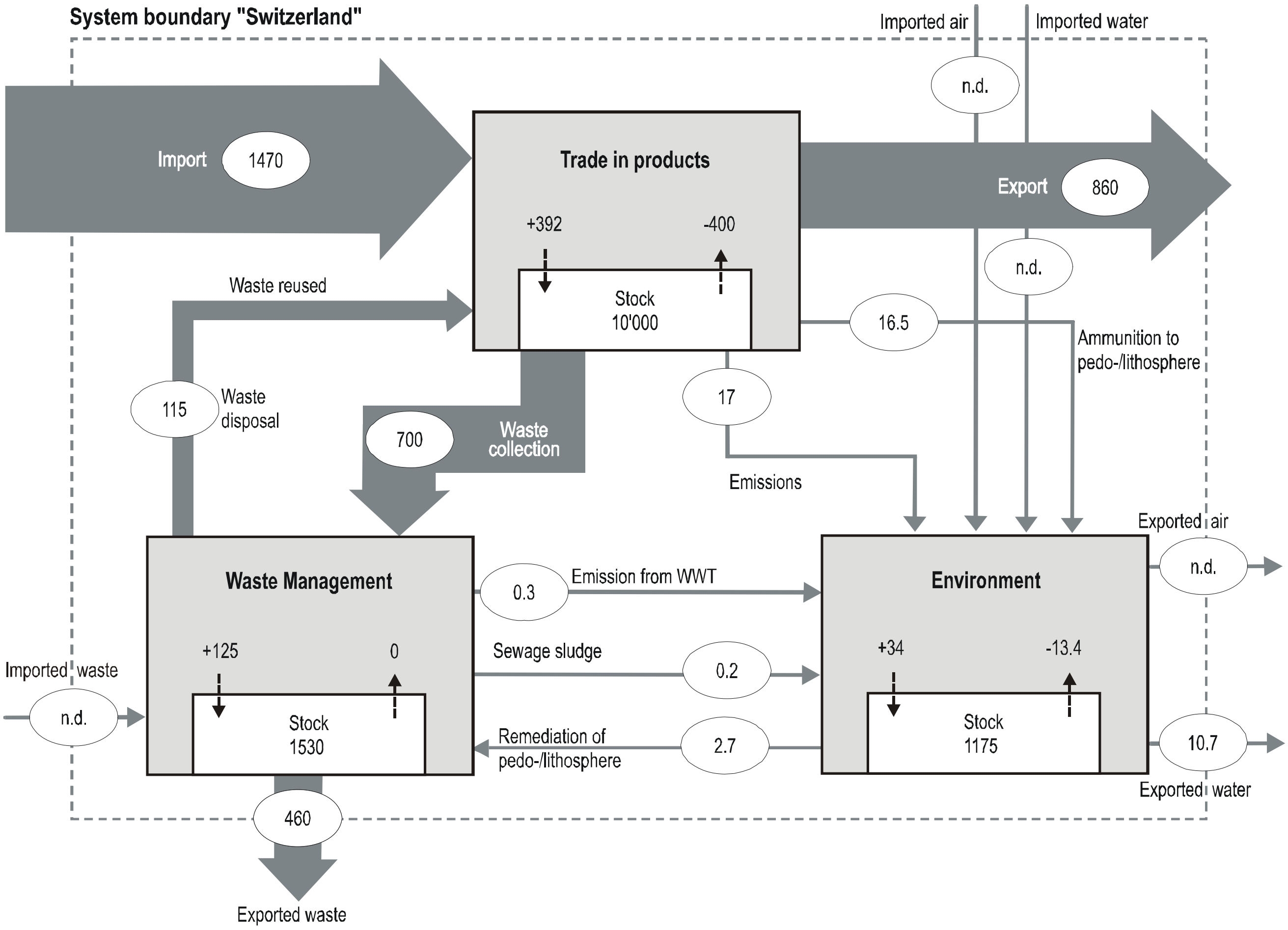
In 2001 about 1630 tons of antimony were imported into Switzerland, of which about 8 % were used for production and 92 % in finished products. Some 5 % of total 'trade in products' goods were reused from collected waste, 60 % antimony in imported and produced goods were exported and 40 % were consumed in Switzerland. Of the consumed goods, around 2 % of Sb in ammunition went directly into the pedosphere. Overall, the antimony stock in consumption in Switzerland amounted to 10300 tons, excluding 8370 in inorganic construction materials. Around 73 % of the rest of the stock was allocated to plastics in FR products, 16 % to metal products and the rest to nonmetal products. The "Consumption" stock decreased by 0.1 % in 2001. While the stock of FR products has increased, the stock of lead-acid batteries containing antimony has decreased over the past 10 years. It is not expected that antimony consumption in metal products will increase in the next years, simply because today lead-acid car batteries produced with lead-calcium instead of lead-antimony alloys are increasingly being used.

Of the 770 tons antimony disposed of in 2001, 210 tons were incinerated and around 140 tons were landfilled, mainly after incineration. Seepage out of landfills was estimated to be negligible and the stock of antimony in landfills is steadily increasing. A significant amount of antimony disposed of in 2001, was reused within Switzerland (around 160 tons) or exported for landfilling (around 70 tons). Almost 100 tons were exported in products for reuse, or incineration.

In 2001, around 6 tons of Sb were deposited from the atmosphere away from roadsides. About 2.7 tons of Sb in soils at shooting ranges were removed for remediation purposes, while at the same time 16.5 tons of Sb entered the pedosphere through shooting practice. This results in an annual increase in stock into the pedo-/lithosphere of around 1 %.

Figure 4.26 shows that Sb stocks in Switzerland are large (15'420 tons). The stock in landfills is approximately 1530 tons, that in the top 2cm of soil, 28 tons, and 1150 tons at shooting ranges. In 2001 approximately 185 tons of antimony entered landfills and the pedo-/lithosphere as a result of landfilling, shooting and atmospheric deposition. A very large stock of 7535 tons antimony in FR products has accumulated in consumption. The metal products in the consumption stock are 1600 tons, and the rest (1100 tons) can be ascribed to nonmetal products.

Fig. 4.26 > Fluxes in the total system 'Switzerland' "Construction waste" has not been included here.



4.4.1 Data uncertainty

The quality of data is very varied. For some products, such as acid lead batteries, the import/export data is available and the amounts recycled in the one recycling plant in Switzerland are known. In this case the antimony concentrations may be the greater source of data uncertainty. In other cases, such as PVC or polyester usage, European averages have to be extrapolated to the Swiss market. In these cases a larger degree of uncertainty is to be expected.

Table 4.2 summarizes possible sources of error. It shows that flame-retarded products dominate antimony consumption in Switzerland. Also important are antimonial lead products and, lubricants and brake pads. The errors associated with these products could be as large as ±100 %, alone from uncertainties in antimony concentrations. The database (FOEN, 2002) used for estimates of flame retarded products depends on European statistics. The Federal Government of Switzerland customs statistics provide a good check for consumption data. There is more weakness in the production statistics when they use partially finished products that are hard to determine from the statistics.

Very positive and in support of our material flow analysis, the amounts of antimony in waste streams, estimated from a database of antimony concentrations and FOENs waste management statistics, are in good agreement with antimony inputs to waste management calculated of the nonmetal and flame retardant products. It should be noted, however, that the concentration of antimony in construction wastes to be incinerated was set at 130 mg/kg to balance antimony in products to waste and the waste streams. This value could not be verified but lies within the range for non-hazardous wastes.

We think that we have not overlooked any products. However, the possible use of antimony as a eutectic alloy to reduce the melting point of aluminum metal for products used in the automotive industry has been reported (Bonsignore and Daniels, 1991). We could not find any further information other than that antimony did not easily form alloys with aluminum or iron. We therefore assumed that such products would be of minor importance.

Tab. 4.2 > Data uncertainty.

Products	Percentage consumption +/-%	Comments
Metal products		
Lead-acid batteries	15	The quality of the product data depends largely on export/import statistics and information from a limited number of sources regarding product quantities (Tab. 7.4). We have little information on the use of antimony in Swiss munitions production. Antimony concentrations could vary as much as +/- 100 % (see Tab. 7.3). Unfortunately there is no independent means of validating the information. However, the proportion of the metal products of the total antimony consumption agrees quite well with the American market (Tab. 5.1)
Ammunition and shot	2	
Rolled and extruded lead products	7	
Nonmetal products		
PET bottles	2	The quality of the product data depends largely on export/import and product statistics for the PET products, polyester resins, PVC, lubricants and brake pads. (Tab. 7.13). Antimony concentrations could vary as much as +/- 100 % (see Tab. 7.12). Again, the proportion of the metal products of the total antimony consumption agrees quite well with the American market (Tab. 5.1).
PET	< 2	
PVC	< 2	
Polyester resins	< 2	
Glass	2	
Ceramics, enamels	< 2	
Pigments	2	
Lubricants	7	
Brake pads	5	
minor non-metal products	< 2	
Flame retarded products		
EE products	34	Flame retarded products dominate the quantities of consumed antimony-containing products. They also provide the major source of antimony in MSW waste and thus antimony flows can be validated.
ASR products:	8	
building materials	14	
Waste streams		
Different waste categories	FOEN statistics provide an excellent database.	
Environmental factors		
Water	Scientific literature provides and FOEN statistics and reports provide an good database. Data on atmospheric deposition in urban areas or next to busy roads is missing so estimates of emissions from brake pad erosion cannot be validated.	
Soil		
Atmospheric deposition		

5 > Conclusions

The conclusions presented here are based on the data collated for 2001.

The antimony consumption pattern in Switzerland is similar to other industrialized countries.

Metal, nonmetal and flame retarded products make up, 20 %, 17 % and 63 % of consumption in Switzerland respectively. Comparison of US consumption (Carlin, 2002) to Swiss consumption of the 3 product groups shows that, similarly to USA, Swiss consumption of the 3 product groups is similar in that metal and non-metal products contribute around 20 % of total consumption and FR products containing antimony are used about three times as much as the other products (Tab. 5.1). It should be noted that Switzerland consumes significantly less PVC and antimony associated with ClFR than the European average (2 to 3 times less, APME, 2003). The USA data is probably underestimated since it only includes primary consumption of antimony and because not all companies responded to the USGS survey (Carlin, 2002). Estimated values from Weber (Industrial Minerals, 2000) for 1998 indicate much higher consumption values for US antimony consumption in FR. Also, our figures included both primary and secondary consumption.

Tab. 5.1 > Comparison of antimony consumption data from different areas to consumption data estimations for Switzerland.

Product group / area	Consumption in area		Consumption in Switzerland	Source
	Amount	Extrapolated using population ratio (Tab. 2.1)		
Metal products USA[1]	2'760	72 (21 %)	129 (23 %)	Table 3.7
Nonmetal products USA[1]	2'710	71 (21 %)	114 (21 %)	Table 3.13
Flame retardants USA[1]	7'420	193 (58 %)	433 (56 %)	Tables 3.22 and 3.23
Brominated FR[2] USA Western Europe **tons BFR**	 22'800 18'880	 593 748	 703	Table 3.19
Chlorinated FR in Western Europe[3] **tons ClFR**	11'200	444	98 somewhat lower	Table 3.20

tons Sb per 2001.
Source: [1]Carlin, USGS (2002); [2]Weber (2000) – Fig. 4.3; [3]Frost and Sullivan 1999

Much of the antimony imported into Switzerland is exported and the remainder is added to the stocks of the system.

In 2001 around 95 % of antimony that was imported into Switzerland was offset by the export of products and waste streams including APC residues to be landfilled. Approximately 74 % of the antimony remaining in Switzerland was landfilled, 20 % was deposited in the environment and the remainder (10 %) increased the stock of TIP. The amount of antimony released to the environment from "waste management" appears to be small and is most likely to be a local problem.

Future trends in the consumption of antimony will be dominated by the demand for flame retardants.

The largest portion is used for EE products and household goods (76 %) and to same smaller extent in vehicles (10 %) and in building materials (14 %). Future demand for antimony trioxide in flame retardants depends on the following factors: demand for flame retardants, competition from other flame retardants, product quality and price, and government and industry laws and regulations.

The demand for flame retardants in the European market in general has been projected by Frost & Sullivan (1999) to rise by 5 % per year for the next several years. Additive producers have developed new products to overcome some of the disadvantages of halogenated flame retardants, such as corrosiveness to process equipment, high smoke generation, halogen free, environmental unfriendliness, and combustion gas toxicity. According to Weber (2000) a new grade of mineral flame retardants (aluminium trihydrate and magnesium hydroxide) which meet thermal stability are finding increasing use in plastic applications. Plastic additive producers continue to increase the quality and range of their products and services to remain competitive. However, the price of antimony has sharply risen during 2001 and is continuing to do so. The main restraint in future growth of antimony trioxide consumption is the potential imposition of bans on the use of halogenated flame retardants. The European Commission's draft directive issued in 2000 proposes that all plastics containing brominated flame retardants are separated out from electrical and electronic before recycling and disposal.

At present antimony-containing plastics recycled from electrical and electronic goods are mainly reused abroad as secondary sources of energy (ie. they are incinerated). Users of such materials (eg. the cement industry) are noting increases in antimony concentrations in their products. Thus, a market for such products may be restricted in the future.

The estimated stock of antimony in flame retarded products is very large (around 13'000'000 tons). In comparison to the reported collection of discarded electrical and electronic products (60'000 tons, Section A1-4.1) are relatively small, indicating that the stock will remain significant for decades. It should be noted that the amount of collected products has risen to roughly 80'000 tons since 2001 (FOEN, 2004).

The demand for antimony for use in other products is dominated by antimonial lead used in lead-acid batteries, lubricants and brake pads. However, the demand for antimony may decrease for certain products in the long-term.

Following observations can be made:

> The demand for antimony in lead alloys has fallen during the past two decades, due to both environmental restrictions on the use of lead and the increased use of secondary material. Consumption of antimony in lead alloys is forecast to fall further in the early 2000's, following the introduction of further voluntary and legislative restrictions on the use of lead, especially in the shot market (Roskill, 2001).
> An area of growth for antimony metals is the expanding semiconductor market. However, only trace amounts of antimony are used in semiconductors and even if the market share would reach its full capacity in Switzerland amounts of antimony still would be much below a ton Sb consumed.
> Of the plastics using antimony trioxide as catalyst or stabilizer generally, the demand for antimony trioxide in PET catalysts is forecast to show strong growth over the next decade by some 10 % increase globally. Growth of PET packaging (bottles) is one of the products mostly responsible for this rise. Industry sources estimated in the late 1990's that if one-half of beer packaging were converted to PET single serving bottles, demand for PET would double (Roskill, 2001).
  However, alternative catalysts to antimony exist, and with the unwelcome publicity that antimony can leach into mineral water as a result of storage in PET bottles is likely to lead to a change in the future.
> The demand for antimony in the CRT manufacture is forecast to rise by 3 % to 7 % per year. However, flat screens are likely to dominate the future market. Glass used in upcoming technologies no longer needs to contain heavy metals (mainly lead) as a filter for X-rays, so the flows of antimony in glass products will decrease in the long term (Oberle, 2004).
> Consumption of break fluids (lubricants) has decreased by 15 % in the past 3 years because of improvements in more efficient car designs, although consumption of cars increase in the same time by 3.7 % in Switzerland (VSS, 2003).
> It remains to be seen whether the use of antimony sulfide will be restricted in the manufacture of brake pads. This topic has only recently been brought to the attention of the scientific community (in 2005).
> New products, for which little information exist today that antimony are continually coming onto the market. These will have to be included in future studies. One example is the rewritable disc (CDs and DVDs).

Much of the antimony imported into Switzerland is exported and the remainder is added to the stocks of the system.

In 2001 around 90 % of antimony that was imported into Switzerland was offset by the export of products and waste streams including APC residues to be landfilled. Approximately 74 % of the antimony remaining in Switzerland was landfilled, 20 % was deposited in the environment and the remainder (10 %) increased the stock of TIP. The amount of antimony released to the environment from "waste management" appears to be small and is most likely to be a local problem, I.E. emissions associated with waste treatement or landfilling that are a problem with respect to water treatement.

The largest emissions of antimony to the environment are the result of the use of antimony in brake pads and shooting practice.

The statistics regarding the emission of antimony to the environment via antimonial lead bullets are well documented by the Swiss authorities. Changes in the way shooting ranges are managed and the collection of spent bullets will lead to a reduction of emissions. The remediation of existing shooting ranges is being considered at many of the over 2000 shooting ranges in Switzerland. Antimony appears to be mobile in chalky soils common in Switzerland, compared to lead and may lead to the contamination of groundwater.

The emissions that result from the wear of brake pads are difficult to assess because little quantitative data on the composition of brake pads is available. However, recent studies suggest (Weckwerth, 2005) that the impact could be considerable. Given the importance of this antimony source, it would be necessary to investigate this antimony source further.

There are significant data gaps.

There are problems associated with both determining the usage of antimony and assessing the effects of this usage.

1. There is an inordinately large number of different products on the market that contain antimony. Many of the industrial associations do not know that antimony is a part of the products produced or imported by their members. In particular, the statistical data of product trade available from the Swiss customs authorities are insufficiently precise to determine the product flows. Considering that antimony compounds are imported in such large quantities, a separate entry should be allocated.
2. Emissions to the atmosphere from production are unknown and should be better determined. The emissions from brake pad erosion are only very rough estimates. Also in this study we could not extend our examinations to trucks and trains, so our values are probably conservative.
3. Very little is known on the impact of antimony on human health on the biota in general. The extent and effect of antimony uptake by humans through direct contact with, for example, flame retarded products, deserves investigation.

> Index

Abbreviations

ABS
Acrylonitrile-butadiene-styrene

AGM
Absorbed glass mat

ATH
Aluminum trihydrate

ASR
Auto shredder residue

BFR
Brominated flame retardants

ClFR
Chlorinated flame retardants

CIS
Commenwealth of Independent States

CRT
Cathode ray tube

DecaBDE
Decabromodiphenyl ether

DMT
Dimethyl terephathate

EDP
Electronic data processing equipment

EE
Electrical and electronic appliances

EPDM
Ethylene propylene diene rubber membrane

EPS
Expanded polystyrene

EZV
Swiss Federal Customs Administration

FCC
Fluid catalytic cracking

FR
Flame retardants

LED
Light emitting diodes

LCD
Liquid crystal display

MWIP
Municipal waste Incineration plant(s)

MSW
Municipal solid waste

MSWI
Municipal solid waste incineration

n.d.
not determined

OctaBDE
Octabromodiphenyl ether

PBT
Polybutylene terephthalate

PE
Polyethylene

PentaBDE
Pentabromodiphenyl ether

PMx
Airbourne particulate matter with diameter of x μm

PP
Polypropylene

PS
Polystyrene

PU
Polyurethane

PV
Photovoltaic cells

PVC
Polyvinyl chloride

FOEN
Federal Office for the Environment

SLI batteries
Starting, lighting, ignition batteries

TBBPA
Tetrabromobisphenol A

TPA
Terephthalic acid

UPS
Uninterruptible power supply

WTP
Waste treatment processes

WWT
Wastewater treatment

WWTP
Wastewater treatment plant

XPS
Extruded polystyrene

Figures

Tables

Bibliography

Achternbosch M., Bräutigam K.-R., Hartlieb N., Kupsch C., Richers U., Stemmermann P. 2003: Heavy Metals in Cement and Concrete Resulting from the Co-incineration of Wastes in Cement Kilns with Regard to the Legitimacy of Waste Utilisation, Wissenschaftl. Berichte, FZKA 6923, Umweltbundesamt Deutschland.

Albemarle Corporation 2003: "SAYTEX Flame retardants", *www.albemarle.com/saytexwire.htm.*

Alchemy Castings 2003: "Bullet alloys / Casting alloys / Fusible alloys", Hamilton, On., Canada, *www.alchemycastings.com.*

Alexander-David M. 2006: Antimonemissionen von Bremsbelägen in der Schweiz für das Jahr 2001. Semesterarbeit. Eidgenösische Technische Hochschule (ETH), Zürich.

Alusuisse Martinswerk GmbH 1999: *www.martinswerk.de,* belongs since 2001 to Albemarle Corporation.

Amspec Chemical Corporation 2003: "Amspec chemical and custom compounding", *www.amspecorp.com/amspec/fras.htm.*

APME 1995: "Plastic and material of choice for the electrical and electronic industry – Plastic consumption and recovery in Western Europe 2000", Report no. 2008, Association of plastics manufacturers in Europe (APME), Brussels, Belgium.

APME 2001: "Incineration of PET packaging articles and municipal solid waste containing PET", Association of Plastics Manufacturing in Europe, Brussels, Belgium.

APME 2003: "Plastics -an analysis of plastics consumption and recovery in Europe", Association of Plastics Manufacturing in Europe, Brussels, Belgium.

Artimport 2003: "Britannia metal – what it is, how it is made, its marks", *www.artimport.it/brit_metal_ingl.html.*

Association PRS PET-Recycling Switzerland 2004: Jean-Claude Würmli, personal communication.

ATV Fachausschuss 1988: "Die Zusammensetzung von Deponiesickerwässern", Arbeitsbericht der ATV-Arbeitsgruppe 7.2.26 "Sickerwässer aus Industrie- und Sonderabfalldeponien", 7.2 (Industrieabwasser mit organischen Inhaltsstoffen)", Müll und Abfall 2/88.

Baccini P., Bader H.-P. 1996: "Regionaler Stoffhaushalt – Erfassung, Bewertung und Steuerung", Spektrum Akademischer Verlag Heidelberg, ISBN 3–86025–235–6.

Bart G., Von Gunten H.R. 1976: "Spurenelemente in der Aare (Schweiz)", Schweiz. Z. Hydrol. 39/2, 1977, Birkhäuser Verlag Basel.

BASF 2000: "Sicopal pigments for coatings – weather-restistant inorganic bismuth vandate pigments with high hiding power", TI/P 3374, BASF, Gemany, *www.basf.de.*

Belevi H., Baccini P. 1988: Long-term behaviour of municipal solid waste landfills. Waste Manag. Res, 7: 43–56.

BFS (Swiss Federal Statistical Office), Neuchâtel 2003: “Statistisches Jahrbuch der Schweiz”, Verlag Neue Zürcher Zeitung, ISBN 3–03823–020–0.

Blay K. 2000: Sorption wässriger Antimon-Spezies an bodenbildende Festphasen und Remobilisierung durch natürliche Komplexbildner. PhD Thesis, Technical University of Munich, Munich, pp. 192.

Bonsignore P.V., Daniels E.J. 1991: Antimony in aluminium scrap. Modern casting, May, 28–29.

Boyle R.W., Jonasson I.R. 1984: “The geochemistry of antimony and its use as an indicator element in geochemical prospecting”, J. Geochem. Explor., 20, 223–302.

Braungart M., Pott I., Sinn C. 1998: “Mögliche Gesundheits- und Umweltbelastungen durch die Einführung von PET-Mehrwegflaschen”, Abschlussbericht, EPEA Internationale Umweltforschung GmbH, Hamburg, Deutschland.

BSEF 2000: Bromine Science and Environmental Forum “An introduction to brominated flame retardants”, *www.firesafety.org.*

Bubendorff H. 2004: Metallum AG, 4133 Pratteln, personal communication.

Buckingham D.A., Carlin Jr. J.F. 2002: Antimony Statistics. *http://minerals.usgs.gov/ds/2005/140/antimony.xls*

Campine 2003: “Antimony: PET catalyst”, *www.campine.be/uk/antimony_p.html.*

Carlin Jr. J.F. 1992–2003: “Antimony”, U.S. Geological Survey Minerals Yearbooks (USGS), *www.usgs.gov.*

Carn Metals Index 2003: “Pewter”, Pewter Information, *www.carnmetl.co.uk/pewter.htm.*

Chemico Chemicals Pvt. Ltd. 2004: “Antimony compounds”, *www.chemicochemicals.com.*

Chemox 2003: “Metallic Compounds for Industry”, Speciality chemicals distribution, *www.chemox.co.uk.*

Crew Development Corporation 2001, 2002: “Annual reports 2001, 2002”, Great Britain, *www.crewgroup.com*

Christensen T.H., Kjeldsen P., Albrechtsen H.-J., Heron G., Nielsen P.H., Bjerg P. L., Holm P.E. 1994: “Attenuation of landfill leachate pollutants in aquifers”, Crit. Rev. Environ. Sci. Technol., 24(2), 119–202.

Christie T., Braithwaite B. 2002: “Mineral Commodity Report 2 – Antimony”, Institute of Geological and Nuclear Sciences Limited, *www.med.govt.nz/crown_minerals/docs/comreports/report02.*

Cookson Semiconductors 2000: “Material Safety Data Sheet”, revised 01.07.2000, *www.cooksonsemi.com.*

Council of the European Communities 1976: “Council directive 76/464/EEC”, 4. Mai 1976 on pollution caused by certain dangerous substances discharged into the aquatic environment of the community. Official Journal L 129, 18/05/1976:23–29.

Council of the European Communities 1998: “Council directive 98/83/EC”, 3. November 1998 on the quality of water intended for human consumption. Official Journal L 330, 05/12/1998:32–54.

Danish Environmental Protection Agency 1999: “Brominated flame retardants – 1. Introduction to brominated flame retardants”, *www.mst.dk/udgiv/Publications/1999/87–7909–416–3/html/kap01_eng.htm.*

Doe Run Company 2000: “Recycling and smelting processes”, St. Louis, Missouri, USA, *www.doerun.com.*

DuPont 2004: “DuPont polymer modifiers”, *www.dupont.com/industrial-polymers/plastics/.*

Eberhard Recycling AG 2004: Kloten, Kt. Zürich.

Edenburn D.L. 2001: “Flame retardants in automotive plastics”, Arbemarle Corporation, *www.bsef-site.com/2001_02_07Revised_0/M27.pdf.*

Environment Australia 1999: Emission estimation technique manual for petroleum refining. National Pollution Inventory. *www.npi.gov.au/handbooks/approved_handbooks/petroleum.html*

ESPI 2004: “High Purity Metals”, *www.espimetals.com/metals/catantimony.htm*

EZV 1998–2002: Swiss Foreign Trade Statistics (Schweizerische Aussenhandelsstatistik), Eidg. Zollverwaltung, Bern.

Federal Department of Defense 2004: Bundesamt für Betriebe des Heeres, Bern, Viktor Schärer – personal communication.

Filella M., Belzile N., Chen Y. W. 2002: “Antimony in the environment: a review focused on natural waters I. Occurrence”, Earth-Sci. Rev., 57(1–2), 125–176.

Filella M., May P.M. 2003: “Computer simulation of the low-molecular-weight inorganic species distribution of antimony(III) and antimony(V) in natural waters”, Geochem. Cosmochem. Acta. 67, 4013–4031.

FOEN 2004a: “Elektronikschrott in der Schweiz 2001”, Künzler Bossert & Partner GmbH, Dr. U. Waber.

FOEN 2004b: Metallische und nichtmetallische Stoffe im Elektronikschrott: Stoffflussanalyse. Schriftenreihe 374

FOEN statistics 2004: www.umwelt-schweiz.ch/imperia/md/content/abfall/siedlungsabfall_d.pdf and www.umwelt-schweiz.ch/imperia/md/content/abfall/abfall+kapazitaet_d.pdf.

FOEN 2001: "Overview of waste quantities and recycling in 2001", www.umwelt-schweiz.ch/imperia/md/content/abfall/ueberblick_d2001.pdf.

FOEN, Department for water protection and fisheries 2001: "Abwässer aus Kehrichtverbrennungsanlagen (KVA)", Schlussbericht der BSH Umweltservice AG, www.umwelt-schweiz.ch/imperia/md/content/abfall/sonderabfallstatistik_01_d.pdf, www.umwelt-schweiz.ch/imperia/md/content/abfall/tab12_d.pdf and www.umwelt-schweiz.ch/imperia/md/content/abfall/tab12–02_d.pdf.

FOEN statistics 1993–2003:, www.umwelt-schweiz.ch/buwal/eng/fachgebiete/fg_abfall/zahlen/statistiken/index.html.

FOEN, Bern, Environmental Series no. 338 2002: "Selected polybrominated flame retardants – substance flow analysis".

FOEN, Bern, Environmental Series no. 295, 1997: "Cadmium – Stoffflussanalyse".

FOEN, Bern, Environmental Series no. 251, 1996: "Stoffflussanalyse Schweiz – Anleitung" (material flow analysis for Switzerland).

FOEN, Bern, Environmental Series no. 245, 1995: "Bauprodukte und Zusatzstoffe in der Schweiz".

Frost & Sullivan 1999:, Frost & Sullivan market engineering 1999, Research services, Mountain View, CA, USA.

FSID 1990: Foundation for the study of infant death "PVC mattresses and cot death: the facts", www.sids.org.uk/fsid/mattresscont.htm.

Gebel T. 1999a: "Metalle/Antimon", In: Umweltmedizinisches Handbuch, Wichmann-Schlipköter-Fülgraff (eds.), 17. Ergänzungslieferung (11/99), ecomed, Landsberg.

Gebel T. 1999b: "Arsenic and Drinking Water Contamination", Science 283:1459–1459.

Global development advisors 2000: "United States Antimony", UAMY, www.usantimony.com.

GS Electronic GmbH 2003: "Castin – lead free solder", www.gselectronic.de/aim_engl.htm

GWI 2004: Great Western Inorganics, "Product Series", www.greatwesterninorganics.com/company.htm

Healthy Light 2003: "The healthy light catalog", www.healthylight.com.

Helminiak N. 2006: Personal communication. PLASCON GmbH, Weil am Rhein, Germany www.plascon-gmbh.de

Hillgrove 2000: "Presentation annual general meeting 2000", Gold and Antimony Mines, Amidale, Australia, Straits Resources Ltd., www.straits.com.au.

Hiratsuka S., Horie H., Kowata T., Koike K., Shimizu K. 2003: "Influence of steel scrap on microstructure and mechanical properties of spheroidal graphite cast iron", Material Transactions, Vol. 44, No. 7:1419–1424.

Hischier R. 2004: EMPA SG, personal communication.

Huber M. 2004: SEV (Schweizerischer Elektrotechnischer Verband), Fehraltdorf ZH, personal communication.

Hüglin C. 2000: "Verkehr und Umwelt: Anteil des Strassenverkehrs an den PM_{10}- und $PM_{2.5}$- Immissionen, Chemische Zusammensetzung des Feinstaubes und Quellenzuordnung mit einem Rezeptormodell", NFP41, EMPA Dübendorf.

IAOIA 2004: International Antimony Oxide Association, www.iaoia.org. Written communication.

ILZSG – International Lead and Zinc Study Group 2001: "The market of lead: Present and future drivers for change", www.ilzsg.org.

ITRI (Industrial Technology Research Institute USA) 2000: News release, www.itri.com.

Jeep Tech 2003: "Batteries" www.jeeptech.com/electrical/.

Johnson C.A., Kaeppeli M., Brandenberger S., Ulrich A., Baumann W. 1999: "Hydrological and geochemical factors affecting leachate composition in municipal solid waste incinerator bottom ash: Part II", The geochemistry of leachate from Landfill Lostorf, Switzerland, J. Contam. Hydrol., 40, 239–259.

Johnson Matthey Catalysts 2003: "VERTEC Polyester and PET Catalysts Technology", Cleveland UK, www.jmcatalysts.com.

Jörg M. 2004:, SwissBat (Verband Schweizerischer Batterienhersteller), Bern, personal communication.

Kapp alloy 2003: "Antimonial tin", www.kappalloy.com/Solder-Electronic/html

Kastien H. 2004: Swiss Lack AG, 6015 Reussbühl, www.swisslack.ch, personal communication.

KCM S.A. 2003: "Alloys with low content of antimony for batteries", www.kcm.bg/prod0204.htm.

Keller, Th., Desaules, A 2001: "Böden der Schweiz – Schadstoffgehalte und Orientierungswerte (1990–1996)", Environm. Materials No. 139, FOEN, CH–3003 Bern. 115 p.

Knopf D. 2000, 2001, 2002: "Switzerland", Mining Annual Review, Mining Communications Ltd.

Kompass 2004:, CD plus Kader, Version 19 and www.kompass.com.

Kupper T. 2002: "Auswirkungen der Einleitung von Industrieabwasser in die öffentliche Kanalisation auf den Schwermetallgehalt von Klärschlamm und gereinigtem Abwasser unter besonderer Berücksichtigung von Arsen und Antimon", SEA, EPFL.

Krüger R 1999: "Our contribution to environmental friendliness in textile production", Acordis Industrial Fibers GmbH, Wuppertal, Germany, www.acordis.com.

Landiss 2003: "Car batteries are not 12 Volts", www.landiss.com/battery.htm.

Leuz A.-K., Hug S., Wehrli B., Johnson C.A. 2006: Fe-catalyzed oxidation of antimony. *Accepted by Environ. Sci. Technol.*

Magnacharge 2003: "Batteries – all you ever want to know", www.magnacharge.com.

Masters H. 1999–2003: "Antimony", Mining Annual Review, Mining Communications Ltd.

Maurer M. 2004: EAWAG 2004, www.eawag.ch/publications/eawagnews/www_en57/en57d_printer/en57d_maurer_p.pdf.

McCarthy S., Tucci V. 2003: "Annual report environmentally benign resins and additives, for use in the wire and cable industry", Toxics use reduction Institute, University of Massachusetts Lowell, USA, www.turi.org.

Meier K. 2004: Swissmem Zürich, personal communication.

Mineral Information Institute 2003: "Antimony", www.mii.org/Minerals/photoant.html.

Morf L. 2002: "Die KVA als Instrument der Erfolgskontrolle in der Abfallwirtschaft der Schweiz", Endbericht zum Pilotprojekt 2000–2001: KVA St. Gallen und KVA Weinfelden, GEO Partner AG.

MRC Polymers 2001: 'Product introduction spring 2001', www.mrspolymers.com/product_intro.htm.

Müller U. 2004:, VSS lubes (Swiss Association of Lubricants Industry", 8001 Zürich, personal communication.

NABO 2001: The National Soil Survey, "Overview of soil pollutant contents in Swiss soils (1990–96)", based on Keller Th., Desaules A. (2001) "Böden der Schweiz – Schadstoffgehalte und Orientierungswerte (1990–1996)", Environm. Materials No. 139, FOEN, CH–3003 Bern. 115 p.

Nakamura Y., Tagami K., Vchida S. 2006: "Antimony mobility in Japonese agricultural soils and the factors affecting antimony sorption behaviour", Environmental Pollution, Vol. 141:321–326.

Nilsson N.H. 2001: "Memo on the project: Analysis for bromine in electronic parts", Environment and Waste Technology, Danish Environmental Protection Agency, www.mst.dk/udgiv/publications/2001/87–7944–837–2/html/app03.htm.

NPi 1999: "Emission estimation technique manual for petroleum refining", National Pollution Inventory, Environment Australia, 1999.

NYACOL Nano Technologie Inc. 2003: "Colloidal antimony pentoxide flame retardant additives", www.nyacol.com.

Oberle O. 2004:, Schott Glas, Germany, personal communication

Packaging Graphics 2004: "Definition of plastic resins", www.packaginggraphics.net.

Peichel L., Wäber M., Reifenhäuser W. 1994: Schwermetallmonitoring mit der Standartisierten Graskultur. Z. Umweltchem. Ökotox, 6(2), 63–69.

Perfect Power 2003: "IBE 12V large flooded batteries", www.perfectpower.net/en-us/dept_1532.html.

Peters Ch. A. 2002: "The basis for compositional bullet lead comparisons", Research and Technology, Forensic Science Communications, Vol. 4, No.3, July 2002, www.fbi.gov/hq/lab/fsc/bachissu/july2002/peters.htm.

Prengaman R. D., Siegmund A. 2001: "Grid alloys for automobile batteries in the new millennium", Journal of Power Sources, 95(1–2): 224–233.

Rischgasser H. 2004: Kunstoff Verband Schweiz (KVS), personal communication, www.kvs.ch.

Roskill Information Service Ltd. 2001: The Economy of Antimony, 9th edition, London UK.

RUAG Ammotec 2004: Thun, Peter Spatz – personal communication.

Sanitas Troesch AG 2004:, 8031 Zürich, personal communication.

Schweizerische Nationalbank 2003: Statistisches Monatsheft, Januar 2003, Ressort Statistik, Zürich (monatsheft@snb.ch).

Seddon R., Harper J.F. 2001: “Influence of flame retardant additives on the processing characteristics and physical properties of ABS”, Macromol.Symp., 169:109–119.

Senn E. 2004: Scherrer und Söhne AG, Jakob, 8002 Zürich, personal communication.

S.EN.S 2003: Stiftung Entsorgung Schweiz, Fachbericht 2003, Elektro- und Elektronikgeräteentsorgung. *www.sens.ch/*

Shotyk W., Kraechler M., Chen B. 2004: Antimony in recent, ombrotrophic peat from Switzerland and Scotland: Comparison with natural background values (5320 to 8020 ^{14}C yr BP) and implications for the global atmospheric Sb cycle. Global Biogeochem. Cycles, 18(1),

Slooff W., Bont P.F.H., Hesse J.M., Loos B. 1992: “Exploratory report antimony and antimony compounds”, Report no. 710401020, National Institute of Public Health and Environmental Protection Bilthoven, Netherlands.

Smith A.H. 1988: “Epidemiologic Input to the Environment Risk Assessment”, Archives of Environmental Health, Vol. 43:124–127.

SRI International 1997: CA, U.S.A., *www.sri.com.*

STMi 2003: “Chemical semiconductor devices”, *www.st.com.*

Stengele Markus 2004: IMMA2K AG, Elektronikschrott-Recycling, 8105 Regensdorf, personal communication.

Stiftung Autorecycling Schweiz 2004: Jahresbericht 2001.

SWICO-Recycling 2006: *www.swico.ch/de/recycling.asp*

SWISSMEM 1999–2002: “Panorama – Zahlen und Fakten”, 8032 Zürich, *www.swissmem.ch.*

The Fiber Organon 2002: “Fibrefacts”, annual world surveys of manufactured fiber production, Fiber Economics Bureau, USA, *www.fibresource.com.*

The Household Encyclopedia of general information 2003: “How to make homemade fireworks”, 1st published 1881, *www.publicbookshelf.com/public_htm.*

Tohka A., Zevenhoven R. 2001: “Processing wastes and waste-derived fuels containing brominated flame retardants”, Helsinki University of Technology Department of Mechanical Engineering, *www.eny.hut.fi/library/publications/tkk-eng/TKK-ENY–7_print.pdf.*

Thöni L., Krieg F., Siewers U. 1999: Testing Bergerhoff method to determine the bulk deposition loads of 49 elements. Atmos. Environ., 33, 337–344.

Thöni L., Seitler E. 2004: “Deposition von Luftschadstoffen in der Schweiz, Moosanalysen 1990–2000” Environm. Materials No. 180, Air, FOEN, CH–3003 Bern, 140 p., *www.biodiversitymonitoring.ch; www.worldatlas.com.*

Townsend Tarnell Inc. TTI) (1999: “Flame retardant market”, Business research group Ltd., Houston, TX, USA.

Triad 2001: “Stibnite, Antimony Ore, High-Grade”, *www.triad-publishing.com/Store/p-MIN-SB–01.html*

UAMY (United States antimony) 2001: “Investment highlights”, *www.usantimony.com.*

Ullmann’s Encyclopedia of Industrial Chemistry 1993: Antimony and antimony compounds”, Gerhartz W. (ed.), 5th ed., Volume A3:55–76.

Umicore 2003: Brussels Belgium, *www.um.be.*

United Nations Environmental Program (UNEP) 1999: “Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal” (with amended Annex I and two additional Annexes VIII and IX, adopted at the fourth meeting of the Conference of the parties in 1998). SBC No. 99/001. UNEP, Geneva.

United States Environmental Protection Agency 1979: “Water related Fate of the 129 Priority Pollutants”, Vol. 1, USEPA, Washington D.C., USA, EP–400/4–79–029A.

United States Environmental Protection Agency 1995: “Antimony Trioxide”, (CASNR 1309–64–4), Integrated Risk Information System, 09.01.1995, USEPA, Washington D.C., USA, *www.epa.gov/iris//subst/0676.htm.*

United States Environmental Protection Agency 1998: “Toxics Release Inventory”, USEPA, Washington D.C., USA, Doc. 745-R-OO–007.

United States Environmental Protection Agency 1999: “Antimony Compounds – Air Toxic Website”, December 1999, USEPA, Washington D.C., USA, Doc. 7440–36–0. *www.epa.gov/ttn/atw/hlthef/antimony.html.*

United States Environmental Protection Agency 1999: “National Primary Drinking Standards”, USEPA, Washington D.C., USA, Doc. 810-F–94–001.

USAC (United States Antimony Corporat) 2001–2003: “Montana Brand Antimony Oxide Products”, *www.usantimony.com/products/ant_oxide.html.*

Vishay Telefunken 2003: “The constitutents of semiconductor components”, Germany, *www.vishay.com.*

von Uexküll O., Skerving S., Doyle R., Braungart M. 2005: Antimony in brake pads – a carcenogenic component? J. Cleaner Prod., 13, 19–31.

VROM 1991: "Stoffen en Normen", Overzicht en achtergronden van belanggrijke stoffen en normen in het milieubeleid (Handboek milieuvergunningen, band 3, Alpen an de Rijn, The Netherlands, Samson.

VSKI 2004: Swiss Association of the ceramics industry, 8006 Zürich, personal communication.

VSS lubes 1999–2003: Swiss Association of Lubricants Industry, "Basic statistical data" 8001 Zürich.

Weber G. 2004: communication consultant, Büro BGW, 8035 Zürich; personal communication.

Weber M. 2000: "Mineral flame retardants", Industrial Minerals, *www.martinswerk.de:* 6p.

Weckwerth G. 2005: Von Asbest zu Antimon: Das weiterhin bestehende Krebsrisiko von Bremsbelägen. Immissionsschutz. 1/2005, 15–20.

Wirth K. 2004:, Compumet AG, Trading company specialized in solder and antimony products, Rheinfelden, BL, personal communication.

Wittemann R., Dick B. 1998: "Powering the network", C&D Technologies, *www.cdtechno.com.*

World Bureau of Metal Statistics 2000:, *www.metalworld.com.*

World Health Organization 2003: "Drinking Water guidelines", 3rd edition, *www.who.int/water_sanitation_health/GDWQ/updating/3rdedition.htm.*

Zobrist J., Sigg L., Schoenenberger U. 2004: "NADUF – thematische Auswertung der Messresultate 1974 bis 1998", Schriftenreihe der EAWAG Nr.18, ISBN: 3–906484–33–5.

> Appendix I

The appendix is concerned with all detailed figures and calculations required for the mass balance of antimony through Switzerland. Data was gathered from the Federal Customs Administration (EZV), from different industrial associations and unions, from the literature and in some cases analytically, especially for the waste management and environmental section. Where data was not available, international figures where compared based on population data. Uncertainties and estimations are in detail documented in Chapter 2.4 (Methodical procedure).

A1 Trade in products

A1-1 Compounds and intermittents

Tables 7.1 and 7.2 below correspond to Tables 3.1 and 3.2 in Chapter 3 representing the concentrations used in antimony compounds and intermittents, respectively the import/export flow rates of the compounds.

Tab. 7.1 > Concentration of antimony in compounds and products.

Compounds	% Sb	% Sb used for calculations	Source
Antimony ore and concentrates Stibine Antimony Ingots	34–72 97.6 99	53	Triad (2001) Roskill (2001) Roskill (2001)
Antimonal lead	2–19.5	10.75	Christie and Brathwaite (2002)
Antimony oxides (antimony trioxide, antimony tetraoxide, antimony pentoxide)	75–83	79	Chemox (2003) Amspec (2003) USAC (2001)
Sodium antimonate	48	48	Chemox (2003) Chemico (2004)
Antimony chlorides (antimony trichloride, antimony pentachloride)	40–53	46.5	Chemico (2004)
Antimony sulfides (antimony trisulfide = stibnite, antimony pentasulfide)	60–72	66	Chemico (2004)
Antimony (III) bromide	68	68	GWI (2004)
Antimony fluorides (antimony trifluoride, antimony pentafluoride)	∅ 34	34	ESPI (2004)
Intermetallics: InSb AlSb GaSb	 52 82 64	 52 82 64	Purity 99.99999 %, concentration corresponds to atomic mass of molecule

For most of the compounds the concentrations of antimony in the chemicals varies greatly based on company's purification processes. We have reported the range of known Sb concentrations used in compounds. Therefore, to calculate Sb concentrations in compounds an average concentration has been employed.

The minor chemical compounds listed in Table 3.2 containing antimony are usually used at high purity (>99.9 %) for laboratory purpose as analytical agents, or like the intermetallics, for electronic devices and semiconductors. Thus, the concentration of antimony in these compounds corresponds to the atomic mass of Sb in the specific molecule.

The imports and exports of compounds (Table 7.2) were determined from the data of the Federal Customs Administration (EZV, 2001) where available. No data was published for antimony oxides and sodium antimonate. The data for sodium antimonate was extrapolated from Table 1.3 using the population data for industrial countries (Table 2.1). The data for antimony oxide was estimated from Table 1.3 (Chapter 1.4) using the figures for Europe and extrapolated using the population data (Table 2.1) for Western Europe and taking an annual 3 % increase for Europe into consideration.

Tab. 7.2 > Flows of goods and substances in imported and exported goods.

Detailed listing for compounds.

Compounds	Imported into Switzerland in 2001	Exported from Switzerland in 2001	National consumption in 2001	Sb consumption in 2001	Source
	tons/year	tons/year	tons/year	tons/year	
Antimony ore and concentrates	10	-	10	5.3	1
Antimonial lead	4.1	313.9	–309.8	–33.3	1
Antimony oxides	210–1’152	-	681	538	2
Sodium antimonate	122	-	122	58.6	3

Source: 1 EZV (2001); 2 Estimation and averaged (Masters H., Mining Annual Review, 2000; Weber, Industrial Minerals, 2000); 3 Estimation (Roskill, 2001).

A1-2 Metal products

Tables 7.3 below correspond to Table 3.4 in Chapter 3 representing the concentrations used in antimony metal products.

For most of the metallurgical products the concentrations of antimony varies greatly based on company's own recipes. We have reported the range of known Sb concentrations used in the metal products. Therefore, to calculate Sb concentrations in products an average concentration has been employed, unless otherwise stated.

Tab. 7.3 > Concentration of antimony in compounds and products.

Metal products	% Sb	% Sb used for calculations	Source
Lead-acid batteries: SLI	0 to > 2 10 max.	2	Roskill (2001)
Lead-acid batteries: Deep-cycle	5–6 10 max.	5.5	Bubendorff, 2004 Roskill (2001), Perfect Power (2003)
Lead-acid batteries: UPS	0 to > 2	2	Roskill (2001), PQ1 (2003)
Ammunition and shot	2–5 ∅ 0.5–3 10 max.	weighted average	RUAG (2004), Roskill (2001), Peters (2002)
Bearing metals	6–16.2	11.1	Roskill (2001)
Rolled and extruded lead products	4–6 4–12	5	Senn (2004) Roskill (2001)
Cable sheathing	0.7–1	0.85	Roskill (2001)
Solder (Sn/Sb)	< 1 for EE 0.05 for surface technology	0.53	Roskill (2001)
Weights	3–4	3.5	Roskill (2001)
Fusible alloys	9 max.	4.5	Roskill (2001), Alchemy Castings (2003)
Type metal	2–28	15	Roskill (2001)
Copper alloys	0.05–0.6	0.33	Roskill (2001)
Pewter	0.5–8	4.25	Carn Metals (2003)
Semiconductors	Trace amounts	-	Roskill (2001), Yukio (2001)
Magnetic steel	0.02	0.02	Hiratsuka et al. (2003)

A1-2.1 Import/export flow rates of metal products

The imports and exports of metal products (Table 7.4) were determined from the data of the Federal Customs Administration (EZV, 2001) where available. Where data was not available, sources, calculations and assumptions used to estimate the trade of metal products is explained below:

Cable sheathing

According to Kompass (2004) only one company in Switzerland still trades lead cable sheathing, but only on special request (Kompass, 2004). For 2001 no entry for cable sheathing was found from the import/export listings of the EZV.

Tab. 7.4 > Flows of goods and substances in imported and exported goods – detailed listing of metal products.

Table 7.4 corresponds to Table 3.5 of the import/export flow rates of metal products.

Metal products	Imported into Switzerland in 2001	Exported from Switzerland in 2001	National consumption in 2001	Source
	tons/year	tons/year	tons/year	
Lead-acid batteries: SLI	10'600	147	10'453	1
Lead-acid batteries: Deep-cycle	3'960	6'078	- 2'118	1
Ammunition and shot	104.9	120.8	- 15.9	2
Bearing metals	7.2	-	7.2	3
Rolled and extruded lead products:	9'033.1	8'831.3	201.8	2
• Refined lead	6'220.4	581.2	5'639.2	2
• Antimony is the predominant other element besides lead	40.1	3'062.2	- 3022.1	2
• Other lead alloys	837.2	430.7	406.5	2
• Waste and scrap from lead products	51.7	4479.5	- 4427.8	2
• Waste and scrap from zinc electroindustry products	9.8	105	- 95.2	2
• Bars, rods, profiles and wire from lead	127.4	46.2	81.2	2
• Foils and ribbons with a thickness < 0.2mm	13.3	0.3	13	2
• Plates and sheets	808.5	77.1	731.4	2
• Powder and tinsel	173	0.0	173	2
• Pipes, connectors elbows from lead	5.8	0.2	5.6	2
• Other lead products without surface treatment	467.9	43.5	424.4	2
• Other lead products with surface treatment	278	5.4	272.6	2
Weights	135.8	143.3	- 7.5	2

Source: 1 Bubendorf, Metallum AG (2004); 2 EZV (2001); 3 Estimation.

Semiconductors

No data for semiconductors could be found from the import/export listings of the EZV and according to M. Huber (SEV, 2004), the SEV also does not have any trade and production data. However, there is a small amount of semiconductor production from several manufacturers of process control devices in Switzerland, such as ABB, Siemens CH, Philips CH.

World consumption of intermetallics in semiconductors has been forecast to increase from 19 tons in 1998 to 25 tons in 2005 (Roskill, 2001). This amounts to an average increase of 0.86 tons per year, and 21.6 tons for 2001 globally. For Switzerland, using the population data for industrial countries (Table 2.1), this converts to 0.132 tons of intermetallics (as InSb, AlSb or GaSb) and 0.09 tons of Sb in 2001. From this amount, based from indications given to us (SEV, 2004) about 50 % is imported and 50 % is produced in Switzerland. Antimony, which is used as part of the soldering mixture for semiconductors, has a negligible impact in this area and on the overall mass balance. Therefore, we have not integrated the amounts in the mass balance.

Bearing metals

The data published for bearing metals from the EZV did not indicate the alloy composition of the bearings. For instance, the major part of bearing metals are steel, aluminum-tin and other metals not containing antimony. Therefore, the data for 2001 was extrapolated from Table 1.3 using the population data for USA. It was assumed that bearing metals were only imported (Table 7.4).

A1-2.2 Production flow rates of metal products

Tab. 7.5 > Flows of goods and substances produced in Switzerland – compiled listing of metal products.

Table 7.5 corresponds to Table 3.6 of the production flow rates of metal products.

Metal products	National production in 2001 tons/year	Sb consumed from production in 2001 tons/year	Source
Ammunition and shot	(9'436) 320.7	(84.9) 8.7	(1) 2
Rolled and extruded lead products	540	27	1, 3

Source: 1 Bubendorff, Metallum AG (2004) at a Sb concentration of 9000 ppm shown in brackets;
2 RUAG Ammotec, Thun (personal information from Peter Spatz (2004) – estimation of actual processed material;
3 Senn, Scherrer und Söhne AG (2004).

The production of metal products was determined from data given by Swiss industrial societies and associations where available. Where data was not available, sources, calculations and assumptions used to estimate the production of metal products are explained below:

Ammunition

According to Bubendorff, Metallum AG (2004) reused antimonial lead at a concentration of 9000 ppm is shipped to RUAG for production.

Rolled and extruded lead products

Consumption data for Switzerland could only be roughly estimated because collection of metal scraps from rolled and extruded lead products are not very well documented. In Switzerland lead sheets are worked from recycled scrap from Metallum AG, about 450 to 500 tons per year and from one company in Zürich, about 50 to 80 tons per year (Bubendorff, 2004; Senn, 2004) for consumption in Switzerland at a concentration of 9000 ppm.

A1-2.3 Consumption flow rates of metal products

The consumption of metal products (Tables 7.6) was determined from Tables 7.4 and 7.5. Where data was not available, sources, calculations and assumptions used to estimate the consumption of metal products in Switzerland during 2001 is explained below.

Ammunition

The consumption data was calculated from ammunition consumption data given by the Swiss Federal Department of Defence (personal information from Viktor Schärer 2004). According to Schärer the amounts of ammunition containing antimony, consumed privately for hunting etc., are negligible.

Tab. 7.6 > Flows of goods and substances of consumed goods – compiled listing of metal products.

Metal products	Sb consumed from trade in 2001 tons/year	Sb consumed from production in 2001 tons/year	National Sb consumption in 2001 tons/year
Lead-acid antimony based batteries: SLI	198.6	no production	198.6
Lead-acid antimony based batteries: Deep-cycle (traction)	–116.5	no production	–116.5
Ammunition and shot	–0.5	8.7	8.2
Bearing metals	0.8	no production	0.8
Rolled and extruded lead products	**10.1**	**27**	**37.1**
• Cable sheathing	no trade	no production	-
• Weights	–0.26	no production	–0.26

A1-2.4 Accumulation of metal products stock

Tab. 7.7 > Product consumption during the past years.

Table 7.7 corresponds to Table 3.8.

Metal products (tons/year)	Consumption 1999	2000	2001	Average national consumption for 2001	Source
Lead-acid antimony based batteries: SLI	9’858	10’267	10’435	10’186.7	1
Lead-acid antimony based batteries: Deep-cycle (traction)	–1’794	–2’747	–2’118	–2’219.7	1
Ammunition and shot	418	416	431	421.7	2
Rolled and extruded lead products	500–580	500–580	500–580	540	3
Weights	88.7	57.4	–7.5	46.2	4

Source: 1 Bubendorf, Metallum AG (2004); 2 Federal Department of Defense, Switzerland (2004); 3 Senn (2004), Bubendorff (2004); 4 EZV (1999, 2000, 2001).

Tab. 7.8 > Consumption of antimony in bearing metals during the past years.

Country	Consumption (tons Sb/year)								Average consumption	Source
	1993	1994	1995	1996	1997	1998	1999	2001		
USA	45	36	53	44	45	33	32	-	41	1
Switzerland	1.17	0.94	1.38	1.14	1.17	0.86	0.83	0.80	1.04	2

Source: 1 Roskill (2001); 2 Table 2.1 (population data for USA).

Tab. 7.9 > Consumption of cable sheathing during the past years.

Country	Consumption (x1000 tons/year)						Average consumption	Source
	1994	1995	1996	1997	1998	1999		
Austria	9.1	7.1	3.03	2.52	2.52	-	4.85	1
UK	9.4	9.9	9.8	9.8	9.8	9.7	9.73	1
Germany	7.7	8.3	8.0	4.44	3.33	2.82	5.77	1
Switzerland	0.68	0.73	0.71	0.39	0.29	0.25	0.51	2

Source: 1 Roskill (2001); 2 Table 2.1 (population data for Germany).

Tab. 7.10 > Stock of metal products.

Metal products	Average national consumption for 2001 (tons)		Life cycle	Stock	Source Life cycle
	product	Sb	years	tons Sb	
Lead-acid antimony based batteries: SLI	10'186.7	193.5	5	967.7	1
Lead-acid antimony based batteries: Deep-cycle (traction)	–2'219.7	–122	∅ 6 (5–7)	–732	1
Ammunition and shot	421.7	16.2	1	16.2	2
Bearing metals	9.4	1.04	∅ 18.2	18.9	3
Rolled and extruded lead products	**540**	**27**	**40**	**1'080**	**4**
• Cable sheathing	510	4.3	40	172	4
• Weights	46.2	1.6	+40	64	5

Source: 1 Jörg, 2004; Bubendorff, 2004; 2 Author's assumption; 3 Baccini and Bader (1996), Jörg (2004), VSS (2001); 4 FOEN Bern, Environmental Series no. 245 (1995); 5 Author's assumption.

The accumulation of metal product stocks (Tables 7.7 to 7.9) were determined from an estimation of the product volume today and of past years (usually from 1999 to 2001), taking the data from the Federal Customs Administration (EZV, 1999–2001) where available, as well as the life cycle of the product categories. Where data was not available, calculations and assumptions used to estimate consumption and the stock of metal products is explained below:

Batteries

SLI batteries contain 1.8–2 % antimony (Jörg, 2004) and deep-cycle batteries 5–6 % (Bubendorff, 2004; Jörg, 2004). However, based on the fact that quantities and concentrations of different antimonial lead products differ, we have taken the most accurate value: An average concentration of 9000 ppm Sb in Pb-Acid batteries has been measured by Metallum AG, which is the only battery recycling company in Switzerland (Bubendorff, Metallum AG (2004). Therefore, to calculate the Sb flows we used the values of actual antimony content in SLI and deep-cycle batteries for the entries 'Trade in products' and for the entries 'Waste management' and 'Environment' we used the recycling Sb concentrations of 9000 ppm.

Ammunition

The amount of Sb in ammunition depends on the bullet type and is given in Table 7.11 (below).

The weight of the Pb/Sb-part for the different bullets, as well as the Pb- and Sb-amount per bullet, was taken into consideration for the Sb concentration calculations using a weighted average based on the data in Table 7.11.

The life cycle of the ammunition type containing antimony is assumed to be one year, based on the assumption that the bullets are not stored more than a year, since large stocks are uneconomical and in supply chain management not recommended.

Tab. 7.11 > Composition of metals in shot and ammunition and total Pb and Sb entry into the soil from 1970 to 2003.

	GP 90	GP 11	PP 41	Total
Total amount of bullets 1970–2003[1]	644392353	2289486000	401757383	3335635736
Sb content as lead alloy (%)[2]	2	5	5	
Weight of Pb/Sb part [g]	3.05	8.55	6.42	
Pb content [g]	2.99	8.12	6.10	
Sb content [g]	0.06	0.43	0.32	
Pb entry into soil [t]	1926.09	18596.35	2450.32	22972.76
Sb entry into soil [t]	**39.31**	**978.76**	**128.96**	**1147.03**

Source: [1]Federal Department of Defense, Switzerland (2004); [2]RUAG Ammotec, Thun (personal information from Peter Spatz).

Bearing metals

The consumption change over time of bearing metals in Switzerland for 2001 (Table 7.8) was compared to the lubricant consumption (Table 7.19, because metal bearings and lubricants are closely related as they are both used for motor vehicles and large machinery. Consumption of lubricants decreased from 1999 to 2001 by 3.3 % (VSS, 2001)

Bearings with antimony are mainly used in railway and motor vehicle applications and in large machinery. Based on Baccini and Bader we assumed a life cycle of 35 years for railway applications and large machinery with a quantitative portion of 40 % and 7 years for motor vehicles based on VSS (2001) with a quantitative portion of 60 %.

Rolled and extruded lead products

Rolled and extruded lead products are used in construction. The lead is weatherproof and can last for decades, therefore to estimate the life cycle of these products life cycles of construction materials generally used with lead was used to calculated the stock.

Cable sheathing

The data was extrapolated using the population data for Germany in Table 2.1 (Table 7.9). The Austrian data was omitted to estimate Swiss consumption, because consumption there, especially during 1994 and 1995, in relation to population compared with Germany and UK appeared exceptionally high.

A1-3 Nonmetal products

Tab. 7.12 > Concentration of antimony in compounds and products.

Table 7.12 corresponds to Table 3.9 and 3.10 in Chapter 3 representing the concentrations used in antimony nonmetal products.

Nonmetal products	% Sb	% Sb used for calculations	Source
Thermoplastics: PET[1]	∅ 0.005–0.25 0.03 max.	0.02	Johnson Matthey Catalyst (2003), APME (2001), Campine (2003), AMSPEC Chem. (2004)
Thermosets: Polyester resins[1]	∅0.005–0.25 0.03 max.	0.02	Johnson Matthey Catalyst (2003), Campine (2003)
Thermoplastics: PVC[2]	0.0064 0.007	0.007	Roskill (2001)* FSID-Foundation (1990)
Glass	0.1–0.6	0.35	Roskill (2001), Stengele, (2004)
Ceramics	5–6	5.5	Roskill (2001)
Pigments	2–4, > 5	4	BASF (2000), Slooff et al. (1992)
Lubricants	11 max.	5.5	Roskill (2001)
Brake pads[3]	0.8–4.2	2.6	Weckwerth (2005), von Uexküll et al. (2005), Alexander-David (2006)
Ammunition primer Explosives	11 max.	5.5	Roskill (2001)
Fireworks, matches	12–14	13	Roskill (2001), The Household Enzyclopedia (2003)
Rubber	1–8	4.5	Slooff et al. (1992)
FCC	0.00008	0.00008	Chemico Chemicals (2004), NPi (1999)
Fluorescent light bulbs	Trace amounts	-	Healthy Light (2004)
Mordant	2–4	3	Personal assumption based on reported concentrations in pigments, which are also dyes

Source: [1]Average concentration of PET was assumed at 200 ppm based on Braungart et al. (1998); [2]In 1999 Japanese demand for PVC totalled 2.46 million tons and consumption of antimony trioxide in this market was estimated at below 200 tons. Based on the given data a very small amount of 0.0064 % as Sb can be extrapolated for PVC stabiliser; [3]Alexander-David (2006) data was adopted.

For most of the nonmetallurgical products the concentrations of antimony vary greatly as a reflection of the different formulations of the many production companies. Unless otherwise stated, average Sb contents from the range of known Sb concentrations listed in Table 7.12 were adopted. Information on Sb content in mordants could not been found, most probably because it is one of several post-treatment agents and may be rarely used.

A1-3.1 Import/export flow rates of nonmetal products

Tab. 7.13 > Flows of goods and substances in imported and exported goods – detailed listing of nonmetal products.

Table 7.13 corresponds to Table 3.11 of the import/export flow rates of nonmetal products.

Nonmetal products	Imported into Switzerland in 2001	Exported from Switzerland in 2001	National consumption in 2001	Source
	tons/year	tons/year	tons/year	
Thermoplastics – PET (bottles)	6'500	-	6'500	1
Thermoplastics – PET:	**20'401.4**	**1'221.4**	**19'180**	**2, 3**
• PET textile fibres	1'478.9.	815.3	663.6	3
• PET film food packaging	1'885	406.1	1'478.9	3
• PET raw material and goods made of mixed materials	17'037.5	-	17'037.5	2
Thermosets – Polyester resins:	**19'983.7**	**12'336.7**	**7'647**	**2, 3**
Thermoplastics – PVC:	**177'973.5**	**86'800.5**	**91'173**	**2, 3**
• PVC raw material	137'329	73'878.6	63'450.4	3
• PVC pipes	10'424.6	229	10'195.6	3
• PVC flooring and plates	2'780.2	12'692.9	–9'912.7	3
• PVC mixed-material goods	27'439.7	-	27'439.7	2
Glass	not known	not known	2'257.4	4
Ceramics	not known	not known	3.1	5
Pigments	not known	not known	255	4
Lubricants	741	16	725	6
Brake pads	1200	84.6	1115.4	7
Minor nonmetal market:				
Ammunition primer & explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant	not known	not known	n.d.	4

Source: 1 FOEN (2001); 2 Estimation APME (2003); 3 EZV (2001); 4 Carlin (2001), Roskill (2001) – only consumption of Sb known;
5 Umicore (2003) – only consumption of Sb known; 6 VSS (2001);
7 Estimate from Alexander-David (2006) and Stiftung Autorecycling Schweiz (2004).

The imports and exports of nonmetal products were determined from the data of the Federal Customs Administration (EZV, 2001) where available. Where data was not available, sources, calculations and assumptions used to estimate the trade of nonmetal products is explained below:

PET bottles

Consumption was calculated from collection data published by FOEN (2001) and BFS (2003) based on Figure 7.3 and Table 7.33.

Plastics:
PET, Polyester resins, PVC

Import and export data published from the EZV for PET (textile fibres, film food packaging), polyester resins and PVC did not list specific types of plastic contents (PVC, PET etc.) in finished products, such as appliances, decorative products or credit cards and medical products, nor did they take into consideration packaging films. Moreover, PET raw material was not listed. Therefore, data was taken and extrapolated from an analysis for plastic consumption in Europe from APME (2003) taking into consideration that Switzerland consumed 1.6 % of total consumption in Western Europe (APME, 2003). The publication reports data on consumption per country and type of plastic based on quantities of raw plastic material produced from global plastic producers and takes into account all plastic consumption per country, including amounts not listed by EZV, such as type of plastic parts in many goods made out of mixed materials.

Glass

No data has been published for CRT glass by the EZV. Only data for CRT of EE recycling is known (VSKI, 2004, Stengele, 2004). The only data on antimony consumption in CRT glass published can be found by Carlin (1992–2003). Therefore, an estimate is made based on the data of antimony consumption published by USGS (Carlin, 2001) taking into consideration that according to published data from Roskill (2001) Europe consumes about 60 % of US antimony consumption. The estimated values of Sb consumption are shown in Table 7.13. The quantities for national consumption were estimated based on concentration values from Table 7.12.

Ceramics

The data published for bathtubs and sinks from the EZV did only specify porcelain tubs and sinks, data for ceramic bathtubs and sinks were not evident. Moreover, besides porcelain, bathtubs and sinks today are made mostly of acrylic (Sanitas Troesch, 2004).

For glass and ceramic products antimony is used in the form of sodium antimonate. According to Umicore (2003) about 97.9 % of sodium antimonate is used for glass and only 2.1 % is used for ceramics. Therefore, the amount of antimony used for ceramics and glazes was extrapolated from the consumption data of CRT glass. The estimated values of Sb consumption are shown in Table 7.15. The quantities for national consumption were estimated based on concentration values from Table 7.12.

Pigments

No data has been published for pigments by the EZV. According to M. Kastien from SwissLack (2004) and to the Swiss association of lacquer and color manufacturers no data is available on imported pigments containing antimony. The only data on antimony consumption published can be found by Carlin (1992–2003). Therefore, an estimate is made based on the data of antimony consumption published by USGS (Carlin, 2001) taking into consideration, according to published data from Roskill (2001), that European consumption is about 60 % of US antimony consumption. The estimated values of Sb consumption are shown in Table 7.15. The quantities for national consumption were estimated based on concentration values from Table 7.12.

Lubricants

According to U. Müller (VSS, 2004) small amounts of lubricants are exported every year only for product exchange; and for most of the lubricants concentrations of components in the mixture vary greatly based on company's own recipes.

Brake pads

Only car brake pads were considered. Brake pads used in trucks and trains were omitted from consideration because of the complexity of brake types and lack of data. Brake pads are mainly produced in Asia. The available information for brake pad composition was sparse. Data and assumptions were based on the semester study of Alexander-David (2006), based on own measurements of brake pad material and the publications of Weckwerth (2005) and von Uexküll et al. (2005). Alexander-David estimates that the average weight of brake pads in a car is around 1 kg, assuming that 50 % of cars have 8 brake pads, while the rest have drum brakes at the rear. The average Sb content measured by Alexander-David was 2.6 wt %. Exports are only related to used cars.

Minor nonmetal market

Generally, no or insufficient data on antimony were available for minor products, which are used only occasionally or in negligible quantities. These products include ammunition primer and explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant. No data for these products are published by the EZV. However, it was possible to make an estimate for minor products based on data of antimony consumption published by USGS, which was the only data that could be found on antimony consumption of these products (Carlin, 1992–2003). When extrapolating the data It was taken into consideration, that according to published data from Roskill (2001), Europe consumes about 60 % of US antimony consumption. The estimated values of Sb consumption are shown in Table 7.15. Because the quantity of different products consumed are not known the consumed antimony was not converted to weight of products.

A1-3.2 Production flow rates of nonmetal products

Based on our findings no nonmetal products are produced in Switzerland. However, several recycled products are melted to and reproduced again.

Tab. 7.14 > Flows of goods and substances produced in Switzerland – compiled listing of nonmetal products

Table 7.14 corresponds to Table 3.12 of the production flow rates of nonmetal products.

Nonmetal products	National production in 2001 tons/year	Sb consumed from production in 2001 tons/year	Source
Thermoplastics – PET (bottles)	25'220	5	1
Thermoplastics: PET	1'330.1	0.27	2
Thermosets: Polyester resins	530.3	0.11	2
Thermoplastics: PVC	6'322.9	0.44	2

Source: 1 FOEN (2001), Association PRS (2004);
2 APME (2003).

A1-3.3 Consumption flow rates of nonmetal products

The consumption of nonmetal products (Tables 7.15) was determined from Table 7.13. Where data was not available, sources, calculations and assumptions used to estimate the consumption of nonmetal products in Switzerland during 2001 are explained below.

Tab. 7.15 > Flows of goods and substances of consumed goods – compiled listing of nonmetal products.

Nonmetal products	Sb consumed from trade in 2001 tons/year	Sb consumed from production in 2001 tons/year	Sb consumed in 2001 tons/year
Thermoplastics: PET (bottles)	1.3	5	6.3
Thermoplastics: PET	3.85	0.27	4.12
Thermopsets: Polyester resins	1.53	0.11	1.64
Thermoplastics: PVC	6.4	0.44	6.84
Glass	7.9	no production	7.9
Ceramics	0.17	no production	0.17
Pigments	10.2	no production	10.2
Lubricants	39.9	no production	39.9
Brake pads	29	no production	29
Minor nonmetal market: Ammunition primer and explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant	8.5	no production	8.5

A1-3.4 Accumulation of nonmetal products stock

Tab. 7.16 > Product consumption during the past years.

Nonmetal products (tons/year)	Consumption			Average consumption	Source
	2000	2001	2002		
Thermoplastics: PET	49’607	50’733	52’966	51’102	1
Thermosets: Polyester resins	7’743	7’647	7’538	7’643	1
Thermoplastics: PVC	89’124	91’173	92’660	90’986	1

Source: 1 Estimation APME (2003).

Tab. 7.17 > Consumption of antimony in CRT glass during the past years.

Country	Consumption (tons Sb/year)						Average consumption	Source
	1997	1998	1999	2000	2001	2002		
USA	1204.2	1087.7	1096.5	843.9	507.1	494.4	872	1
Europe	1512.5	1366.2	1377.2	1059.9	636.9	621.1	1095.6	2
Switzerland	18.8	17	17.1	13.2	7.9	7.7	13.6	3

Source: 1 Carlin USGS (1997–2002); 2 Table 2.1 (population data for Europe excl. Russia); 3 Table 2.1 (population data for USA.

Tab. 7.18 > Consumption of antimony in ceramics during the past years.

Country	Consumption (tons Sb/year)						Average consumption	Source
	1997	1998	1999	2000	2001	2002		
USA	25.8	23.3	23.5	18.1	10.9	10.6	18.7	1
Europe	32.4	24.6	29.5	22.7	13.7	13.3	22.7	2
Switzerland	0.4	0.36	0.37	0.28	0.17	0.16	0.29	3

Source: 1 Carlin USGS (1997–2002) -2.1 % of antimony consumption in glass; 2 Table 2.1 (population data for Europe excl. Russia); 3 Table 2.1 (population data for USA.

Tab. 7.19 > Product consumption during the past years.

Nonmetal products (tons/year)	Consumption			Average consumption for 2001	Source
	1999	2000	2001		
Lubricants	750	700	725	725	1

Source: 1 VSS (1999–2001).

Tab. 7.20 > Consumption of antimony in pigments during the past years.

Country	Consumption (tons Sb/year)						Average consumption	Source
	1997	1998	1999	2000	2001	2002		
USA	824	881	1020	620	653	565	761	1
Europe	1035	1106.5	1281	778.7	820.2	709.6	955.2	2
Switzerland	12.9	13.7	15.9	9.7	10.2	8.8	11.9	3

Source: 1 Carlin USGS (1997–2002); 2 Table 2.1 (population data for Europe excl. Russia); 3 Table 2.1 (population data for USA).

Tab. 7.21 > Consumption of antimony in the minor nonmetal market (ammunition primer and explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant) during the past years.

Country	Consumption (tons Sb/year)						Average consumption	Source
	1997	1998	1999	2000	2001	2002		
USA	179	335	221	537	544	548	394	1
Europe	224.8	420.8	277.6	674.5	683.3	688.3	494.9	2
Switzerland	2.8	5.2	3.5	8.4	8.5	8.6	6.2	3

Source: 1 Carlin USGS (1997–2002);
2 Table 2.1 (population data for Europe excl. Russia);
3 Table 2.1 (population data for USA).

The accumulation of nonmetal products stock (Table 7.22) was determined from an estimate of the product volume today and of past years (usually from 1999 to 2001), taking the data from the Federal Customs Administration (EZV, 1999–2001) where available, as well as the life cycle of the product categories. Where data was not available, sources, calculations and assumptions used to estimate the stock of nonmetal products are explained below:

Thermoplastics PET

> An average life cycle for films and fibers in packaging and for textiles of 3 years was assumed.

Thermoset Polyester resins

> An average life cycle for transportation (7 years), electrical appliances (11 years), building materials (40 years) was adopted.

Thermoplastic PVC

> An average life cycle for building materials (40 years), electrical appliances (11 years), medical equipment (13 years), toys (5 years – author's assumption) and credit cards, bottles cling films (3 years – author's assumption) was adopted.

Glass

> An average life cycle of EE electronics was assumed: EDP (5.9 years), office and communication electronics (7.5 years).

Lubricants

> Break-pad and disk-clutch fluids are normally not changed in a car, *ie* they last during the life cycle of a car.

Brake pads

> Imports have been estimated on the basis that brake pads are renewed every 4 years on average. Wear of 75 % is assumed at the time of change.

Ceramics

> Life cycles of building materials were adopted.

Pigments

> Lifecycles of building materials were adopted.

Minor nonmetal market

> It was assumed that matches and fireworks had a life cycle of one year, as these products are consumed instantaneously. Fluorescent light bulbs and mordant used in cloth was assumed to be used for 5 years.

Tab. 7.22 > Stock of nonmetal products in Switzerland in 2001.

Table 7.22 corresponds to Table 3.14.

Nonmetal products	Average consumption for 2001 (tons)		Life cycle	Stock	Source
	product	Sb	years	tons Sb	
Thermoplastics – PET (bottles)	29'786	6	1	6	1,2
Thermoplastics – PET					
textile fibers, packaging, raw material	21'316	4.3	3	12.9	3
Thermosets: Polyester resins	7'643	1.5	19.3	29	4,6,7
Thermoplastics					
PVC	90'986	6.4	14.4	92.2	4,5
Glass	-	13.6	6.7	91.1	6
Ceramics	-	0.29	40	11.6	4
Pigments	-	11.9	40	476	4
Lubricants	725	39.9	7	279.3	7
Brake pads	1115	29	4	87	8
Minor nonmetal market: Ammunition primer and explosives, FCC, matches, fireworks, rubber, fluorescent light bulbs, mordant	-	6.2	3	18.6	9

Source: 1 BFS (2003) for 2001 consumption, life cycle 1 year; 2 Association PRS PET (2004); 3 Author's assumption; 4 FOEN Bern, Environmental Series no. 245 (1995); 5 Author's assumption; 6 APME (1995); 7 VSS (2003); 8 Only 75 % of product is used before pads are changed (Alexander-David, 2006); 9 Author's assumption.

A1-4 Flame retardants

Tab. 7.23 > Concentration of antimony in products and the ratio of antimony trioxide to flame retardant.

Table 7.23 correspond to Table 3.15 in Chapter 3 representing the concentrations used in antimony compounds and products.

Flame retardants	% Sb in plastics of product	Sb_2O_3:FR[1,2]	Source
Plastic casings (bromine based):			
Computers + monitors	2–8	0.35	Nilsson (2001)
Servers	2–8	0.35	Nilsson (2001)
Notebooks	2–8	0.35	Nilsson (2001)
Laser printers	2–8	0.35	Nilsson (2001)
Inkjet printers	2–8	0.35	Nilsson (2001)
Copying machines	2–8	0.35	Nilsson (2001)
Calculators	2–8	0.35	Nilsson (2001)
Communications technology (telephones, mobile telephones)	2–8	0.35	Nilsson (2001)
Home entertainment electronics (TV + HiFi)	2–8	0.35	Nilsson (2001)
Household appliances	2–8	0.35	Nilsson (2001)
Cables EPDM	2–8	0.35	Nyacol (2003)
Electric tools, small EE components	2–8	0.35	Roskill (2001)
Vending machines, electric toys and games	2–8	0.35	Roskill (2001)
Medical appliances (x-ray equipment, laboratory instrumentation and devices, live-saving equipment)	2–8	0.35	Roskill (2001)
Lighting, monitoring and process control devices	2–8	0.35	Roskill (2001)
Vehicles (cars, car radios, trucks, motorcycles, trains (locomotives and passenger coaches), aircrafts> 15 tons	2–8	0.35	
Building material and textiles:	-	-	
Small EE components (cables, plugs, switches, lighting appliances (chlorine and bromine based)	2–8 1–10	0.35 0.22	Nilsson (2001) Rosskill (2001) USAC (2003)
EPS, XPS, PE, polyurethane foams (bromine based)	2–4	0.35	Nyacol (2003), Nilsson (2001)
Rubber (bromine based)	2–4	0.35	Nilsson (2001)
PE, PP (bromine based) PVC, vinyl siding and window frames, flooring (chlorine based)	2–4 1–10	0.35 0.22	Nyacol (2003) Nilsson (2001) Roskill (2001) USAC (2003)
Adhesives(bromine based)	1.5–8	0.35	Nilsson (2001)
Resins: paper, colour and pigments (chlorine and bromine based)	1.5–15	0.35	Nyacol (2003) Roskill (2001)
Textiles und upholstery (bromine based)	1–10	0.35 0.22	Nyacol (2003) Roskill (2001)

Flame retardants	% Sb in plastics of product	Sb_2O_3:FR[1,2]	Source
Semiconductors: **Epoxy and silicone for computer chips (SbO3, SbO5):**			
Computer	0.1–2	0.35	Cookson (2000) STMi (2003) Vishay (2003)
Photocopier, printer, fax	0.1–2	0.35	Cookson (2000) STMi (2003) Vishay (2003)
Telephone	0.1–2	0.35	Cookson (2000) STMi (2003) Vishay (2003)
Home entertainment electronics	0.1–2	0.35	Cookson (2000) STMi (2003) Vishay (2003)
Household appliances	0.1–2	0.35	Cookson (2000) STMi (2003) Vishay (2003)
Other appliances	0.1–2	0.35	Cookson (2000) STMi (2003) Vishay (2003)

Note: [1]35 % Sb in relation to bromine/antimony trioxide ratio; [2]22 % Sb in relation to chlorine/antimony trioxide ratio.

For most of the plastic products the concentrations of antimony in the mixture varies greatly based on company's own recipes. Formulations in different applications will depend on thermal stability, cost, tinting strength, change in physical properties, smoke considerations, streaking, blend ability and the flame retardant specification. We have reported the range of known Sb concentrations used in fire retardant products. For brominated flame retardants a ratio of Br to Sb_2O_3 from 2:1 to 5:1 (which relates to a ratio of Br to Sb of 2:0.79 to 5:0.79) is commonly used (Seddon and Harper, 2001; Albemarle Corporation, 2003; NYACOL, 2003; Nilsson, 2001; and Roskill, 2001). For chlorinated flame retardants antimony trioxide additions to PVC are reported at 1–10 % by weight (Roskill, 2001). Usually, three to four parts of chlorinated flame retardant is used to one part of antimony trioxide on a weight basis (USAC, 2003). Generally, to calculate Sb concentrations in products an average concentration of 35 % Sb_2O_3, in relation to bromine/antimony ratio has been employed and an average concentration of 22 % Sb_2O_3, in relation to chlorine/antimony ratio in relation to PVC.

A1-4.1 Brominated flame retardants – Flows and stocks

The imports and exports of brominated flame retardants were determined from the data of the Federal Customs Administration (EZV, 2001).

For reasons of simplicity and to be coherent with FOEN No. 338 (2002) the same product groups using BFR are listed below. No import and export figures were available for building materials or textiles, FOEN assumed that these products are produced entirely within Switzerland.

Tab. 7.24 > Flows of goods and substances in imported and exported goods – detailed listing of brominated flame retardants.

Table 7.24 corresponds to Table 3.17 of the import/export flow rates of flame retardants.

Brominated flame retardants	Imported into Switzerland in 2001 1000 tons/year	Exported from Switzerland in 2001 1000 tons/year	National consumption in 2001 1000 tons/year	Source
EDP and office electronics	**42.7**	**6.5**	**36.2**	**1**
• Computers, monitors, servers	17.1	2.6	14.5	1
• Notebooks	1.5	0.1	1.4	1
• Laser printer, inkjet printers	17.5	1.3	16.2	1
• Copying machines	6.0	1.6	4.4	1
• Calculators	0.6	0.9	–0.3	1
Communications technology	**13.6**	**4.0**	**9.6**	**1**
• Telephone appliances	4.3	2.6	1.7	1
• Mobile telephones	6.0	0.3	5.7	1
• Fax machines	3.3	1.1	2.2	1
Household electronics	**26.6**	**5**	**21.6**	**1**
• Radio receivers, amplifiers	5.5	1.5	4.0	1
• CD players	0.7	0.03	0.67	1
• Tape recorders	1.0	0.1	0.9	1
• Record players	0.06	0.02	0.04	1
• TV monitors	16.5	2.6	13.9	1
• Video recorders	2.2	0.1	2.1	1
• Video cameras	0.6	0.6	0	1
• Photo cameras	0.04	0	0.04	1
• Electrical toys and games	0	0	0	1
Household appliances – small	**7.1**	**9.0**	**–1.9**	**1**
• Small household appliances	4.7	7.3	–2.6	1
• Electric heaters	1.5	0.2	1.3	1
• Scales	0.9	1.5	–0.6	1
• Alarm clocks	0	0	0	1
Household appliances – large	**101.8**	**55.4**	**46.4**	**1**
• Tumbler driers	5.1	9.4	–4.3	1
• Household refrigerators, deep-freezers	28.7	4.9	23.8	1
• Washing machines	10.6	0.7	9.9	1
• Sewing machines	0.6	0.6	0	1
• Vacuum cleaners	7.4	1.3	6.1	1
• Dishwashers	14.5	7.5	7.0	1

Brominated flame retardants	Imported into Switzerland in 2001 1000 tons/year	Exported from Switzerland in 2001 1000 tons/year	National consumption in 2001 1000 tons/year	Source
• Espresso machines	2.1	5.5	–3.4	1
• Microwave ovens	2.3	0.04	2.26	1
• Ovens, cookers, hotplates	6.0	1.9	4.1	1
• Air-conditioners, ventilators	24.5	23.6	0.9	1
Special appliances	**2**	**5**	**–3**	**1**
• Electric tools	2	5	–3	1
Small EE components	**50.5**	**55.5**	**–5**	**1**
• Plug switches, etc.	11.7	15.0	–3.3	1
• Cables	38.8	40.5	–1.7	1
Vehicles	**616.5**	**272.0**	**344.5**	**1**
• Cars	500.3	193.8	306.5	1
• Trucks	96.7	65.1	31.6	1
• Motorcycles and scooters (mopeds)	7.3	7.3	0	1
• Trains (locomotives)	2.4	1.9	0.5	1
• Trains (passenger coaches)	9.8	3.9	5.9	
• Aircraft > 15 t	0.05	0.01	0.04	1
Building materials and textiles	**-**	**-**	**-**	**1,2**

Source: 1 EZV (2001); 2 FOEN, No. 338 (2002).

Antimony trioxide is used in all halogenated (brominated and chlorinated) flame retardants as additive (MRC Polymers, 2001; Tohka und Zevenhoven, 2001; Danish Environmental Protection Agency, 1999; Edenburn, 2001). In 2002 the FOEN has published a material flow analysis for Switzerland on brominated flame retardants (FOEN, No. 338, 2002) which has collected all data on brominated flame retardants required to carry out a substance flow analysis for the year 1998. For reasons of coherence and simplicity the flux of antimony in brominated FR was linearly extrapolated from the 'trade in product' data of that study. The same product groupings are used.

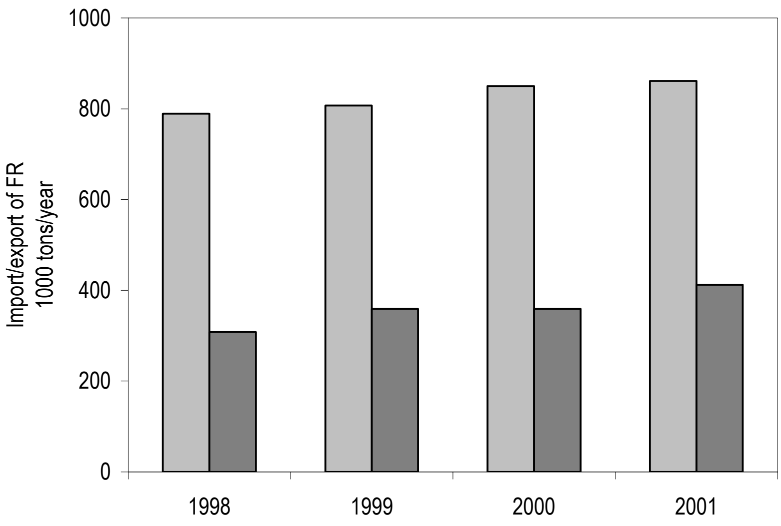
The import and export data from the Federal Customs Administration (EZV, 2001) from 1998 to 2001 are listed in Table 7.25. As already stated in the afore-mentioned FOEN study, production data is difficult to obtain. The production data used by the study was adopted for our estimations. The import/export data was used to examine possible overall changes in trade. It was found that, overall, trade in Switzerland increased by 8 % from 1998 until 2001 (fig. 7.1). It was assumed that production also increased by 8 % over this time period and so the trade figures in the FOEN report were adjusted accordingly.

Tab. 7.25 > Flows of goods and substances in imported and exported finished products which contain brominated flame retardants.

Products Import / Export (I/E) Switzerland	Flows of goods and substances (1000 t/a)							
	1998[1]		1999[2]		2000[2]		2001[2]	
	Import	Export	Import	Export	Import	Export	Import	Export
EDP and office electronics	46.6	(?)56	50.9	7.1	47.2	4.9	42.7	6.5
Communications technology	3.1	2.2	13.1	4.9	15.8	5.1	13.6	4.0
Household electronics	21.6	3.8	24.4	4.1	26.9	4.5	26.6	5.0
Household appliances – small	14.2	8.4	4.4	5.4	5.4	7.5	7.1	9.0
Household appliances – large	89.7	64.8	89.7	38.5	98.8	48.7	101.8	55.4
Special appliances	3.6	0.2	2.1	4.5	6.1	3.8	2.0	5.0
Small EE components	33.2	38.0	45.7	55.4	52.0	55.9	50.5	55.5
Vehicles	586.1	134.7	576.8	239.0	597.6	228.7	616.5	272.0
Building materials and textiles	n.b.	n.b.	---	---	---	---	---	---
Total	**789.1**	**308.0**	**807.1**	**358.9**	**849.8**	**359.1**	**860.8**	**412.4**

[1]FOEN, No. 338 (2002), Tables 5–17, 5–18therein; [2]EZV (1998–2001); [3]Schweizerische Nationalbank (2003) , Statistisches Monatsheft, Januar 2003; [4]Average import and export changes from 1998–2000 compared to 200

Fig. 7.1 > Flow of goods of imported (light bars) and exported (dark bars) finished products (CH containing brominated flame retardants during 1998–2001.



The concentrations of flame retardant materials vary widely as a function of time and manufacturer. Antimony content was estimated as follows:

> The sum of the contents of the four different types of brominated compounds (PentaBDE, OctaBDE, DecaBDE, TBBPA) listed in the FOEN study (FOEN, 2002) were used to determine a BFR content for each of the product groups for trade, pro-

duction and the stock. The factor was used to estimate the BFR contents of the products listed in Tables 7.26, 7.27 and 7.29.

> An average of 35 % antimony trioxide content in brominated flame retardants was used to estimate the antimony trioxide content and a factor of 0.83 to obtain the antimony content.

Tab. 7.26 > Flows of consumed goods and substances from imported and exported goods – brominated FR and antimony concentrations.

Table 7.26 corresponds to Table 3.19 in Chapter 3.

Brominated flame retardants	National consumption in 2001[1]	Brominated FR consumed in 2001[2]	Sb_2O_3 consumed from trade in 2001[3]	Sb consumed from trade in 2001[3]
	1000 tons	tons	tons	tons
EDP and office electronics	36.2	445	148	123
Communications technology	9.6	63.7	21.2	17.6
Household electronics	21.6	29.6	9.9	8.2
Household appliances – small	–1.9	–2.4	–0.8	–0.7
Household appliances – large	46.4	37.9	12.6	10.5
Special appliances	–3	–13.4	–4.5	–3.7
Small EE components	–5	–0.9	–0.3	–0.2
Vehicles	345	144	47.8	40
Building materials and textiles	-	-	-	-

Source: [1]EZV (2001); [2]FOEN, No. 338 (2002), extrapolated from Tables 5–17 and 5–18;
[3]Average concentration of antimony in brominated FR based on Tables 7.1 and 7.23.

Tab. 7.27 > Flows of goods and substances produced in Switzerland compiled listing of brominated flame retardants.

Table 7.27 corresponds to Table 3.21 in Chapter 3.

Brominated flame retardants	National production in 2001[1]	BFR consumed from production in 2001[1]	Sb_2O_3 consumed from production in 2001[2]	Sb consumed from production in 2001[3]
	1000 tons	tons	tons	tons
EDP and office electronics	41.3	338.7	112.9	93.7
Communications technology	2.7	14.0	4.7	3.9
Household electronics	5.0	19.4	6.5	5.4
Household appliances – small	11.2	6.9	2.3	1.9
Household appliances – large	32.9	27.1	9.0	7.5
Special appliances	12.6	70.0	23.3	19.4
Small EE components	173.4	29.8	9.9	8.2
Vehicles	4.1	0.8	0.3	0.2
Building materials and textiles	51.2	215.1	71.7	59.5

Source: [1]FOEN, No. 338 (2002), extrapolated from Table 5–15; [2]Average concentration of antimony in brominated FR based on Table 7.23;
[3]Average concentration of antimony in brominated FR based on Tables 7.1 and 7.23.

Tab. 7.28 > Flows of goods and substances of consumed goods of brominated flame retardants – compiled listing of antimony concentrations.

Table 7.28 corresponds to Table 3.22 in Chapter 3.

Brominated flame retardants	Sb consumed from trade in 2001 tons year^{-1}	Sb consumed from production in 2001 tons year^{-1}	Total Sb consumed in 2001 tons year^{-1}
EDP and office electronics	123	93.7	217
Communications technology	17.6	3.9	21.5
Household electronics	8.2	5.4	13.6
Household appliances – small	–0.7	1.9	1.2
Household appliances – large	10.5	7.5	18
Special appliances	–3.7	19.4	15.7
Small EE components	–0.2	8.2	8
Vehicles	40	0.2	40.2
Building materials and textiles	-	59.5	59.5

Tab. 7.29 > Stock of brominated flame retardants.

Table 7.29 corresponds to Table 3.24 in Chapter 3.
The extrapolated stock is based on the life cycle shown in the Table.

Brominated flame retardants	Life cycle[2] years	Stock of goods[1] 1000 tons	Stock of BFR tons	Stock of Sb_2O_3[3] tons	Stock of Sb tons
EDP and office electronics	7.4	574	2452	817	678
Communications technology	7.5	92	618	206	171
Household electronics	14.8	394	2515	838	696
Household appliances – small	7.5	70	88	29	24
Household appliances – large	14.8	1174	957	319	265
Special appliances	13.1	126	562	187	155
Small EE components	23.8	3927	2333	778	646
Vehicles[4]	13	4538	2051	684	567
Building materials and textiles	40	2040	12441	4147	3442

Source: [1]FOEN, No. 338 (2002), taken from Table 9–13; [2]FOEN, No. 338 (2002), extrapolated from Table 5–22;
[3]Average concentration of antimony in brominated FR based Table 7.23; [4]Life cycle cars and trucks averaged

A1-4.2 Chlorinated flame retardants and construction products – Flows and stocks

It is reported that ClFR only have a 16 % of the share of market for halogenated flame retardants in Europe (Weber (2000).

The use of ClFR is mainly associated to the consumption of PVC. In Switzerland construction activities consume about 72 % (PVCH, 2006, so there is a close connection between ClFR and construction.

According to McCarthy and Tucci (2003) an average 52 % of all PVC products are flame retarded. Only ClFR are used in PVC products and a concentration of 5.5 % ClFR and a concentration ratio of 22 % of Sb_2O_3 to chlorinated flame retardants is usual (Weber, 2000). However, the high chloride content in PVC results in a flame-retarding effect even without flame-retardant addition. Thus the use of flame retardants is has become minimal over the last years (Helminiak , 2006; see also 3.4.1.2).

For estimates of antimony flow in construction products, the amounts traded PVC products in Switzerland were used. It was assumed that 72 % of PVC listed in Table 7.13 was used for construction purposes and that 52 % were flame retarded. It was further assumed that the market share of flame retardants was 3 % and that the Sb content was 1.2 %. The resultant factor is 0.000135 tons Sb/tons PVC.

Finally, a life cycle of 40 years for building products and of 23.8 years for small EE components was used analog to Table 7.29 (Stock). Tables 3.18, 3.20, 3.23, 3.25 in Chapter 3 show the flows of ClFR.

A1-5 Waste management

The following Tables (Table 7.30, 7.31 and 7.32) list the most important treatment of products in the Waste Management system.

Tab. 7.30 > Type of waste treatment of metal product.

Metal products	Destination of waste
Lead-acid batteries: SLI	100 % recycling
Lead-acid batteries: Deep-cycle	100 % recycling
Lead-acid batteries: UPS	100 % recycling
Ammunition and shot	100 % transfer to pedo-/lithosphere
Bearing metals	100 % recycling
Rolled and extruded lead products	100 % recycling
Cable sheathing	100 % recycling
Solder (Sn/Sb)	100 % recycling
Weights	100 % recycling
Semiconductors	100 % recycling
Fusible alloys	negligible
Type metal	negligible
Copper alloys	negligible
Pewter	negligible
Magnetic steel	negligible

Tab. 7.31 > Type of waste treatment of nonmetal product.

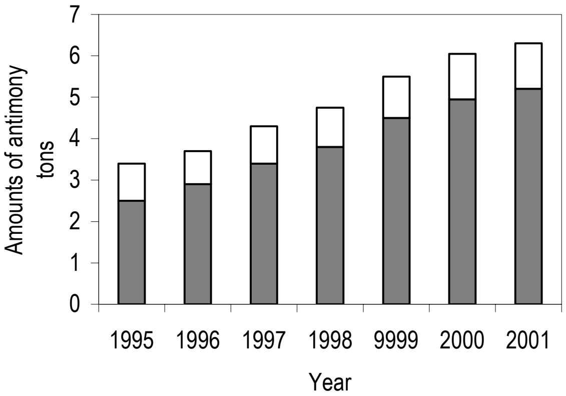
Nonmetal products	Destination of waste
PET	83 % recycling, 16 % incineration, 1 % landfill
PVC	70 % incineration, 8 % landfill, 7 % reuse
Polyester resins	70 % incineration, 8 % landfill, 7 % reuse
Glass	Export to recycling
Ceramics, enamels	70 % incineration, 8 % landfill, 7 % reuse
Pigments	70 % incineration, 8 % landfill, 7 % reuse
Lubricants	Incineration (in cement kiln)
Ammunition primer, explosives	Atmosphere
Brake pads	Atmosphere and incineration
Fireworks, matches	Atmosphere
Rubber	88 % incineration, 12 % landfill
FCC	Atmosphere
Fluorescent light bulbs	88 % incineration, 12 % landfill
Mordant	negligible

Tab. 7.32 > Type of waste treatment of flame retardants.

Flame retardants	Destination of waste
Plastic casings:	
Computers and monitors	plastic wastes: 46 % collection (then 55 % exported mainly as secondary fuel, 10 % reused, rest incinerated) 48 % directly to incineration 6 % to landfill
Servers	
Notebooks	
Laser printers	
Inkjet printers	
Copying machines	
Calculators	
Communications technology (telephones, mobile telephones)	
Home entertainment electronics (TV + hifi)	
Household appliances	
Cables (PVC, EPDM)	
Electric tools, small EE components	
Vending machines, electric toys and games	
Medical appliances (x-ray equipment, laboratory instrumentation and devices, live-saving equipment)	
Lighting, monitoring and process control devices	
Vehicles (cars, car radios, trucks, motorcycles, trains (locomotives and passenger coaches), aircrafts> 15 tons	100 % collection, then 27 % export & 67 % incineration
Buildingmaterial and textiles:	
Small EE components (cables, plugs, switches, lighting appliances,	100 % collection and incineration
EPS, XPS, PE foams	
Rubber	
PE, PP films and coatings	
Adhesives	
Resins: paper, color and pigments	
Textiles und upholstery (PP)	
Semiconductors: Epoxy and silicone for computer chips (SbO_3, SbO_5)	
Computer	47 % collection, then 27 % export & 67 % incineration 53 % incineration 6 % landfill
Photocopier, printer, fax	
Telephone	
Home entertainment electronics	
Household appliances	
Other appliances	

Figure 7.3 (corresponding to Tab. 7.33) shows that around 80 % of PET was recycled around year 2000. This represents an increase in the recycling rate of 10 % from 1995 to 2001.

Fig. 7.3 > Development of PET consumption, collection and treatment (expressed as Sb consumed).



BFS, 2003.

Tab. 7.33 > Increased use and recycling of PET from 1995–2001.

PET distribution	1995	1996	1997	1998	1999	2000	2001
PET consumed (tons)	17'039	18'289	21'358	23'875	27'683	30'122	31'553
Sb in PET consumed (tons)	3.4	3.7	4.3	4.8	5.5	6.0	6.3
PET recycled (tons)	12'609	14'448	17'086	19'100	22'700	24'700	26'000
Sb in PET recycled (tons)	2.5	2.9	3.4	3.8	4.5	4.9	5.2
% PET recycled	74	79	80	80	82	82	82.4
Sb in PET incinerated (tons)	0.89	0.77	0.85	0.96	1.00	1.08	1.11

BFS, 2003.

Table 7.34 shows the FOEN (2004) statistics on waste incinerated in 2001. A concentration of 37 mg/kg (Morf, 2002) was adopted for municipal solid waste, imported waste and "rest".

The concentration of antimony in construction wastes to be incinerated was set at 130 mg/kg to balance antimony in products to waste and the waste streams. This value is below the average antimony content in PVC (200 mg/kg) and construction products flame retarded with BFR (around 280 mg/kg). These flame-retarded products are diluted by a factor that we do not know, with other burnable materials in the waste. We know of no supporting measurements of antimony in construction wastes.

Tab. 7.34 > Wastes for incineration in 2001.

Waste	Amount tons	Sb concentration mg/kg	Source
Municipal solid waste	2'244'000	48	1
Construction waste	400'000	*64*	2
Sewage sludge	119'800	3.5	3
Imported waste	50'000	48	4
Rest	80'000	48	
ASR and household goods	28'690	330	Table 7.40
EE shredder residues	17'300	1700	5
	Total Sb input	**179 tons**	
Used only in cement kilns as secondary fuels			
used oil	41'000	n.d.	
solvents and distillates	22'000	n.d.	
tyres and rubber	18'000	n.d.	
plastics	24'000	n.d.	
Rest	17'000	n.d.	
Hazardous waste incineration			
Total burnable waste	365'800	n.d.	

FOEN statistics, 2004.

Source: 1 Morf, 2002;
2 This value is estimated to balance the antimony input and output to MSWI plants. It is derived from flame retarded materials in construction material;
3 Kupper, 2002;
4 (90 % MSW, 6 % construction waste, 4 % other wastes (assumption ASR) yields 47 mg/kg) The assumption is made that the concentration equals that of Swiss MSW;
5 FOEN,2004, Schriftenreihe 374.

Tab. 7.35 > Average Sb concentration of municipal solid waste incineration (MSWI) residues from 14 municipal solid waste incinerators in Switzerland.

Data collated from information supplied by the MSWI plants: AG Oftringen, AG Turgi, AG Buchs, BE Bern, BE Brügg (Biel) , BS Basel, FR Posieux, GE Les Cheneviers, GL Niederurnen, GR Trimmis, LU Luzern, NE Colombier, NE La Chaux-de-Fonds, SG St.Gallen, SG Kirchberg, SG Buchs, SO Zuchwil, TG Weinfelden, VD Lausanne, VS Gamsen, VS Sion, VS Monthey, ZH Dietikon, ZH Zürich I (Josefstrasse), ZH Zürich II (Hagenholz), ZH Winterthur, ZH Horgen, ZH Hinwil.

MSWI residues	Amount tons	Content	n[1]	Assumed Content
Municipal solid waste bottom ash[2]	650'000	107 mg/kg	73	100 mg/kg
Fly ash[3]	67'280	1527mg/kg	82	1500 mg/kg
Filter cake[3]	8'930	732 mg/kg	11	800 mg/kg
Waste water	1.9×10^6 m³	270 mg/m³	169	270 mg/m³
			Total Sb output	**179 t**

Notes [1]no. of samples; [2]landfilled in Switzerland; [3]APC residues = (fly ash+filter cake). In 2001 approximately 60 % was exported to underground landfills

Tab. 7.36 > Average Sb concentration in sewage sludge from 34 waste water treatment plants in Switzerland.

Waste	Concentration	n[1]	Concentration used
Waste water			
Sewage sludge	1.94–4.61[2] mg/kg	188	3.5 mg/kg

Kupper, 2002.

Notes: [1]no. of samples; [2]including 5 samples from WWTP Emmental.

Tab. 7.37 > Wastes landfilled in 2001.

Waste category	Municipal solid waste	Sewage sludge	Construction Waste	MSWI bottom ash
Total amount (tons)	2'550'000	200'000[1]	11'000'000	650'000
Landfilled amount (tons)	306'000	4'600	1'600'000	630'000
Average Sb- concentration (mg/kg)	37	3. 5	0.3[2]	100
Sb- amount (tons)	11.322	0.015	0.48	63

FOEN statistics, 2004.

Notes: [1]60'000 t went into agriculture; [2]Value assumed to equal the average concentration of the earth's crust.

Tab. 7.38 > Antimony stock in MSW and MSWI bottom ash landfills.

Year	MSW produced	MSW			MSWI bottom ash		
	mio tons	mio tons	mio m³	tons Sb	mio tons	mio m³	tons Sb
1932	0.52	0.50	0.30	4.24	0.01	0.01	0.06
1940	0.59	0.54	2.78	39.82	0.01	0.13	0.72
1950	0.70	0.65	6.25	89.54	0.02	0.37	2.10
1960	1.05	0.93	10.72	153.49	0.04	0.74	4.23
1970	1.64	1.27	16.82	241.76	0.12	2.05	12.04
1980	2.29	1.43	23.19	393.09	0.29	5.37	71.40
1990	2.93	1.39	28.73	601.97	0.51	11.89	298.53
2000	2.59	0.88	31.71	756.67	0.57	19.86	706.09
2001	2.55	0.77	31.82	763.27	0.59	20.75	765.38
						Total	**1530**

Data source:FOEN, 2004b.

The data used for the estimation of the antimony stock in landfills is shown in Table 7.38. The assumptions made for the estimation of the antimony stock in landfills were as follows:

i There was a linear growth in population
ii The proportion incinerated was taken from FOEN (2004b).
iii The densities of MSW and MSWI bottom ash is 0.6 tons/m³ and 1.6 tons/m³ respectively. (Christensen et al., 1994; Johnson et al, 1999).
iv The content of Sb was assumed to be 8.6 mg/kg, i.e. equal to the present-day average soil concentration in both wastes. This value was also assumed for MSWI bottom ash because antimony content has only increased in recent years as a result of the introduction of antimony-containing FR.

Tab. 7.39 > Emissions from landfills in 2001.

	MSW		MSWI bottom ash	
Landfilled waste	mio m³	area, km²	mio m³	area, km²
	31.82	2.12	20.75	1.38
leachate m³/a	Sb content, mg/L	Sb tons/a	Sb content, mg/L	Sb tons/a
	0.015	0.01	0.03	0.012

For the calculation of the leachate from landfill we assumed on average a landfill depth of 15m, 1m of rainfall per year, evaporation of 70 % and leachate of 30 %, assuming grass coverage (Belevi and Baccini, 1988).

The concentration of Sb in the leachate water in MSWI bottom ash was given by Johnson et al. (1999) to be 30 µg/L. The concentration of leachate water in MSW was not available for Sb. In absence of any information it was assumed that Sb would behave in a similar fashion to arsenic, since they are in the same group (15) of the periodic table. An average concentration of 15 µg/L was adopted (ATV, 1988; Christensen et al., 1994).

Tab. 7.40 > Average amounts of shredder wastes and Sb concentrations.

Shredder material	Analysed concentration mg/kg	Amount tons	Source
EE and household shredder residues	1700	30 % of 57'650 t	1
Auto shredder residues (ASR)	330	17'000 incinerated 20'000 exported	2
"Rest" from ASR, not vehicles	330	11'690 incinerated 13'670 exported	2
EAWAG measurements from Thommen AG	0–250	range of 7 samples	own measurements

Source: 1 FOEN statistics (2004); 2 Morf (2002).

A1-6 Environment

Tab. 7.41 > Concentrations of antimony in the aqueous environment.

Environmental category	Sb content	Source
River Rhine	0.37 $\mu g/L$	EAWAG, in 3 samples taken in Basel, 11.8.04
Average hydrosphere	0.2 $\mu g/L$	Range: 0.07–0.8 $\mu g/L$ Bart and Von Gunten (1976) Filella et al. (2002)
Assumed average discharge leaving Switzerland	5.33×10^{10} m^3/a	Zobrist et al. (2004)

Tab. 7.42 > Concentrations of antimony in soils (0–20 cm) taken from the National Soil Observation Network (NABO), Keller and Desaules.

	Median	Average	Max	Min	90 %-Quantile	10 %-Quantile	n
Soil content mg/kg	0.1	8.59	2'706	0.020	1.460	0.045	563
Stock tons	28 t (median, agricultural soils 0–2 cm); 414 t (90 % quantile, agricultural soils 0–2 cm)						
Average Lithosphere mg/kg	0.3 Boyle and Jonasson (1984)						

Tab. 7.43 > Concentrations of Sb in Pm_{10} emissions.

Sb in PM_{10} emissions	Basel (Agglomeration) (n=120)	Bern (City/heavy traffic) (n=120)	Chaumont (Countryside) (n=120)	Zurich-Kasernen-hof (City/park) (n=121)	Zurich-Wiedikon (City/heavy traffic) (n=59)
Detection limit (ng/m^3)	0.18	0.18	0.18	0.18	0.18
Median (ng/m^3)	0.6	5.5	0.1	1.2	9.5
Standard deviation (ng/m^3)	0.5	2.5	0.2	1.1	4.8
Min. (ng/m^3)	< detection limit	1.1	< detection limit	< detection limit	1.7
Max. (ng/m^3)	3	13	1	6	21
Measurements < Detection limit (%)	10	0	69	2	0

Hüglin, 2000.

Tab. 7.44 > Deposition rates in Switzerland.

Study	Site	Sb deposition rate mg/m².year	Deposition rate for the area of Switzerland tons Sb/year
Thöni et al. 1999 Thöni and Seitler, 2004 Sampling of wet and dry deposition with Bergerhof collectors	Hagenmoos	0.151	Average deposition rate: 6.8
	Zugerberg	0.165	
	Ticino	0.175	
Shotyk et al. 2004 Analysis of peat	Etang de la Gruyère	0.128	5.3
		Average	6.1

> Apendix II

The Tables in Appendix II list transfer coefficients, product tonnage and antimony amounts for different antimony-flows in products in Switzerland in 2001 illustrated in Chapter 3.

A2 Metal products

Tab. 8.1 > Pb-acid-batteries data 2001.

From – To	Transfer coefficients (%)	Pb-acid-batteries (tons)	Sb (tons)
Import – Trade	100	14’600	419
Trade – Export	42.6	6’225	337
Trade – Consumption	57.4	8’335	82.1
Stock “Consumption” – Consumption	53.6	14’044.4	126
Consumption – Collection	100	23’170	209
Collection – Reuse	67.9	15’726	142
Collection – Export	32.1	7’444	67
Reuse – Production CH	60	8’880	80
Reuse – Export	40	6’290	56.6

Tab. 8.2 > Ammunition data 2001.

From – To	Transfer coefficients (%)	Ammunition (tons)	Sb (tons)
Import – Production (from Metallum AG)	n.d.	(2’963)	(80)
Production – Trade	100	321	8.7
Import – Trade	100	104	2.8
Trade – Export	33.9	122	3.3
Trade – Consumption	66.1	305	8.2
Stock “Consumption” – Consumption	51.2	126	8.3
Consumption – Pedo-/Lithosphere	100	431	16.5
Pedo-/Lithosphere – Collection	0.2	54	2.7
Collection – Reuse	100	54	2.7
Reuse – Landfill	20	11	0.5
Reuse – Export	80	43	2.2

Tab. 8.3 > Rolled and extruded lead products (RELP) including bearing metals (BM) and weights (W) 2001.

From – To	Transfer coefficient (%)	Antimonial[1] lead products (tons)	RELP Sb (tons)	BM Sb (tons)	W Sb (tons)	Total Sb (tons)
Import – Trade	100	9'176	451.7	0.8	4.7	457
Trade – Export	92.2	8'975	441.6	-	5	447
Production – Trade	100	540	4.9	-	-	27
Trade – Consumption	7.8	742	15	0.8	–0.3	37.6
Stock "Cons" – Consumption[2]	19.9	4'298				215
Consumption – Collection	100	5'050				253
Collection – Reuse	8.9	900				45
Collection – Export	91.1	4'150				208
Reuse – Production	60	540				27
Reuse – Export	40	360				18

Notes: [1]Includes all Rolled and extruded lead products (RELP), bearing metals (BM) and weights (W); [2]Cable sheathing is neither traded nor produced in Switzerland anymore. However, we assumed that there is still some stock (Tab. 8.9) in Switzerland, which is included in the total stock of the Sb-flows.

A3 Nonmetal products

Tab. 8.4 > PET bottles data 2001.

From – To	Transfer coefficient (%)	PET bottles (tons)	Sb (tons)
Import – Trade	100	6’500	1.3
Reuse – Production	100	25’220	5
Production – Trade	100	25’220	5
Trade – Consumption	100	31’550	6.3
Consumption – Collection	83.4	26’000	5.2
Consumption – Landfill	0.1	277	0.05
Consumption – Incineration	16.5	5’260	1.05
Collection – Reuse	96.2	25’220	5
Collection – Incineration	3.8	780	0.2
Incineration – Export	32.3	*(1’950)*	0.4
Incineration – Landfill	67.3	*(4’060)*	0.84
Incineration – WWT	0.4	*(50)*	0.01
WWT – Hydrosphere	33.3	15	0.003

Tab. 8.5 > PET data 2001.

From – To	Transfer coefficients (%)	PET s.l. (tons)	Sb (tons)
Import – Trade	100	20’400	4.1
Trade – Export	5.7	1’220	0.25
Reuse – Production	100	1’330	0.27
Production – Trade	100	1’330	0.27
Trade – Consumption	94.3	19’180	4.1
Consumption – Stock “Consumption”	6.6	1’330	0.27
Consumption – Collection	100	18’220	3.7
Collection – Reuse	7.0	1’330	0.27
Collection – Incineration	70.8	13’580	2.7
Collection – Export	22.1	4’250	0.85
Incineration – Export	67.3	*(4’370)*	0.9
Incineration – Landfill	32.3	*(9’050)*	1.8
Incineration – WWT	0.4	*(54.2)*	0.01
WWT – Hydrosphere	33.3	17.5	0.004

Tab. 8.6 > Polyester resins data 2001.

From – To	Transfer coefficients (%)	Polyester resins (tons)	Sb (tons)
Import – Trade	100	19'980	4
Trade – Export	60	12'340	2.47
Reuse – Production	100	530	0.11
Production – Trade	100	530	0.11
Trade – Consumption	40	8'200	1.64
Consumption – Stock "Consumption"	6.7	530	0.11
Consumption – Collection	100	7'630	1.52
Collection – Reuse	69.3	530	0.08
Collection – Incineration	23.4	5'030	1.01
Collection -Export	32.3	1'700	0.34
Incineration – Export	67.3	*(1'745)*	0.35
Incineration – Landfill	32.3	*(3'635)*	0.727
Incineration – WWT	0.4	*(20.1)*	0.004
WWT – Hydrosphere	33.3	6.5	0.001

Tab. 8.7 > PVC data 2001.

From – To	Transfer coefficients (%)	PVC (tons)	Sb (tons)
Import – Trade	100	177'970	12.5
Trade – Export	47.1	86'800	6.1
Reuse – Production	100	6'320	0.44
Production – Trade	100	6'320	0.44
Trade – Consumption	52.9	97'710	6.84
Consumption – Stock "Consumption"	6.4	6'320	0.44
Consumption – Collection	100	91'190	6.38
Collection – Reuse	69.3	6'320	0.44
Collection – Incineration	23.4	75'714	5.3
Collection -Export	32.3	11'286	0.8
Incineration – Export	67.3	*(24'286)*	1.7
Incineration – Landfill	32.3	*(51'429)*	3.6
Incineration – WWT	0.4	*(257)*	0.02
WWT – Hydrosphere	33.3	83	0.006

Tab. 8.8 > CRT-glass data 2001.

From – To	Transfer coefficients (%)	CRT-glass (tons)	Sb (tons)
Import – Trade	100	n.d.	n.d.
Trade – Export	n.d.	n.d.	n.d.
Trade – Consumption	n.d.	2'260	7.9
Stock "Consumption" – Consumption	n.d.	1'630	5.7
Consumption – Collection	100	3'900	13.6
Collection – Export	18	700	2.4
Collection – Reuse	82	3'190	11.2
Reuse – Export	100	3'190	11.2

Tab. 8.9 > Ceramics data 2001.

From – To	Transfer coefficients (%)	Ceramics (tons)	Sb (tons)
Import – Trade	100	n.d.	n.d.
Trade – Export	n.d.	n.d.	n.d.
Trade – Consumption	n.d.	3.1	0.17
Stock "Consumption" – Consumption	n.d.	2.6	0.14
Consumption – incineration	83	4.5	0.25
Consumption – landfill	17	0.9	0.05
Incineration – export	67.3	*(1.8)*	0.1
Incineration – landfill	32.3	*(2.7)*	0.15
Incineration – WWT	0.4	*(0.4)*	0.02
WWT – Hydrosphere	33.3	83	0.006

Tab. 8.10 > Pigments data 2001.

From – To	Transfer coefficients (%)	Pigments (tons)	Sb (tons)
Import – Trade	100	n.d.	n.d.
Trade – Export	n.d.	n.d.	n.d.
Trade – Consumption	n.d.	255	10.2
Consumption – Incineration	88	224	9
Consumption – Landfill	12	31	1.2
Incineration – Export	32.3	*(73)*	2.9
Incineration – Landfill	67.3	*(153)*	6.1
Incineration – WWT	0.4	*(1)*	0.04
WWT – Hydrosphere	33.3	0.33	0.013

Tab. 8.11 > Lubricants data 2001.

From – To	Transfer coefficients (%)	Lubricants (tons)	Sb (tons)
Import – Trade	100	741	40.8
Trade – Export	2.2	16	0.9
Trade – Consumption	97.8	725	39.9
Consumption – Collection	100	725	39.9
Collection – Incineration	85	616	33.9
Collection – Reuse	14.8	107	5.9
Reuse – Export	0.3	107	5.9
Collection – Export	0.2	2.2	0.1
Incineration – Export	32.3	*(199)*	10.9
Incineration – Landfill	67.3	*(414)*	22.8
Incineration – WWT	0.4	*(2.5)*	0.2
WWT – Hydrosphere	33.3	0.8	0.04

Tab. 8.12 > Brake pads data in 2001.

From – To	Transfer coefficients (%)	Brake pads (tons)	Sb (tons)
Import – Trade	100	1200	31.2
Trade – Export	7	85	2.2
Trade – Consumption	93	1115	29
Consumption – Stock “Consumption”	48	962	25
Stock “Consumption”	-	4’460	87
Stock “consumption” – Consumption	26.4	885	23
Consumption to environment	33	654	17
Consumption – Collection	19	385	10
Collection – Incineration	100	385	10
Incineration – Export	32.3	*(123)*	3.2
Incineration – Landfill	67.3	*(262)*	6.8
Incineration – WWT	0.4	*(4)*	0.1
WWT – Hydrosphere	33.3	0.1	0.03

Tab. 8.13 > Minor non-metal market products data 2001.

From – To	Transfer coefficients (%)	Sb (tons)
Import – Trade	100	n.d.
Trade – Export	n.d.	n.d.
Trade – Consumption	n.d.	8.5
Consumption – Collection	100	8.5
Collection – Incineration	100	8.5
Incineration – Export	32.3	2.8
Incineration – Landfill	67.3	5.7
Incineration – WWT	0.4	0.03
WWT – Hydrosphere	33.3	0.01

A4 Flame retardants

Tab. 8.14 > Brominated FR in EE and household goods data 2001 for 'trade in products'.

Tables 3.17, 3.19, 3.21, 3.22 and 3.24.

From – To	Transfer coefficients (%)	EE-and household goods (tons)	Sb (tons)
Import – Production	100	279'000	137
Production – Trade	100	279'000	140
Import – Trade	100	114'000	160
Trade – Export	2	9'900	5
Trade – Consumption	98	393'000	295
Consumption – Stock "Consumption"	65	269'100	202
Stock "Consumption"	-	2'974'000	2635

Tab. 8.15 > Brominated FR in EE and household goods data from EE shredder plant in 2001 for 'waste management' and 'environment'.

From – To	Transfer coeffcients (%)	EE-and household goods (tons)	Amount of plastics (19 %)	Sb in plastics (tons) (0.5 %)
Consumption – Collection	46.0	39'300	7'470	35
Consumption – Landfill	6.4	4'490	850	4
Consumption – Incineration	47.6	51'700	9'820	46
Collection – Export	60.7	18'000	3'420	16
Collection – Incineration	34.5	18'000	3'420	16
Collection – Reuse	4.8	3'370	640	3
Reuse – Production	100	3'370	640	3
Incineration – Export	32.3	*(14'600)*	2'780	20.7
Incineration – Landfill	67.3	*(30'300)*	5'760	41.4
Incineration – WWT	0.4	281	53	0.25
WWT – Hydrosphere	33.3	112	21	0.1

FOEN, 2004.

Tab. 8.16 > Nonmetal shredder residues (NSR) data 2001.

Household appliance treated in auto shredder plants.

From – To	Transfer coefficients (%)	NSR (tons)	Sb (tons)
Consumption – Collection	100	25'360	8.4
Collection – Incineration	46.1	11'690	3.9
Collection – Export	53.9	13'670	4.5
Incineration – Export	32.3	*(3'780)*	1.3
Incineration – Landfill	67.3	*(7'870)*	2.6
Incineration – WWT	0.4	*(47)*	0.02
WWT – Hydrosphere	33.3	15	0.005

Tab. 8.17 > Auto shredder residues data 2001.

From – To	Transfer coefficients (%)	ASR (tons)	Sb (tons)
Import – Trade	99.2	2’206’612	72
Trade – Export	43.7	975’207	32
Import – Production	0.8	4’959	0.6
Production – Trade	100	4’959	0.6
Trade – Consumption	56.3	1’231’405	40
Consumption – Stock “Consumption”	88.6	1’090’909	23
Consumption – Collection	11.4	140’496	17
Stock “Consumption”	-	4’685’950	567
Collection – Incineration	76.5	107’438	13
Collection – Export	23.5	33’058	4
Incineration – Export	32.3	*(33’058)*	4
Incineration – Landfill	67.3	*(74’380)*	9
Incineration – WWT	0.4	*(330)*	0.04
WWT – Hydrosphere	33.3	22	0.013

Tab. 8.18 > Building materials containing CIFR and BFR data 2001.

From – To	Transfer coefficients (%)	Material (tons)	Sb concentration ton/ton	Sb (tons)
Import – Trade	75.9	161’900	0.0002[1]	34
Trade – Export	37	79’050	0.0002[1]	17
Import – Production	24.1	49’180	0.0012[2]	60
Production – Trade	100	49’180	0.0012[2]	60
Trade – Consumption	63	154’000	0.0005[1+2]	77
Consumption – Stock	16	102’000	0.0005[1+2]	51
Stock “Consumption”	-	7’960’000	0.0005[1+2]	3’980
Consumption – Collection	84	195’500	0.00013[3]	26
Collection – Incineration	100	200’000	0.00013	26
Incineration – Export	32.3	*(61’540)*	*(0.00013)*	8
Incineration – Landfill	67.3	*(138’460)*	*(0.00013)*	18
Incineration – WWT	0.4	*(770)*	*(0.00013)*	0.1
WWT – Hydrosphere	33.3	230	*(0.00013)*	0.03

Comments: [1]CIFR; [2]BFR; [3]burnable construction waste.

Tab. 8.19 > Municipal solid waste data 2001.

From – To	Transfer coefficients (%)	MSW (tons)	Sb (tons)
From consumption	100	2'550'000	122
Consumption – Incineration	88	2'240'000	108
Consumption – Landfill	12	305'400	15
Incineration – Export	32.3	724'300	35
Incineration – Landfill	67.3	1'510'000	73
Incineration – WWT	0.4	8'100	0.4
WWT – Hydrosphere	33.3	2'700	0.1

Tab. 8.20 > Sewage sludge data 2001.

From – To	Transfer coefficients (%)	Sewage sludge (tons)	Sb (tons)
Consumption – Waste water treatment	100	200'000	0.65
Waste water treatment – Incineration	67.7	135'400	0.44
Waste water treatment – Landfill	1.5	4'600	0.01
Waste water treatment – Pedo-/Lithosphere	30.8	60'000	0.2
Incineration – Export	32.3	*(43'730)*	0.14
Incineration – Landfill	67.3	*(91'120)*	0.3
Incineration – WWT	0.4	*(540)*	0.002
WWT – Hydrosphere	33.3	175	0.0006

Tab. 8.21 > Construction waste data 2001.

From – To	Transfer coefficients (%)	Construction material (tons)	Sb (tons)
Trade – Consumption	100	4'304'750	17.2
Consumption – Stock "Consumption"	100	4'304'750	17.2
Stock "Consumption"	-	2'092'700'000	8370
Stock "Consumption"– Consumption	100	4'706'410	25.4
Consumption – Collection	100	6'357'010	25.4
Collection – Reuse	68	4'304'750	17.2
Collection – Incineration	6	383'350	1.5
Collection – Landfill	26	1'669'800	6.7
Reuse – Trade	100	4'304'750	17.2
Incineration – Export	32.3	*(123'820)*	0.5
Incineration – Landfill	67.3	*(257'920)*	1
Incineration – WWT	0.4	*(1'530)*	0.006
WWT – Hydrosphere	33.3	495	0.002