Australian Government
Department of Health and Aged Care
Australian Industrial Chemicals Introduction Scheme

Cadmium sulfide pigments

Evaluation statement

22 December 2022

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AICIS evaluation statement

Subject of the evaluation

Cadmium sulfide pigments.

Chemicals in this evaluation

Name	CAS registry number
Cadmium sulfide (CdS)	1306-23-6
C. I. Pigment Yellow 37	68859-25-6

Reason for the evaluation

Evaluation Selection Analysis (ESA) indicated a potential environmental risk.

Parameters of evaluation

Cadmium sulfide (CAS RN 1306-23-6) and C. I. Pigment Yellow 37 (CAS RN 68859-25-6) have been assessed for their risk to the environment according to the following parameters:

- Default domestic introduction volumes of 100 tonnes per year (t/year)
- Industrial use as pigments listed below in the 'Summary of introduction, use and end use' section
- Expected emission into soil and sewage treatment plants (STPs) following consumer and commercial use.

These chemicals have been assessed as a group because they have the same chemical composition (CdS) and share the same use patterns.

Summary of evaluation

Summary of introduction, use and end use

There is currently no specific information about the introduction, use and end use of the chemical in Australia. Based on information in the public domain, artist's paints containing cadmium sulfide are readily available in Australia.

Based on international use information, these substances are expected to be used as pigments in:

- Paint and coating products
- Plastic and polymer products

- Arts, crafts and hobby products.

Historical information indicated use as a pigment in tattoo inks.

Minor quantities may be used in other specialised (non-pigment) applications.

There is no information available on the domestic use volumes of these chemicals. Data from international jurisdictions indicate that 10–100 tonnes of cadmium sulfide (CAS RN 1306-23-6) is used in the European Union (EU) annually.

Environment

Summary of environmental hazard characteristics

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. The primary environmental effects of the chemicals in this group are expected to be caused by release of cadmium(2+) ions, which are very toxic to aquatic organisms.

Environmental hazard classification

Chemicals in this group satisfy the criteria for classification according to the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) for environmental hazards as follows. This evaluation does not consider classification of physical and 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 chemicals in this group is their potential to release bioavailable cadmium ions, which are very toxic to aquatic organisms, into the environment.

Cadmium sulfide pigments identified in this group are used in a variety of products including paints and plastics. These uses may result in diffuse emissions of cadmium ions to water, sediment, and soil compartments.

Available information from international sources indicates that the use of cadmium sulfide pigments is in decline following increased regulation. The quantity of cadmium released from any paints or articles containing cadmium sulfide pigments are not expected to be significant relative to total background and other anthropogenic cadmium releases. The industrial use of these chemicals in Australia are unlikely to pose a significant risk to the environment.

Conclusions

The evaluation conclusions 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.

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

Supporting information

Grouping Rationale

This evaluation considers environmental risks associated with the industrial use of two inorganic substances consisting of cadmium sulfide. These substances are expected to have similar physical and chemical properties. Both chemicals have known applications as pigments. The risk evaluation of these substances has been conducted as a group because of their similar properties and use patterns.

Chemical identity

Cadmium sulfide is a yellow inorganic compound with the chemical formula CdS. Cadmium sulfide is naturally occurring and is present in zinc ore (Buxbaum 2005). The CAS registry number (CAS RN) 1306-23-6 is expected to correspond to CdS of any crystal structure. Cadmium sulfide is commonly produced industrially through precipitation reactions of dissolved cadmium metal with sodium sulfide (Buxbaum 2005).

The C. I. Pigment Yellow 37 (CAS RN 68859-25-6), or Cadmium Yellow Dark, is cadmium sulfide that has the specific β-wurtzite crystal packing structure. Cadmium Yellow Dark can be manufactured through the solid-state reaction of cadmium oxides or cadmium carbonates with sulfur, or by using heat treatment on produced cadmium sulfide to convert it to the desired crystal structure. Other pigments may be produced by doping these cadmium sulfides with zinc and/or selenium, but those pigments are not considered in this evaluation.

Chemical name	cadmium sulfide (CdS)
CAS RN	1306-23-6
Synonyms	cadmium sulphide cadmium(2+) sulfide cadmium yellow
Molecular formula	CdS
Molecular weight (g/mol)	144.46

Chemical name	C.I. Pigment Yellow 37
CAS RN	68859-25-6
Synonyms	Cadmium Yellow Dark C. I. 77199
Molecular formula	CdS

Relevant physical and chemical properties

Physical and chemical data were available for cadmium sulfide (CAS RN 1306-23-6). No specific data for Cadmium Yellow Dark were available. While Cadmium Yellow Dark is expected to have different optical properties to other forms of cadmium sulfide, the environmentally relevant properties, such as transformation/dissolution in water, are expected to be comparable. All physical and chemical properties were obtained from the registration dossier for cadmium sulfide submitted under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation in the EU (REACH 2020).

Cadmium sulfide is a yellow solid that sublimes at 861°C. The vapor pressure of cadmium sulfide is unmeasured but is expected to be very low due to its high sublimation point.

Cadmium sulfide is poorly water soluble (ATSDR 2012), but when it dissolves it is expected to form cadmium(2+) and sulfide (2-) ions (Mantoura et al. 1978).Transformation/dissolution data obtained using the OECD Transformation and Dissolution protocol (OECD T/Dp) and relevant to the GHS classification strategy for metals (UNECE 2007) are given in the following table:

Transformation/dissolution Data (1 mg/L loading, pH = 6)	7 days: 2.71 µg/L (exp.) 28 days: 5.75 µg/L (exp.)

Cadmium sulfide pigments, such as Cadmium Yellow Dark, are reported to be poorly water soluble in addition to having excellent light fastness, heat resistance and colour properties (Buxbaum 2005; ECHA 2015a).

Introduction and use

Australia

No current manufacture or introduction of cadmium sulfide or cadmium yellow pigments into Australia have been identified. Based on information in the public domain, artist's paints containing cadmium sulfide are readily available in Australia.

Historically, in Australia, cadmium sulfide pigments were manufactured in a single factory in Geelong, Victoria during the 1970s (De Silva and Donnan 1981). However, historical uses of cadmium sulfide pigments are beyond the parameters of this evaluation.

Cadmium and its compounds are listed on the *Poisons Standard* (SUSMP) February 2022 (TGA 2022), which restricts the use of paints containing cadmium.

International

Cadmium sulfide and Cadmium Yellow Dark have reported international use as pigments in polymers, alkyl resin enamels, rubber articles, paints, and ceramic articles (ECHA 2015a; NICNAS 2014a; NICNAS 2014b; REACH 2020).

In the EU, cadmium sulfide is registered under REACH at 10–100 tonnes per annum, with uses relating to pigments and semi-conductor applications (REACH 2020). Cadmium sulfide pigments are primarily used in paints for safety, defence and aerospace applications, in addition to the manufacture of plastic masterbatches (ECHA 2012; ECHA 2015b). European Chemicals Agency (ECHA) data indicates that a maximum of 20 tonnes per year of cadmium pigments are incorporated into plastics in the EU (ECHA 2015a). Uses of cadmium and its compounds in paints and plastics are restricted in the EU under Annex XVII of the ECHA REACH Regulation (ECHA 2020).

A recent analysis of 1500 consumer plastic articles in the EU detected cadmium in only 7% of articles, with a median detected concentration of 209 mg/kg (Turner 2019). Cadmium has been detected in beached plastics globally with typical detected cadmium levels below 10 mg/kg (Turner and Filella 2021). However, cadmium has been detected in the order of 20,000 mg/kg in recycled or historic plastic articles (Turner 2019).

Use of cadmium sulfide pigments is declining due to increased restrictions on cadmium compounds in articles (Buxbaum et al. 2012; Kirk-Othmer 1999). Recent data from the International Cadmium Association (ICdA) suggests only 768 tonnes of pigments containing cadmium were manufactured globally in 2019, down from 4500 tonnes in 1980 (ICdA 2006; ICdA 2021a; UNEP 2010).

Cadmium sulfide was also reported in the past to have been used as a component in tattoo inks (Tindall and Smith 1962). Cadmium sulfide has additional site-specific listed uses in semi-conductors, and historical uses in cathode ray tubes (NCBI 2022; REACH 2020). Historical uses of cadmium sulfide are not within the parameters of this evaluation, and site-limited use in semi-conductors is unlikely to lead to environmental release of cadmium and will not be considered further in this evaluation.

Existing Australian regulatory controls

Environment

Cadmium and cadmium compounds are subject to reporting requirements under the Australian National Pollutant Inventory (NPI 2021).

Cadmium and cadmium compounds are listed in the *Poisons Standard* June 2022 (TGA 2022). The standard legislates the sale, manufacture, supply and use of paints containing cadmium of cadmium compounds at more than 0.1% by weight of the non-volatile content. These paints must not be applied to:

- a roof or any surface used in the collection or storage of potable water
- furniture
- any fence, wall, post, gate or building other than one used exclusively for industrial purposes
- any premise used for the manufacture, processing, preparation, packing or serving of products intended for human or animal consumption.

Default guideline values have been published for cadmium in the ANZ Water and Sediment Quality Guidelines (ANZ WQG 2000). A summary is provided below:

- 0.2 µg Cd/L in low hardness freshwater (95% species protection, high reliability)
- 0.7 µg Cd/L in marine water (99% species protection, high reliability)

- 1.5 mg Cd/kg dry weight (dw) in sediments.

International regulatory status

United Nations

Chemicals in this group are not currently identified as Persistent Organic Pollutants (UNEP 2001), ozone depleting substances (UNEP 1987), or hazardous substances for the purpose of international trade (UNEP & FAO 1998).

Canada

Chemicals containing cadmium are listed as a broad class of compounds ('Inorganic cadmium compounds') under Schedule 1 (the Toxic Substances List) of the Canadian Environmental Protection Act 1999 (CEPA) (Government of Canada 2020).

European Union

In 2013, cadmium sulfide was listed as a substance of very high concern (SVHC) (ECHA 2013).

Cadmium and its compounds are restricted in the EU under Annex XVII of the ECHA REACH Regulation (ECHA 2020). Cadmium compounds cannot be used in substances and preparations placed on the market for sale at the following concentrations (of elemental cadmium) in:

- plastic materials ≥0.01% by weight
- paints ≥0.01% by weight
- brazing (soldering/welding) fillers ≥0.01% by weight.

Cadmium concentrations in ceramics and glass articles that come into contact with foodstuff are restricted by Guideline No. 84/500/EC (EEC 2005).

United States of America

Restrictions on metals in plastics vary according to state legislations. Currently, 19 states have restrictions on the use of cadmium (plus lead, mercury and hexavalent chromium) in packaging and packaging components where the sum of the content of these four metals must not exceed 100 ppm by weight (TPCH 2021).

Environmental exposure

The chemicals in this evaluation are used as pigments in paints and plastics articles. These uses may result in diffuse emissions of cadmium sulfide or cadmium ions to water and soil compartments.

Use of surface coatings and paints may result in the release of additives, such as pigments, to the terrestrial and aquatic compartments through abrasion, weathering and disposal of painted articles (Bandow and Simon 2016; OECD 2009). Exposure modelling suggests up to 1% of dry paint volume is lost to weathering and abrasion during the service life of the article, with the remainder ending up in landfill after disposal (OECD 2009). When paint containing cadmium is used in urban areas these releases may contribute to cadmium sulfide concentrations in urban runoff. In Europe, paints and coatings are not listed as major sources of cadmium in urban wastewater from domestic sources or urban runoff (Bandow and Simon 2016; ICON 2001). In Australia, paints containing cadmium above a certain concentration have use restricted to industrial sites, which is expected to limit the number of potential exposure locations.

Polymer or plastic articles that contain cadmium sulfide pigments may be susceptible to abrasion and leaching processes over their lifecycle and after disposal. Leaching of the plastic over the article's use lifetime ultimately results in diffuse emissions of cadmium(2+) directly into the soil or water compartment. The OECD exposure scenario for inorganic additives in plastics suggests that 0.01% of the pigment volume will be lost due to degradation and abrasion over the service life of the plastic. After disposal, the OECD scenario and PVC leaching studies suggest that pigments remaining in plastic articles in landfill are not expected to be released through leaching (ARGUS 2000; OECD 2014). However, the leaching and dissolution of cadmium (2+) ions from plastics and pigments has been demonstrated under enhanced simulated sunlight. This process may result in increased rates of cadmium leaching to water and soil compared to rates proposed in the OECD exposure scenario (Liu et al. 2017; Liu et al. 2020; Turner and Filella 2021).

Although cadmium has been detected in recycled plastic products, the release of cadmium from these products is not expected to be different to other plastics containing cadmium pigments (Turner 2019). Wastes from plastics recycling processes may contain cadmium and other hazardous materials and are expected to be disposed of as hazardous waste.

While some cadmium may be released from paints and plastic products following use of the chemicals in this group, this is considered minor compared to levels of cadmium released to STPs, waters and soils through other anthropogenic processes such as metal mining and refining activities, emissions from combustion of coal and oil, and the use of phosphate fertilisers which may contain traces of cadmium as an impurity. Cadmium pigment consumption has seen a steady decline globally since the 1980s due to increased regulation and hazard awareness (Buxbaum et al. 2012; ECHA 2015a; ICdA 2006; 2021b).

Release from specialised semiconductor uses is expected to be negligible.

Environmental fate

Chemicals in this group may be released into the terrestrial and aquatic compartments as cadmium sulfide or as cadmium(2+) ions. When cadmium sulfide undergoes dissolution in the environment it forms a cadmium cation and a sulfide anion (ATSDR 2012). Cadmium sulfide pigments are poorly soluble, but dissolution over several years can lead to high concentrations in environmental compartments (Gustafsson 2013).

Detailed reporting on environmental speciation, partitioning and bioaccumulation for cadmium ions is found in the Inventory Multi-tiered Assessment and Prioritisation (IMAP) assessment for water-soluble cadmium(2+) salts (NICNAS 2019). In summary, cadmium(2+) ions are expected to be mobile in soils and waters, with potential to bioaccumulate through dietary intake or direct uptake from water. While the cadmium(2+) hydrated complex is the primary form of dissolved cadmium in freshwater, high amounts of dissolved organic matter or hardness levels result in the formation of organic and carbonate complexes, respectively, which limit bioavailability (ATSDR 2012; Mantoura et al. 1978).

The sulfide ions released upon dissolution are expected to enter the biogeochemical sulfur cycle and either be deposited in sediments as insoluble sulfides or undergo oxidation to sulfates, which are ubiquitous in the environment (Canfield et al. 2005).

Removal of cadmium sulfide from STPs will depend on the extent of dissolution prior to entering the STPs. Dissolved cadmium(2+) ions typically undergo 40-75% STP removal from wastewater, with the remainder being released to effluent. Undissolved cadmium sulfide is expected to predominantly be removed from sewage by incorporation to sludge. Cadmium that is incorporated to sludge may be applied to soil through the application of biosolids to agricultural land (Bandow and Simon 2016; ICON 2001).

Predicted environmental concentration (PEC)

A PEC was not calculated as part of this evaluation, as cadmium sulfide pigments are expected to ultimately form cadmium ions in the environment. These cadmium ions are indistinguishable from environmental cadmium arising from other sources. Concentrations of cadmium in Australian rivers, sediment and soil are typically below relevant trigger values for freshwater quality and similar to guideline values for sediments. Cadmium sulfide pigment use is not currently estimated to significantly contribute to these levels.

Cadmium is naturally present at very low background concentrations in all environmental compartments. Cadmium concentrations in soils (<0.1 to 0.5 mg/kg dry weight) were previously discussed in the IMAP assessment on water-soluble cadmium(2+) salts (NICNAS 2019).

Australian pristine freshwater typically contains 0.07-0.1 µg Cd/L (Alloway 1990), which is in agreement with monitoring data from the EU (0.004-0.2 µg Cd/L) (Pan et al. 2010). A typical concentration in mixed domestic and industrial wastewater influent is 0.5 µg Cd/L (NPI 2011). Provided cadmium removal from wastewater in STPs is between 40 and 75% (Bandow and Simon 2016; ICON 2001), STP effluent is expected to be below or on par with the water quality guideline of 0.2 µg Cd/L.

Background cadmium concentrations in Australian sediments are estimated at 0.1–0.2 mg Cd/kg dw (Simpson et al. 2013). Cadmium has been detected in concentrations up to 3 mg/kg dw in some urban locations (Allinson et al. 2015), which exceeds the default guideline value of 1.5 mg Cd/kg dw. However, cadmium from pigments and paints are not attributed as major sources of urban runoff contaminants (ICON 2001).

House dust monitoring in Sydney homes reported a geometric mean cadmium concentration of 1.9 mg/kg (Chattopadhyay et al. 2003) which lies close to global averages (mean of 18 studies is 2.4 mg/kg) (Tan et al. 2016). It has been suggested that possible sources of cadmium in household dust include smoking and coloured articles (National Research Council (US) Subcommittee on Zinc Cadmium Sulfide 1997).

Environmental effects

The environmental effects of cadmium sulfide pigments result from their dissolution into cadmium ions. A detailed account of the environmental effects of cadmium ions is available in the IMAP Environment Tier II assessment of water soluble cadmium(2+) salts (NICNAS 2019).

In summary, cadmium(2+) ions are highly toxic, and there is an ongoing consensus that they pose a bioaccumulation hazard.

Bioavailable forms of cadmium(2+) are very toxic to aquatic life, sediment-dwelling organisms and toxic to terrestrial organisms. The toxicity of cadmium ions to aquatic organisms is strongly influenced by water chemistry, including pH, hardness, and DOM. The presence of other metal ions (e.g. iron and zinc) can strongly influence the hazards associated with cadmium ions in soil.

Effects on Aquatic Life

The toxic effects of these chemicals have been assessed collectively by reference to ecotoxicity data available for cadmium(2+) ions. The water hardness of the test medium is reported as concentration of calcium carbonate.

Acute toxicity

The most sensitive taxon is provided for reference (NICNAS 2019):

Taxon	Endpoint	Method
Fish	96 h LC50 = 0.77 µg/L	*Oncorhynchus mykiss* (rainbow trout) Flowthrough conditions, test substance concentrations measured Hardness $CaCO_3$ = 20 mg/L OECD TG 203

Chronic toxicity

The most sensitive taxon is provided for reference (NICNAS 2019):

Taxon	Endpoint	Method
Invertebrates	7 d EC10 = 0.08 µg/L	*Daphnia magna* (water flea) Flowthrough conditions, test substance concentrations measured Hardness $CaCO_3$ = 30 mg/L OECD TG 202

Endocrine effects/activity

Long term exposure to cadmium can affect reproduction, endocrine and immune systems, development, growth and behaviour of aquatic organisms (US EPA 2016).

Predicted no-effect concentration (PNEC)

The primary environmental effects of the chemicals in this group are expected to be caused by the release of cadmium ions. Based on this assumption, existing guideline values for cadmium ions were considered in place of a PNEC value. The trigger values published for cadmium in the Australian and New Zealand guidelines for water and sediment quality are used in this evaluation (ANZ WQG 2000). The water and sediment quality trigger values represent thresholds above which further assessment of potential toxicity may be required to ensure environmental quality.

The quality guideline values for cadmium have been presented under the *Existing Australian Regulatory Controls* section.

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 consider the unique properties of inorganic substances and their behaviour in the environment (UNECE 2007; US EPA 2007).

GHS classification of environmental hazard

The aquatic hazards associated with the chemicals in this group are dependent on their capacity to release cadmium ions at concentrations that exceed identified acute toxicity thresholds for cadmium ions. Therefore, the GHS classification of cadmium sulfide, and by extension Cadmium Yellow Dark, are based on the available ecotoxicity values for the cadmium(2+) ion as identified in the IMAP Environment Tier II assessment of water soluble cadmium(2+) salts (NICNAS 2019). This is in accordance with the classification procedure for metals and metal compounds under Annex 9 of the GHS (UNECE 2007).

The chemicals in this evaluation are classified as Acute and Chronic Aquatic Category 1 as the low-loading 7-day transformation/dissolution data for cadmium sulfide (2.71 μg/L) is greater than the acute toxicity LC_{50} value for the most sensitive taxon, *Oncorhynchus mykiss* (0.77 μg/L).

Environmental risk characterisation

The chemicals in this group contain cadmium, which can be released to the environment from their use as a pigment in paints and plastic articles. Releases of cadmium to the environment are of concern due to the high toxicity of cadmium and its potential to bioaccumulate.

Cadmium is present in all environmental compartments at varying background levels. Available monitoring reports total concentrations of cadmium, and does not distinguish between cadmium arising from industrial, diffuse, and agricultural sources. Anthropogenic emissions of cadmium in Australia are dominated by metal mining and refining activities, fossil fuel combustion, and fertiliser use. The release of cadmium to the environment from pigment use of the listed chemicals in this group is not expected to be significant.

Although the quantity of cadmium pigment in articles entering Australia is unknown, international information suggests cadmium sulfide pigments are being used in decreasing quantities due to increased regulation and hazard awareness.

Therefore, it is unlikely that the current use of the cadmium sulfide pigments considered in this evaluation pose an unreasonable risk to the Australian environment.

Uncertainty

This evaluation was conducted based on a set of information that may be incomplete or limited in scope. In particular, the volumes of cadmium sulfide pigments for industrial uses in Australia are unknown.

The most consequential areas of uncertainty for this evaluation are:

- No domestic introduction volume data are available for the chemicals in this group. Should information become available to indicate that the chemicals in this group are used in high volumes or they are released directly to the environment, the outcome of this evaluation may change.
- The quantity of articles containing cadmium sulfide pigments that enter the country is unknown. Should further information on this become available, the outcome of this evaluation may change.

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