Australian Government

Department of Health and Aged Care
Australian Industrial Chemicals Introduction Scheme

Water soluble arsenic compounds

Evaluation statement

26 June 2023

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AICIS evaluation statement

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Water soluble arsenic compounds

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Reason for the evaluation

Evaluation is needed to provide information on environmental risks.

Parameters of evaluation

This evaluation considers the environmental risks associated with industrial uses of the chemicals. The chemicals are listed on the Australian Inventory of Industrial Chemicals (the Inventory). The chemicals in this group have been assessed for their risks to the environment according to the following parameters:

- Industrial uses listed in the '**Summary of introduction, use and end use**' section

- Expected release into sewage treatment plants, the water, soil, and air compartments.

These chemicals have been assessed as a group because all 13 inorganic arsenic chemicals are readily soluble in water and can release bioavailable forms of arsenic. This is expected to characterise their environmental fate and ecotoxicity profiles. This evaluation provides information on the environmental fate and effects of arsenic ions that may be referred to in future evaluations of arsenic-containing substances listed on the Australian Inventory of Industrial Chemicals (the Inventory).

Summary of evaluation

Summary of introduction, use and end use

Arsenic pentoxide (As_2O_5, CAS No. 1303-28-2) and arsenic trioxide (As_2O_3, CAS No. 1327-53-3) were reported to be introduced into Australia in volumes of <0.1 tonnes per year (t/year) and 100–1000 t/year, respectively. Available information indicates that most of the arsenic trioxide volume is introduced for non-industrial uses.

No specific Australian use, import, or manufacturing information has been identified for the other chemicals in this group.

Based on domestic and international use information, the end uses of the substances in this evaluation are:

- Colourant in ceramic glazes
- Adhesive and sealant products
- Manufacture in semi-conductors
- Starting materials for other arsenic chemicals
- Manufacture of glass and ceramics
- Fabric, textile, and leather products not covered by other end uses.

Potential uses in metal manufacture are not considered in this evaluation.

Environment

Summary of environmental hazard characteristics

The primary environmental effects of the chemicals in this group are expected to be caused by the release of arsenic ions, which are very toxic to aquatic organisms and bioaccumulate in most organisms.

It is not currently possible to categorise the environmental hazards of metals and other inorganic chemicals according to standard persistence, bioaccumulation, and toxicity (PBT) hazard criteria. Nevertheless, there is an international consensus that bioavailable forms of arsenic are highly toxic to the environment.

Environmental hazard classification

The classification of the water soluble arsenic chemicals in this evaluation are based on the identified ecotoxicity values for As(V) and As(III), in accordance with the classification procedure for metals and metal compounds under the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) (UNECE 2021).

The aquatic hazards associated with the chemicals in this group are dependent on their capacity to release As(V) and As(III) oxyanions at concentrations that exceed identified acute toxicity thresholds. All the chemicals in this group are classified as Acute Aquatic Category 1, as all their EC50 values were substantially lower than their measured or predicted solubilities and the lowest EC50 of the dissolved As(V) oxyanion is <1 mg/L. They are also classified as Chronic Aquatic Category 1 as arsenic has the potential to bioaccumulate in aquatic organisms. This does not consider classification of physical or human health hazards:

Environmental Hazard	Hazard Category	Hazard Statement
Hazardous to the aquatic environment (acute / short-term)	Aquatic acute 1	H400: Very toxic to aquatic life
Hazardous to the aquatic environment (long-term)	Aquatic chronic 1	H410: Very toxic to aquatic life with long lasting effects

Summary of environmental risk

The principal environmental concern for the chemicals in this group is their potential to release bioavailable arsenic ions into the environment. Arsenic is recognised as a highly toxic environmental contaminant. High acute exposures cause immediate mortality and chronic exposures cause mortality and/or impaired growth across all taxa. Toxicity and bioaccumulation of arsenic is generally highest in aquatic organisms, followed by sediment-dwelling and terrestrial organisms.

The known industrial uses of these chemicals in Australia require very low volumes in sectors in which their use and disposal are highly controlled. The chemicals are most likely to be released to air, water, and soil compartments via spills, leaks during manufacturing of chemicals, glass, ceramics, and abrasion of articles during industrial processes. Arsenic emissions arising from such processes are expected to be small compared to other sources of arsenic in Australia, such as mining, metal manufacture and burning of fossil fuels.

Therefore, the industrial use of these chemicals in Australia is not expected to pose a significant risk to the environment.

Conclusions

The conclusions of this evaluation are based on the information described in this evaluation statement.

The Executive Director is satisfied that the identified environment risks can be managed within existing risk management frameworks. This is provided that all requirements are met under environmental, workplace health and safety and poisons legislation as adopted by the relevant state or territory.

Note: Obligations to report additional information about hazards under *Section 100* of the *Industrial Chemicals Act 2019* apply.

Supporting information

Rationale

This evaluation considers the environmental risks associated with industrial uses of 13 water-soluble inorganic arsenic chemicals.

The risk assessment of these chemicals has been carried out as a group because all 13 inorganic arsenic chemicals are readily soluble in water and can release bioavailable forms of arsenic. This assessment considers compounds that contain arsenic in one of 2 oxidation states, +3 and +5, commonly denoted as As(III) and As(V), respectively. Because inorganic arsenic readily cycles between these 2 oxidation states in all environmental compartments (Kitchin and Ahmad 2003; Oremland and Stolz 2003; WHO 2003), the environmental hazard, fate, and risk of water-soluble arsenic(+3) and arsenic(+5)-containing chemicals are considered together.

Chemical identity

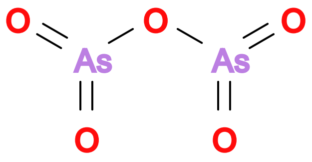
Arsenic can exist in one of 4 oxidation states, -3, 0, +3, and +5. Arsenic is generally present in the environment in the +3 or +5 oxidation state, commonly denoted as As(III) and As(V), respectively and can interconvert between As(III) and As(V) depending on environmental conditions. Arsenic is a metalloid that does not dissociate to positively charged ions (cations) like most metals in water. Instead, inorganic arsenic exists bound to oxygen and possesses a negative charge, known as an oxyanion.

In natural waters, dissolved inorganic arsenic compounds that contain As(V) will hydrolyse to form one of the following arsenic acid species (arsenates): H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$, AsO_4^{3-}. As(III)-containing inorganic compounds will hydrolyse to one of the following arsenous acid species (arsenites): H_3AsO_3 or $H_2AsO_3^-$. The degree of protonation in solution will depend on the pH. For arsenic acid, the main As(V) species at pH <2 is H_3AsO_4, followed by $H_2AsO_4^-$ between pH 2 and 7, $HAsO_4^{2-}$ between pH 7 and pH 12, and AsO_4^{3-} at pH >12. For arsenous acid, the main As(III) species at pH <9.5 is H_3AsO_3 and $H_2AsO_3^-$ at pH > 9.5 (Smedley and Kinniburgh 2002). Within typical environmental pH ranges of 6.5 to 8.5, the dominant As(V) species will be a mixture of $H_2AsO_4^-$ and $HAsO_4^{2-}$, and the dominant As(III) species will be H_3AsO_3. For simplicity, this evaluation will discuss arsenic oxyanions as either As(V) or As(III), regardless of the degree of protonation, unless otherwise specified.

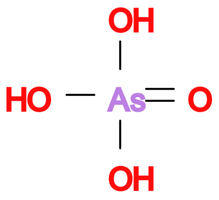
Arsenous acid (CAS No. 13465-58-9) is not listed on the Inventory, but the As(III)-containing compounds that are being evaluated in this group will dissolve/hydrolyse to arsenous acid in solution. Therefore, the structure and physical and chemical properties are provided in the relevant sections.

Arsenic (V) chemicals

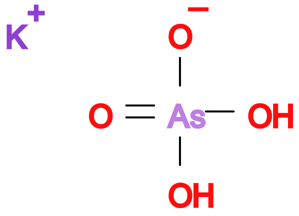
Chemical name	Arsenic oxide (As_2O_5)
CAS No.	1303-28-2
Synonyms	Arsenic pentoxide Diarsenic pentaoxide Diarsenic pentoxide
Molecular formula	As2O5
Molecular weight (g/mol)	229.84
SMILES	O=[As](=O)O[As](=O)=O
Structural formula:	



Chemical name	Arsenic acid (H_3AsO_4)
CAS No.	7778-39-4
Synonyms	-
Molecular formula	AsH3O4
Molecular weight (g/mol)	141.94
SMILES	O=[As](O)(O)O
Structural formula:	



Chemical name	Arsenic acid, monopotassium salt
CAS No.	7784-41-0
Synonyms	Arsenic acid (H_3AsO_4), potassium salt (1:1) Potassium dihydrogen arsenate Potassium arsenate
Molecular formula	AsH2O4.K
Molecular weight (g/mol)	180.03
SMILES	O=[As](O)(O)O.[K]
Structural formula:	



Chemical name	Arsenic acid, dipotassium salt
CAS No.	21093-83-4
Synonyms	Dipotassium arsenate Potassium arsenate
Molecular formula	AsHO4.2K
Molecular weight (g/mol)	218.12
SMILES	O=[As]([O-])([O-])O.[K+].[K+]

Chemical name	Arsenic acid, sodium salt
CAS No.	7631-89-2
Synonyms	Arsenic acid, sodium salt (1:?) Sodium arsenate
Molecular formula	AsH3O4.xNa
Molecular weight (g/mol)	Unspecified

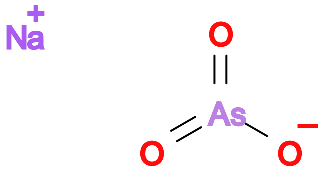
Chemical name	Arsenic acid, disodium salt
CAS No.	7778-43-0
Synonyms	Disodium hydrogenarsenate Disodium arsenate Sodium arsenate Arsenic acid (H_3AsO_4), sodium salt (1:2)
Molecular formula	AsHO4.2Na
Molecular weight (g/mol)	185.90
SMILES	O=[As]([O-])([O-])O.[Na+].[Na+]

Chemical name	Arsenic acid, disodium salt, heptahydrate
CAS No.	10048-95-0
Synonyms	Disodium arsenate heptahydrate Sodium arsenate dibasic heptahydrate Dibasic sodium arsenate ($Na_2HAsO4.7H_2O$) Sodium acid arsenate, heptahydrate
Molecular formula	AsHO4.2Na.7H2O
Molecular weight (g/mol)	312.01
SMILES	O.O.O.O.O.O.O.O=[As]([O-])([O-])O.[Na+].[Na+]

Chemical name	Arsenic acid, trisodium salt
CAS No.	13464-38-5
Synonyms	Trisodium arsenate Arsenic acid (H_3AsO_4), sodium salt (1:3)
Molecular formula	AsO4.3Na
Molecular weight (g/mol)	207.89
SMILES	O=[As]([O-])([O-])[O-].[Na+].[Na+].[Na+]

Chemical name	Arsenenic acid, sodium salt
CAS No.	15120-17-9
Synonyms	Sodium meta-arsenate
Molecular formula	AsO3.Na
Molecular weight (g/mol)	145.91
SMILES	O=[As](=O)[O-].[Na+]

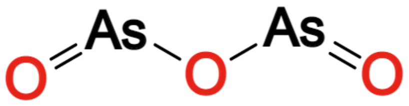
Structural formula:



Arsenic(III) chemicals

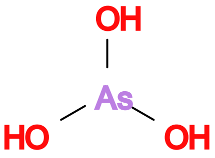
Chemical name	Arsenic oxide (As_2O_3)
CAS No.	1327-53-3
Synonyms	Arsenic trioxide Diarsenic trioxide Arsenous oxide
Molecular formula	As2O3
Molecular weight (g/mol)	197.84
SMILES	-

Structural formula:



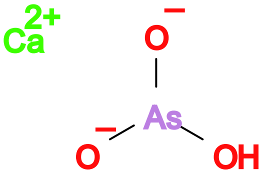
Chemical name	Arsenous acid
CAS No.	13464-58-9
Synonyms	Arsorous acid Arsenious acid
Molecular formula	H3AsO3
Molecular weight (g/mol)	125.94
SMILES	O[As](O)O

Structural formula:

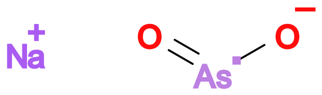


Chemical name	Arsonic acid, calcium salt (1:1)
CAS No.	52740-16-6
Synonyms	Calcium arsenite Arsenous acid, calcium salt (1:1)
Molecular formula	AsHO3.Ca
Molecular weight (g/mol)	164.01
SMILES	O[As]([O-])[O-].[Ca++]

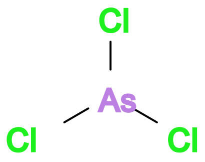
Structural formula:



Chemical name	Arsenenous acid, sodium salt
CAS No.	7784-46-5
Synonyms	Sodium arsenite Sodium dioxoarsenate Arsenenous acid, sodium salt (1:1)
Molecular formula	AsO2.Na
Molecular weight (g/mol)	129.91
SMILES	O=[As][O-].[Na+]
Structural formula:	



Chemical name	Arsenous trichloride
CAS No.	7784-34-1
Synonyms	Arsenic trichloride
Molecular formula	AsCl3
Molecular weight (g/mol)	181.28
SMILES	Cl[As](Cl)Cl
Structural formula:	



Relevant physical and chemical properties

All the compounds in this group are solids under ambient conditions, except for arsenic acid, which can exist as a solid or liquid, arsenous acid, which is reported to only exist in solution, and arsenous trichloride, which is reported to be a liquid (NCBIa n.d.; Othmer et al. 2004). Arsenic acid and sodium arsenite are also reported to be hygroscopic (NCBIb n.d.).

In water, arsenic pentoxide will hydrolyse to arsenic acid and arsenic trioxide and arsenous trichloride will hydrolyse to form arsenous acid. The salts of arsenic acid and arsenous acid will dissociate to the oxyanions of As(V) and As(III), respectively. The solubilities and dissociation constants, expressed as pKa values, of the most relevant compounds in this group are presented in the table below:

Chemical name	CAS No.	Water solubility (mg/L)	pKa
Arsenic pentoxide (As_2O_5)	1303-28-2	658 000	Deliquesces to arsenic acid in air
Arsenic acid (H_3AsO_4)	7778-39-4	590 000	$pKa_1 = 2.25$ $pKa_2 = 6.77$ $pKa_3 = 11.5$
Arsenic trioxide (As_2O_3)	1327-53-3	21000 (25°C)	Hydrolyses to arsenous acid in water
Arsenous acid (H_3AsO_3)	13464-58-9	Only known to exist in aqueous solution	pKa = 9.23

Arsenic pentoxide water solubility and pKa data were obtained (Othmer et al. 2004). All remaining data for arsenic acid, arsenic trioxide, and arsenous acid taken from National Research Council (US) (1977).

No quantitative water solubility data were located for dipotassium arsenate (CAS No. 21093-83-4), sodium arsenate (CAS No. 7631-89-2), trisodium arsenate (CAS No. 13464-38-8), sodium meta-arsenate (CAS No. 15120-17-9), or sodium arsenite (CAS No. 7784-46-5). However, based on similar salts and qualitative descriptions of water solubility of these chemicals, they are also considered readily soluble in water.

The dissociation or hydrolysis of the chemicals in this group will also release hydrogen, potassium, sodium, calcium, and chloride ions. These ions are ubiquitous in the environment and are not considered further in this evaluation.

The vapour pressure of arsenic trioxide is moderately volatile at 100°C, becoming more volatile as temperature increases (highly volatile >240°C) (National Research Council (US) 1977). More than 90% of atmospheric arsenic is sorbed to aerosols, particularly fine aerosols (PM2.5) and has an average atmospheric residence time of 4.1 days in the East Asian region (Wai et al. 2016). Arsenic trichloride is highly volatile at room temperature (1333 pascals at 23.5°C) and readily forms hydrogen chloride and arsenic trioxide (NCBIa n.d.).

Introduction and use

Australia

In Australia, available information indicates that the main industrial uses of chemicals in this group are in laboratory settings. While reported introduction of these chemicals into Australia are in volumes up to 1000 t/year, only a small proportion is expected to be for industrial use.

Of the 13 chemicals in this group, only arsenic pentoxide and (As_2O_5) and arsenic trioxide (As_2O_3) have reported Australian introduction information. Volumes reported in response to a voluntary call for information were <0.1 and 100–1000 t/year, respectively (NICNAS 2013). Reported uses for arsenic pentoxide were laboratory/analytical uses. Arsenic trioxide was introduced for laboratory/analytical, pharmaceutical, and wood preservation uses, and on-selling without reformulation by wholesale resellers. The pharmaceutical and wood preservation uses are not considered in this evaluation as they are considered to be therapeutic and agricultural uses, respectively and are not covered under the *Industrial Chemicals Act 2019*. Indicated volumes of the industrial uses were <1 and <2 kg/year for arsenic pentoxide and arsenic trioxide, respectively. The remainder of the total introduced volume of arsenic trioxide is expected to be for its non-industrial uses, which are beyond the parameters of this evaluation.

Reports of arsenic spills at ammonia production plants also suggests that arsenic trioxide has previously been used to remove carbon dioxide during ammonia production (Smith et al. 2003). This use was not reported in the above call for information, and it is unclear if arsenic trioxide remains in use for this purpose in Australia.

No specific Australian use, import, or manufacturing information has been identified for the other chemicals in this group.

International

Internationally, the main industrial uses of these chemicals are as starting materials for other arsenic compounds. The chemicals are also used in the manufacture of glass, ceramics, semiconductors, and as a mordant in tanning, dyeing, and printing. Although reportedly produced in volumes up to 8339 t/year, a large portion is used for non-industrial applications. Potential uses in metal manufacturing processes have been identified but will not be considered in this evaluation.

Internationally, arsenic trioxide (As_2O_3) and arsenic acid (H_3AsO_4) have the highest reported introduction volumes. Arsenic trioxide , arsenic pentoxide, and arsenic acid are listed as OECD High Production Volume (HPV) chemicals (OECD 2020), which indicates that these chemicals are produced in volumes >1000 tonnes/year.

In Europe, the reported Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) Total Tonnage Band for arsenic trioxide is 100–1000 t/year (REACHa n.d.) and 1–10 t/year for arsenic acid (REACHb n.d.). Arsenic trioxide is reported to be a reagent/intermediate in the zinc refining process and manufacture of arsenic metal (REACHa n.d.). Uses of chemicals in metal manufacture will not be considered in this evaluation. Both arsenic trioxide and arsenic acid are reportedly used as fining agents in glass manufacture. Arsenic acid is also used in the production of copper foil for printed circuit boards (REACHb n.d.). Arsenic trichloride is registered as an intermediate in the manufacture of arsenic containing substances (REACHc n.d.).

In the United States of America (USA), the 2020 reported production volumes for arsenic acid and arsenic trioxide are 106 tonnes and 8147 tonnes, respectively (US EPA 2020). The reported volume for arsenic trioxide is likely underestimated as it also included an unknown amount that was reported as confidential business information.These 2 chemicals are predominantly used as starting materials for other arsenic compounds, mainly pesticides (US EPA 2020; USGS 2021). Uses of chemicals in the preparation of agricultural products are not considered industrial under the *Industrial Chemicals Act 2019* and are beyond the parameters of this evaluation.

Arsenic acid, trisodium salt (CAS No. 13464-38-5) and arsenenic acid, sodium salt (CAS No. 15120-17-9) also have reported use in the manufacture of other arsenic chemicals, but no volume data were identified (Grund et al. 2012).

Arsenic trichloride has various uses, including as a dopant for semiconductor manufacture, colourant in ceramic glazes, starting material for organoarsenic compounds, in the preparation of chlorine derivatives, and as a starting material for production of high purity arsenic metal (Grund et al. 2012; Safe Work Australia 2002). Uses of chemicals in metal manufacture will not be considered in this evaluation.

Arsenic pentoxide is used as a component in metal adhesive (NCBIc) and as a decolouring agent in glass manufacture (Glass Alliance Europe 2012).

Potassium arsenate and trisodium arsenate have uses as mordant/drying chemicals in tanning and printing (Galleria Chemica; Grund et al. 2012).

No specific uses were identified for arsenic acid, dipotassium salt (CAS No. 21093-83-4), arsenic acid, sodium salt (CAS No. 7631-89-2), and arsonic acid, calcium salt (1:1) (CAS No. 52740-16-6).

Several of the chemicals in this group are or have been used in high volumes in agriculture as pesticides, herbicides, and a wood preservative (APVMA 2005; Grund et al. 2012; Othmer et al. 2004). Arsenic trioxide use in pesticide and other agricultural chemicals, was reported to be approximately 7461 tonnes, not including an undisclosed CBI volume, in 2020 in the USA (US EPA 2020). These non-industrial uses are beyond the parameters of this evaluation.

Existing Australian regulatory controls

Environment

Arsenic and arsenic compounds are subject to reporting under the Australian National Pollutant Inventory (NPI). Under the NPI, estimated emissions of arsenic and arsenic compounds are required to be reported annually by facilities that:

- use or emit 10 tonnes or more of arsenic or arsenic compounds,
- burn more than 2000 tonnes of fuel,
- consume more than 60000 megawatt hours of electricity (excluding lighting and motive purposes)
- have an electricity rating of 20 megawatts during a reporting year (Australian Government Department of the Environment 2015).

Emissions may be intentional, accidental, or incidental releases arising through industrial processes. Additionally, emissions of arsenic and arsenic compounds from diffuse sources, such as burning of fuel and windblown dust, are periodically estimated by state and territory environment authorities. Diffuse emissions data are updated much less frequently than facility data (NPI 2017).

The chemicals in this evaluation are covered by the group entry for ‘arsenic’ listed in Schedule 7 (dangerous poison) in the *Poisons Standard* (the *Standard for the Uniform Scheduling of Medicines and Poisons*—SUSMP) (TGA 2022). Limited exemptions apply. Schedule 7 chemicals are labelled with 'Dangerous Poison'. These are ‘substances with a high potential for causing harm at low exposure and which require special precautions during manufacture, handling, or use. These poisons should be available only to specialised or authorised users who have the skills necessary to handle them safely. Special regulations restricting their availability, possession, storage or use may apply.’

The chemicals in this evaluation are also covered by the entry for ‘arsenic and its compounds’, which are restricted hazardous chemicals under ‘Schedule 10 (Prohibited carcinogens, restricted carcinogens and restricted hazardous chemicals)’ of the Work Health and Safety (WHS) regulations (WHS 2011). Specifically, use is restricted in abrasive blasting at a concentration of greater than 0.1% as arsenic; and for spray painting.

Import of toys, pencils or paint brushes, and erasers resembling food in scent or appearance that are coated or contain more than 25 milligrams of arsenic per kilogram (mg As/kg) are prohibited under the *Customs (Prohibited Imports) Regulations 1956* (Commonwealth of Australia 1956).

In Australia, default guideline values for arsenic in water and sediments are outlined in the Australia New Zealand Guidelines for Fresh and Marine Water Quality (ANZ Water Quality Guidelines) (ANZG 2018a). High reliability default guideline values for As(III) and As(V) in freshwater have been determined (ANZG 2018a). To protect 95% of species in a *slightly-moderately disturbed* ecosystem, the default guideline values are 24 and 13 micrograms per litre (µg/L) for As(III) and As(V), respectively. There are no reliable default guidelines for As(III) or As(V) in marine waters but the low reliability environmental concern levels are 2.3 µg As(III) /L and 4.5 µg As(V)/L. These values are only intended to be used as interim indicative levels. The recommended default sediment quality guideline value for arsenic is 20 milligrams per kilogram dry weight (mg/kg dw) (ANZG 2018b).

Nationally, an upper limit of 20 mg As/kg dw in biosolids has been recommended (NRMMC 2004). In soils, generic soil quality guidelines for arsenic in fresh and aged soils are outlined in the Site Contamination NEPM to protect soil-dwelling species (Australian Government 2013). The generic soil guidelines for urban, residential and open space are 50 and 100 mg/kg for fresh (contamination <2 years old) and aged soils (contamination >2 years old), respectively. These guidelines are for the protection of 70% of species and expressed as total arsenic (Australian Government 2013). For irrigated soil, a cumulative contaminant loading limit guideline value has been set at 20 kilograms of arsenic per hectare (kg As/ha).

International regulatory status

United Nations

The chemicals in this group are not currently identified as hazardous substances for the purpose of international trade (UNEP & FAO 1998). Arsenic containing wastes are listed on Annex VIII of the Basel Convention and subject to certain control procedures (UNEP 1989). A recent report also identified arsenic and arsenic compounds as a group of chemicals of emerging risk (UNEP 2020).

Canada

Inorganic arsenic compounds are listed under Schedule 1 (the Toxic Substances List) of the Canadian Environmental Protection Act 1999 (CEPA 1999) (Government of Canada 2020).

European Union

All chemicals in this group are included in the arsenic compounds group that is subject to restriction in treatment of industrial waters (REACH Annex XVII) (ECHAb n.d.).

Arsenic pentoxide (CAS No. 1303-28-2) is listed on REACH Annex I and is subject to conditions of prior informed consent for import and export in the EU (ECHAd n.d.).

Arsenic acid (CAS No. 7778-39-4), arsenic trioxide (CAS No. 1327-53-3), and arsenic pentoxide (CAS No. 1303-28-2) have been identified as substances of very high concern based on their carcinogenic properties and are listed on the REACH Authorisation List (Annex XIV) (ECHAe n.d.). Authorisation must be obtained for these chemicals to be used in the European Union.

United States of America

Arsenic is listed on the Priority Pollutants List, which requires state regulatory bodies to adopt numeric criteria for all pollutants listed (US EPAa n.d.). Arsenic compounds, which include any unique chemical substance that contains arsenic as part of that chemical’s infrastructure, are listed on the Toxic Release Inventory (US EPAb n.d.).

Environmental exposure

Based on available data, industrial uses of these chemicals are in laboratory settings and the manufacture of other arsenic chemicals, glass, ceramics, semiconductors. Other industrial uses include purification of ammonia and as a mordant in tanning, dyeing, and printing. These uses may result in emissions of arsenic to air, water, and soil compartments.

Spills and leakage during ammonia production and tanning, dyeing, and printing may result in environmental releases to soil and surface waters (Smith et al. 2003). Use and disposal of arsenic chemicals in laboratory settings is expected to be highly controlled. These controls should minimise environmental releases.

In glass and ceramic production, arsenic is incorporated into articles (Glass Alliance Europe 2012) and environmental release can occur through abrasion, wear, and leaching. Glass beads are a loose abrasive used in sandblasting, a common industrial process for preparing surfaces for a variety of purposes (DTSC). This blasting process can be performed in enclosed systems like blasting chambers or cabinets, or on open sites, e.g. buildings, bridges, tanks, or boats (Safe Work Australia 2012). The resultant dust and any arsenic present in the glass beads can then be released to wastewater and/or landfill if collected from an enclosed system, or directly released to environmental compartments when blasting is conducted in an open site. Arsenic concentrations are specifically restricted in abrasive blasting under Work Health and Safety Regulations (WHS 2011).

According to data reported to the NPI, 116 tonnes of arsenic were emitted to the Australian environment in 2020/2021 (NPI n.d.). Emissions of arsenic were primarily to air, at 90% (105 tonnes) of total reported arsenic emissions in 2020/2021, with lower volumes to land

(4 tonnes) and water (8 tonnes) (NPI n.d.). The major sources of estimated arsenic emissions were dominated by metal ore mining and non-ferrous metal manufacture where arsenic is present as a contaminant. These sources account for 78% (91.2 tonnes) of total arsenic emissions reported to the NPI. In contrast, arsenic emissions from the uses for arsenic-containing compounds considered in this evaluation were much lower. The highest reported arsenic emissions were 0.2 tonnes (0.17% of total emissions) from glass and glass product manufacturing and 0.1 tonnes (0.093% of total emissions) from ceramic manufacturing in 2020/2021. Arsenic emissions from both uses were 100% to air. Atmospheric emissions of arsenic are typically in the form of particulate arsenic trioxide, an As(III)-containing chemical (Cullen and Reimer 1989; WHO 2001).

Arsenic removal from wastewater in a sewage treatment plant is often difficult or requires special treatment. For example, approximately 30% of total recoverable arsenic was removed from municipal wastewater entering a typical sewage treatment plant (Ge et al. 2020). The arsenic removed during treatment will adsorb to sludge, which may be applied to land as biosolids, and the arsenic that remains in the effluent will be released to surface waters. Due to restrictions on general public uses of arsenic, the chemicals in this evaluation are not expected to substantially contribute to the total arsenic concentrations in wastewaters received at sewage treatment plants (TGA 2022).

Environmental fate

Dissolution, speciation, and partitioning

Industrial use of the chemicals in the evaluation may release arsenic compounds to air, surface waters and soils. Arsenic compounds released to air will be deposited to terrestrial and aquatic environments, where they will dissolve to form As(III)- or As(V)-containing oxyanions. Environmental arsenic cycles through the water, sediment, and soil compartments, where it can exist in the dissolved and adsorbed phases, as either As(III)- or As(V)-containing species. The phase and oxidation state of arsenic in these environmental compartments is primarily determined by pH, redox potential, and microbially-mediated oxidation/reduction.

Atmospheric arsenic is primarily emitted as arsenic trioxide, approximately 90% of which is sorbed to particulate matter, predominantly to particulate matter ≤2.5 micrometres (µm) ($PM_{2.5}$) (Cullen and Reimer 1989; Wai et al. 2016; WHO 2001). Arsenic remains in the atmosphere sorbed to particulate matter for a global average of 4.5 days (Wai et al. 2016). Atmospheric oxidation of As(III) is slow, so will remain as arsenic trioxide in the atmosphere (Bissen and Frimmel 2003). Arsenic is removed from the atmosphere via wet and dry deposition and will enter terrestrial and aquatic environments as arsenic trioxide) (Wai et al. 2016).

All the chemicals in this group are readily soluble and are expected to form inorganic As(III)- or As(V)-containing oxyanions upon dissolution. Under typical pH values (pH 6.5–8.5) and oxidising conditions, arsenic will predominantly exist as As(V). However, this is not fixed, and arsenic can readily cycle between As(III) and As(V) states across a broad range of environmental conditions.

In general, the behaviour of arsenic in marine waters and freshwaters are similar. In the pH range typical of most natural waters, pH 6.5–8.5, As(V) is in varying proportions of $H_2AsO_4^-$ and $HAsO_4^{2-}$, and As(III) is present as the neutral arsenous acid, H_3AsO_3 (Smedley and Kinniburgh 2002). The ratio of As(III) and As(V) species will also depend on whether conditions are oxidising or reducing.

Under oxidising conditions, typical of aerobic surface waters and soils, As(V) is the main oxidation state present. As(III) is the dominant oxidation state under reducing conditions found in groundwaters, anoxic sediments, and the bottom anaerobic layers of water bodies. The oxidation state of arsenic is also influenced by microbially-mediated oxidation/reduction processes. Microbially-mediated oxidation/reduction of arsenic can occur in orders of magnitude faster than the oxidation/reduction from abiotic processes. As a result, higher concentrations of As(III) may be found in oxidising conditions than expected based on thermodynamics only (Smedley and Kinniburgh 2002).

Dissolved As(V) and As(III) partitions from water to the sediment phase by precipitation and adsorption. Under extremely reducing conditions, As(III) can precipitate to an insoluble sulfide (Smedley and Kinniburgh 2002). As(V) precipitates with aluminium and iron at low pH and with calcium and magnesium at high pH. Adsorption occurs over a much broader range of environmental conditions, but adsorbed arsenic is also readily released by changes in pH and redox conditions and by competitive ion displacement. In sediments, As(V) oxyanions adsorb strongly to metal oxides, particularly iron, aluminium and manganese and clay, when pH is below 6, but become more mobile as pH increases (US EPA 2004). As(III) is neutral in solution and only binds significantly to iron hydroxides, making As(III) much more mobile than As(V). Once sorbed and incorporated to the sediment, As(V) can be reduced to As(III) as the sediment or overlying water becomes more reducing. This results in reductive dissolution, where the As(III) no longer binds as strongly to the mineral surface and is released into the sediment porewaters. (Bauer and Blodau 2006; Pothier et al. 2020). The As(III) is then able to diffuse upwards and become the predominant species as close as 1 mm below the sediment/water interface and may be released into the overlying waters (Barral-Fraga et al. 2020; WHO 2001). Thermal stratification and seasonal turnover/flushing, a common occurrence in Australian freshwaters, can then bring As(III) accumulated in the bottom layers of the water to the surface (Sinclair Knight Merz 2013; Smedley and Kinniburgh 2002).

Anoxic events in freshwater systems can also mobilise high concentrations of As(III) from the sediment to overlying waters over a short period of time. These events can be induced by changing environmental conditions, e.g. anoxic conditions induced by low flow events during drought or extreme wet/dry seasons (Barral-Fraga et al. 2020).

Dissolved organic matter can also play an important role in maintaining high levels of dissolved As(V) and As(III) in water and soil porewaters. Dissolved organic matter stabilises As(V) and As(III) in the dissolved phase by forming covalent bonds and ternary complexes with the oxyanions, preventing solid phase sorption, and/or by competing for mineral adsorption sites (Barral-Fraga et al. 2020; McCleskey et al. 2004; Pothier et al. 2020).

As in sediments, the mobility of arsenic in soils is controlled by adsorption and desorption processes (Bhattacharya et al. 2002). An additional factor that is relevant to mobility of arsenic in agricultural soils is the use of phosphate fertilisers. Phosphates from fertilisers compete with As(V) ions for the same binding sites on iron (hydr)oxides, clays, and organic matter. Increased phosphate concentration in soil can cause release of As(V) from soil binding sites into the soil porewater (Barral-Fraga et al. 2020). Although industrial uses of chemicals in this group may result in arsenic incorporated into biosolids, which may then be applied to land, most anthropogenic arsenic in agricultural soils is from historical use of arsenic-based herbicides and pesticides.

Biotransformation

Inorganic arsenic chemicals can be absorbed by organisms and undergo biotransformation processes, including oxidation/reduction and transformation into organic arsenic species, e.g. simple methyl-arsenic species and arsenic-containing sugars and lipids (Zhang et al. 2022).

Biotransformation of arsenic is a common means of arsenic detoxification within organisms, and includes multiple intracellular processes, and can result in the formation of over 300 organic arsenic species (Zhang et al. 2022). Biotransformation by microorganisms can remobilise arsenic adsorbed to organic carbon and sediments (Pothier et al. 2020).

Arsenic biotransformation processes are complex, but in general, arsenic biotransformation follows the order: reduction of As(V) or oxidation of As(III), biomethylation to methyl-arsenic species, and biosynthesis of arsenic-containing sugars and lipids (Rahman and Hassler 2014; Zhang et al. 2022). Biotransformation of inorganic arsenic species to simple organic arsenic species (i.e. methyl-arsenic species) primarily occurs in primary producers, followed by transformation to more complex organoarsenic species in herbivores, and very little biotransformation occurring in higher trophic level organisms, e.g. fish (Maher et al. 2009; Rahman et al. 2012). One exception is synthesis of arsenobetaine, which is the primary arsenic species found in carnivorous animals, e.g. fish (Foster and Maher 2016; Maher et al. 2009). The synthesis pathway of arsenobetaine is still unclear but it is thought to be synthesised in herbivores (e.g. gastropods) and carnivores (e.g. fish) from precursor arsenic species that have been accumulated through dietary arsenic exposure (Foster and Maher 2016).

Microorganisms may excrete inorganic As(III), rather than organic arsenic species, under some conditions. For example, in phytoplankton, when phosphorus concentrations are in excess and growth rate is fast, inorganic As(V) is absorbed, then reduced and excreted as inorganic As(III) (Levy et al. 2005; Rahman and Hassler 2014).

Bioaccumulation

Bioaccumulation of total arsenic, as various species, occurs in aquatic and terrestrial organisms but is more common in aquatic organisms. In general, bioaccumulation of arsenic at lower trophic levels occurs primarily via waterborne exposure, and dietary exposure in higher trophic levels. Biomagnification of arsenic does not occur except for arsenobetaine, an organic arsenic species, which has the potential for biomagnification through dietary exposure.

Among aquatic organisms, marine organisms typically accumulate much higher concentrations of arsenic than freshwater organisms. For example, total arsenic concentrations in marine algae and fish have been reported to range between 0.1–382 mg/kg and 0.05–450 mg/kg, respectively (Rahman et al. 2012). Marine sediment dwelling polychaetes (e.g. worms), that are exposed to both dissolved and sediment-bound arsenic, typically accumulate the highest internal arsenic concentrations, ranging between 5–>2700 mg/kg dw (Neff 1997). In freshwater organisms, total arsenic concentrations typically range from 0.05–64.2 mg/kg dw (Rahman et al. 2012).

The types of bioaccumulated arsenic compounds also vary between marine and freshwater organisms. Marine organisms usually contain between 85–>90% of total arsenic as organic arsenic, primarily arsenosugars in phytoplankton and arsenobetaine in fish, with small proportions of inorganic arsenic or other organic arsenic species (Rahman et al. 2012). Freshwater organisms have much more diverse distribution and speciation of bioaccumulated arsenic (Rahman et al. 2012). In some cases, inorganic arsenic can dominate the total arsenic accumulated in freshwater phytoplankton, whereas methyl-arsenic species and/or arsenosugars are more important in macroinvertebrates. Arsenobetaine ranges from the dominant to relatively minor arsenic species in freshwater fish (Erickson et al. 2019).

Bioaccumulation in terrestrial organisms is less well understood but known to occur, particularly in plants which can take up As(V) species from soil instead of phosphate. Arsenic accumulation has been identified in the edible portions of vegetable crops, including rice, green bean, lima bean, spinach, cabbage, tomato, and radish (WHO 2001). Bioaccumulation in rice has been a particular concern in rice, given its high consumption in some countries. A study conducted on Australian-grown rice varieties measured inorganic arsenic concentrations ranging between 16–250 µg/kg. Four samples were above 200 µg As/kg, the recommended maximum level for inorganic arsenic in polished rice (Maher et al. 2018).

Background total arsenic concentrations in terrestrial organisms tends to be <1000 µg/kg (WHO 2001). Other terrestrial plants are known hyperaccumulators of arsenic, e.g. some terrestrial ferns in the *Pteris* genus accumulating 435 to 1685 mg/kg of arsenic (Koller et al. 2007; Ma et al. 2001).

Biomagnification of inorganic arsenic species does not occur. Inorganic arsenic concentrations decrease with increasing trophic level, typically by an order of magnitude with each increase in trophic level (Zhang et al. 2022). Biomagnification of the organoarsenic species, arsenobetaine, has been observed in some cases. This is usually through dietary exposure for higher taxa, e.g. fish that feed on phytoplankton and invertebrates that contain the appropriate precursors for arsenobetaine synthesis or organisms that contain arsenobetaine (Foster and Maher 2016; Rahman et al. 2012).

Transport

Atmospheric arsenic emissions have the potential for long range transport. Significant arsenic enrichment in snowpack of the Antarctic Plateau indicates that intercontinental transport is possible (Wai et al. 2016). According to modelling conducted by Wai et al. (2016) that considered natural and anthropogenic sources of atmospheric arsenic, up to 90% of arsenic deposition over the Antarctic is attributed to emissions from South America.

Arsenic is emitted to the atmosphere from mining, smelting and fossil fuel use. More than 90% of atmospheric arsenic is present as arsenic trioxide sorbed to fine particulate matter and is removed by wet and/or dry deposition (Gomez-Caminero et al. 2001). This particulate matter has a residence time of 4.5 and 4.1 days globally and in the East Asian region, respectively (Wai et al. 2016).

The uses of arsenic identified in this evaluation are not likely to significantly contribute to long range transport of arsenic.

Predicted environmental concentration (PEC)

A PEC for the water-soluble arsenic chemicals in this evaluation was not calculated. These chemicals form arsenic oxyanions and subsequent biotransformation products that are indistinguishable from environmental arsenic arising from other sources. Environmental concentrations of arsenic are typically expressed as total arsenic, with speciation measurements only determined for specific site assessments.

Arsenic is naturally released into the environment by weathering and erosion of rocks and soils, volcanic emissions, dust storms and bushfires (Smith et al. 2003; Wai et al. 2016). In Australia, arsenic concentrations are typically similar to natural background levels, except in locations where arsenic is emitted from local mining and smelting operations, there is legacy contamination from mining practices or arsenic-containing chemicals have been used in agricultural practices, e.g. contamination from pesticide use in fruit orchards and treatment of stock animals (Smith et al. 2003).

In unpolluted Australian freshwaters, arsenic concentrations are typically <10 µg As/L (Smith et al. 2003). In nearshore marine environments, arsenic concentrations range between 1–3 µg As/L (Neff 1997). In open marine waters of the coast of South Australia, concentrations of inorganic arsenic were 1.1–1.6 µg As/L (Maher 1985). Arsenic concentrations in marine sediments along the east coast of Australia had arsenic concentrations between, 2–180 mg/kg, but were generally below 50 mg/kg (Smith et al. 2003).

Little Australian data are available on arsenic concentrations and sources in wastewater entering sewage treatment plants. An investigation into concentrations of critical contaminants in domestic wastewater reported arsenic concentrations below the limit of detection, indicating that households are a small contributor to arsenic concentrations in wastewater (Tjadraatmadja and Diaper 2006). No Australian information was identified on the removal rates of arsenic in sewage treatment plants. For a municipal sewage treatment plant in New Jersey, USA, less than 30% of dissolved arsenic was removed by traditional biological wastewater treatment, where average influent and effluent concentrations were 2.43 and 1.63 µg As/L, respectively (Ge et al. 2020). These values are within the range of background concentrations of Australian surface waters.

Natural background soil arsenic concentrations depend on the nature of the parent material and are extremely variable across Australia. Concentrations in soils are typically below 50 mg/kg, with a mean of 5–6 mg/kg (Smith et al. 2003). Limited monitoring data are available for arsenic concentrations in biosolids and agricultural soils. The average arsenic concentration in biosolids used in the National Biosolids Research Program was 5 mg/kg and the minimum recorded ambient background of arsenic in Australian agricultural soil is 0.2 mg/kg (Sorvari et al. 2009). This is well below the recommended upper limit of 20 mg As/kg dw in biosolids.

Environmental effects

Arsenic is recognised as a highly toxic environmental contaminant, mutagenic agent that disturbs normal DNA functions and/or causes direct breakages, and carcinogen (Bennett et al. 2012; Jomova and Valko 2011; Lu and Zhu 2011; UNEP 2020; WHO 2003). In the environment, organisms will be primarily exposed to inorganic arsenic via waterborne exposure.

The environmental effects of the arsenic compounds in this group will primarily result from the release of As(III) and As(V) oxyanions into the environment. Methyl arsenic species, arsenic-containing lipids and sugars, and biologically-synthesised organoarsenic species are much less toxic e.g., arsenobetaine is to 200-fold less toxic than inorganic arsenic (US EPA 1979). The inorganic arsenic oxyanions are; therefore, considered to be the primary hazardous species.

Uptake of arsenic by organisms is unintentional and a result of the structural similarities between As(V) and phosphate, an essential macronutrient, or by passive diffusion of the uncharged inorganic As(III) species. As(III) is considered to be more broadly toxic because of its ability to strongly bind with thiol groups and cause inactivation of up to 200 enzymes, whereas the toxic mode of action for As(V) is restricted to replacing phosphate, which is critical in cellular energy production (Barral-Fraga et al. 2020; Zhang et al. 2022).

Effects on Aquatic Life

Bioavailable forms of As(III) and As(V) are toxic to aquatic life in short and long term exposures, but their toxicities can differ significantly. In some studies, the oxidation state of arsenic is not determined, and test concentrations are reported as total or dissolved arsenic. Toxicity endpoints presented are given in terms of total dissolved arsenic except where the oxidation state is specified.

The toxicity of arsenic oxyanions to aquatic organisms is strongly influenced by water chemistry. For photosynthetic organisms, algae and plants, phosphate is an essential macronutrient. Phosphate and As(V) are chemical analogues, and in general, As(V) toxicity decreases with increasing phosphate concentration. Phosphate concentrations are reported for algal and plant toxicity results where it was measured.

Acute toxicity

The following acute median lethal concentrations (LC50) and median effect concentrations (EC50) values for freshwater and marine organisms across 3 trophic levels are presented together with relevant water chemistry parameters from studies published in the scientific literature. DOC and TOC refer to dissolved organic carbon and total organic carbon, respectively:

Taxon	Endpoint	Method
Fish	96 h LC50 = 7.05 mg As(III)/L	*Danio rerio* (Zebrafish) pH = 8.1–8.2 DOC = not reported (Seok et al. 2007)
	96 h LC50 = 17.8 mg As(V)/L	*Xyrauchen texanus* (Razorback sucker) pH = 8.1 DOC = not reported (Hamilton and Buhl 1997)

Taxon	Endpoint	Method
Invertebrate	48 h EC50 = 1.58 mg As(III)/L 48 h EC50 = 1.72 mg As(V)/L	*Ceriodaphnia dubia* (freshwater crustacean) Immobility pH = 7.9–8.3 DOC = not reported Separate As(III) and As(V) exposures (Rahman et al. 2014)
	96 h LC50 = 3.04 mg As(III)/L	*Harpacticoida; Ameiridae* (groundwater copepod) Mortality pH = 4.2–5.6 TOC = 3–13 mg C/L (Hose et al. 2016)

Taxon	Endpoint	Method
Algae	48 h EC50 = 0.180 mg As(V)/L	*Chlorella salina* (marine green microalga) Algal growth inhibition pH = 8.1 DOC = <1 mg C/L PO_4^{3-} = 0.15 mg/L (Golding et al. 2022)
	72 h EC50 = 14.6 mg As(III)/L 72 h EC50 = 0.254 mg As(V)/L	*Monoraphidium arcuatum* (freshwater microalga) Algal growth inhibition pH = 7.6 DOC = not reported PO_4^{3-} = 0.15 mg/L Separate As(III) and As(V) exposures (Levy et al. 2005)

Freshwater algae have been reported to be more sensitive to As(V) than As(III) in some cases. Marine algae and fish are generally reported to be more sensitive to As(III) (Cullen and Reimer 1989; Levy et al. 2005; WHO 2001).

Variability in aquatic toxicity can also be attributed to exposure time, testing conditions (e.g., phosphate concentration), life stage of the organism, acclimation of the test organism to arsenic prior to test, and whether arsenic exposure was waterborne, dietary, and/or both.

Chronic toxicity

The chronic toxicity of As(V) and As(III) to freshwater and marine organisms was critically evaluated for the derivation of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018a). No observed effect concentrations (NOEC), lowest observed effect concentrations (LOEC), and 10% effect concentrations (EC10) used for ANZG derivation and values from other studies are presented:

Taxon	Endpoint	Method
Fish	29 d NOEC = 2.13 mg As(III)/L	*Pimephales promelas* (fathead minnow) Growth (mean length) pH = 7.2–8.1 DOC = not measured (Lima et al. 1984)
	28 d LC50 = 16.6 mg As(V)/L	*Oncorhynchus mykiss* (juvenile rainbow trout) pH = 7.5–8.0 DOC = not reported (Erickson et al. 2011)
Invertebrates	80 h EC10 = 0.014 mg As(V)/L	*Acartia sinjiensis* (marine copepod) Larval development pH = 8.2 DOC = <1 mg/L (Golding et al. 2022)
	28-d LC10 = 0.04 mg As(III)/L	*Harpacticoida; Ameiridae* (groundwater copepod) Mortality pH = 4.2–5.6 TOC = 3–13 mg C/L (Hose et al. 2016)

Taxon	Endpoint	Method
Algae	48 h EC10 = 0.013 mg As(V)/L	*Chlorella salina* (marine green microalga) Algal growth inhibition pH = 8.1 DOC = <1 mg/L PO_4^{3-} = 0.15 mg/L (Golding et al. 2022)
	72 h LOEC = 3.75 mg As(III)/L 72 h LOEC = 0.081 mg As(V)/L	*Monoraphidium arcuatum* (freshwater microalga) Algal growth inhibition pH = 7.6 DOC = not measured PO_4^{3-} = 0.15 mg/L Separate As(III) and As(V) exposures (Levy et al. 2005)

Effects on sediment dwelling life

Sediments are a critical environmental compartment in the cycling of arsenic. Sediments can retain large concentrations of total arsenic through adsorption and precipitation processes. Sediments also possess the reducing conditions that enable the reduction of As(V) to As(III) and dissolution of As(III) into porewaters. Therefore, benthic organisms can be directly exposed to high concentrations of both As(V) and As(III) in the sediment pore water, and by ingestion of sediment particles.

According to a recent review, there are only a limited number of chronic ecotoxicological studies for arsenic sediment toxicity to benthic species (Hermansson and Ytreberg 2022). The most sensitive chronic toxicity reported is a growth EC10 of 22.1 mg/kg dw for an oligochaete, *Branchirua sowerbyi*, a particle-feeding invertebrate that lives in the sediment (Lobo et al. 2021). The least sensitive endpoint is a growth EC20 of 239 mg/kg dw for the crustacean *Hyalella azteca* (Goulet and Thompson 2018).

Effects on terrestrial life

Dissolved and weakly bound forms of As(III) and As(V) are readily bioavailable to terrestrial organisms, particularly plants.

In a species sensitivity distribution conducted for 27 plant species, including important food crops, the 95% species protection level for plant growth is 25.3 mg/kg total arsenic in soil (Sun et al. 2012). Cucumber and kidney beans were the most sensitive, with EC50 values of 16.3 and 14.9 mg/kg, respectively, and sweet potatoes the least sensitive (EC50 795 mg/kg).

Despite the toxicity of arsenic in soils typically decreasing with soil age, bioavailability and toxicity can be increased by release of arsenic into the pore waters induced by application of fertilisers or during anoxic events after flooding (Dradrach et al. 2020).

In terrestrial vertebrates, both As(III) and As(V) compounds have been identified as carcinogenic and both acutely and chronically toxic. Acute toxicity ranges from 14.6 to 500 mg/kg body weight and 8 to 200 mg/kg body weight for As(III) and As(V) compounds, respectively (NICNAS 2013a; 2013b).

Predicted no-effect concentration (PNEC)

The primary environmental effects of the chemicals in this group are expected to be caused by the release of arsenic oxyanions. In place of PNECs for the water and sediment compartments, the default guideline values for arsenic have been used, as outlined in the ANZ Water Quality Guidelines and Guidelines for Sediment Quality (ANZG 2018a; 2018b). In place of a PNEC for the soil compartment, the generic soil quality guideline published for arsenic in the *National Environment Protection (Assessment of Site Contamination) Measure 1999* has been used (Australian Government 2013).

The water quality guidelines represent thresholds above which further assessment of potential toxicity may be required to ensure environmental quality. For freshwater systems, the high reliability guideline values for protection of 95% of species in *slightly-to-moderately disturbed* systems are 24 µg As(III)/L and 13 µg As(V)/L. For marine systems, only low reliability guideline values are available; 2.3 µg As(III)/L and 4.5 µg As(V)/L. These marine values should only be used as an indicative interim value (ANZG 2018a). For sediments, the default guideline value is 20 mg/kg dw (ANZG 2018b).

For soils where the contaminant has been present for more than 2 years (aged soil), the generic soil quality guideline values are 40 and 100 mg total As/kg for areas of ecological significance and urban, residential, and public open space, respectively. These guidelines are for the protection of 70% of species and expressed as total arsenic (Australian Government 2013).

Categorisation of environmental hazard

It is not currently possible to categorise the environmental hazards of metals and other inorganic chemicals according to standard persistence, bioaccumulation, and toxicity (PBT) hazard criteria. These criteria were developed for organic chemicals and do not take into consideration the unique properties of inorganic substances and their behaviour in the environment (UNECE 2017; US EPA 2007). However, there is an international consensus that bioavailable forms of arsenic are highly toxic to the environment (UNEP 2020).

GHS classification of environmental hazard

The chemicals in this evaluation satisfy the criteria for classification according to the GHS for environmental hazards. The aquatic hazards of the chemicals in this group have been classified based on the available acute toxicity values for the soluble As(V) oxyanion in accordance with the classification procedure for metals and metal compounds under the GHS (UNECE 2017). The lowest acute toxicity value for the As(V) oxyanion was used to classify both As(V) and As(III)-containing chemicals because it was the lowest overall toxicity endpoint and As(V) is the dominant inorganic arsenic species present under relevant environmental conditions. The classifications for each arsenic-containing chemical were made after correcting for the molecular weight of the respective arsenic-containing chemical. The lowest EC50 of the dissolved As(V) oxyanion is <1 mg/L. All the weight corrected EC50 values for each arsenic-containing chemicals in this group were substantially lower than their measured or predicted solubilities. Therefore, all chemicals in this evaluation are classified as Acute Aquatic Category 1. They are also classified as Chronic Aquatic Category 1 as arsenic has the potential to bioaccumulate in aquatic organisms.

Environmental risk characterisation

The chemicals in this group contain arsenic ions, which can be released to the environment from their industrial uses in the manufacture of glass, ceramics, purification of ammonia and as a mordant in tanning, dyeing, and printing. Arsenic is recognised as a highly toxic environmental contaminant. High acute exposures cause immediate mortality and chronic exposures cause mortality and/or impaired growth across all taxa. Toxicity and bioaccumulation of arsenic is generally highest in aquatic organisms, followed by sediment-dwelling and terrestrial organisms.

The release of arsenic to the Australian environment from industrial uses of these chemicals is expected to be limited. Available information indicates that only low volumes are likely to be used for industrial purposes. Release to air, water, and soil compartments via spills, leaks, and abrasion of articles during manufacturing or industrial processes are the most likely emission scenarios for the industrial uses of chemicals in this evaluation. Releases of arsenic from relevant industries account for very little of the total arsenic emissions reported to the National Pollutant Inventory, compared to metal ore mining, non-ferrous metal manufacture, and burning of fossil fuel. Arsenic-containing chemicals for personal and professional use in Australia are highly controlled. Available concentrations of arsenic in household effluent, wastewater effluent, and biosolids do not exceed national guidelines.

Therefore, the industrial use of these chemicals in Australia is not expected to pose a significant risk to the environment.

Uncertainty

This evaluation was conducted based on a set of information that may be incomplete or limited in scope. Some relatively common data limitations can be addressed through use of conservative assumptions (OECD 2019) or quantitative adjustments such as assessment factors(OECD 1995). Others must be addressed qualitatively, or on a case-by-case basis (OECD 2019).

The most consequential areas of uncertainty for this evaluation are:

- The Australian use and volume data available for the chemicals in this group is limited and from 2013. Should information become available to indicate higher volumes of current industrial use of chemicals in this group, the outcome of this evaluation may change.

- Limited information on concentrations in STP effluent and biosolids were identified in this evaluation. Should information become available to indicate higher concentrations, the outcome of this evaluation may change.

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