ANALYSIS OF ALTERNATIVES

non-confidential report

Legal name of applicant(s):	Boliden Kokkola Oy
Prepared by:	REACHLaw Oy
Substance:	Diarsenic trioxide (EC 215-481-4)
Use title:	Use of diarsenic trioxide in the purification of metal impurities from the leaching solution in the zinc electrowinning process
Use number:	1

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1 SUMMARY

Boliden Kokkola Oy (BKO) is a zinc manufacturer located in the city of Kokkola on the west coast of Finland. It is part of the Swedish Boliden Group which is a mining and smelting company. BKO uses diarsenic trioxide (As_2O_3) in its solution purification step as described below.

The vast majority of the world's zinc is produced by the roast-leach-electrowinning (RLE) hydrometallurgical process. In this process, a very pure zinc sulphate solution must be prepared for zinc electrowinning (meaning electro-extraction of zinc); therefore the purification process is one of the most important unit processes in zinc hydrometallurgy. Several impurities from the zinc ore concentrate must be removed from the zinc sulphate solution before the electrowinning step, where zinc is separated from the solution by electrolysis. As_2O_3 is used in one of the purification steps to selectively precipitate the metal impurities.

The use applied for by BKO is the use of As_2O_3 in the purification of metal impurities from the leaching solution in the zinc electrowinning process. The function of As_2O_3 is to eliminate impurities such as copper, cobalt and nickel from the zinc electrowinning solution, without the co-precipitation of cadmium. This function is essential to the success of the whole zinc production process, and cannot be made redundant.

It should be emphasised that any suitable alternative would be a substance that results in the removal of the impurities of the zinc ore and is also feasible at an industrial level. Since the purification is an essential step in the zinc production process, modifying this step would require major overhaul of the whole process and significant investment. As a result it is necessary that only processes with an established industrial track record should be considered.

A literature search and consultation with a third party have been conducted to elucidate an industrial scale alternative to As_2O_3. It was found that diantimony trioxide (Sb_2O_3) or antimony potassium tartrate ($K_2Sb_2(C_4H_2O_6)_2$) in the so-called antimony compound based process are used by other companies within the same industry. The antimony compound based processes can remove the metal impurities, although it will reduce the overall production efficiency. In addition, cadmium is co-precipitated with copper, cobalt and/or nickel, which hampers the further utilisation of these valuable metals. To achieve the same result as the As_2O_3 based process, a further purification step must be introduced to separate cadmium from the other metals.

Potential alternative No.1 Sb_2O_3 was found to be technically feasible and available but economically unfeasible. The risk assessment of the use of As_2O_3 in BKO conducted in the CSR show that the process is strictly controlled. Risks are reduced to a minimum level. In addition, Sb_2O_3 is classified as Carc. 2. The changeover to the Sb_2O_3 based process would cause substantial costs, which exceed the potential benefits to human health and the environment. Therefore Sb_2O_3 is not considered a suitable alternative, because it is economically unfeasible and without significant risk reduction potentials.

Potential alternative No. 2, $K_2Sb_2(C_4H_2O_6)_2$ was also found to be technically feasible and available but economically unfeasible. Since the substance is not registered, its complete hazard/risk profile is not yet known and classification cannot be determined. However, a literature review indicates that the substance may induce mutations in humans and there is also concern about potential carcinogenicity. The National Institute of Technology and Evaluation (NITE) of Japan has classified $K_2Sb_2(C_4H_2O_6)_2$ according to the Globally Harmonised System of Classification and Labelling of Chemicals (GHS) as: Acute Tox. 3 (oral), Skin Irrit. 3, Muta. 2, Carc. 2, STOT-SE 1 (respiratory tract irritation), STOT-RE 1 (lung, heart), STOT-RE 2 (liver), Aquatic acute 3, Aquatic chronic 3. As previously stated, the risk assessment of the use of As_2O_3 in BKO conducted in the CSR show that the process is strictly controlled. Risks are reduced to a minimum level. The changeover to the $K_2Sb_2(C_4H_2O_6)_2$ process would require the same investments as for the changeover to the Sb_2O_3 based process. The costs would be substantial and they would exceed the potential benefits to human health and the environment. Therefore $K_2Sb_2(C_4H_2O_6)_2$ is not considered a suitable alternative, because it is economically unfeasible and without significant risk reduction potentials.

Apart from the antimony compound based alternatives, no other industrial scale alternative has been found based on the Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metal Industries[1] (draft version 3 dated February 2013).

In conclusion, the search for replacements to As_2O_3 in BKO has not yielded suitable alternatives or technologies to date. BKO is committed to actively follow the developments in the field, and adapt any solutions proven to be suitable.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.)*:

There is no confidential information in this section of the report.

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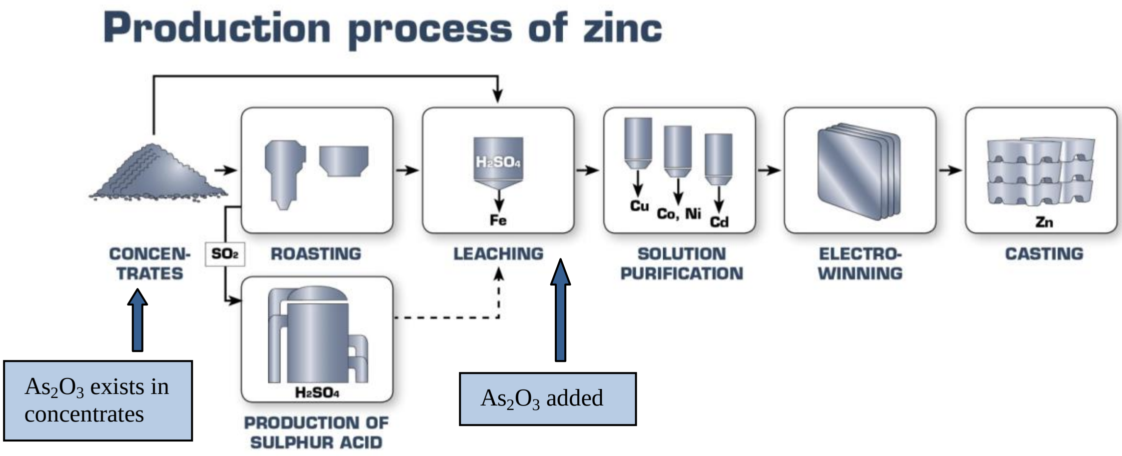
[1] European Commission (2013)

2 ANALYSIS OF SUBSTANCE FUNCTION

2.1 BACKGROUND

More than 80% of the world's production of zinc from the ore concentrate is obtained by the roast-leach-electrowinning (RLE) hydrometallurgical process (Figure 1). In the roast-leach process, very pure zinc sulphate solution must be prepared for zinc electrowinning; therefore the purification process is one of the most important unit processes in zinc hydrometallurgy. In this process, several impurities of the zinc concentrate, including but not limited to copper, cobalt, nickel and/or cadmium, must be removed from the zinc sulphate solution before the electrowinning step, where zinc is separated from solution by electrolysis.

Figure 1. Production process of BKO



As_2O_3 exists in concentrates

As_2O_3 added

These metals may either contaminate the resulting zinc metal (Cu, Cd) or act as harmful elements in the process decreasing current (energy) efficiency of the electrowinning process (Co, Ni). If large enough amounts of Co or Ni pass through to electrowinning, zinc production becomes impossible due to extensive dissolution of zinc metal from the cathode. The reason for this is explained below.

The zinc electrowinning process is unusual from a thermodynamic point of view because zinc metal has a more negative reduction potential than hydrogen:

$$2H^+ + 2e^- \rightarrow H_2 \qquad e^0 = 0\ V \qquad (1)$$

$$Zn^{2+} + 2e^- \rightarrow Zn^0 \qquad e^0 = 0.76\ V \qquad (2)$$

Therefore, hydrogen gas would be expected to evolve at the expense of zinc deposition. However, zinc metal is electrowon economically from acidic zinc sulphate solution because hydrogen evolution has a high over-potential on zinc metal. In order to maintain this large over-potential, almost all impurities in the solution must be completely removed. Any remaining impurities will act as catalysts for hydrogen evolution, causing large drops in current efficiency.

These metal impurities are removed from the solution using zinc powder as a reducing agent to give a metallic precipitate of copper or cadmium, or compounds containing cobalt or nickel. Diarsenic trioxide is needed in the cobalt and nickel removal step. Without any additive, the precipitation kinetics of cobalt and nickel (reaction $Co^{2+} + Zn \rightarrow Zn^{2+} + Co_{(s)}$ and $Ni^{2+} + Zn \rightarrow Zn^{2+} + Ni_{(s)}$) is too slow and zinc powder consumption is too high for an economical industrial process.

The following chemical reactions of As_2O_3 and dissolved metal concentrates (3-8) take place in the processing stages of BKO in manufacturing and selective precipitation of copper and cobalt in the zinc purification process.

As_2O_3 is first used in forming arsenous acid as an essential reactant to selectively precipitate Co and Ni out of the process solution and to concentrate them completely in the copper concentrate. To prevent any negative influence to the energy efficiency in the electrolysis, it is important to remove Co and Ni to a very low content (< 0.05 mg/l).

As_2O_3 is first dissolved in 48 % NaOH solution: $As_2O_3 + 2NaOH \rightarrow 2NaAsO_2 + H_2O$ (3)

Solution purification is done in three metal selective steps: 1) copper removal, 2) cobalt and nickel removal, and 3) cadmium removal. Arsenic trioxide is needed in the second step (reactions 4 and 5) to precipitate cobalt and nickel.

The arsenic present in this solution reacts in the solution purification step according to following types of reactions:

$2As^{3+} + 2Co^{2+} + 5Zn \rightarrow 2CoAs + Zn^{2+}$, in which Ni can replace Co (4)

$2As^{3+} + 6Cu^{2+} + 9Zn \rightarrow 2Cu_3As + 9Zn^{2+}$ (5)

Here As^{3+} describes only the solution species of As(III).The stoichiometry of the intermetallic compound (M_xAs_y) produced is also variable (M = Cu, Co or Ni). Copper is used as a buffer to capture the rest of arsenic that is excess to the reaction needs (4).

Arsenic is removed from the metal arsenide (As III) (Co_xAs_y, Ni_xAs_y...) filter cakes by oxidising these insoluble precipitates in alkaline solution to soluble arsenate (As (V)) form. Metals stay precipitated, mainly as oxides/hydroxides and are processed further.

Metal-arsenic oxidation and arsenic dissolution reactions (6)-(7)

$2\ Cu_2As + 4O_2 + 6NaOH \rightarrow 3CuO + 3Cu + 2Na_2AsO_4 + 3H_2O$ (6)

$2CoAs + 6NaOH + 3.5\ O_2 \rightarrow 2Co(OH)_2 + 2Na_2AsO_4 + H_2O$, in which Ni can replace Co (7)

The resulting solution containing Na_3AsO_4 reacts with ferric iron in leaching circuit:

$2Na_3AsO_4 + Fe_2(SO_4)_3 \rightarrow 2FeAsO_4 + 3Na_2SO_4$ (8)

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.)*:

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2.2 FUNCTION OF AS_2O_3

The function of As_2O_3 is to eliminate impurities such as copper, cobalt and nickel from the Zn electrowinning solution, without the co-precipitation of the cadmium. As described in Section 2.1, this function is essential to the zinc electrowinning process.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.)*:

There is no confidential information in this section of the report.

3 IDENTIFICATION OF POSSIBLE ALTERNATIVES

The search for alternatives can be considered from two angles. One is to look for a substance or a series of substances that can make the function unnecessary; the other is to look for a substance or a series of substances that can perform the same function.

3.1 ALTERNATIVES THAT MAKE THE FUNCTION UNNECESSARY

As was already described in Section 2.1, zinc electrowinning is sensitive to metallic impurities, especially in relation to current efficiency and the purity of the deposited zinc. The essential function of the As_2O_3 is, therefore, to eliminate impurities such as copper, cobalt and nickel from the electrowinning solution. If this function cannot be fulfilled, zinc has to be produced using a different process other than electrowinning. The other processes that are used to recover zinc from zinc ores are pyrometallurgy and the solvent extraction technologies.

In the pyrometallurgical process the reduction of zinc ores to its metal form takes place in a smelting furnace. This process consumes large amount of energy and is expensive. Furthermore, dust and heavy metal emissions are higher than in the hydrometallurgical process. Five of the six plants that existed in the European Union in 2000s have been closed, mainly for environmental and economical reasons. At present the process is only in use in China, India, Japan and Poland. The production facilities in the pyrometallurgical process are very different from the facilities in the hydrometallurgical process.

The solvent extraction technology based process is used in the processing of non-sulphide primary materials (zinc ores) and for the treatment of a variety of secondary materials (recycling). Currently such processes are only used where the sources of such raw materials are close by, which is not the case for BKO. The production facilities are also very different from the facilities used in BKO.

In conclusion, BKO needs to rely on the electrowinning process. In such a process, the function of eliminating metal impurities from the electrolysis solution is necessary and essential.

3.2 LIST OF POSSIBLE ALTERNATIVES

Two industrial scale alternatives were identified as possible candidates, which could perform the function of eliminating metal impurities from the leaching solution (the term used here to indicate the impure electrolysis solution). The main alternative substances used in such processes are:

1) Diantimony trioxide, Sb_2O_3; or
2) Antimony potassium tartrate, $K_2Sb_2(C_4H_2O_6)_2$.

These two antimony compounds can be used interchangeably in the so-called antimony compound based process.

Apart from the antimony compounds, no other industrial scale alternative exists, within Europe, according to the Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metal Industries[2].

Outside of Europe, Annaka Refinery, a Member of the Toho Zinc Company was said to use 1-Nitroso-2-naphthol based technology to purify the cobalt impurity from the leaching solution. However, very limited information is available to BKO in order for them to judge either the process solutions suitability or the possible capability of this alternative technology for their process.

Additionally, it is understood that some Chinese producers are utilising one or more alternative processes. No further information is available to investigate what these possible alternatives are, and whether they would be feasible in a European context.

It is expected that, as no manufacturing information is readily available, BKO would need to develop any of these processes from the concept level up. This would include at least three years of laboratory work followed by one year of pilot testing. Subsequently, a demonstration plant would need to be built. If the demonstration plant would show potential, the investment and construction planning could be initiated. It would realistically take more than 10 years before the alternative process was operational and would require substantial investment. Furthermore, should these processes be adopted by BKO, there is no guarantee that they would be economically feasible. Consequently, none of these technologies will be available to BKO at the time of the sunset date.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.)*:

There is no confidential information in this section of the report.

3.3 DESCRIPTION OF EFFORTS MADE TO IDENTIFY POSSIBLE ALTERNATIVES

3.3.1 RESEARCH AND DEVELOPMENT

Diarsenic trioxide solution purification technology used in the zinc electrowinning process has been successfully in use for over 90 years. The industry in general has not identified feasible alternative solutions to replace As_2O_3 at the industrial scale, aside from the antimony compound based technology. On a laboratory scale, some recent research has been carried out using solvent extraction or chelating adsorption to separate the metallic impurities from the leaching solution.

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[2] European Commission (2013)

Success has been achieved in separating copper from the leaching solution, but neither cobalt nor nickel[3].

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There is no confidential information in this section of the report.

3.3.2 DATA SEARCHES

The databases that have been searched include:

- ProQuest-database (http://www.proquest.co.uk/en-UK/);
- Nelli-portaali (http://www.nelliportaali.fi/); and
- Alli-database (https://alli.linneanet.fi/vwebv/searchBasic?sk=fi_FI/).

The key words that have been used in the searches include:

- zinc;
- arsenic or antimony; and
- solution purification.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.)*:

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3.3.3 CONSULTATIONS

Main consultation was conducted through interviews with Outotec. Outotec is an engineering and technology company specialized in providing technologies and services for metal and mineral processing industries. Outotec provides complete technological solutions for metallurgical and mineral processing industries, including engineering, equipment deliveries and various services. Outotec is listed in the Helsinki Stock Exchange and has offices in 25 countries as well as operations in 80 countries. The number of employees in 2012 was 4500. The revenue was €1.386 billion and R&D expenditure was €34 million in 2011. Outotec has over 5500 national patents or patent applications, 660 patent families and 70 trademarks. It is the world leader in several metal processing technologies, including zinc production. It is also the only engineering company in the

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[3] Friedrich, B. et al. (2001) & Laatikainen, K. et al. (2010)

world that can offer technologies related to both arsenic and antimony compounds based solution purification processes.[4]

Table 1. The recent references of Outotec in zinc processing industries are:

Customer	Location	Start-up Year	Capacity t/a Zn	Process description
Hindustan Zinc Ltd.	Dariba, India	2010	210 000	Roaster, Acid Plant, Leaching, Purification (Sb process), Tankhouse, Melting&Casting
Hunan Zhuye Torch Metals	Zhuzhou, China	2008	130 000	Direct leaching, Indium precipitation, Iron removal and solution purification (As process), process automation and electrification
Hindustan Zinc Ltd.	Chanderiya II, India	2007	180 000	Roaster, Acid Plant, Leaching, Conversion, Purification (Sb process), Tankhouse, Melting & Casting
Hindustan Zinc Ltd.	Chanderiya I India	2005	170 000	Roaster, Acid Plant, Leaching, Purification (Sb process), Tankhouse, Melting&Casting
Boliden	Odda, Norway	2004	50.000	Direct leaching, Solution purification (Sb process), process automation and electrification
Boliden	Kokkola, Finland	2001	260.000	Direct leaching, Modernisation of Solution purification (As process), process automation and electrification
Boliden	Kokkola, Finland	1998	225.000	Modernisation and expansion of Solution purification (As process) including process automation and electrification
MMC Akita	Akita, Japan	1993	100.000	Cd removal (Fluidised Bed Technology)
Ruhr Zink	Datteln, Germany	1993	170.000	Cd removal (Fluidised Bed Technology)

Outotec has confirmed that only Sb_2O_3 and $K_2Sb_2(C_4H_2O_6)_2$ should be considered as alternatives able to perform the function of eliminating metal impurities from the leaching solution. In addition, it provided an estimation of the required investment and the production efficiency change, if BKO

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[4] See http://www.outotec.com/ for more information

was to change to the antimony compound based technology. The economic feasibility analysis is based on this estimation.

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There is no confidential information in this section of the report.

4 SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES

4.1 OVERALL RISK REDUCTION OF CESSATION OF USE

The site specific exposure assessment of the As_2O_3 use in the CSR demonstrates that the risks of using As_2O_3 in the solution purification process at BKO's zinc plant are reduced to a minimum level.

Arsenic is present in the raw material of the production of zinc and other non-ferrous metals and consequently, will always be present in the releases of zinc plants in small quantities, even if As_2O_3 was not intentionally used as a process chemical. The influence of the use of As_2O_3 in human exposure and environmental emissions of the zinc plant is very small and accounts for only a small fraction of the total environmental and man *via* the environment exposure.

Handling of As_2O_3 at BKO's zinc refinery takes place under strictly controlled conditions. Overall emission levels of As at BKO from all known sources have met the requirements of local environmental permissions and existing EU legislation, such as the Directive on Integrated Pollution Prevention and Control (IPPC)[5], and comply with emission limit values based on the BAT. Emissions and discharges of As to the environment are monitored continuously and reported monthly/annually (water)/(air) to the supervising regional authority. In the early 2000s, the plant underwent large scale modification to improve work safety and control of its releases to the environment. Since then, emissions of As have been lowered and the permission limits have not been violated.

In this section, the overall environmental emissions of As due to the use of As_2O_3 will be presented first. Next the risks levels and their impacts on environment and workers as well as the general population will be discussed.

4.1.1 OVERALL ENVIRONMENTAL EMISSIONS OF ARSENIC

Changes in the level of annual releases are predominantly affected by the volume of the annual zinc production and the quality (e.g. As content) of the raw material used. If the use of As_2O_3 were

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[5] To be replaced by the Industrial Emissions Directive (IED) in 2014

stopped, the reduction in the emission of arsenic to the environment from the Kokkola Industrial Park (KIP) would only be a few kilograms per year. Table 2 below describes the overall annual emissions of As to air and surface water in the KIP area (year 2011 emission data) and the level of releases arising from the use of As_2O_3 only.

Table 2. The releases of As in the year 2011 from the KIP area.

	Total annual release of As from Kokkola Industrial Park (all sources)	**Release of As arising from the use of As_2O_3**
Release to Air	35 kg	< 3 kg
Release to Sea	133 kg	4.7 kg

4.1.2 IMPACT TO LOCAL AND REGIONAL ENVIRONMENT

Current releases from the BKO zinc plant to the local environment (air, soil and surface water) are very well controlled and at very low level in terms of released volumes. Table 3 below summarises risk characterisation ratios (RCRs) for the local environment in the vicinity of the BKO/KIP area. Risks are controlled if the RCR is less than one. All RCRs for the use of As_2O_3 in BKO's refinery are significantly below 1 indicating very low risk levels.

Table 3. Summary of RCRs of the local environment

Protection target	Risk characterisation ratio (RCR)*
Marine water (brackish water)	0.024
Sediment (marine water)	0.0015
Predator (marine water)	0.0017
Top predator (marine water)	0.00035
Agricultural soil, No direct release (precipitation/fallout)	0.0016
Predator (terrestrial)	0.000076

* RCR = Exposure Concentration/Predicted No Effect Concentration (or Dose)

For the larger regional area around Kokkola, the calculated RCRs are orders of magnitude lower than that for the local area. So the impact of As emission to local and regional environment on cessation of the use of As_2O_3 would be small, if any. No further impact valuation is conducted because the eco-toxicity properties have threshold values and adequate control has been demonstrated in Chapters 9 and 10 of the Chemical Safety Report (CSR).

4.1.3 IMPACT TO AIR QUALITY IN KOKKOLA

The impact of the As emission to air in the Kokkola area is expected to be very low or insignificant.

Directive 2004/107/EC has set a target value for As with the aim of minimising harmful effects of airborne As on human health, paying particular attention to sensitive populations and the environment as a whole. The target value set in 2004/107/EC for As in ambient air is 6 ng/m^3 for the total content in the inhalable particles (PM_{10}) fraction averaged over a calendar year. This target value is the public-health protective value and may be associated with an approximate one-in-a-hundred thousand (1: 100 000) increased lifetime risk of cancer.

Concentration of arsenic in community air (ng/m^3) has been monitored continuously in inhalable particles (PM_{10}) in Ykspihlaja and Kokkola city centre for decades. Both of the locations are relatively close to the zinc plant (2-5 km). Concentrations of As in ambient air in Kokkola have already been significantly below the target value for a long period of time (> 10 years) before the directive was implemented in Finnish legislation. The recent measured average concentrations of As in inhalable particles (PM_{10}) have been 0.37-1.11 ng/m^3 (years 1999-2011).

4.1.4 IMPACT TO GENERAL POPULATION (MAN VIA THE ENVIRONMENT)

Estimation of the overall exposure to the general population of As *via* environment accounts for all known sources (breathed air, drinking water, vegetables, meat, fish, dairy products produced locally etc.). The overall exposure to the general population arising from the use of As_2O_3 at BKO was estimated by using the EUSES exposure modelling tool. Conservative and intentionally overestimated default values were used in this calculation. A local As daily dose of 0.358 µg/kg could be calculated (RCR =0.21) indicating that risks to the general population arising from the use of As_2O_3 at BKO are controlled at a level of low concern. The impact to the general population (man *via* environment) is therefore expected to be very low or insignificant.

4.1.5 IMPACT TO OCCUPATIONAL HEALTH

Current use of As_2O_3 in the purification of zinc sulphate solution in BKO is strictly controlled. Risks to workers are adequately reduced to a level of low concern when the site specific risk reduction measures are implemented and personal protective equipment are used as advised. A complete end to occupational exposure of As cannot be expected, even if As_2O_3 use would cease. If the use of As_2O_3 was stopped at BKO, the exposure related to one task would phase out (1 person, 4 hours/day, 200 days per year). The cessation of As_2O_3 use could also be expected to influence the landfill workers (3-5 persons, 8 hours/day), since the concentration in stabilised landfill waste would reduce from the current level of 0.48% (range 0.63-0.39) to ca. 0.30%.

4.1.6 VALUATION OF THE IMPACTS TO HUMAN HEALTH AND ENVIRONMENT IN THE CESSATION OF THE AS_2O_3 USE

The valuation of impacts based on the carcinogenicity alone is considered sufficient because risks of all other hazard types have been demonstrated to be under control (Chapters 9 and 10 of the CSR), in other words the impact of those hazard types is negligible. In addition, ECHA guidance[6] has stated that impact analysis should focus on the Annex XIV property, which is carcinogenicity in As_2O_3's case.

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[6] ECHA (2011a)

The detailed analysis can be found in the socio-economic analysis report. It is concluded that the current risk to the environment is considered under control and no impact due to remaining risks is expected. The estimated costs to human health due to the use of As_2O_3 in BKO range from €13,406,181 to €33,515,491. The estimated values are very conservative in nature, which should be treated as the worst case scenario. In other words, the maximum reduction of human health and environment impacts in the cessation of the As_2O_3 use is €13,406,181 to €33,515,491.

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4.2 ALTERNATIVE 1

4.2.1 SUBSTANCE ID AND PROPERTIES

Table 4. Substance information of alternative 1

Substance name	**EINECS**	**CAS**	**Classification (CLP)**	**REACH status**
Diantimony trioxide Sb_2O_3	215-175-0	1309-64-4	***Harmonized classification*** Carc. 2	Registered over 1000 t/y

Previous risk assessments of diantimony trioxide were published by US EPA (2012), Environment Canada/Health Canada (2010), EU (2008) and OECD (2008). The following summary of human health risks and environmental risks is based on these evaluations.

Toxicokinetics

Diantimony trioxide is poorly soluble in aqueous solution and scarcely absorbed in human. At relevant human exposure levels an oral absorption of 1% is assumed. Dermal absorption of Sb_2O_3 is considered negligible based on an *in vitro* experiment and absorption *via* inhalation has been calculated to be 6.82% based on modelling. Animal studies have shown that orally administered Sb_2O_3 suspension distributes to most organs with the highest concentrations found in whole blood, thyroid and bone marrow. Antimony is excreted mainly in the faeces. In humans, antimony has also been detected in low amounts in foetal liver as well as in human breast milk, placenta, amniotic fluid and umbilical cord blood, indicating that antimony can be distributed to the foetus and excreted in breast milk.

Acute toxicity

Animal studies on acute oral exposure are relatively old and do not comply with current standards. In most of cases, they indicate that the oral LD_{50} was in excess of 20,000 mg/kg bw in rats.

A guideline compliant acute inhalation toxicity study has been conducted in rats. This study shows no signs of toxicity by Sb_2O_3, LC_{50} (4 hours) > 5.20 mg/L (5,200 mg/m^3).

One study on dermal exposure in rabbits indicates the LD_{50} is higher than 8,300 mg/kg bw. The overall conclusion is that Sb_2O_3 is considered to be of low acute inhalation, oral and dermal toxicity. Based on the available dose descriptors there has been no need to classify the substance for acute toxicity according to the CLP Regulation No. 1272/2008.

Irritation

No reliable data is available for skin irritation by Sb_2O_3. There is some evidence from human case studies that Sb_2O_3 induces skin irritation. However, it is considered that there is no concern for skin irritation expected from the environmental exposure of the substance.

Animal studies show that Sb_2O_3 causes mild eye irritation, which is reversible. Observed effects on eye do not trigger classification for eye irritation.

One acute inhalation toxicity animal study assessed the irritation potential to the respiratory tract, indicating that Sb_2O_3 is not irritating to the respiratory system.

Sensitisation

Based on the guideline compliant skin sensitisation study, Sb_2O_3 is not a skin sensitizer.

Repeated dose toxicity

The repeated oral and inhalation toxicity of Sb_2O_3 has been investigated in several animal studies. Those conclusive studies show that Sb_2O_3 is toxic to lungs. In a chronic inhalation study (12 months), the substance was administered to rats *via* whole body inhalation at three dose levels (0, 0.06, 0.51 or 4.50 mg/m^3). Repeated inhalation exposure to Sb_2O_3 induced toxic effects in the lung, most pronounced in the high-dose group. Based on impaired lung clearance, the NOAEC for repeated dose inhalation toxicity were considered to be 0.51 mg/m^3. In another guideline compliant subchronic oral study, however, Sb_2O_3 did not cause systemic toxicity in rats at doses 1686 mg/kg bw/day (males) and 1879 mg/kg bw/day (females).

Genetic toxicity

Trivalent antimony compounds, including Sb_2O_3, generally show negative results in *Salmonella* mutagenicity assays, but are positive in mutagenicity tests with animal and human cells. Diantimony trioxide induces structural chromosome aberrations in cultured mammalian cells *in vitro*. In *in vivo* cytogenicity studies diantimony trioxide has produced negative results. Thus, it is generally concluded that a possible local genotoxic effect of Sb_2O_3 would only be biologically relevant at concentration levels that also cause particle overload. In conclusion, there is no concern for genotoxicity of Sb_2O_3.

Carcinogenicity

There are several chronic toxicity/carcinogenicity studies in rats showing evidence that Sb_2O_3 is a carcinogenic substance. In these studies, inhalation of antimony trioxide has produced lung neoplasms. The most likely mechanism for the lung carcinogenicity is impaired lung clearance and particle overload followed by an inflammatory response, fibrosis and tumours. Consequently, Sb_2O_3 can be regarded as a threshold carcinogen, with the NOAEC of 0.51 mg/m^3 based on impaired clearance of particles also being used for carcinogenicity. The substance has the harmonized CLP classification for carcinogenicity (Carc. 2).

Toxicity to reproduction

For reproductive toxicity there is no study available for Sb_2O_3. However, in repeated dose toxicity studies *via* oral route no histopathological changes have been observed in reproductive organs of male and female rodents. Based on these observations, Sb_2O_3 is not toxic to male or female reproductive tissues and there is no concern for male or female fertility.

Developmental toxicity

The developmental toxicity of Sb_2O_3 has been investigated in only one study. In this inhalation study rats were exposed at doses up to 6.3 mg/m^3. No evidence of developmental toxicity was observed, and thus the NOAEC for developmental toxicity was concluded to be 6.3 mg/m^3. However, the highest dose did not give relevant maternal toxicity. In conclusion, there is no concern for Sb_2O_3 induced developmental toxicity.

Environmental fate

In the environment Sb_2O_3 will slowly dissolve and transform into $Sb(OH)_3$, which is oxidised to $[Sb(OH)_6]^-$ under oxygenated conditions. Antimony, being a natural element, cannot by definition be degraded. Eventually antimony will end up in either soil or sediment, depending on the release, the form of antimony, and meteorological conditions, etc. When released into air, antimony compounds are expected to be adsorbed on to particle matter. Antimony compounds may be eluted from soil and released from decomposed rock and anthropogenic sources. In natural waters, dissolved antimony exists almost exclusively in the two valency states +3 and +5 as $Sb(OH)_3$ and $[Sb(OH)_6]^-$, respectively. They may then be transported to rivers and adsorbed onto sediment. In sediment, they are combined with iron hydroxide, manganese and aluminium.

No fully reliable bioaccumulation studies are available and measured data from different aquatic organisms have been used to calculate tentative BCF-values. For marine fish the BCFs vary between 40 and 15000 whereas for freshwater fish the BCF values are less than 14. For invertebrates tentative BCFs in the range of 4000-5000 have been calculated. As opposed to these values a study with caged species of amphipod indicate a BCF-value of approximately 0.06. It should be noted that there is considerable uncertainty in these BCF values. After reviewing the readily available information on bioaccumulation potential of antimonial compounds, it can be concluded that their bioaccumulation potential is low-to-moderate.

Aquatic toxicity

Aquatic toxicity tests were conducted using $SbCl_3$ as the source of antimony, except for the marine fish, for which the source of antimony was $K[Sb(OH)_6]$. The lowest reliable LC_{50} values for fish, invertebrates and algae vary between 1.8 mg Sb/L – 36.6 mg Sb/L. The reported aquatic toxicity values are above the solubility limits of antimony at the pH levels used in these studies. Based on these values Sb_2O_3 has not been classified for short-term aquatic hazard. Chronic aquatic toxicity tests are conducted for freshwater fish, invertebrates and algae. In these tests NOEC values vary between 1.1 – 2.1 mg Sb/L indicating that there is no need to classify Sb_2O_3 for long-term aquatic hazard.

Sediment toxicity

Antimony compounds were reported to be strongly adsorbed in soil and sediment with the presence of iron-, manganese-, and aluminium oxides. Since they occur as anions, such as $[Sb(OH)_6]^-$, they may exhibit a weak affinity for organic carbon. The lowest chronic toxicity data for sediment organisms were observed for the midge: 14-d NOEC (growth) = 78 mg Sb/kg ww ($SbCl_3$ used).

Terrestrial toxicity

The lowest reliable terrestrial toxicity data were determined in a soil spiked with Sb_2O_3 and aged for 31 weeks before testing. Reliable NOEC values have been determined for plants, invertebrates and microorganisms. The lowest measured NOEC values vary between 370 – 710 mg Sb/kg bw. Since the equilibrium pore water concentration was not reached during the study period used, the NOEC values were recalculated using the pore water concentrations measured at the NOEC (9.7 mg Sb/L (plants and invertebrates) and 18.7 mg Sb/L (microorganisms)), and the equilibrium solid:liquid distribution coefficient (K_d) for antimony for this soil, i.e. 38 L/kg. Based on the above chronic toxicity data there is no need to classify Sb_2O_3 for long-term aquatic hazard.

Table 5. Comparison of classifications of As_2O_3 and Sb_2O_3

Diarsenic Trioxide *Harmonized classification*	**Diantimony Trioxide** *Harmonized classification*
Acute Tox. 2	
Skin Corr. 1B	
Carc. 1A	Carc. 2
Aquatic Acute 1	Not classified for environmental hazards
Aquatic Chronic 1	

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and*

number, page number, etc.): There is no confidential information in this section of the report.

4.2.2 TECHNICAL FEASIBILITY

The Sb_2O_3 based process is currently in use by some companies in the zinc production industry, so in that sense it is technically feasible. It is capable of removing the metal impurities, but cadmium will co-precipitate with copper, cobalt and/or nickel, which hampers the further utilisation of these valuable metals. To achieve the same result as the As_2O_3 based process, a further purification step must be introduced to separate cadmium from the other metals. Apart from that, compared to the As_2O_3 based technology the Sb_2O_3 based process has the following advantages and disadvantages (information source Outotec).

Table 6. Summary of technical differences in the processes based on As_2O_3 and Sb_2O_3

Difference of the Sb_2O_3 based process		**Consequences**	**Impact on cost for BKO to change to this alternative**
Disadvantages of the Sb_2O_3 based process	Higher zinc dust consumption	Lower production capacity, therefore less revenues	Significant
	Lower quality of by-product	The metal impurities (such as copper) and cadmium will be precipitated simultaneously, which yields lower quality of copper as a by-product. To achieve similar results, investment for additional purification steps is required.	Significant
	Requires lower impurity levels in leaching solution (raw material)	Requirement on the raw material will be higher, which may increase amount paid on the raw material.	Some, but difficult to quantify
	Higher process chemical consumption	Higher operating expenses	Marginal
Advantages of the Sb_2O_3 based process	Smaller plant area	Lower investment on land	No impact, because the plant exists and enough land has been acquired already
	Robust process for treating solutions with lower impurity concentrations	Allows bigger mistake margin, in other words requirements on the employee skills are lower.	No impact, because the current personnel has been trained to operate a more demanding

			process.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.)*:

There is no confidential information in this section of the report.

4.2.3 ECONOMIC FEASIBILITY

The economic feasibility of changing to the Sb_2O_3 based process is discussed and analysed below. The cost items are the same for the two alternative substances examined in this report, as they are both antimony compounds and therefore require the same changes to current operations. The analysis focuses on the changes in BKO’s costs and revenues, and does not regard the wider impact on society, as this will be considered in the socio-economic analysis.

Methodology

The ECHA guidance document for undertaking socio-economic analysis recommends that costs and benefits are expressed in an annualised form in authorisation applications[7]. This means that an equivalent annual value for the investment costs is added to the annual operating costs to derive an annualised cost. These annualised costs can then be aggregated to a net present value for the relevant time period. This methodology is also to be used when estimating the economic feasibility.

The assumptions made in the cost calculations are outlined below.

Time period: The new machinery equipment would be installed at the beginning of 2014 and has an expected lifetime of 20 years, i.e. until the end of 2033. The lifespan of the current facility is also expected to be 20 years from the end of 2013, i.e. until the end of 2033. As such, the time period for the economic feasibility analysis will be 20 years.

Discount rate: The values are calculated with the 4% discount rate recommended in the European Commission’s guidelines[8]. The net present values are discounted to the current year of 2013. The uncertainties related to the discount rate will be examined in the sensitivity analysis later on in this chapter.

Price level: All values are expressed in Euros and in the price levels and currency exchange rates of 2012. This is because the calculations are based on the income statement of 2012, which is the most recent data available. All prices are VAT free.

Zinc price: The zinc price used in the calculations is $1,948/tonne, the treatment charge is €179.01 and the EUR/USD exchange rate is 1.2935. These are the average numbers of 2012.

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[7] ECHA (2011b)

[8] European Commission (2009)

Costs of changing to the antimony compound based process

The various cost items related to the changeover are outlined below.

Machinery investment costs[9]

In the antimony process, the metal impurities are precipitated simultaneously, which yields lower quality of copper as a by-product. In order to achieve similar results as in the As_2O_3 process, machinery investment is required for additional purification steps. Furthermore, production needs to be shut down during the machinery changeover and new process run-up, which would result in lost revenue at the beginning of 2014. The lifetime of the new machinery is 20 years, i.e. it would be operational until the end of 2033. It is assumed that a minimum level of sustaining investments is undertaken.

Operating costs

Energy consumption and waste management costs would stay the same as in the As_2O_3 process.

The antimony process requires lower impurity levels in the leaching solution, which means that the requirements on raw material would be higher. This, in turn, may increase raw material costs. While this is likely to have some impact on the operating costs, it is difficult to quantify it.

The antimony process is more robust and this would allow a larger mistake margin, which means that requirements on employee skills would be lower. This would have no impact in the short term, as the current staff have been trained to operate a more demanding process. However, in the long term it could have an impact on staff numbers and skills.

Revenue loss

The change from the use of arsenic to antimony would increase zinc powder consumption, leading to a 3.5% decrease in production capacity. This change in production volume would, in turn, result in less revenue. It would be expected that the new antimony compounds based process would be fully operational by the beginning of 2015. There is no impact to the other products that BKO sells.

Table 7. Economic impacts of changing from the As_2O_3 process to the antimony process

	Cost	**Comment**
Investment in machinery equipment	Confidential	Necessary to yield equally high quality by-product results as in the "applied for use" scenario
Production shutdown	Confidential	Production shutdown during the

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[9] Investment costs estimated by Outotec

		machinery change and new process run-up
Energy consumption	No change	Energy consumption will stay the same.
Other operation costs	Some impact but difficult to quantify	The lower impurity level requirements in the leaching solution may increase raw material costs
More robust process	No impact in the near term	The process allows bigger mistake margin, which means that requirements on employee skills are lower. There will be no impact in the near term, as the current personnel have been trained to operate a more demanding process.
Lost revenue due to capacity decrease	Confidential	The decreased production capacity of 3.5% results in lost revenue due to decreased treatment charges and sales of free zinc and a reduced premium.

Comparative cost analysis

Tolling method

BKO produces zinc using the tolling method, which means that it is paid a treatment charge to refine zinc concentrate owned by Boliden Commercial AB. Boliden Commercial AB buys the concentrate from the corporation’s internal and external suppliers, and provides it to BKO for treatment. BKO returns the produced zinc to Boliden Commercial AB. According to the commercial terms, 85% of the zinc contained in the raw material is payable according to the London Metal Exchange price. The difference between the zinc yield percentage and the payable zinc yield (85%) is called free zinc. At BKO the free zinc is in the high international level.

The income of BKO consists of the treatment charge, free zinc sales, regional metal premium, and sales from the subsidiary metals/precious metals collected from the impurity of the metal concentrate. The income is also affected by price-sharing clauses, which determine that changes in the metals’ market prices are shared between the mines and the smelters. The treatment charge and price-sharing clause levels are determined by the balance between global mined production and the smelter’s demand for raw material. The value of the free zinc is determined by the London Metal Exchange price. The regional metal premiums are negotiated on an individual customer basis and are affected by the regional balance between metal supply and demand.

Because of the tolling method, the net sales and operating profit do not provide a comprehensive image of the scale of the BKO plant’s financial operations. The change from the As_2O_3 process to the antimony process would result in a decrease in received treatment charges and in the sales of free zinc as well as a reduced premium. As this is only one part of total production, expressing the costs on a “per unit” basis will not accurately illustrate the real costs. Because of this, the costs will be calculated on a total production basis instead of a “per unit” basis.

Calculations

As explained earlier, the change to the antimony based process will result in three major costs that can be monetised: an investment in machinery equipment in 2014, a temporary production shut-down in 2014 and an annual revenue loss from 2015 to 2033.

ECHA’s SEA guidelines recommend that the investment costs are annualised for the time period of the analysis. Both the machinery equipment and the temporary production shut-down will be calculated as investment costs, as they occur only once. By annualising them, it will be easier to compare them with the annual revenue loss starting in 2015.

The investment costs are annualised over a 20 year time frame applying the 4% discount rate recommended by the European Commission. The two annualised costs derived through Excel’s PMT function are demonstrated in the table below.

Table 8. Annualised investment costs

Investment cost	Confidential
Discount rate	4%
Lifetime of investment	20 years
Annualised cost	**Confidential**

The two annualised cost streams are shown together with their aggregated net present value in the table below.

Table 9. Changes in costs on a yearly basis

	2014	**2015**	**2016**	**…**	**2033**
Investment	Confidential	Confidential	Confidential	Confidential	Confidential
Revenue loss		Confidential	Confidential	Confidential	Confidential
Total cost	Confidential	Confidential	Confidential	Confidential	Confidential
NPV in 2013	**€104,224,977.25**				

Consequences

By combining the annualised investment-related costs and lost revenue, we can see that the net present cost (in 2013) to BKO of changing to the antimony compounds based process would be approximately €104 million.

However, these numbers only demonstrate those direct economic costs that can be monetised. As described below, the wider economic impact on the company's future performance will in fact be significantly larger.

The change to the antimony compound based process would reduce BKO's return on capital employed (ROCE) by approximately 5 percentage points. ROCE is a measure of the returns that a company is achieving from the capital employed, i.e. all its long-term funds (equity plus non-current liabilities). It indicates the efficiency and profitability of the company's assets and liabilities. As such, a reduced ROCE will make BKO less attractive from its owners view, which will make the owners less likely to invest in developing the plant or even in maintaining its current level.

As a consequence, there would be a reduction in the expansion investments that BKO continually undertakes (i.e. projects undertaken to develop the plant). It is anticipated that the sustaining investments would be reduced too, i.e. the projects to maintain the general condition of the plant (e.g. replacement of parts, etc.). What is expected to follow from this lack of investment is a creeping decline of the general condition of the plant, resulting in lower availability of equipment and thus decreased production and profitability. This, in turn, will decrease the levels of investment even further, resulting in a spiral of decline.

It is important to note that the numbers used in the calculations are from 2012, which was a relatively good year for BKO. However, the company operates in a cyclical industry that is sensitive to economic trends and market conditions. As such, it needs to be able to cope in an economic downturn. In the scenario of changing to the antimony compound based process, BKO's ability to stay profitable during bad economic times will worsen significantly.

Cost transferability

Zinc metal is a commodity product, which is produced without differentiation by zinc metal producers around the world. Its price is determined daily by supply and demand at the London Metal Exchange.

Global zinc mine (i.e. raw material) production was 12.95 million tonnes (Mt) in 2012. In the same year, the smelters' global zinc metal production capacity was 15.622 Mt. The global zinc consumption was 12.81 Mt. The Wood Mackenzie forecast for 2013 was 13.24 Mt of global zinc mine production, 16 Mt of global zinc metal production capacity and 13.52 Mt of global zinc consumption.[10]

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[10] Wood Mackenzie (2013)

These data shows that the zinc metal production capacity has been exceeding both the raw material (zinc mine) production and the consumption volume of zinc. It implies that, caught in the middle, the zinc metal producers are not exactly the price setters.

Therefore, it can be concluded that the cost incurred by changing from the As_2O_3 process to the antimony compound based process is not transferable to the players along the supply chain, neither upstream nor downstream. The cost as a whole has to be borne solely by BKO.

Sensitivity analysis

The methodology used in the above economic feasibility study is the cost calculation method recommended in the ECHA's guidance document. The investment costs have been annualised and the net present costs calculated by applying the 4% discount rate. Assumptions regarding zinc prices, exchange rates and treatment charges are based on average numbers of the year 2012. As the assumptions are based on real and recent numbers, the analysis is considered robust and transparent.

Nevertheless, the zinc industry is very cyclical and sensitive to global economic conditions. In order to be prudent, the sensitivity analysis below looks at how the conclusions are affected by changes in the price of zinc, the EUR/USD exchange rate and the treatment charge. Furthermore, the costs are also re-calculated by applying BKO's own Internal Rate of Return (IRR).

<u>Zinc price, treatment charge and exchange rate</u>

The zinc price, treatment charge and exchange rate variables are closely connected and are therefore examined simultaneously. The table below presents how changes to each variable at a time affect the final cost to BKO. The ranges of the variables are minimum and maximum values that are considered realistic based on values in the past.

The only cost item that changes in the calculations is the annual revenue loss, and the table below outlines how that affects the net present cost to BKO. The first row contains the values used in the main analysis. After that, the variable being analysed for its sensitivity is marked in italics and underlined in each row.

Table 10. Sensitivity analysis for zinc price, treatment charge and exchange rate

Zinc price	**Treatment charge (€/tonne)**	**EUR/USD exchange rate**	**Annual revenue loss**	**Net present value of changeover to BKO**
$1948	179.01	1.2931	Confidential	-€104.225 million
$1948	179.01	*<u>1.450</u>*	Confidential	-€96.597 million
$1948	179.01	*<u>1.150</u>*	Confidential	-€112.964 million
$1948	*<u>250</u>*	1.2931	Confidential	-€118.785 million
$1948	*<u>150</u>*	1.2931	Confidential	-€98.264 million
<u>$2500</u>	179.01	1.2931	Confidential	-€112.118 million
<u>$1500</u>	179.01	1.2931	Confidential	-€97.822 million

As shown in the last column above, the net present cost to BKO is significant with all tested variables. We will also see how the results are affected by using a combination of all variables giving the highest and the lowest costs simultaneously. The results are shown in the table below.

Table 11. Sensitivity analysis: worst and best case scenarios

Zinc price	**Treatment charge (€/tonne)**	**EUR/USD exchange rate**	**Annual revenue loss**	**Net present value of changeover to BKO**
$2500	250	1.15	Confidential	-€138.234 million
$1500	150	1.45	Confidential	-€85.596 million

The sensitivity analysis of the zinc price, treatment charge and EUR/USD exchange rate has demonstrated that even the application of all the “best”, as well as all the “worst”, values gives a significant net present cost to BKO, making the alternative clearly economically unfeasible.

Discount rate

The values have been re-calculated with BKO’s own Internal Rate of Return (IRR). However, as the IRR is claimed confidential due to competition reasons, the results (including Table 12) are not made available in the public version of the AoA.

Conclusions

The analysis above has demonstrated that the cost of changing to the antimony compound based process would amount to a net present value of approximately €104 million. This amount is based only on those direct costs that are easily monetised. In reality, the change would results in consequence much larger than the direct costs, such as decreased investments and a creeping decline of the general conditions of the plant.

As a player in the highly cyclical and volatile industry of zinc production, BKO cannot afford such a decrease in its profitability. A continuous development of the plant is essential to maintain its competitiveness in the global market.

Based on the significant net present cost as well as the long-term economic consequences of changing to the antimony process, it can be concluded that the alternative is not economically feasible. The sensitivity analysis also supports this conclusion with a range of different variables.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

The confidential information is contained in Section 4.3 Economic feasibility, on page 2 of the Confidential Annex to Analysis of Alternatives.

4.2.4 REDUCTION OF OVERALL RISK DUE TO TRANSITION TO THE ALTERNATIVE

Based on the intrinsic properties described in Section 4.2.1, the Sb_2O_3 is in general less toxic than As_2O_3. Some risk reduction would, therefore, be expected if the process used Sb_2O_3 in as strictly a controlled environment and to an equivalent level to that of the As_2O_3 process.

However, several factors should be considered. The risks of the process based on As_2O_3 are demonstrated to be under control, as shown in Chapters 9 and 10 of the CSR. Furthermore, arsenic compounds are always present in the zinc ore and, as demonstrated in Table 2 in Section 4.1, any cessation in its use will result in less than a 9% reduction in releases to the air and less than a 4% release to the sea, whilst increasing the environmental exposure of antimony. The current risk management measures carried out in BKO are also optimised for the As_2O_3 process and therefore the possibility exists that, during a changeover period, and shortly thereafter, risks may increase due to inexperience with the Sb_2O_3 process.

Furthermore, the local ecosystem has adapted to the presence of arsenic over the course of several decades. By introducing a new hazardous substance, the balance in the ecosystem may be disturbed and the consequences are difficult to predict. In addition, Sb_2O_3 has a harmonized CLP classification of Carc. 2 and is contained on the ChemSec SIN list of substances that meet the criteria for SVHC classification under the REACH regulation and, with annual tonnage of > 10,000 tonnes for mostly non-intermediate uses, it is conceivable that this substance could become subject to authorisation sometime in the near future.

The uncertainty as to the possible authorisation of this prospective alternative provides a major risk to BKO should they begin moving their process to using it. Huge technological investments would be needed with no guarantee that an authorisation application would not be required for the alternative before the lifespan of the modified plant elapsed. Additionally, any move to an antimony based process will only result in slight reductions to arsenic release, with commensurate increase in antimony releases and may also have a knock-on effect for the local ecosystem.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.2.5 AVAILABILITY

The substance is commercially available and affordable.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.2.6 CONCLUSION ON SUITABILITY AND AVAILABILITY FOR ALTERNATIVE 1

The conclusion drawn on Alternative 1, Sb2O3, are summarised below.

Table 12. Summary of the analysis of the alternative 1

Criteria	**Conclusion**
Technical feasibility	Feasible
Economic feasibility	NPV of accumulative cost related to the transition to the alternative in the next 20 years is: €104 million
Reduction of overall risk due to transition to the alternative	The risk with the current process is already reduced to a minimum. The change to Sb_2O_3 is unlikely to have significant beneficial impacts on human health and the environment. Any move to an antimony based process will only result in slight reductions to arsenic release, with commensurate increase in antimony releases and may also have a knock-on effect for the local ecosystem. The maximum benefit to human health and environment if a non-hazardous substance is introduced is in the range of €13.4 million to €33.5 million, as explained further in the socio-economic analysis report.
Availability	Available
Conclusion	**The change to the Sb_2O_3 based process is economically unfeasible and without substantial risk reduction potential, therefore this alternative cannot be considered suitable for BKO.**

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.3 ALTERNATIVE 2

4.3.1 SUBSTANCE ID AND PROPERTIES

Table 13. Substance information of alternative 2

Substance name	**List**	**CAS**	**Classification (CLP)**	**REACH status**
Antimony potassium tartrate $K_2Sb_2(C_4H_2O_6)_2$	608-190-2	28300-74-5	***No harmonized classification****	Pre-registered, envisaged registration date 31/5/2018

*There is a harmonized classification, index no 051-003-00-9, for antimony compounds with the exception of the tetroxide (Sb_2O_4), pentoxide (Sb_2O_5), trisulphide (Sb_2S_3), pentasulphide (Sb_2S_5) and those specified elsewhere in Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation).

The literature review of the toxicological information on antimony potassium tartrate ($K_2Sb_2(C_4H_2O_6)_2$) indicates that the existing data raises some health concerns. There is indication that the substance may induce mutations in human and there is also concern about potential carcinogenicity[11]. In general, the available information on $K_2Sb_2(C_4H_2O_6)_2$ is very limited and relatively old. Thus, the hazard assessment of most endpoints is based on published results of the experiments that often do not fulfil the current guideline requirements of the toxicological studies.

Acute toxicity

Acute toxicity of $K_2Sb_2(C_4H_2O_6)_2$ has been investigated in experimental animals. A review of this data shows that oral route of administration resulted LD_{50} value of 600 mg/kg/bw for mouse and 115 mg/kg bw for rat and rabbit[12]. In human the reactions to the substance are variable and are dependent on size, age and general health. It is reported that the fatal dose in man is 130 mg, although a 15,000 mg dose has been survived[13]. The signs and symptoms of oral exposure may include abdominal cramps, nausea, vomiting and diarrhoea. Exposure to dust or fumes may cause gingivitis, rhinitis, chest tightness, shortness of breath, bronchitis, pulmonary edema, headache and dizziness[14]. There is no data available on acute systemic effects after administration of the substance *via* dermal route.

Irritation

Antimony compounds are skin irritants although antimony dermatitis typically occurs during chronic occupational exposure. When $K_2Sb_2(C_4H_2O_6)_2$ is rubbed on the skin in the form of ointment, it produces little irritation at first but produces a pustular eruption if applied for long periods. This is due to the decomposition of the double salt by the acid secretions of the follicles

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[11] Paton and Allison (1972); Merian et al. (2004); El Aser et al. (1979); & Kelada et al. (1972)

[12] Browning (1969)

[13] Gosselin et al. (1984)

[14] Renes (1953) & Taylor (1966)

leading to formation of the more irritating antimony oxides and other compounds[15]. Although there is evidence that the exposure to a high concentration of the substance produces eye irritation[16], the data available is of poor quality and insufficient for assessment.

Generally dusts and fumes of antimony and its compounds are irritants to the respiratory tract and mucous membranes and inhalation causes conjunctivitis, laryngitis, pharyngitis, tracheitis, rhinitis and bronchitis[17]. After single exposure at high concentration, $K_2Sb_2(C_4H_2O_6)_2$ caused airway irritation and pulmonary edema.

Sensitisation

Currently there is no data available to evaluate the skin sensitisation potency of antimony potassium tartrate.

Repeated dose toxicity

The medicinal use of antimony potassium tartrate often causes symptoms of overdose, since the therapeutic dose is close to the toxic dose. Adverse effects, especially on the heart and cardiovascular system have been detected. In 7 out of 12 patients undergoing a course of $K_2Sb_2(C_4H_2O_6)_2$ therapy electrocardiographic abnormalities were observed. These changes were attributed to intoxication of the heart muscle[18].

Further signs and symptoms of chronic exposure of $K_2Sb_2(C_4H_2O_6)_2$ by inhalation may include laryngitis, tracheitis, bronchitis, pneumonitis, pneumoconiosis, ulceration of the nasal septum and larynx, and contact allergy to metal[19].

Moreover, hepatotoxicity is observed typically during prolonged therapy with antimony potassium tartrate[20]. There is also evidence in animal studies that the organ chiefly affected after oral, subcutaneous and intravenous (IV) administration is the liver[21]. These observations are supported by the results of toxicokinetic studies where more than 50% of labelled $K_2Sb_2(C_4H_2O_6)_2$ was detected in liver following the iv administration[22]. Toxicity of $K_2Sb_2(C_4H_2O_6)_2$ was investigated in the 13 week IP injection study in rats and mice[23]. The substance was given at doses of 0, 1.5, 3, 6, 12 and 24 mg/kg bw and the injection interval was 3 times per week. Based upon histopathology and clinical pathology, the liver was identified as the most sensitive target organ for $K_2Sb_2(C_4H_2O_6)_2$ toxicity. There was evidence of hepatocyte degeneration and necrosis, accompanied by dose related elevations in activities of liver specific serum enzymes derived from

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[15] Hayes (1991)

[16] Pohanish (2002)

[17] Renes (1953) & Taylor (1966)

[18] Browning (1969)

[19] NITE (2010)

[20] Pohanish (2002)

[21] Browning (1969)

[22] Abdel-Wahab (1974)

[23] NTP (1992)

the cytosolic cell compartment. Based on these results the NOAEL was established 5.1 mg/kg bw/day.

The most recent short-term drinking water study showed $K_2Sb_2(C_4H_2O_6)_2$ to be of low toxicity in rats and mice. No clinical signs were detected that were related to chemical treatment. Increases in relative liver weight occurred in male and female rats that were given the highest dose of $K_2Sb_2(C_4H_2O_6)_2$; in addition, there was an increase in relative kidney weight in females from this dose group. There were no histopathological changes attributed to chemical treatment, except in dosed male rats, where protein droplets normally present in the cytoplasm of the renal tubular epithelium were stained somewhat more prominently than in the kidney of control rats. The NOAEL in this 14-day study was 168 mg/kg bw/day in rats.[24]

Genetic toxicity

Trivalent antimony compounds, including $K_2Sb_2(C_4H_2O_6)_2$, generally show negative results in Salmonella mutagenicity assays, but are positive in mutagenicity tests with animal and human cells.

Antimony potassium tartrate increased the frequency of chromosomal aberrations in bone marrow cells of rats at 6, 24, and 48 hours after single injection[25]. In another study, the substance at a low concentration (2.3×10^{-9} M), produced a significant increase in chromosomal aberrations in 48 hour cultures of human leukocytes[26]. Furthermore, results from the related chemical, piperazine antimony tartrate, has also demonstrated clastogenicity in *in vivo* test. The substance has also been shown positive in several mutagenicity test systems of human cells *in vitro*[27]. Based on these results there is concern that $K_2Sb_2(C_4H_2O_6)_2$ may have the possibility to induce heritable mutations in the germ cells in humans.

Carcinogenicity

There is some evidence that occupational antimony exposure is associated with an increased risk of lung cancer. There is also some concern about the potential carcinogenicity of $K_2Sb_2(C_4H_2O_6)_2$, based on an unconfirmed association between drug treatment and bladder tumours in human[28]. However, three chronic carcinogenicity studies with antimony potassium tartrate were negative in rats and mice, but these studies were considered inadequate for assessment of carcinogenicity because of obvious limitations in dose, route, sample number and histopathology[29].

Toxicity to reproduction

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[24] NTP (1992)

[25] El Nahas (1982)

[26] Paton and Allison (1972)

[27] Merian et al. (2004)

[28] El Aser et al. (1979) & Kelada et al. (1972)

[29] Kanisawa and Schroeder (1969) & Schroeder et al. (1970)

Antimony compounds generally have been found to cause premature births and spontaneous abortions in women, growth retardation in children and sexual dysfunction in males. The potential reproductive toxicity of $K_2Sb_2(C_4H_2O_6)_2$ has been evaluated in one good quality repeated toxicity study in rats and mice[30]. Sperm motility, morphology and vaginal cytology were investigated in animals administered antimony potassium tartrate intraperitoneally for 13 weeks. The only effect in reproductive tissue evaluation was a decrease in the testicular weights of mice but these changes were not dose-related. Antimony potassium tartrate treatment did not affect sperm count or motility, and there were no effects on the average oestrous cycle length in females. Thus, the NOAEL for reproduction toxicity (rat, mouse) is concluded to be > 10.2 mg/kg bw / day, the highest exposure level tested. Based on these observations there is no concern that $K_2Sb_2(C_4H_2O_6)_2$ would have adverse effects on male or female fertility.

Environment risks

Currently there are no specific studies conducted for $K_2Sb_2(C_4H_2O_6)_2$ to assess environmental hazards. Environmental hazard assessments conducted for antimony trioxide is considered to be valid for various antimony compounds, including antimony potassium tartrate. Both Sb_2O_3 and $K_2Sb_2(C_4H_2O_6)_2$ dissolve in the aqueous environment releasing antimony in the trivalent state. In aerobic water, dissolved antimony mostly occurs at the pentavalent state, the primary species being $[Sb(OH)_6]^-$. In anaerobic water, antimony is primarily Sb(III), probably as $Sb(OH)_3$. There is no conclusive evidence to support a significant difference in the ecological hazards associated with exposure to pentavalent or trivalent forms of antimony.

The National Institute of Technology and Evaluation (NITE) of Japan has classified antimony potassium tartrate into acute toxicity category 3 based on the LC_{50} value of 12 mg/L obtained from the fish study. Based on this acute classification and on their conclusions that the behaviour of the substance in water and its bioaccumulation potential are unknown, they have classified the substance for chronic category 3 according to GHS.

Table 14. Comparison of classifications of diarsenic trioxide and antimony potassium tartrate

Diarsenic Trioxide *Harmonized classification*	**Antimony Potassium Tartrate** *No harmonized classification**	
	C&L inventoy[**]	*NITE* [***]*according to GHS*
Acute Tox. 2	Acute Tox. 4 (oral)	Acute Tox. 3 (oral)
Skin Corr. 1B	Acute Tox. 4 (inhalation)	Skin Irrit. 3
Carc. 1A		Muta. 2

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[30] NTP (1992)

		Carc. 2
		STOT-SE 1 (respiratory tract irritation)
		STOT-RE 1 (lung, heart) STOT-RE 2 (liver)
Aquatic Acute 1	Not classified for environmental hazards	Aquatic acute 3
Aquatic Chronic 1		Aquatic chronic 3

* There is a harmonized classification, index no 051-003-00-9, for antimony compounds with the exception of the tetroxide (Sb_2O_4), pentoxide (Sb_2O_5), trisulphide (Sb_2S_3), pentasulphide (Sb_2S_5) and those specified elsewhere in Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation). The classification is: Acute Tox. 4 (Oral); Acute Tox.4 (Inhalation); Aquatic Chronic 2.

**C&L Inventory database of ECHA;

http://echa.europa.eu/web/guest/information-on-chemicals/cl-inventory-database

***National Institute of Technology and Evaluation of Japan; http://www.safe.nite.go.jp/english/index.html

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.3.2 TECHNICAL FEASIBILITY

The $K_2Sb_2(C_4H_2O_6)_2$ based process is in essence the same as the Sb_2O_3 based process. The two compounds are used interchangeably in industry. So the technical feasibility analysis is the same as in 4.2.2.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.3.3 ECONOMIC FEASIBILITY

The $K_2Sb_2(C_4H_2O_6)_2$ based process is in essence the same as the Sb_2O_3 based process. The two compounds are used interchangeable in industry. So the economic feasibility analysis is the same as in 4.2.3.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.3.4 REDUCTION OF OVERALL RISK DUE TO TRANSITION TO THE ALTERNATIVE

Based on the intrinsic properties described in Section 4.3.1, there is evidence that $K_2Sb_2(C_4H_2O_6)_2$ could also be mutagenic and carcinogenic. However, the substance may be regarded as a threshold carcinogen. $K_2Sb_2(C_4H_2O_6)_2$ is also generally less toxic than As_2O_3. Some risk reduction would, therefore, be expected if the process used $K_2Sb_2(C_4H_2O_6)_2$ in as strictly a controlled environment and to an equivalent level to that of the As_2O_3 process.

However, several factors should be considered. The risks of the process based on As_2O_3 are demonstrated to be under control, as shown in Chapters 9 and 10 of the CSR. Furthermore, arsenic compounds are always present in the zinc ore and, as demonstrated in Table 2 in Section 4.1, any cessation in its use will result in less than a 9% reduction in releases to the air and less than a 4% release to the sea, whilst increasing the environmental exposure of antimony. The current risk management measures carried out in BKO are also optimised for the As_2O_3 process and therefore the possibility exists that, during a changeover period, and shortly thereafter, risks may increase due to inexperience with the $K_2Sb_2(C_4H_2O_6)_2$ process.

Furthermore, the local ecosystem has adapted to the presence of arsenic over the course of several decades. By introducing a new hazardous substance, the balance in the ecosystem may be disturbed and the consequences are difficult to predict. If after further study and registration under REACH, $K_2Sb_2(C_4H_2O_6)_2$ will be classified as carcinogenic and mutagenic according to CLP, it may undergo the authorisation route in the future.

The uncertainty as to the possible authorisation of this prospective alternative provides a major risk to BKO should they begin moving their process to using it. Huge technological investments would be needed with no guarantee that an authorisation application would not be required for the alternative before the lifespan of the modified plant elapsed. Additionally, any move to an antimony based process will only result in slight reductions to arsenic release, with commensurate increase in antimony releases and may also have a knock-on effect for the local ecosystem.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.3.5 AVAILABILITY

The $K_2Sb_2(C_4H_2O_6)_2$ based process is in essence the same as the Sb_2O_3 based process. The two compounds are used interchangeably in industry. Antimony potassium tartrate is currently available on the market and is affordable.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

4.3.6 CONCLUSION ON SUITABILITY AND AVAILABILITY FOR ALTERNATIVE 2

Table 15. Summary of the analysis of alternative 2

Criteria	**Conclusion**
Technical feasibility	Feasible
Economic feasibility	NPV of accumulative cost related to the transition to the alternative in the next 20 years is: €104 million
Reduction of overall risk due to transition to the alternative	The risk with the current process is already reduced to a minimum. The change to $K_2Sb_2(C_4H_2O_6)_2$ is unlikely to have significant beneficial impacts on human health and the environment. Any move to an antimony based process will only result in slight reductions to arsenic release, with commensurate increase in antimony releases and may also have a knock-on effect for the local ecosystem. The maximum benefit to human health and environment if a non-hazardous substance is introduced is in the range of €13.4 million to €33.5 million, as explained further in the socio-economic analysis report.
Availability	Available
Conclusion	**The change to the $K_2Sb_2(C_4H_2O_6)_2$ based process is economically unfeasible and without substantial risk reduction benefit, therefore this alternative cannot be considered suitable for BKO.**

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

5 OVERALL CONCLUSIONS ON SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES

In the search of a suitable alternative for the As_2O_3 based process used by BKO, no other industrial scale solution has been identified other than the so-called antimony compound based technology.

Although the antimony based zinc production process does indeed exist industrially, the proprietary As_2O_3 based process used by BKO is superior in a number of ways as described in Section 4.2.2. If

BKO has to change to the antimony compound based process, its production efficiency will decrease, which is a cost item in addition to the investment and related costs. The cost of changing to the antimony compounds based process would amount to a net present value of approximately €104 million. This amount is based only on those direct costs that are easily monetised. In reality, the change would result in consequences much larger than the direct costs, such as decreased investments and a creeping decline of the general condition of the plant. As a company operating in the highly cyclical and volatile industry of zinc production, BKO cannot afford such a decrease in its profitability. Continuous development of the plant is essential to maintain its competitiveness in the global market.

The changeover to the antimony compounds based process would therefore be a step back in the technology sense and economically highly unfavourable.

In addition, the plant underwent large scale modification to improve work safety and control of its releases to the environment in the early 2000s. Its work safety and environmental releases are currently strictly controlled and pose very little risks to society. Even though it is true that the carcinogenicity is a non-threshold property and traditional risk assessment method can’t fully evaluate the risks involved, the impacts of the remaining risk were evaluated and proven to be inferior compared to the cost of not being able to continue using As_2O_3.

Should BKO change to the antimony compound based process, there will be a resultant imbalance of costs and benefits. The antimony alternatives are economically unfeasible and lack substantial risk reduction potentials. Apart from the antimony compounds, no other industrial scale alternative could be identified. Therefore, it is concluded that there is currently no suitable alternative to replace the As_2O_3 use at BKO.

Reference to section in *Confidential Annex to Analysis of Alternatives (file name, section name and number, page number, etc.):*

There is no confidential information in this section of the report.

6 RESEARCH PLAN TO REDUCE RISKS

BKO is committed to actively follow all development in the area, and adapt a suitable solution to replace As_2O_3 once available. But as one single company, it is difficult for BKO alone to play a significant role in such large scale and critical process step development. It requires general scientific know-how development, and it will take a long time for such solutions to be developed. The function As_2O_3 performs is associated with the substances’ intrinsic properties, and is not something easily adapted. In addition, because of the high amount of investment needed, there needs to be demonstrable success in an alternative before any decision can be made to move to it. To illustrate, the As_2O_3 and antimony compounds based technologies have been in use since 1929, and not much has changed since then apart from increased and more modern risk management measures.

On an industry level, it is estimated that the next major technology innovation may happen, at the earliest, in 20-30 years. So for BKO the adaptation of suitable alternatives is not considered realistic until then. BKO has nevertheless planned its R&D activities to improve the operational conditions and risk management measures to further reduce the risks associated with the use of As_2O_3 in the current process.

As the zinc production industry is very capital intensive, any changes to operations require substantial investments and involve a high degree of uncertainty. BKO's current facilities are in excellent condition and are expected to be operational for at least 20 more years. Due to the long investment cycle, any major changes to the plant's operations would only be recommendable when the next major technical overhaul takes place, which is likely to be in 20-30 years.

It is therefore suggested that BKO is granted authorisation for a review period that will coincide with the next major changes to the plant, as it is highly unlikely that any feasible alternatives will be available to the company in the short- to mid-term. A long review period would allow BKO to take advantage of the investments already made in the plant's production efficiency and environmental performance. The socio-economic analysis supports this conclusion, as the remaining risks associated with the continued use of As_2O_3 are low while the socio-economic benefits are high.

7 GLOSSARY

Annex XIV	Chemicals requiring authorisation under REACH
AoA	Analysis of Alternatives
As	Arsenic
As_2O_3	Diarsenic trioxide
BAT	Best Available Techniques
BCF	Bioconcentration factor
BKO	Boliden Kokkola Oy
bw	Body weight
Cd	Cadmium
CLP	Chemicals Labelling and Packaging
CMR	Carcinogenic, Mutagenic or toxic to Reproduction
Co	Cobalt
CSR	Chemicals Safety Report
Cu	Copper
dw	Deionised water
ECHA	European Chemicals Agency
ES	Exposure Scenario
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
IP injection	Intraperitoneal injection
IPPC	Directive on Integrated Pollution Prevention and Control
IRR	Internal rate of return
$K_2Sb_2(C_4H_2O_6)_2$	Antimony potassium tartrate
K_d	Partition (or distribution) coefficient
KIP	Kokkola Industrial Park
LC_{50}	Lethal concentration, 50%
LD_{50}	Lethal dose, 50%
LME	London Metal Exchange
mg	Milligram
Mt	Million tonnes

ng	Nanogramme
Ni	Nickel
NITE	National Institute of Technology and Evaluation of Japan
NOAEC	No Observed Adverse Effect Concentration
NOAEL	No Observed Adverse Effect Level
NPV	Net present value
OC	Operating conditions
PM_{10}	Particulate matter in the air with diameter less than or equal to 10 micrometer
RCR	Risk characterisation ratios
REACH	Registration, evaluation, authorisation (and restriction) of chemicals
RLE	Roast-leach-electrowinning
RMM	Risk management measures
ROCE	Return on capital employed
Sb	Antimony
Sb_2O_3	Diantimony trioxide
$SbCl_3$	Antimony trichloride
$Sb(OH)_3$	Antimonous acid
$[Sb(OH)_6]^-$	Antimonate ion
SEA	Socio-economic Analysis
SVHC	Substances of Very High Concern
VAT	Value Added Tax
Zn	Zinc

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