Resources, Conservation and Recycling 108 (2016) 54–62

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

How can we adapt to geological scarcity of antimony? Investigation of antimony's substitutability and of other measures to achieve a sustainable use

M.L.C.M. Henckens*, P.P.J. Driessen, E. Worrell

Utrecht University, Copernicus Institute of Sustainable Development, Heidelberglaan 2, 3584CS Utrecht, The Netherlands

ARTICLE INFO

Article history:
Received 4 August 2015
Received in revised form 4 November 2015
Accepted 17 January 2016
Available online 23 January 2016

Keywords:
Sustainable use
Primary antimony
Substitution
Material efficiency
Recycling

ABSTRACT

Antimony is an element that is applied in many useful applications for mankind. However, antimony resources are very scarce, when comparing the current extraction rates with the availability of antimony containing ores. From an inter-temporal sustainability perspective, current generations should not deprive future generations from extractable ores. The extraction rate of a mineral resource is defined sustainable, if such a rate can be sustained for 1000 years assuming the same consumption per capita in all countries of the world. To achieve a sustainable extraction of antimony, it is necessary to reduce the current extraction with 96% compared to the primary antimony extraction in 2010. We have investigated whether such an ambitious extraction reduction goal would be technically feasible, without losing any of the current services that are provided by antimony. Reduction of the use of primary antimony can be achieved through (a combination of) substitution, improved material efficiency and recycling. Because the potential of material efficiency and recycling are limited in the case of antimony, the focus is on substitution of antimony in its applications.

The major application of antimony (more than 50%) is in flame retardants. It appears that about 95% of antimony in flame retardants can be replaced by other components or systems. Overall, the substitutability of antimony in all its applications is estimated at around 90%.

The required additional extraction reduction needs to be realized by improved material efficiency and further recycling, especially from the remaining antimony containing flame retardants and from lead-alloys.

1. Introduction

Antimony is an element that is used in many applications that are useful for humanity, e.g. as component in flame retardants, as catalyst to produce polyester, in lead-acid batteries and in lead alloys. However, antimony reserves are very scarce. Comparing the extractable global resources of antimony according to the UNEP approach (2011) with the current pace of extraction of antimony as provided by USGS (2015a), antimony is one of the scarcest mineral resources. According to Henckens et al. (2014) the extractable global resources of antimony are exhausted before 2050 if the antimony extraction rate continues to increase with the current pace. This does not mean that antimony will have disappeared from the earth's crust by that year, but the relatively easily extractable ores will. Further extraction of antimony will then become much more expensive due to e.g. low ore grades, deep mining, remote locations and high energy costs. Seen the utility of antimony for humankind it is therefore important to look at ways to reduce its extraction to a sustainable level, but without losing any of the services currently provided by antimony.

What is the sustainable level of extraction and use of primary antimony?

Henckens et al. (2014) propose the following operational definition for the sustainable extraction of raw materials: *The extraction rate of a material is sustainable, if (1) a world population of 9 billion can be provided of that material for a period of at least 1000 years assuming that, (2) the average per capita consumption level of the material is equally divided over the world's countries.*

This approach is based upon four points of departure:

(1) The available amount of extractable ores. According to UNEP (2011), the approximate upper limit of the extractable amount

* Corresponding author.
E-mail address: theo.henckens@gmail.com (M.L.C.M. Henckens).

http://dx.doi.org/10.1016/j.resconrec.2016.01.012
0921-3449/

of a mineral resource is 0.01% of the total amount of that mineral in the top 1 km of the continental part of the earth's crust. This is supported by Erickson (1973), Skinner (1976) and Rankin (2011).

(2) The current extraction rate and the expected future increase of the extraction rate. This can be based on USGS data.

(3) Long-time-availability of sufficient extractable ores for future generations (according to the normative principle of inter-generational equity). What is "long time" in this framework? Theoretically, it should be for eternality, but this is not possible, since ores are not renewable. For practical reasons, Henckens et al. (2014) propose a period of 1000 years as an approximation of quasi-perpetuity. Their argument is that an ore depletion period of 100 years (just a few generations ahead) would be too short a period for sustainable extraction, whereas an order of magnitude longer period of 10,000 years seems unnecessarily long in their view.

(4) The principle right of the citizens of the world on an equitable share of the available mineral resources (according to the normative principle of intra-generational responsibility). In an operational definition for sustainable extraction it would not be justified to depart from the status quo of present inequality. Henckens et al. (2014) therefore propose to depart from the assumption that in 2050, all countries in the world have the same pro capita level of consumption of mineral resources as the industrialized countries at this moment.

According to the 3R approach (Reduce, Reuse, Recycle), there are three main technical ways to reduce the use of primary materials: substitution of the resource in its applications, improved material efficiency and increased recycling. In case a substantial use reduction of a scarce mineral resource is necessary, Henckens et al. (2015) propose to investigate these types of measures in the following sequence: (1) substitution of the resource, (2) material efficiency of the resource's applications remaining after substitution, (3) recycling of the resource from the applications remaining after substitution and material efficiency measures. This approach will result in a specific mixture of the three measures for achieving the required reduction rate. However, in practice, various other scenarios are thinkable as well or economically more optimal.

In this paper we will investigate whether and how it would be possible to reduce the extraction of antimony to less than 4% of the current extraction at a global scale.

The intention of this investigation is not to make a blue print of measures to be taken, but to demonstrate whether or not a 96% reduction of the use of primary antimony is feasible at all with current technologies without losing the services provided by antimony.

We will base ourselves on literature data. With regard to the substitutability of antimony in flame retardants and glass we have consulted specialized experts.

2. The occurrence, extractable amounts and sustainable extraction of antimony

Since 110 years, China is the main antimony supplier of the world (Tri-star resources, 2015). The main mine is in the province of Hunan in the center of the east part of China. The geological conditions in this area (high porosity karst type area in or nearby active tectonic fault lines) have been favorable for the formation of deposits with a high concentration of antimony, especially stibnite (Sb_2S_3). Both in 2012 and 2013, China had 75% of the world production of antimony.

See Table 1 and Fig. 1.

Table 1
Antimony producing countries (metric tons; USGS, 2015c).

	2009	2010	2011	2012	2013
China	140,000	150,000	150,000	136,000	120,000
Canada	64	9000	10,000	6000	76
South Africa	2673	3239	3175	3066	2400
Bolivia	2990	4980	3947	5088	5081
Burma	3700	5900	7000	7400	9000
Russia	3500	6040	6348	7300	8700
Turkey	1400	1400	2400	7300	4600
Tajikistan	2000	2000	4500	4248	4675
Australia	1000	1106	1577	2481	3275
Kyrgyzstan	700	700	1500	1200	1200
Peru	145				
Mexico	74	71	100	169	294
Total	158,246	184,436	190,547	180,252	159,301

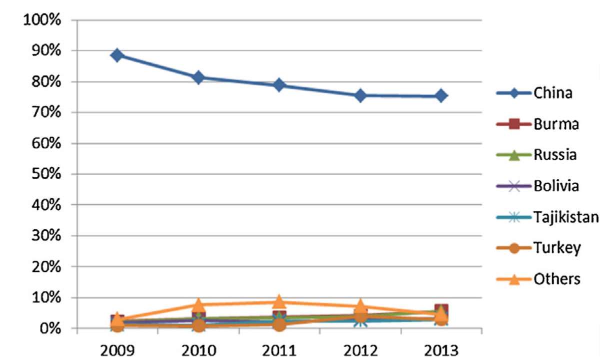

Fig. 1. Share of antimony production of the main antimony mining countries between 2009 and 2013 (USGS, 2015a).

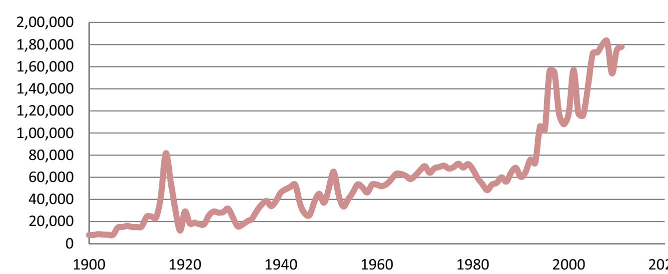

Fig. 2. Development over time of antimony world production (tons).
Source: Derived from USGS (2015b)

Fig. 2 shows that, since 1900 there is a quite steady increase of global antimony production. In recent years, the annual amount of extracted antimony shows relatively large variations, but the production trend is still upward.

Over a period of 113 years, between 1900 and 2013, the average annual production increase was 5.6%. See Table 2 for more details for selected periods.

Based on UNEP (2011) we suppose that the extractable global amount of antimony is 0.01% of the total amount of antimony in the top 1 km of the continental earth's crust. The extractable global antimony resources, according to the vision of UNEP (2011), are 8 million tons. This is about twice as much as USGS's latest reserve base estimation of antimony in 2009, which is 4.3 million tons.

Table 2
Global production trends of antimony (USGS, 2015b).

Average annual increase between 1900 and 2013	5.6%
Average annual increase between 1950 and 2013	2.8%
Average annual increase between 1990 and 2013	5.8%
Average annual increase between 2000 and 2013	3.3%