SUBSPORT Specific Substances Alternatives Database - Chromium VI and compounds

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1. Profiling Chromium VI and its compounds

1.1. Chemical identification

Profiling a chemical, under this chapter, means establishing its basic characteristics: identity and physico-chemical hazards. Uses and functions will be described in chapter 2.

Chromium and its compounds have been known and used since antiquity. It can be found in nature, especially in the oxidation state III, while the oxidation state VI is more likely to be generated in industrial processes. Other oxidation states (I, II, IV, V) are rare. Its properties, like passivation or the intense colour of some of its compounds determined its use on a large scale in various industries. Some of the most used chromium compounds are presented in table 1 .

Table 1. Substance identification: non exhaustive examples of chromium VI compounds

Chemical name	Ammonium dichromate
Identification number	CAS: 7789-09-5 EC: 232-143-1
Other names	Dichromic acid diammonium salt, ammonium bichromate
Chemical name	**Barium dichromate**
Identification number	CAS: 10294-40-3 EC: 233-660-5
Other names	Chromic acid barium salt, barium chromate oxide, CI Pigment Yellow 31, Lemon chrome
Chemical name	**Calcium chromate**
Identification number	CAS: 13765-19-0 EC: 237-366-8
Other names	Chromic acid calcium salt, calcium monnochromate, calcium chromium oxide, calcium chromate yellow
Chemical name	**Chromium trioxide**
Identification number	CAS: 1333-82-0 EC: 215-607-8
Other names	Chromic acid, chromium anhidride, chromium oxide
Chemical name	**Lead chromate**
Identification number	CAS: 7758-97-6 EC: 231-846-0
Other names	Chromic acid lead salt, chrome green, chrome yellow
Chemical name	**Potassium chlorochromate**
Identification number	CAS: 16037-50-6 EC: 240-174-7
Other names	Peligot's salt, chlorochromic acid potassium salt
Chemical name	**Potassium chromate**
Identification number	CAS: 7789-00-6 EC: 232-140-5
Other names	Chromic acid dipotassium salt
Chemical name	**Potassium dichromate**
Identification number	CAS: 7778-50-9 EC: 231-906-6
Other names	Chromic acid dipotassium salt, bipotassium chromate
Chemical name	**Silver chromate**

Identification number	CAS: 7784-01-2 EC: 232-043-8
Other names	Chromic acid disilver salt
Chemical name	**Sodium chromate**
Identification number	CAS: 7775-11-3 EC: 231-889-5
Other names	Chromic acid disodium salt, chromium disodium salt oxide, disodium chromate
Chemical name	**Sodium chromate dihydrate**
Identification number	CAS: 7789-12-0 EC: -
Other names	Chromic acid disodium salt, diydrate, sodium dichromate, sodium dichromate, dihydrate
Chemical name	**Strontium chromate**
Identification number	CAS: 7789-06-2 EC: 232-142-6
Other names	Chromic acid strontium salt, deep lemon yellow
Chemical name	**Zinc chromate**
Identification number	CAS: 13530-65-9 EC: 232-142-6
Other names	Chromic acid zinc salt, buttercup yellow, chromium zinc oxide
Chemical name	**Chromic chromate**
Identification number	CAS: 24613-89-6 EC: 246-356-2
Other names	Dichromium tris(chromate), chromium III chromate

1.2. Hazard identification

Characterising a substance based on its hazards, shows why it should not be used, but it is also essential in alternatives assessment, when comparing it to the substitute.
Hazards are intrinsic to the chemical, which means that regardless of the way a chemical is used, these characteristics do not change. The goal of the substitution processes is to advance inherently safer chemicals and products, consistent with the principles of green chemistry.
This approach allows the reviewer to assess whether or not an alternative is indeed preferable from an environmental, health and safety perspective.

The sources specified in the methodology (click here) were generally used to identify the hazards of the most used chromium VI compounds. Other sources were used, as mentioned in the references.

Table 2. Hazard characteristics of some of the most used hexavalent chromium compounds

Properties	Compounds	Source of information
Physical Hazards		
Explosivity	Many reactions may cause fire or explosion (Chromic VI oxide)	CDC [45]
Flammability	Not combustible but enhances combustion of other substances. Many reactions may cause fire or explosion (Chromic VI oxide)	CDC [45]

Properties	Compounds	Source of information
Oxidizing	Chromium trioxide and chromic chromate classified Ox sol. 1 (H271 - May cause fire or explosion; strong oxidizer), Sodium dichromate, ammonium dichromate, potassium dichromate Ox. Sol. 2 (H272- May intensify fire; oxidizer)	CLP, List of harmonised classification and labelling of hazardous substances [2]
Other properties of reactivity	Some chromium powders may be pyrophoric	EspiMetals [3]
Human Health Hazards		
Acute toxicity		
Highly toxic	Sodium chromate, sodium dichromate, ammonium dichromate, potassium dichromate, chromium trioxide, strontium chromate classified as Acute Tox 3 or Acute Tox 4 (H302-Toxic if swallowed / H312 - Harmful in contact with skin)	CLP, List of harmonised classification and labelling of hazardous substances [2]
Skin or eye corrosion / irritation	Sodium chromate, sodium dichromate, ammonium dichromate, potassium chromate, potassium dichromate, chromium trioxide, classified as Skin Corr. 1A or 1B (H314-Causes severe skin burns and eye damage/H315-Causes skin irritation)	CLP, List of harmonised classification and labelling of hazardous substances [2]
Chronic toxicity		
Carcinogenicity	Sodium chromate, sodium dichromate, ammonium dichromate, potassium chromate, potassium dichromate, chromium trioxide, lead chromate, strontium chromate, classified as Carc. 1A or 1B (H350- May cause cancer)	CLP, List of harmonised classification and labelling of hazardous substances [2] IARC monograph [44]
Mutagenicity	Sodium chromate, sodium dichromate, ammonium dichromate, potassium chromate, potassium dichromate, chromium trioxide, , classified as: Muta 1B (H340- May cause genetic defects)	CLP, List of harmonised classification and labelling of hazardous substances [2]
Reproductive toxicity (including developmental toxicity)	Sodium chromate, sodium dichromate, ammonium dichromate, potassium dichromate, classified as Repr. 1B (H360FD- May damage fertility. May damage unborn child). Chromium trioxide is Repr 2 (H361f- Suspected of damaging fertility)	CLP, List of harmonised classification and labelling of hazardous substances [2]
Endocrine disruption	Not listed by OECD, EU Endocrine disruptor database, SIN list	SDSC methodology [4]

Properties	Compounds	Source of information
Respiratory or skin sensitization	Sodium chromate, sodium dichromate, ammonium dichromate, potassium chromate, potassium dichromate, chromium trioxide, chromic chromate classified as: Skin sens. 1 (H317-May cause an allergic skin reaction)	CLP, List of harmonised classification and labelling of hazardous substances [2]
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Toxic metabolites	Chromium III compounds	HSDB [51]
Environmental Hazards		
Acute/chronic aquatic toxicity	Sodium chromate, sodium dichromate, ammonium dichromate, potassium chromate, potassium dichromate, chromium trioxide, chromic chromate, lead chromate, strontium chromate classified as: Aquatic acute 1 (H400-Very toxic for aquatic life) and Aquatic Chronic 1 (H410-Very toxic for aquatic life with long lasting effects)	CLP, List of harmonised classification and labelling of hazardous substances [2]
Bioaccumulation	Chromium VI bioconcentration factor in fish- BCF<1 but over 100 in oyster and mussel.	US EPA [5]
Persistence	Chromium VI may exist in aquatic media as water-soluble complex anions and may persist in water, though it is often reduced to chromium III	US EPA [5]
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	Scorecard -Montreal Protocol [7]
Monitoring – has the substance been found in human or environmental samples?	Chromium (Cr III and VI) can accumulate in lung tissue , e.g. long after occupational exposure of welders.	Raithel et al. [8]

1.3. Specific regulations

Chromium VI compounds fall under the general regulations on chemicals, like the Directive 98/24/EC [9] on protection of the health and safety of workers from the risks related to chemical agents at work, the REACH Regulation [10] or the Directive regarding carcinogens and mutagens [11].

There are also several legal texts that specifically refer to chromium VI.
The RoHS – Directive 2002/95/EC [12] on the restriction of the use of certain hazardous substances in electrical and electronic equipment states that new electric and electronic equipments put on the market after 1 july 2006 shall not contain chromium VI.

Exemptions were granted for:

- hexavalent chromium as an anti-corrosion of the carbon steel cooling system in absorption refrigerators
- hexavalent chromium in corrosion preventive coatings of unpainted metal sheetings and fasteners used for corrosion protection and Electromagnetic Interference Shielding in equipment falling under category three of Directive 2002/96/EC (IT and telecommunications equipment). Exemption granted until 1 July 2007.

According to the End-of Life Vehicles Directive 2000/53/EC [13], after 1 July 2003 materials and components of vehicles put on the market will not contain chromium VI with the exception of "Corrosion preventative coating on numerous key vehicle components (maximum 2 g per vehicle)."

Commission Regulation (EC) No 1048/2005 [14] amending Regulation (EC) No 2032/2003 on the second phase of the 10-year work programme referred to in Article 16(2) of Directive 98/8/EC concerning the placing of biocidal products on the market bannes chromium trioxide as active substance in wood preservation biocides [15]. The EU Regulation 528/2012 concerning biocides [16] restricts putting carcinogens on the market, which applies to certain chromium compounds.

The Toys Directive 2009/48 [17] regulates the maximum level of chromium that is allowed to migrate from different materials in toys. Chromium cannot be deliberately added to toys, however there is limit value for the occurrence of chromium due to contamination. There are limit values for both chromium (III) and chromium (VI),but the value for chromium (III) is higher since it is considered to be less toxic. There is also an European standard for toy safety (EN 71-3:2013) that specifies a limit value of how much chromium is allowed to migrate from the material [18].

Levels of chromium (VI) greater than 0.002% dry weight is not allowed in cement. The chromium compounds that are classified as carcinogenic, mutagenic or toxic for reproduction (category 1 or 2) are forbidden in chemical products that are sold to the general public according to EC regulation 1907/2006 REACH Annex XVII [10].

Chromium levels in packaging are also regulated by the Packaging and Packaging Waste Directive (EC directive 94/62)[19].

The Directive 2003/2/EC [20] that restricts the use of arsenic, also restricts (indirectly) the use of chromium VI as part of the wood preservative known as CCA-chromated copper arsenate.

PARCOM recommendations support the reduction of chromium pollution in general and includes, for example, the wet processes in the textile industry [21].
Voluntary and sector specific initiatives discourage the use or presence of highly hazardous substances among which chromium compounds, for example the Global Organic Textile Standard – GOTS [22] or EU-Ecolabel [23].

2. Identifying functions and uses

2.1. Uses of Chromium VI compounds

Chromium VI compounds have a large variety of uses in many sectors. Examples of the use of some representative compounds are presented in table 3.

Table 3. Examples of the main uses of chromium VI compounds.
For the description of sectors NACE Codes (Statistical Classification of Economic Activities in the European Community) have been used here.

Sector	Function	Product, article	Source of information
Chromium trioxide			
24.3: Manufacture of paints, varnishes and similar coatings, printing ink and mastics 28: Manufacture of fabricated metal products, except machinery and equipment	Anti-corrosion	Coatings	TURI [24]
20: Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Biocide	Wood preservatives	
Lead chromate			
24.16: Manufacture of plastics in primary forms	Pigment	Plastics	TURI [24]
24.3: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	Pigment	Inks, paints	
Potassium chromate			
19.1: Tanning and dressing of leather	Tanning agent	Leather	TURI [24]
17: Manufacture of textiles	Mordant	Textile dyes	
93.0: Other service activities 05.02: Operation of fish hatcheries and fish farms	Biocide	Algecides	
24: Manufacture of chemicals and chemical products	Oxidising agent	Reagents	
17: Manufacture of textiles	Pigment	Textile dyes	
Potassium dichromate			
17: Manufacture of textiles	Pigment	Textile dyes	TURI [24]
20: Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	Biocide	Wood preservatives	
Silver chromate			
24: Manufacture of chemicals and chemical products	Catalyst	Catalyst	TURI [24]
24.3: Manufacture of paints, varnishes and similar coatings, printing ink and mastics 28: Manufacture of fabricated metal products, except machinery and equipment	Anti-corrosion	Coatings	
24.64: Manufacture of photographic chemical material	Sensitizer/Developer	Photographic media	

Ammonium dichromate			
19.1: Tanning and dressing of leather	Tanning agent	Leather	TURI [24]
24.64: Manufacture of photographic chemical material	Sensitizer	Photographic media	
17: Manufacture of textiles	Pigment	Textile dyes	
Sodium chromate			
17: Manufacture of textiles	Pigment	Textile dyes	TURI [24]
24.3: Manufacture of paints, varnishes and similar coatings, printing ink and mastics	Pigment	Inks, paints	

Source: adapted from TURI [24]

Chromite worldwide production was estimated at 13 millions metric tones in 2002. Chromium ore is mined in 20 countries but over 80% is concentrated in four of them: South Africa , Kazakhstan, India, Turkey. This makes chromium a strategic import material for many countries, especially the big consumers, like the USA [26].

Though chromium and its compounds are largely used, statistic data are scarce at national and international level.

For example, the consumption of chromium and chromium compounds in Denmark in 1999 was 25,000-30,000 tons/year - of which more than 50% was used as metallic chromium, and the remaining quantity as chromium compounds and as trace constituents; the consumption of chromium (VI) compounds is considered to fall, and is estimated at 50-53 tons/year, in 2003 [25].

Average consumption of chromium, chromium compounds and chromium as a trace constituent in Denmark between 1998 and 2000, by field of application, as well as figures on the consumption of Cr (VI) for relevant applications is provided in table 4.

Table 4. Consumption of chromium, chromium compounds and chromium as a trace constituent in Denmark (average for the years 1998, 1999 and 2000)

Field of application	Consumption (tonnes/year)	Percentage %	Of which Cr(VI) (tonnes/year)
Chromium, metallic			
– Iron and steel	24,300–29,300	97	–
– Aluminium alloys	11–106	0.2	–
– Copper alloys	6–9	0.03	–
Chromium compounds			
– Surface treatment	37.7	0.14	37.7
– Pigments in paint and plastic	12.6–116.7	0.23	1–2
– Impregnation	8.8	0.03	8.8
– Tanning	164–302	0.8	0.016–0.035
– Hardeners	13–47	0.11	<<1
– Laboratory chemicals	<1	0	<1
– Other applications	208–522	0.77	–

Chromium as a trace constituent – Coal and oil – Cement	 147 67	 0.53 0.24	 – 2.1–4.2
In total	**24,964–30,354**	**100**	**49.6–52.7**

Source: Danish EPA , 2003 [25]

2.2. Exposure to chromium VI compounds

Occupational exposure

The European database for Carcinogens Exposure (CAREX) [27] estimated a number of 785,692 persons exposed to chromium VI compounds in the EU in 1999. The first ten sectors with the highest estimated number of exposed persons are presented in table 5.

Table 5. Estimated population occupationally exposed to chromium VI, in EU in 1999 - first ten sectors with the highest number of exposed persons

Sector	Exposed persons
Manufacture of fabricated metal products	178329
Manufacture of machinery except electrical	114452
Personal and household services	85616
Manufacture of transport equipment	82359
Manufacture of electrical machinery, apparatus, appliances	28988
Manufacture of industrial chemicals	27959
Construction	26181
Manufacture of plastic products not elsewhere classified	21557
Manufacture of textiles	19995
Air transport	19507

Source: adapted from CAREX [27]

The US National Occupational Exposure Survey (1981 - 1983) listed 108 detailed occupations for which exposure to chromium VI oxide occurred [28]. Among the occupations with the highest number of exposed persons were those presented in table 6.

Tabel 6. Examples of occupations exposed to chromium trioxide in National USA survey 1981-1883

Occupations exposed to chromium VI oxide	
Janitors and cleaners Metal plating machine operators Painting and paint spraying machine operators Aircraft engine mechanics Chemical technicians Assemblers Clinical laboratory technologists and technicians	Engineering technicians physicists and astronomers Printing machine operators Photoengravers and lithographers Health technologists and technicians Grinding, abrading, buffing, and polishing machine operators

Source: NIOSH, 1983 [28]

A national US campaign performed measurements in companies where exposure to chromium VI by inhalation could occur. Results are presented in table 7, per sector (in bold) and subsectors. In some cases permissible exposure limits (PEL) were surpassed [29].

Table 7. Results of chromium VI measurements in US companies in different sectors (2006-2009)

Industry sector	Number of companies		
	Sampled for Cr(VI)	Confirmed airborne Cr(VI)	Personal Samples > OSHA PEL
CONSTRUCTION	**23**	**21**	**8**
Highway, Street & Bridge	7	6	2
Foundation, Structure, & Building Exterior Contractors	4	4	2
Building Finishing Contractors	2	1	1
Nonresidential Building	5	5	1
Other Specialty Trade Contractors	3	3	2
MANUFACTURING	**437**	**284**	**65**
Bakeries and Tortilla Mfg*)	1	1	1
Footwear Mfg.	1	1	1
Basic Chemical	1	1	1
Glass and Glass Product	3	1	1
Foundries	41	26	6
Forging & Stamping	14	11	3
Architectural and Structural Metals	62	38	7
Boiler, Tank & Shipping Container	27	22	6
Coating, Engraving & Heat Treating	64	52	12
Other Fabricated Metal Mfg.	44	23	5
Agriculture, Construction, and Mining Machinery	15	11	1
Industrial Machinery Mfg.	3	3	1
Commercial and Service Industry Machinery Mfg.	6	4	1
Other General Purpose Machinery	10	7	2
Other General Purpose Machinery	4	3	1
Motor Vehicle Body & Trailer Mfg.	7	4	1
Motor Vehicle Body & Trailer Mfg.	7	4	1
Motor Vehicle Parts	7	5	2

Aerospace Product & Parts	18	11	5
Railroad Rolling Stock	5	5	2
Ship & Boat Building	8	4	2
Other Transportation Equipment Mfg.	3	2	1
Other Misc. Mfg	9	6	2
WHOLESALE TRADE	**16**	**8**	**2**
Metal & Mineral Merchant	2	2	1
Miscellaneous Durable Goods Merchant	9	3	1
TRANSPORTATION & WAREHOUSING	**9**	**6**	**2**
Scheduled Air Transportation	4	2	1
Support Activities for Road Transportation	2	2	1
PROFESSIONAL, SCIENTIFIC & TECHNICAL SERVICES	**1**	**0**	**0**
ADMIN. & SUPPORT & WASTE MANAG. & REMEDIATION SERVICES	**5**	**2**	**0**
EDUCATIONAL SERVICES	**1**	**1**	**1**
ARTS, ENTERTAINMENT & RECREATION	**1**	**1**	**1**
OTHER SERVICES	**7**	**6**	**2**
Machinery & Equipment Repair & Maintenance	2	2	1
Other Personal Services	1	1	1
PUBLIC ADMINISTRATION	**5**	**2**	**0**

Source OSHA [29]

Exposure to chromium VI compounds by inhalation is known to produce acute effects like irritation, epistaxis, asthma, sensitization and dermatitis [30].
Exposure to chromium VI by inhalation has severe effects, like lung and nasal cancer. Other effects include perforation of the nasal spetum, periodontitis and gingivitis.
Long term skin exposure may cause dermatitis, eczema, hypersensitivity, and the so called “chrome holes/ulcerus”. Eye exposure leads to conjunctivitis.
Some of the chromium VI compounds are included in the EU harmonized classification as carcinogens and mutagens [2]. IARC classifies all chromium VI compounds as carcinogen to humans [31].

Environmental exposure

The most important antropogenic sources of chromium VI are fossil fuel combustion, steel industry, chemicals production and metal finishing. Natural sources like volcanos and rock erosion also contribute to the general level of chromium pollution. There are only few valid data on the valence state and on the bioavailability of chromium in the ambient air.
Chromium released into the environment may undergo transformations from one oxidation state to another, depending on ambient characteristics like pH, oxygen, presence of co-pollutants.
Chromium VI is hazardous for aquatic organisms, including mammals.

General population exposure

General population is mainly exposed to chromium VI pollutants in water, air and soil. The level of exposure and the risks are higher near industrial sites that use chromium VI or near waste disposal areas.
Accidental leackages are known for causing major impact on the local population. Proximity to highways also raises the level of risk due to exposure to catalysts and brake linings [32].
Some products containing chromium VI, like textile or leather, are also a risk factor. Recently, a Danish study showed that a high percentage of leather products contain chromium VI [33].

2.3. Prioritizing uses

Consumption levels are important factors in determining the uses that should be addressed as priority when searching for substitution. This information may provide some idea on the exposure to humans and environment. It is reasonable to assume that uses with high consumption level of a certain chemical have the potential to impact more on health and environment. This is indeed one of the indicators considered in practice, because is often more readily available than other data, which are also important: number of wokers exposed and the level of occupational exposure, existence of vulnerable groups (like children), level of environmental emissions and fate.

Occupational exposure should be addressed as a priority, since it is at work that the highest exposure to chromium VI occurs. Prioritisation in this document considered the exposure due to the use of chromium VI compounds. Exposure may however, occur in situations where chromium VI is not actually used but it may be generated as emission. For example chromium in stainless steel is considered to be in metal state (valence zero) but high temperature operating conditions, may cause chromium VI formation. Welding of stainless steel is also an important source of chromium VI exposure. Chromium is a strategic material and when used in high quantities, like steel production, and in strategic applications it generates an increasing dependence on imports. This is one of the reasons that substitutes for chromium in steel are sought after [34].
Emissions in water are important, since water ecosystems are, as mentioned, very likely to be affected and polluted water is highly hazardous for humans, too. Uses for consumer goods are also very important, for example in the case of textiles or leather, that may be in direct and prolonged contact with the skin.

2.4. Conclusion

Due to their potential impact on health and environment, alternatives for the following main uses of chromium VI will be identified and screened:

- anti-corrosive and decorative coating;
- plastic pigments;
- leather tanning;
- textile dyeing mordants;
- pigments for ink, paints and dyes;
- wood treatment.

Because there are documents already freely available that present alternatives for some of the uses above, like for anti-corrosive and decorative coating [24, 39, 50], this document will only perform a screening of their hazards against SUBSPORT SDSC criteria.

In chapter 5 there will be a further evaluation for the textile dyeing mordants. Textile industry impact on the environment is still considerably high and there are also concerns about the chemical safety of textile and apparel products.

3. Preliminary identification of alternatives

Table 8 presents alternatives to some of the most used chromium VI compounds. They are listed without priority, and do not represent recommendation of commercial products by SUBSPORT. A screening of the listed alternatives can be found in chapter 4.

Table 8. Examples of alternatives to some of the most used chromium VI compounds

Use	Chromium VI compounds / Alternatives	Source of information
Plastic pigments	**Lead chromate alternatives:**	
	Chrome rutile yellow (Chrome antimony titanium buff rutile)	BASF [35]
	Niobium sulfur tin zinc oxide	Sheperd [36]
Leather tanning agent	**Ammonium dichromate alternatives:**	
	Chromium sulphate	Sah [37]
	Aluminium chloride basic	Idem
	Zirconium sulphate	Idem
	Iron II sulphate	Idem
	Glutaraldehyde and D-alanine, or D-lysine	Idem
	Wattle bark, myrobolan nuts, chestnut	Idem
Anti-corrosion coatings (hard plating)	**Chromium trioxide alternatives:**	
	Thermal spraying (including High Velocity Oxygen Fuel-HVOF) with: cobalt-tungsten carbide (WCCo) or chrome carbide-nickel chrome (Cr3C2-NiCr) powders	BTI [38] ROWAN Tech.Grp. [39]
	Electroplates with: nickel alloys (NiW, NiWB, NiWB with SiC) nanocrystaline CoP alloys	Idem
	Electroless nickel with: nickel-phosphor (NiP) or NiP-SiC composites or nickel boron (NiB)	Idem
	Physical Vapor Deposition (PVD)/Chemical Vapor Deposition vacuum process: titanium nitride (TiN), or chrome nitride (CrN) or tungsten carbide (WC)	idem
	Heat treatment: Gas nitriding (with ammonia), salt bath nitriding (with cyanides), plasma nitriding with nitrogen	Idem
	Laser and welding methods using Cr (III) or other metals by: Laser/weld cladding Electrospark deposition	Idem
Decorative electoplating	**Chromium trioxide alternatives:**	
	Chromium (III) sulphate	Turi [24]
	Chromic nitride	Turi [24]

Textile dyeing mordants	**Sodium/potassium dichromate alternatives:**	
	Potassium aluminum sulphate	Ashis et al [40]
	Stannous chloride	
	Copper sulphate	
	Iron (II) sulphate	
	Sulfated castor oil (Turkish red oil)	
	Disodium 4-[4-[[5-[(2-bromo-1-oxoallyl)amino]-2-sulphonatophenyl]azo]-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl]-2,5-dichlorobenzenesulphonate (LANASOL 4G)	ChemCAS [41]
	Tetrasodium 4-amino-5-hydroxy-3,6-bis[[4-[[2-(sulphonatooxy)ethyl]sulphonyl]phenyl]azo]naphthalene-2,7-disulphonate	ChemCAS [42]
Wood treatment	**Chromated copper arsenate alternatives:**	
	ACQ-B 66.7% copper oxide and 33.3% quat as didecyldimethylammonium chloride (DDAC) with ammonia carrier	US EPA [43]
	ACQ-C 66.7% copper oxide and 33.3% quat as alkyldimethylbenzylammonium chloride (ADBAC) with ammonia or ethanolamine carrier	Idem
	ACQ-D 66.7% copper oxide and 33.3% quat as didecyldimethylammonium chloride (DDAC) with ethanolamine carrier	Idem

4. Screening out regrettable substitutes

The purpose of this chapter is to eliminate any alternatives that would pose a high risk to the environment or human health. SUBSPORT developed a database containing substances that are not acceptable as alternative due to their hazards (SDSC). The alternatives are all screened against this database. It can be found in the SUBSPORT database by following this link: http://www.subsport.eu/case-stories-database. If a substance meets any of the SUBSPORT screening criteria, it is removed from further consideration as an appropriate alternative, unless the author (SUBSPORT) regards the alternative is still safer than the initial substance and safer substitutes are not or hardly available.

Table 9. Selected alternatives to chromium VI compounds screened against SDSC

Use	Alternatives	Prescreening against SDSC
Anti-corrosion coatings (hard plating)	WCCo: cobalt (CAS:7440-48-4)-tungsten carbide (WC CAS: 12070-12-1)	Cobalt metal with tungsten carbide is listed in SDSC as IARC carcinogen 2A
	Cr3C2:NiCr-chromium carbide (CAS 12105-81-6) -nickel chrome	Chromium carbide- not listed Nickel is listed in SDSC as CLP Regulation: sensitiser 1
	nickel alloys (NiW, NiWB, NiWB with SiC)	Nickel is listed in SDSC as CLP Regulation: sensitizer 1
	nanocrystaline CoP alloys	Cobalt is listed as CLP skin and respiratory sensitizer 1 and IARC: carcinogen group 2B Nanomaterials may also

		have other hazards
	nickel-phosphor (NiP) or NiP-SiC composites	Nickel is listed in SDSC as CLP Regulation: sensitiser 1
	nickel boride (NiB) (CAS 12619-90-8)	Nickel boride is listed in SDSC as CLP carcinogen 1A and sensitizer
	titanium nitride (CAS 25583-20-4)	Not listed
	chromic nitride (CAS 24094-93-7)	Not listed
	tungsten carbide (CAS 12070-12-1)	Not listed
	ammonia (CAS 7664-41-7)	Not listed
	sodium cyanide (CAS 143-33-9),	Listed as Vela et al. neurotoxicant 4
	potassium cyanide (CAS 151-50-8)	Listed as Vela &all neurotoxicant 4
	nitrogen (CAS 7727-37-9)	Not listed
Decorative plating	chromium (III) sulphate (CAS 15244-38-9)	Not listed
	chromic nitride (CAS 24094-93-7)	Not listed
Textile dyeing mordants	potassium aluminum sulphate (CAS 10043-67-1)	Not listed
	stannous chloride (CAS 7772-99-8)	Not listed
	copper sulphate (CAS 7758-98-7)	Not listed
	iron (II) sulphate (CAS 7720-78-7)	Not listed
	sulfated castor oil (CAS 8002-33-3)	Not listed
	disodium 4-[4-[[5-[(2-bromo-1-oxoallyl)amino]-2-sulphonatophenyl]azo]-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl]-2,5-dichlorobenzenesulphonate (CAS 70247-70-0)	Not listed
	tetrasodium 4-amino-5-hydroxy-3,6-bis[[4-[[2-(sulphonatooxy)ethyl]sulphonyl]phenyl]azo]naphthalene-2,7-disulphonate (CAS 17095-24-8)	Not listed
Leather tanning	chromium (III) sulphate (CAS 10101-53-8)	Not listed
	aluminium chloride basic (CAS 1327-41-9)	Not listed
	zirconium sulphate (CAS 14644-61-2)	Not listed
	iron (II) sulphate (CAS 7720-78-7)	Not listed
	glutaraldehyde (CAS 111-30-8)and D-alanine (CAS 338-69-2), or D-lysine	Glutaraldehyde is listed in SDSC as CLP skin and respiratory sensitiser 1
	Wattle bark, myrobolan nuts, chestnut	Not listed
Plastic pigments	chrome antimony titanium buff rutile(CAS 68186-90-3)	Not listed
	niobium sulfur tin zinc oxide (CAS 1374645-21-2)	Not listed
Wood treatment	copper oxide (CAS 1317-38-0) didecyldimethylammonium chloride (CAS 7173-51-5)	Not listed
	copper oxide (CAS 1317-38-0)and alkyldimethylbenzylammonium chloride (CAS 8001-54-5)	Not listed
Carbon printing, photography sensitizer (pigment)	Ammonium Iron citrate (CAS 1185-57-5)	Not listed

The alternatives that pass the screening against the SDSC are:

- **for anti-corrosive and decorative coating:**
  - Physical Vapor Deposition (PVD)/Chemical Vapor Deposition vacuum process with titanium nitride (CAS 25583-20-4) or chromic nitride (CAS 24094-93-7) or tungsten carbide (CAS 12070-12-1)
  - Heat treatment: gas nitriding with ammonia (CAS 7664-41-7), plasma nitriding with nitrogen

- **for plastic pigments:**
  - chrome antimony titanium buff rutile (CAS 68186-90-3)
  - niobium sulfur tin zinc oxide (CAS 1374645-21-2)

- **for leather tanning:**
  - chromium (III) sulphate (CAS 10101-53-8)
  - aluminium chloride basic (CAS 1327-41-9)
  - zirconium sulphate (CAS 14644-61-2)
  - iron (II) sulphate (CAS 7720-78-7)
  - wattle bark, myrobolan nuts, chestnut

- **for textile deying mordants:**
  - potassium aluminum sulphate (CAS 10043-67-1)
  - stannous chloride (CAS 7772-99-8)
  - copper sulphate (CAS 7758-98-7) iron (II) sulphate (CAS 7720-78-7)
  - sulfated castor oil (CAS 8002-33-3) disodium 4-[4-[[5-[(2-bromo-1-oxoallyl)amino]-2-sulphonatophenyl]azo]-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl]-2,5-dichlorobenzenesulphonate (CAS 70247-70-0)
  - tetrasodium 4-amino-5-hydroxy-3,6-bis[[4-[[2-(sulphonatooxy)ethyl]sulphonyl]phenyl]azo]naphthalene-2,7-disulphonate (CAS 17095-24-8)

- **for wood treatment:**
  - copper oxide (CAS 1317-38-0) didecyldimethylammonium chloride (CAS 7173-51-5)
  - copper oxide (CAS 1317-38-0)and alkyldimethylbenzylammonium chloride (CAS 8001-54-5)

5. Characterizing alternatives for textile dye mordants

5.1. Hazard characterization of alternatives

The selected alternatives for chromium VI-containing textile dye mordants are further evaluated in tables 10 -16.

Table 10. Hazard characteristics of potassium aluminum sulphate (CAS 10043-67-1) as alternative to chromium VI textile dyes mordants

Hazards	Properties	Source of information
Physical Hazards		
Explosivity	Data lacking	-
Flammability	not flammable	MSDS [52]
Oxidizing	Data lacking	-
Other properties of reactivity	Corrosive to metals	New Zealand HSNO/GHS Chemical Classifications [53]
Human Health Hazards		
Acute toxicity		
Highly toxic	Large doses of alum are irritant and may be corrosive; gum necrosis and gastrointestinal haemorrhage have occurred. Adverse effects on muscle and kidneys have been reported.	HSDB [51]

Hazards	Properties	Source of information
Skin or eye corrosion / irritation	Irritating to the skin/eye eye irritant categ. 2 (H319)	New Zealand HSNO/GHS Chemical Classifications [53] C&L Inventory – self classification [1]
Chronic toxicity		
Carcinogenicity	Not listed in IARC, CLP	CLP [2], IARC [44]
Mutagenicity	Not listed	Idem
Reproductive toxicity (including developmental toxicity)	Data lacking	-
Endocrine disruption	Not listed	OECD, EU Endocrine disruptor database, SIN list
Respiratory or skin sensitization	Not listed	CLP [2] VITO EC Report [46]
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Systemic Toxicity	Data lacking	-
Toxic metabolites	Data lacking	-
Environmental hazards		
Acute/chronic aquatic toxicity	Slightly harmful in the aquatic environment or are otherwise designed for biocidal action	New Zealand HSNO/GHS Chemical Classifications [53]
Bioaccumulation	Data lacking	-
Persistence	Listed as persistent	Domestic Substance List (DSL) [54]
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	SCORECARD [7]
Monitoring – has the substance been found in human or environmental samples?	The crude lump alum occurs with earth attached	HSDB [51]

Table 11. Hazard characteristics of stannous chloride (CAS 7772-99-8) as alternative to chromium VI textile dyes mordants

Hazards	Properties	Source of information
Physical Hazards		
Explosivity	Potentially explosive reaction with metal nitrates.	TOXNET [55]
Flammability	Not considered to be a fire hazard	MSDS [56]
Oxidizing	Data lacking	-
Other properties of reactivity	Powerful reducing agent. Small quantities of hydrochloric acid are present in aqueous solutions. Absorbs oxygen from air and forms the insoluble oxychloride. Forms an insoluble basic salt when dissolved with much water.	MSDS [56]
Human Health Hazards		
Acute toxicity		
Highly toxic	Acute toxicity. categ. 4 (H302, H312)	C&L Inventory – self classification [1]

Hazards	Properties	Source of information
Skin or eye corrosion / irritation	Skin corrosive 1 B (H314) Eye Dam. 1 (H318) Irritating to the skin/eye	C&L Inventory– self classification [1] New Zealand HSNO/GHS Chemical Classifications [53]
Chronic toxicity		
Carcinogenicity	Not listed in IARC, CLP ,	CLP [2], IARC [44]
Mutagenicity	Muta. 2 (H341)	C&L Inventory – self classification [1]
Reproductive toxicity (including developmental toxicity)	Repr. 2 (H361)	C&L Inventory – self classification [1]
Endocrine disruption	Not listed	OECD, EU Endocrine disruptor database, SIN list
Respiratory or skin sensitization	Skin sens. 1 (H317) Contact sensitisers	C&L Inventory – self classification [1] New Zealand HSNO/GHS Chemical Classifications [53]
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Systemic Toxicity	Data lacking	-
Toxic metabolites	Data lacking	-
Environmental hazards		
Acute/chronic aquatic toxicity	Aquatic acute 1 (H400) Hazardous to the aquatic environment (acute and chronic) - Category 1	C&L Inventory – self classification [1] Japan METI/MOE - GHS Classifications [57]
Bioaccumulation	Data lacking	-
Persistence	Listed as persistent	Domestic Substance List (DSL) [54]
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	SCORECARD [7]
Monitoring – has the substance been found in human or environmental samples?	Data lacking	-

Table 12. Hazard characteristics of copper sulphate (CAS 7758-98-7) as alternative to chromium VI textile dyes mordants

Hazards	Properties	Source of information
Physical Hazards		
Explosivity	Not considered to be an explosion hazard	MSDS [58]
Flammability	Not considered to be a fire hazard	MSDS [58]
Oxidizing	Oxidizing	MSDS [59]
Other properties of reactivity	Soln are strongly corrosive to iron & galvanised iron	HSDB [51]

Hazards	Properties	Source of information
Human Health Hazards		
Acute toxicity		
Highly toxic	Harmful to human target organs or systems Acute toxic catg 4 (H302)	New Zealand HSNO/GHS Chemical Classifications [53] C&L Inventory – harmonised classification [1]
Skin or eye corrosion / irritation	H319 - Causes serious eye irritation H315 - Causes skin irritation	CLP [2]
Chronic toxicity		
Carcinogenicity	Not listed in IARC, CLP Carc 1A (H350)	CLP [2], IARC [44] C&L Inventory – self classification [1]
Mutagenicity	Muta. 2 (H341) Germ cell mutagenicity - Category 2	C&L Inventory – self classification [1] Japan METI/MOE - GHS Classifications [57]
Reproductive toxicity (including developmental toxicity)	Repr. 1B (H360) Toxic to reproduction - Category 2	C&L Inventory – self classification [1] Japan METI/MOE - GHS Classifications [57]
Endocrine disruption	Not listed Potential Endocrine Disruptor	OECD, EU Endocrine disruptor database, SIN list TEDX List of Potential Endocrine Disruptors [60]
Respiratory or skin sensitization	Skin sens. 1 (H317) Skin sensitizer - Category 1	C&L Inventory – self classification [1] Japan METI/MOE - GHS Classifications [57]
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Systemic Toxicity	Data lacking	-
Toxic metabolites	Data lacking	-
Environmental hazards		
Acute/chronic aquatic toxicity	Aquatic Acute 1 (H400) Aquatic Chronic 1 (H410)	C&L Inventory – harmonised classification [1]
Bioaccumulation	Data lacking	-
Persistence	Listed as persistent	Domestic Substance List (DSL) [54]
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	SCORECARD [7]
Monitoring – has the substance been found in human or environmental samples?	Data lacking	-

Table 13. Hazard characteristics of iron (II) sulphate (CAS 7720-78-7) as alternative to chromium VI textile dyes mordants

Hazards	Properties	Source of information
Physical Hazards		
Explosivity	Not considered to be an explosion hazard	MSDS [61]
Flammability	Not considered to be a fire hazard	MSDS [61]
Oxidizing	It oxidizes upon exposure to moisture, forming a brown coating of extremely corrosive basic ferric sulphate	MSDS [61]
Other properties of reactivity	May be corrosive to metals (H290)	C&L Inventory – self classification [1]
Human Health Hazards		
Acute toxicity		
Highly toxic	Acute Tox. 4 (H302)	C&L Inventory – harmonized classification [1]
Skin or eye corrosion / irritation	Skin and serious eye irritation (H315, H319)	C&L Inventory – harmonized classification [1]
Chronic toxicity		
Carcinogenicity	Not listed	CLP [2], IARC [44]
Mutagenicity	Data lacking	-
Reproductive toxicity (including developmental toxicity)	Data lacking	-
Endocrine disruption	Not listed	OECD, EU Endocrine disruptor database, SIN list
Respiratory or skin sensitization	Skin Sens. 1 (H317)	C&L Inventory – self classification [1]-
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Systemic Toxicity	Data lacking	-
Toxic metabolites	Data lacking	-
Environmental hazards		
Acute/chronic aquatic toxicity	Slightly harmful in the aquatic environment or are otherwise designed for biocidal action	New Zealand HSNO/GHS Chemical Classifications [53]
Bioaccumulation	Data lacking	-
Persistence	Listed as persistent	Domestic Substance List (DSL) [54]
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	SCORECARD [7]
Monitoring – has the substance been found in human or environmental samples?	Data lacking	-

Table 14. Hazard characteristics of textile dyes mordants alternative sulfated castor oil (CAS 8002-33-3)

Hazards	Properties	Source of information
Physical Hazards		
Explosivity	Data lacking	-

Hazards	Properties	Source of information
Flammability	HMIS: Flammability 1	Ash (2004) [62]
Oxidizing	Data lacking	-
Other properties of reactivity	HMIS: Reactivity 1	Ash (2004) [62]
Human Health Hazards		
Acute toxicity		
Highly toxic	Data lacking	-
Skin or eye corrosion / irritation	Skin and eye irritant categ. 2 (H315, H319) Eye Dam. Categ. 1 (H318)	C&L Inventory – self classification [1]
Chronic toxicity		
Carcinogenicity	Not listed	CLP [2], IARC [44]
Mutagenicity	Data lacking	-
Reproductive toxicity (including developmental toxicity)	Data lacking	-
Endocrine disruption	Not listed	OECD, EU Endocrine disruptor database, SIN list
Respiratory or skin sensitization	Data lacking	-
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Systemic Toxicity	Data lacking	-
Toxic metabolites	Data lacking	-
Environmental hazards		
Acute/chronic aquatic toxicity	Aquatic Chronic categ. 3 (H412)	C&L Inventory – self classification [1]
Bioaccumulation	Data lacking	-
Persistence	Data lacking	-
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	SCORECARD [7]
Monitoring – has the substance been found in human or environmental samples?	Data lacking	-

Table 15. Hazard characteristics of disodium 4-[4-[[5-[(2-bromo-1-oxoallyl)amino]-2-sulphonatophenyl]azo]-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl]-2,5-dichlorobenzenesulphonate, or Lanasol yellow 4G (CAS 70247-70-0) as alternative to chromium VI textile dyes mordants

Hazards	Properties	Source of information
Physical Hazards		
Explosivity	Dust explosion risk	MSDS [63]
Flammability	Not flammable	MSDS [63]
Oxidizing	No Oxidising properties	MSDS [63]
Other properties of reactivity	Data lacking	-

Hazards	Properties	Source of information
Human Health Hazards		
Acute toxicity		
Highly toxic	Data lacking	-
Skin or eye corrosion / irritation	Skin corrosive 1A (H315), eye Damaging 1 (H319)	C&L Inventory – self classification [1]
Chronic toxicity		
Carcinogenicity	Not listed	CLP [2], IARC [44]
Mutagenicity	Data lacking	C&L Inventory – self classification [1]
Reproductive toxicity (including developmental toxicity)	Data lacking	C&L Inventory – self classification [1]
Endocrine disruption	Not listed	OECD, EU Endocrine disruptor database, SIN list
Respiratory or skin sensitization	Skin and Resp sens. 1 (H317, H334) Asthmagen (ARs) - sensitizer-induced	C&L Inventory – self classification [1] AOEC Exposure Codes - Asthmagen List [64]
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Systemic Toxicity	Data lacking	-
Toxic metabolites	Data lacking	-
Environmental hazards		
Acute/chronic aquatic toxicity	Aquatic chronic 3 (H412)	C&L Inventory – self classification [1]
Bioaccumulation	Data lacking	-
Persistence	Listed as persistent	Domestic Substance List (DSL) [54]
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	SCORECARD [7]
Monitoring – has the substance been found in human or environmental samples?	Data lacking	-

Table 16. Hazard characteristics of tetrasodium 4-amino-5-hydroxy-3,6-bis[[4-[[2-(sulphonatooxy)ethyl]sulphonyl]phenyl]azo]naphthalene-2,7-disulphonate, or Remazol Black B (CAS 17095-24-8) as alternative to chromium VI textile dyes mordants

Hazards	Properties	Source of information
Physical Hazards		
Explosivity	Data lacking	-
Flammability	HMIS: Flammability 0 NFPA: Flammability 1	MSDS [65]
Oxidizing	Oxidizing agent	MSDS [66]
Other properties of reactivity	Stable	MSDS [66]
Human Health Hazards		
Acute toxicity		
Highly toxic	Acute Tox. 3 (H302)	C&L Inventory – self classification [1]
Skin or eye corrosion / irritation	Eye irritant 2 (H320)	C&L Inventory – self classification [1]

Hazards	Properties	Source of information
Chronic toxicity		
Carcinogenicity	Not listed	CLP [2], IARC [44]
Mutagenicity	Data lacking	-
Reproductive toxicity (including developmental toxicity)	Data lacking	-
Endocrine disruption	Not listed	OECD, EU Endocrine disruptor database, SIN list
Respiratory or skin sensitization	Skin and Resp sens. 1 (H317, H334)	C&L Inventory – self classification [1]
Neurotoxicity	Not listed	Vela et al. [49]
Immune system toxicity	Data lacking	-
Systemic Toxicity	Data lacking	-
Toxic metabolites	Data lacking	-
Environmental hazards		
Acute/chronic aquatic toxicity	Aquatic chronic 3 (H412)	C&L Inventory – self classification [1]
Bioaccumulation	Data lacking	-
Persistence	Listed as persistent	Domestic Substance List (DSL) [54]
Greenhouse gas formation potential	Not listed	IPCC [6]
Ozone-depletion potential	Not listed	SCORECARD [7]
Monitoring – has the substance been found in human or environmental samples?	Data lacking	-

5.2 Technical feasibility of alternatives for textile dyeing

Metal mordants alternatives have good technical performances. Some of them are brightening mordants (like the alum and the stannium ones) other have a darkening effect (like the copper and the iron ones). Stanous alternative causes higher loss of fabric tenacity if applied over certain concentrations.

The azo dye mixtures provide levels of fastness comparable to those obtained with chromium based dyes, including for the dark colours. Dye fixation rate can be close to 95%, which reduces the amount of dyes released into the environment, especially in waste water. Shade reproductibility is better than for chromium dyes. Except for the back shade, the process is a one step type, while for chromate dyeing it is a two step process.

5.3 Economical feasibility of alternatives

All alternatives are available on the market. Prices are not prohibitive and reducing waste treatment and taxes, may in some cases cut overall costs.

6. Comparing alternatives

Comparing alternatives should consider various aspects relevant for the substitution. A template example for alternative dye mordants free of Cheromium VI is presented in table 17. More criteria may be added and further detailed evaluations should be performed.

Table 17. Comparing alternatives to chromium VI deye mordants

	Potassium alumi-num sulphate CAS 10043-67-1	Stannous chloride CAS 7772-99-8	Copper sulphate CAS 7758-98-7	Iron (II) sulphate CAS 7720-78-7	Sulfated castor oil CAS 8002-33-3	Lanasol 4G CAS 70247-70-0	Remazol Black CAS 17095-24-8
Health aspects	PROS: not listed hazar-dous by sources inviesti-gated CONS: -	PROS: - CONS: is corrosive to skin and self classified Muta 2 , Repro 2, Skin Sens 1	PROS: - CONS: Self classified Carc 1A, Muta 2, Repr 1B, Skin sens 1	PROS: not listed hazar-dous by sources inviesti-gated CONS: -	PROS: Low toxicity CONS: Skin and eye irritant categ. 2	PROS: CONS: Self classified skin and eye corrosive and Resp sens 1 Occupation al asthma recorded [47] General concern on carcinogeni city of azo dyes [48]	PROS: CONS: Self classified Skin and resp Sens. 1 General concern on carcinogeni city of azo dyes [48]
Environ-mental aspect	PROS: not listed hazar-dous by inviesti-gated sources CONS:	PROS: CONS: Data lacking	PROS: CONS: is classified Aquatic acute and Chronic 1	PROS: Not listed hazar-dous by sources inviesti-gated CONS:	PROS: Not listed hazar-dous by inviesti-gated sources CONS:	PROS: Low level of release into water CONS: Self classified classified aqua chronic 3	PROS: Low level of release into water CONS: Self classified aqua chronic 3
Perfor-mance aspects	PROS: Good perfor-mance for bright hues CONS:	PROS: CONS: causes higher loss of fabric	PROS: Good perfor-mance for dark hues CONS:	PROS: Good perfor-mance for dark hues CONS:	PROS: Performs better than other oil mor-dants	PROS: Very good fixation rates CONS:	PROS: Very good fixation rates CONS:

	Potassium alumi-num sulphate CAS 10043-67-1	Stannous chloride CAS 7772-99-8	Copper sulphate CAS 7758-98-7	Iron (II) sulphate CAS 7720-78-7	Sulfated castor oil CAS 8002-33-3	Lanasol 4G CAS 70247-70-0	Remazol Black CAS 17095-24-8
					CONS:		
Cost aspects	PROS: CONS: Medium-high	PROS CONS: High	PROS: Low-medium CONS:	PROS: CONS: Medium-high	PROS: CONS: Medium	PROS: CONS: Medium	PROS: Low-medium CONS:

Examples of related SUBSPORT case stories are:

Inorganic bismuth vanadate yellow pigments that are lead chromate-free (http://www.subsport.eu/case-stories/272-en)

Phase-out of chrome (III) in tanning processes by switching to vegetable based tanning (http://www.subsport.eu/case-stories/097-en)

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