ANALYSIS OF ALTERNATIVES

Public version

Name of applicants:	$CrO_3$4UK Group: Aalberts Integrated Piping Systems Ltd Borough Ltd Quality Plated Products Ltd Samuel Heath and Sons plc
Submitted by:	$CrO_3$4UK Group
Prepared by:	$CrO_3$4UK Group Technology Sciences Group Consulting Ltd (TSG Consulting) Risk & Policy Analysts Ltd (RPA)
Date:	30th June 2022
Substance:	Chromium trioxide (EC no. 215-607-8, CAS no. 1333-82-0)
Use titles:	Use 1: Industrial use of chromium trioxide for the etch pre-treatment step for functional chromium plating with decorative character for automotive, sanitary, heating and other applications Use 2: Industrial use of chromium trioxide for functional chromium plating with decorative character for automotive, sanitary, heating and other applications
Use numbers:	1 & 2

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Declaration

We, the Applicants (Aalberts Integrated Piping Systems Ltd, Borough Ltd, Quality Plated Products Ltd and Samuel Heath and Sons plc), are aware of the fact that further evidence might be requested by the Health and Safety Executive ('the Agency') to support the information provided in this document.

Also, we request that the information blanked out in the "public version" of the Analysis of Alternatives is not disclosed. We hereby declare that, to the best of our knowledge as of today (30th June 2022), the information is not publicly available, and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signatures: **Date, Place:**

Guy Robinson Chief Executive Officer, UK & Middle East Aalberts Integrated Piping Systems Ltd	30th June 2022 Doncaster
David Brereton Director Borough Ltd	30th June 2022 Leigh on Sea
John Timmins Managing Director Quality Plated Products Ltd	30th June 2022 Birmingham
Martin Harrison Manufacturing Director Samuel Heath and Sons plc	30th June 2022 Birmingham

List of abbreviations

AAST	Acidic Accelerator Salt Spray Test
ABS	Acrylonitrile butadiene styrene
AfA	Application for Authorisation
AFUS	Applied-for use scenario
AoA	Analysis of Alternatives
BS	British Standard (published by the British Standards Institution, BSI)
BS EN	British Standard, European Norm, i.e. a British Standard that implements a European Standard
BS EN ISO	British Standard which implements an identical European and International Standard
CAS	Chemical Abstracts Service
CASS	Copper accelerated salt spray (test)
CLP	Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures (Please note that references in this report to CLP should be taken as referring to GB CLP, as retained EU law following Brexit and the end of the Implementation Period on 31 December 2020, unless otherwise specified.)
CMR	Carcinogenic, mutagenic or toxic to reproduction
COSHH	Control of Substances Hazardous to Health Regulations 2002
Cr(O)	Metallic chromium
Cr(III)	Trivalent chromium
Cr(VI)	Hexavalent chromium
CrO_3	Chromium trioxide
$CrO_3$4UK	The group of four applicants applying for authorisation (Aalberts Integrated Piping Systems Ltd, Borough Ltd, Quality Plated Products Ltd and Samuel Heath and Sons plc)
CSR	Chemical Safety Report
CTACSub	Chromium Trioxide REACH Authorisation Consortium
CVD	Chemical vapour deposition
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
DLC	Diamond-like carbon
EC	European Commission
ECHA	European Chemicals Agency
EEA	European Economic Area, i.e. the EU plus Norway, Iceland and Liechtenstein
EN	European Norm, i.e. European Standard (published by the European Committee for Standardisation, CEN)
ERC	Environmental Release Category
ES	Exposure scenario
EU	European Union
FTE	Full-time equivalent
GB	Great Britain

HSE	Health & Safety Executive
ISO	International Standard (published by the International Organisation for Standardisation, ISO)
IUPAC	International Union of Pure and Applied Chemistry
LEV	Local exhaust ventilation
NSST	Neutral salt-spray test
NUS	Non-use scenario
OC	Operational Conditions
OEM	Original Equipment Manufacturer
PC (1)	Chemical product category
PC (2)	Polycarbonate
PFAS	Per- and polyfluoroalkyl substances
PP	Polypropylene
POM	Polyoxymethylene
PPE	Personal protective equipment
PPM	Parts per million
PROC	Process category
PVD	Physical vapour deposition
R&D	Research and development
RAC	Risk Assessment Committee
REACH	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (Please note that references in this report to REACH should be taken as referring to UK REACH, as retained EU law following Brexit and the end of the Implementation Period on 31 December 2020, unless otherwise specified.)
RMM	Risk Management Measures
RMOA	Regulatory management options analysis
RPE	Respiratory protective equipment
SDS	Safety data sheet
SEA	Socio-economic analysis
SEAC	Committee for Socio-economic Analysis
SP	Substitution Plan
SU	Sector of use
SVHC	Substance of very high concern
UV	Ultraviolet
v/v	Volume by volume
w/w	Weight by weight
WCS	Worker Contributing Scenario
WEL	Workplace exposure limit

Glossary

Term	Definition
Absorption capability	The ability of a coating to absorb light.
Adhesion	Parameter describing the tendency of dissimilar particles or surfaces to cling to one another (for example adhesion of coating to substrate, adhesion of paint to coating and/or substrate).
Alternative	Potential alternative provided to the respective industry sector for their evaluation.
Bath	A tank containing an aqueous chemical mixture or rinse.
Chemical resistance	Parameter describing the ability of solid materials to resist damage by chemical exposure.
Coating	A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be functional, decorative, or both.
Corrosion protection	Means applied to the metal surface, for example by electroplating, to prevent or interrupt oxidation of the metal part leading to loss of material. The corrosion protection provides corrosion resistance to the surface.
Electrical conductivity	The measure of the ability of a material/coating to conduct electric current.
Electroless plating	An autocatalytic method of forming a metal coating using metal ions.
Electroplating	Forming a metal coating on the part by an electrochemical method in an electrolyte containing metal ions and the part is the cathode, an appropriate anode is used and an electrical current is applied.
Etching of plastics	Process changing surface morphology of plastic substrate. This is a pre-treatment step of the process chain preparing the surface before subsequent plating.
Functional chrome plating with decorative character	The electrochemical treatment of metal, plastic or composite surfaces to deposit metallic chromium to achieve an improvement in the surface appearance, level of corrosion protection and to enhance durability. Functional plating with decorative character may include use of chromium trioxide in a series of pre-treatments and surface deposits. Functional plating with decorative character is used widely in automotive, plumbing, household appliances, bathroom, furniture and homeware applications. Functional plating with decorative character includes black chrome plating provided that there is no residual Cr(VI) on the surface of the article at the detection limit.
Implementation	After having passed qualification and certification, the third step is to implement or industrialize the qualified material or process in all relevant activities and operations of production, maintenance and the supply chain.
Jobplater	Companies plating on behalf of their customers and their requirements for different sectors.
Nickel leaching	Due to the nickel present in the coated product, a certain amount of nickel may leach out from the surface in contact with skin, drinking water or other materials. This may cause allergic reactions and a legally implemented Ni threshold is present for consumer goods.
Main treatment	The main treatment, chromium trioxide based electroplating, occurs after the pre-treatment and before a post treatment (if applicable).
Passivation	Process providing corrosion protection to a substrate or a coating.
Post-treatment	Post-treatment processes are performed after the chromium trioxide main treatment. Their application is depending on the respective kind of chromium trioxide based electroplating.

Term	Definition
Pre-treatment	Pre-treatment processes involve the use of solutions specifically designed to create pores for the subsequent main treatment (etching of plastics). The pre-treatment process must also provide chemically active surfaces for the subsequent treatment.
Process chain	A series of surface treatment process steps. The individual steps are not stand-alone processes. The processes work together as a system, and care should be taken not to assess without consideration of the other steps of the process. In assessing alternatives for chromium trioxide, the whole process chain has to be taken into account.
Plating	Electrolytic process that applies a coating of metal on a substrate.
Qualification	(OEM) validation and verification that all material, components, equipment or processes meet or exceed the specific performance requirements which are defined in the certification specifications.
Reflective behaviour	The ability of a coating to reflect light.
Sunlight resistance / UV resistance	Resistance to photochemical degradation under the influence of sunlight, as well as resistance to artificial light.
Temperature change resistance / heat resistance	The ability of a coating to withstand temperature changes and high temperatures.
UV lacquer	UV-lacquers are based on the same components as other wet lacquers, but include photo initiators as a special component. These photo initiators decompose in UV irradiation and promote the coherent lacquer layer.
Wear resistance / abrasion resistance	The ability of a coating to resist the gradual wearing caused by abrasion and friction.

1. Summary

Chromium trioxide is listed in Annex XIV of REACH (entry 16) and is subject to authorisation. Its latest application date was 21 March 2016 and its sunset date was 21 September 2017.

This application for authorisation (AfA) is being made jointly by a group of four companies established in Great Britain (GB) who undertake electroplating using chromium trioxide:

- Aalberts Integrated Piping Systems Ltd (Doncaster, England)
  https://www.pegleryorkshire.co.uk/

- Borough Ltd (Leigh-on-Sea, England)
  https://www.borough.co.uk/

- Quality Plated Products Ltd (Birmingham, England)
  http://www.qppltd.co.uk/

- Samuel Heath and Sons plc (Birmingham England)
  https://www.samuel-heath.com/

The applicants have formed the $CrO_3$4UK group and are submitting a joint AfA under Article 62(2) of REACH. While the products the applicants manufacture and the sectors they serve differ, each company uses chromium trioxide to electroplate articles (referred to as substrates) made from metals and plastics to create a metallic chrome coating. The outer chrome coating is free of chromium trioxide and provides the coated articles with a resistant, durable and safe finish, normally with a bright or matt silver finish although occasionally other finishes such as black are produced. This is referred to as functional chrome plating with decorative character.

Two of the applicants also use chromium trioxide for ‘etching’, which refers to specific type of pre-treatment activity undertaken on plastic substrates. This is an essential step to prepare the substrate for subsequent metal plating and involves roughening the surface of the plastic by removing material from the surface of the substrate. The etching pre-treatment step is generally inter-related in a way that it cannot be separated or individually modified without impairing the overall process or performance of the final product.

Plating using chromium trioxide involves immersion of components in a series of treatment baths containing chemical solutions or rinses under specific operating conditions and is usually the final step in the overall surface treatment process. Pre-treatments (including etching, for plastic substrates) and nickel or copper coatings (‘underplates’) are normally applied to prepare the surface prior to chromium plating. The specific combination of pre-treatments and underplates is important in determining the specific performance criteria and final appearance (bright or matt finish, evenness of the surface etc) of the final coated product and varies depending on the required functionalities and the substrate to which it is applied.

The applicants are all currently in compliance with REACH as a result of the AfA made by the Chromium Trioxide REACH Authorisation Consortium (CTACSub). The CTACSub AfA is the joint upstream application submitted by seven applicants under EU REACH that covers all their downstream users for six defined uses of chromium trioxide[1]. The applicants are amongst these downstream users and use chromium trioxide for functional plating with decorative character (use group 3). The European Commission has published its

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[1] The uses covered are: (1) formulation (2) functional chrome plating (3) decorative chrome plating (4) surface treatment for aeronautics & aerospace industries (5) miscellaneous surface treatment and (6) passivation of tin-plated steel.

decision on the CTACSub application for use groups 1, 2, 4, 5 and 6, but not use group 3 (application ID 0032-003). The transitional arrangements under UK REACH are such that this route to compliance is only available until 30 June 2022. To continue operations beyond this date, the applicants must submit an AfA to the Health & Safety Executive (HSE) under UK REACH.

CTAC was formed in 2012 by more than 150 companies, including chromium trioxide suppliers, formulators and downstream users. One of the applicants of the $CrO_3$4UK group (Borough Ltd) is a former member of CTAC and has the right to use the information gathered by CTAC for this AfA (on their behalf and on behalf of all $CrO_3$4UK group members). This means this Analysis of Alternatives (AoA) uses the information on possible alternatives to chromium trioxide based electroplating processes from the CTACSub dossier as well as information from by the $CrO_3$4UK group obtained separately.

This AfA is for two uses of chromium trioxide, namely:

- Use 1: Industrial use of chromium trioxide for the etch pre-treatment step in the electroplating process for functional chromium plating with decorative character for automotive, sanitary, heating and other applications ('etching').

- Use 2: Industrial use of chromium trioxide for functional chromium plating with decorative character for automotive, sanitary, heating and other applications ('plating').

Not all applicants undertake etching and so Table 1 below shows which applicants are applying for which uses. Where etching is undertaken, it occurs on the same lines as plating and is part of the overall process of applying metallic chrome coatings to substrates. Amalgamating both etching and plating within one overall use has been considered for the purposes of this AfA. However, it has been ruled out on the basis that the challenges associated with identifying potential alternatives are significantly different between etching and plating which are explored further in this AoA and which have subsequent implications for the socio-economic analysis (SEA) and substitution plan (SP).

Applicant	Use 1: Etching	Use 2: Plating
Aalberts Integrated Piping Systems Ltd		✓
Borough Ltd	✓	✓
Quality Plated Products Ltd	✓	✓
Samuel Heath and Sons plc		✓

***Table 1**: Applicants and uses applied for*

The applicants use chromium trioxide for functional chrome plating with decorative character in order to meet the strict performance criteria necessary for regulatory compliance, public safety and customer expectations. The applicants' products are used across numerous sectors, including automotive, sanitary ware, heating/plumbing products, consumer goods, architectural hardware, packaging, signage and other consumer and commercial applications. The focus of this AoA will be on three sectors in particular, namely products used for automotive, sanitary and heating applications, as this covers the majority of sectors into which the applicants' products are supplied. Detailed analysis on other sectors is therefore less productive for the purposes of this AoA so a proportionate approach has been taken. However, **to successfully substitute chromium trioxide in etching and plating processes, any potential alternative must prove suitable across the range of the applicants' products**, not just those in the sectors of focus.

Approximately 22.75 tonnes of chromium trioxide per year are used in etching and functional chrome plating with decorative character within the scope of this AfA.

This AoA relates to the applicants' use of chromium trioxide in the electroplating process, including during the etching pre-treatment stage. It forms part of the demonstration made in support of the $CrO_3$4UK group's AfA to allow for continued use of chromium trioxide following the end of the transition period on 30 June 2022. It seeks to determine whether there are any suitable alternative substances and technologies to the use of chromium trioxide in functional chrome plating with decorative character. In particular, this AoA considers:

a) the technical feasibility of alternatives to chromium trioxide;
b) the economic feasibility of alternatives to chromium trioxide;
c) whether transferring to alternatives would result in reduced overall risks to human health and the environment; and
d) whether the alternatives are available to the applicants, i.e. whether they would be of sufficient quality and accessible in sufficient quantities.

The objective is to provide input for the SEA and SP to help identify the most likely non-use scenario (NUS) in the event that chromium trioxide can no longer be used by the applicants. To this end, the AoA also considers the technical and economic feasibility of alternative business models including transferring the use of chromium trioxide outside of Great Britain (GB) and the European Union (EU).

Using chromium trioxide in functional chrome plating with decorative character provides many advantages due to the resulting properties of coatings deposited from chromium trioxide during electroplating. Key functionalities include[2]:

- enhanced corrosion protection and chemical resistance of finished products;
- wear / abrasion resistance;
- good adhesion performance between coatings and substrates;
- sunlight / UV resistance;
- temperature / heat resistance; and
- highly desirable aesthetic qualities.

Since chromium trioxide became subject to authorisation under REACH, it has been very challenging for industry to find a single suitable alternative (substance or process) which provides the same multi-functionality of coatings generated from chromium trioxide. Indeed, some of the applicants have been researching into suitable alternatives for etching and plating for over 30 years. However, it remains the case that there is no single 'drop-in' alternative at the current time[3].

This AoA considers a range of potential alternatives to chromium trioxide. For **plating**, the most promising and realistic for future development is electroplating based on trivalent chromium-based solutions (chromium sulphate and chromium chloride). Other potential alternatives considered include processes based on physical vapour deposition (PVD). For **etching**, the position is less certain and while alternatives based on sulphuric acid and permanganate-based solutions are being actively explored, the results remain less promising at this stage of development.

All alternatives currently fail because they are not technically and economically feasible. If products had to be manufactured using such alternatives, this would result in significantly inferior product leading to a substantial loss of sales and market share, with customers switching to more durable and reliable product that had been manufactured using chromium trioxide, most likely manufactured outside GB and the EU.

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[2] EIPPCB, 2006, p48, and TURI, 2006, ch6, p6.

[3] Müller et al., 2020, p17.

This means that if the applicants' uses of chromium trioxide were to cease then their only realistic options are 'managerial' in nature, such as ceasing the production and supply of chrome-plated products entirely, relocating manufacturing operations currently undertaken in GB to a non-UK/EU facility, or outsourcing electroplating using chromium trioxide to a third party based outside the UK and the EU. These options are carried forward for further analysis in the SEA in terms of considering the most likely NUS.

Despite the current failings of potential alternatives, the applicants continue to devote time and resources to research and development (R&D) into alternatives. For **plating**, these efforts currently centre on trivalent chromium processes, in an attempt to address their current performance weaknesses. For **etching**, the applicants will continue working with technology providers such as MacDermid Enthone and Atotech on developing solutions to provide viable alternatives although these do not currently exist on the market. It is hoped that the issues with alternatives to both plating and etching can be resolved in the future although at this point in time this is far from clear and not guaranteed.

Substitution plans have been prepared as part of this AfA to demonstrate the applicants' commitment to moving to Cr(VI)-free alternatives. The SP considers the steps proposed to switch to such alternatives in more detail. This involves substantial R&D effort for the investigation of shortlisted alternatives, further detailed investigation of process variables, scale-up of the chosen alternative processes to production trials, conducting those trials and gathering feedback, obtaining customer approvals and qualification, then ultimately transitioning from hexavalent chromium processes to the chosen alternative processes.

The challenges faced by the applicants in terms of substitution should not be understated. For example, the automotive sector remains reluctant to commit to switching to trivalent chromium based plating solutions and, given the complexity of supply chains, it is difficult if not impossible for electroplaters to demand that OEMs change direction. In more recent years there are signs that the sector is preparing to move towards alternatives to Cr(VI)-based products, with technology providers proposing solutions to traditional problems associated with Cr(III)-based plating, although this is likely to take many years to achieve in practice. For sanitary ware, issues remain with corrosion resistance, chemical resistance and aesthetics, especially at the luxury end of the market or in high-use environments such as hotels and other hospitality settings, and alternatives are not currently available across the entire product portfolio, e.g. for products with a matt black chrome finish. For all applicants, the continued availability of imported products from outside GB and the EU where the use of chromium trioxide remains legal (or from EU-based manufacturers who have applied for authorisation successfully) means that competitors will only be too happy to move into any space vacated by the applicants should they not be granted authorisation.

As a result, **a review period of 10 years is requested for plating and 12 years for etching**. These periods are based on what are considered by the applicants to be the schedule required to industrialise alternatives to chromium trioxide for functional chrome plating with decorative character for key applications.

2. Introduction

2.1. The substance

The substance subject to this analysis of alternatives is chromium trioxide (Table 2). Chromium trioxide was included in the EU candidate list of substances of very high concern (SVHC) on 15 December 2010 (ECHA Decision ED/95/2010) and was included in Annex XIV of EU REACH on 17 April 2013 (by virtue of Commission Regulation (EU) 348/2013). This was because of intrinsic properties relating to carcinogenicity and mutagenicity. It was given a latest application date of 21 March 2016 and a sunset date of 21 September 2017. EU REACH, including Annex XIV, was transposed to UK law on 1 January 2021. Transitional arrangements under UK REACH are directly relevant for the applicants, as explained below.

Substance name	CLP classification	Intrinsic properties [4]	Regulatory deadlines
Chromium trioxide EC no. 215-607-8 CAS no. 1333-82-0	Ox. Sol. 1; H271 Carc. 1A; H350 Muta. 1B; H340 Repr. 2; H361f Acute Tox. 3; H301 Acute Tox. 2; H310 Acute Tox. 2; H330 Resp. Sens. 1; H334 Skin Sens. 1; H317 Skin Corr. 1A; H314 STOT RE 1; H372 Aquatic Acute 1; H400 Aquatic Chronic 1; H410	Carcinogenic (cat. 1A) Mutagenic (cat. 1B)	*Latest application date*: 21 March 2016 *Sunset date*: 21 September 2017 *UK REACH latest application date*: [5] 30 June 2022

***Table 2**: About chromium trioxide and its entry on Annex XIV*

Under these transitional arrangements, the applicants are able to continue using chromium trioxide as GB-based downstream users covered by an AfA made further up their supply chain, in this case, by the CTACSub (application ID 0032-003). In line with Article 56(1)(d) of UK REACH, the application was made prior to the latest application date but a decision on that application has still not yet been taken. In addition, following the UK's withdrawal from the EU on 31 January 2020 and the end of the Implementation Period on 31 December 2020, the applicants are covered by the transitional provisions under Article 127GA of UK REACH, which extend the sunset date to 30 June 2022.

2.2. The applicants

2.2.1. Aalberts Integrated Piping Systems Ltd

Aalberts Integrated Piping Systems Ltd ('Aalberts') is well known and respected as one of the world's leading manufacturers of advanced plumbing, heating and engineering products. It bases its reputation through dedication to quality, service, investment, innovation and customer service which has been the hallmark of the company since it was established in the 1890s, originally trading as Pegler Ltd and Yorkshire Fittings Ltd. Energy and water conservation is very much at the forefront of our product development.

Aalberts' product range encompasses a range of product lines for connection technology and valve technology which, together with its design service, offer the ultimate solution for top-quality integrated piping systems. Its products include thermostatic radiator valves, push-fit and press-fit fittings, compression joints, commercial and plumbing valves and commissioning valves. Fittings and valves are made from both metal and plastic components and multiple components are usually required to produce a single saleable

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[4] Intrinsic properties are those referred to in Article 57 of REACH that result in the substance being included in Annex XIV.

[5] Article 127GA of UK REACH sets out transitional arrangements for GB-based downstream users of authorisable substances who were previously covered by an application for authorisation made under EU REACH by an actor further up their supply chain but where the European Commission had not yet finalised its decision on that application. Under Article 127GA, if the application for authorisation had been made to ECHA before the latest application date under EU REACH, the latest application date was before the end of the Implementation Period and the sunset date was on or after 29 March 2017, then the latest application date and sunset date under UK REACH is moved to 18 months after the end of the Implementation Period for those covered by this Article's provisions.

item. Metallic substrates in various brass grades will be chrome-plated at the Doncaster site, whereas plastic substrates of differing types (polypropylene/acetal/nylons) will be chrome-plated by a third party.

***Figure 1**: Aalberts Integrated Piping Systems Ltd, Doncaster*

Aalberts is part of the Integrated Piping Systems Division of Aalberts N.V., a Dutch company that was founded under its former name Aalberts Industries by Jan Aalberts in 1975. Aalberts has over 14,000 employees operating out of 134 locations in over 50 countries around the world. 450 of these employees are directly engaged on R&D activities. Other divisions are associated with hydronic flow control systems, advanced mechatronics and surface technologies, serving markets associated with eco-friendly buildings, semiconductor efficiency, sustainable transportation and industrial niches.

2.2.2. Borough Ltd

Borough Ltd is one of the UK's leading plastic injection moulders and chrome platers of plastics and supports many global automotive brands and their suppliers. To ensure the company delivers the highest quality chrome plating, it continues to invest in the latest injection moulding and electroplating equipment to provide complete control over the components manufactured, which over time have grown larger and more complicated. As well as injection moulding and plating on plastics, Borough also undertakes assembly work, e.g. performing the intricate assembly work required of corporate emblems for vehicle manufacturers with both inserts and die cuts that allow successful fitting to a vehicle.

***Figure 2**: Borough Ltd, Leigh-on-Sea*

Borough was established in 1947 as 'Borough Polishing & Plating'. At the time, use of plastics was not mainstream so the company's original focus was on metal finishing, offering gold, nickel, cadmium, silver &

zinc plating. In the early 1960s the company pioneered the switch from plating on metal to plating on plastics. The business has since grown to employ more than 80 people and delivers some of the highest quality moulded and plated parts available to the automotive industry, working with some of the most recognisable car brands in the world, some of which the company has worked with for decades.

As well as producing parts for automotive applications, other sectors served by Borough include packaging, point of sale, signage and manufacturing, e.g. producing plated plastic parts for domestic appliances. Borough also has a product testing department offering customers a number of services to test the quality and durability of all the parts it moulds and plates.

2.2.3. Quality Plated Products Ltd

Quality Plated Products (QPP) is one of the UK's leading producers and suppliers of chromium plated plastic products to the UK and European markets. The company specialises in plating on plastic, specifically for interior and exterior automotive applications, but also for the sanitary ware, household and white goods, brewery, display and electronics sectors. The company offers a variety of chrome finishes from bright to satin, silver to black.

***Figure 3**: Quality Plated Products Ltd, Birmingham*

Operating since 1965, QPP has established itself as an invaluable member of the supply chain, on average processing and despatching in excess of 45,000 parts a day. As well as normal, day-to-day large volume production, the company has the facility to undertake small volume and prototype runs and can project manage customers' requirements if required, through initial design recommendations, mould tooling, injection moulding of components, plating and assembly, providing a range of services all under one roof. QPP also has a number of on-site laboratory and environmental testing facilities enabling it to ensure that customers' products fully meet the requirements of any UK or EU legislation, whilst continuing research into new decorative finishes.

2.2.4. Samuel Heath and Sons plc

Samuel Heath and Sons plc (Samuel Heath) is a British designer and manufacturer of exceptionally crafted bathroom fittings & architectural hardware, established in 1820. Integrity and provenance are the foundations of Samuel Heath ever since the company first began to manufacture solid brassware from their premises in Birmingham, England. The company began as a traditional brass founder, producing a vast array of products from bedsteads to high quality giftware and fireside accessories. Building upon this industrious heritage, Samuel Heath is now established worldwide as a manufacturer of bathroom accessories, taps, showers and architectural hardware with a reputation for stylish design, quality and performance.

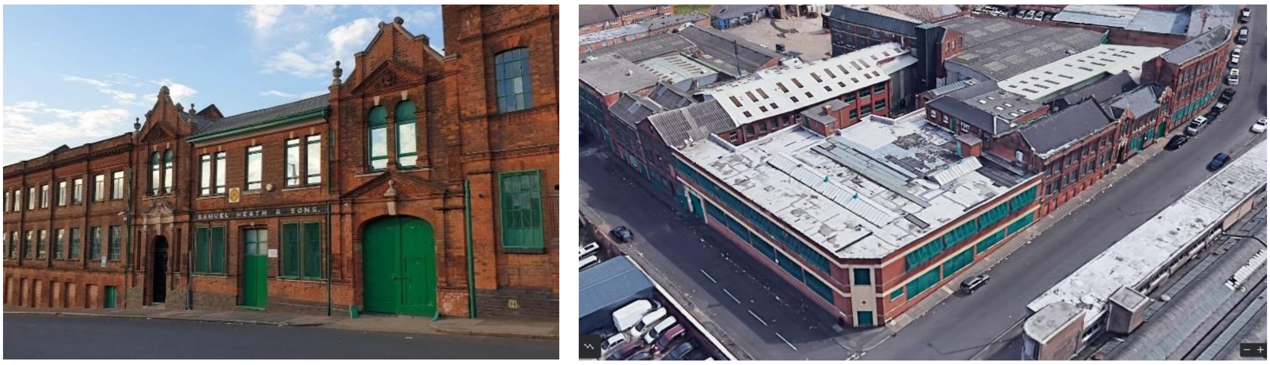

Figure 4: *Samuel Heath and Sons plc, Birmingham*

The company operates at the luxury end of the sanitary ware market. Craftsmanship remains central to the Samuel Heath ethos and manufacturing combines the very latest in modern production techniques with time-served craft skills. Components are formed from brass and then polished by hand to create a flawless finish before undergoing a high-quality electroplating process. Each product is then assembled, checked and packed by hand. All of these processes take place at the company's Birmingham factory, ensuring total control over manufacturing, quality and environmental responsibility.

2.3. The applicants' use of chromium trioxide

The main uses of chromium trioxide within the use category functional chrome plating with decorative character are:

- **Etching**: A pre-treatment processes for plastic substrates
- **Plating**: applying a metallic chrome coating by electroplating on top of specific underplates and on different types of substrates, creating either a bright (shiny) or matte silver look, or a black chrome coating.

The articles being coated are metal or plastic components which will then be assembled into products for automotive, sanitary, heating/plumbing or other applications. A product will often comprise a number of components and may involve the use of both metal and plastic plated parts alongside each other. Those products will often be used in environments where other chrome-plated products are found, such as a bathroom environment or the interior or exterior of a car. This means that a consistent finish that meets the visual expectations of customers is essential, not only between component parts of a single product, but between different products located in the same space.

For automotive applications, chromium trioxide is used within automobile supply chains to manufacture several thousands of metallic chrome plated parts per vehicle manufacturer. Parts cover a wide range of applications, from interior and exterior parts with functional and decorative metallic chrome coating as well as functional metallic chrome coatings (belt locks to injector valves) in vehicle models with a production period of 7-10 years.

For sanitary and heating/plumbing applications, chromium trioxide is used for functional plating of articles with decorative character to manufacture products including, but not limited to bathroom and kitchen taps and mixers, radiator and plumbing fittings and valves, shower heads, hoses, towel rails, and bathroom and kitchen accessories such as soap dishes and mirror frames. These products must maintain performance for periods of many years and withstand use of harsh cleaning chemicals and impurities in water, as well as mechanical forces, under a range of temperatures and conditions. The products must therefore demonstrate resistance to a range of actions (corrosion, chemicals, wear, sunlight, temperature) and hardness. Furthermore, these products must not result in any contamination of water for human consumption or use, since this could present a significant public health issue.

2.4. Benefits of using chromium trioxide

While the science of modern electroplating dates back to the beginning of the 19th century, it took until the early 20th century for chromium plating to begin[6]. During World War II, the use of metals such as chrome was partly put on hold, but its use in applications including those with decorative qualities rapidly expanded during the 1950s and has remained popular ever since. The use of chromium trioxide is well-established, well-understood and achieves the key functionalities required for products used for automotive, sanitary, heating and other applications, mainly based on the characteristics of the hexavalent chromium compound. These key functionalities are:

- **corrosion resistance**, needed to prevent corrosion of the products (the coating itself and the underlying layers) and therefore protect against degradation due to the process of oxidation of a metallic material, due to chemical reactions from the surrounding environment (e.g. water and variable humidity and temperature levels commensurate with the environments in which the applicants' products are used).

- **wear and abrasion resistance**, required to protect the coating and underlying layers from scratches and damage, as well as contribute to high corrosion resistance and to preserve decorative appearance.

- **adhesion**, to ensure metallic chromium deposited from chromium trioxide during electroplating successfully adheres to the underlying substrate, to prevent damage from cracks and/or blistering.

- **chemical resistance**, as chemicals in daily contact with the products (e.g. cleaning agents) can attack the surface, causing corrosion and adversely affecting surface aesthetics. Chemical resistance is all the more important for products likely to be cleaned on a frequent basis, such as those used in hotels and similar hospitality settings. Corrosion prevention prolongs product life and guarantees its decorative appearance.

- **resistance to temperature change and heat**, which has to be high to withstand demanding conditions the products are exposed to, e.g. in automotive applications or in kitchen or bathroom environments.

- **ultraviolet (UV) resistance**, whereby the coating must be sufficiently robust to withstand natural (sunlight) and artificial UV radiation.

- **colour and aesthetics**, in that the finish must achieve a specific aesthetic appearance to satisfy customer demands and expectations. This includes a requirement that products must be capable of colour-matching other products (or components of products) found in the same environment, e.g. where one product in a bathroom requires upgrading if it has reached end-of-life or where multiple chrome components are used on the interior and exterior of vehicles. Surfaces must also be free of any defects such as pores, cracks and blistering.

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[6] Dubpernell, 1984, and Giurlani et al., 2018.

- **longevity**, in that products must be capable of satisfying a minimum period of service life, given product warranties and the often-demanding and aggressive environmental conditions of use, as well as satisfying customer expectations about the quality of the brands.

All of the above-mentioned key functionalities are highly interconnected with each other and therefore it is essential that a potential alternative sufficiently fulfils every minimum requirement to achieve a high-quality surface under the conditions of use.

A number of alternatives are under assessment and these are described further in this AoA. While R&D efforts into substituting chromium trioxide continue (and which are hoped will ultimately be successful), this AoA demonstrates the significant challenges associated with finding a substitute which meets all requirements for each product and application while also being technically and economically feasible. At the present time, there is no ‘drop-in’ replacement available.

2.5. About this analysis of alternatives

Chromium trioxide is listed in Annex XIV of REACH and its use requires authorisation. The applicants currently benefit from transitional measures under Article 127GA of REACH. However, should an AfA not be made by the end of the transitional period then their use will become unlawful.

This AoA has been undertaken as part of work to demonstrate the case for granting the applicants an authorisation to allow for continued use of chromium trioxide during the review period. Its aim is to assess the feasibility of potential alternatives to the use of chromium trioxide for plating and etching. The objective is to identify the most likely ‘non-use scenario’ for the applicants in the event that their use of chromium trioxide must cease, to provide input for the socio-economic analysis (SEA) and substitution plan (SP).

Article 60(5) of REACH provides that when assessing the availability of suitable alternative substances or techniques, all relevant aspects must be taken into account, including:

a) whether the transfer to the alternative would result in reduced overall risks to human health and the environment (as compared to the Annex XIV substance) taking into account risk management measures; and
b) the technical and economic feasibility in Great Britain of alternatives for the applicants for replacement of the Annex XIV substance.

The alternative must also be available for the applicants, i.e. it can be accessed in sufficient quantity and quality for substitution.

3. Annual quantities

3.1. Use 1: Etching

The combined annual quantity for both applicants who use chromium trioxide for the etch pre-treatment step in the electroplating process for functional chromium plating with decorative character is [redacted] tonnes per year.

The non-confidential annual tonnage band for the use of chromium trioxide for etching is 10 – 100 tonnes per year.

3.2. Use 2: Plating

The combined annual quantity for all four applicants using chromium trioxide for functional chromium plating with decorative character for automotive, sanitary, heating and other applications is [redacted] tonnes per year.

The non-confidential annual tonnage band for the use of chromium trioxide for plating is 1 – 10 tonnes per year.

4. Analysis of substance function

Chromium trioxide is used for electroplating a wide variety of products across a number of different sectors, including sanitary ware, automotive parts, engineering equipment, tools, electrical goods, gun barrels, cosmetic products, furniture, architectural accessories, kitchen utensils, white goods, musical instruments and various consumer products.

The thickness of electroplated chromium deposits falls into two classifications[7]: decorative chrome plating and hard chrome plating. In decorative applications, the chrome is plated as a thin (0.25–0.8 µm) layer over nickel, which provides an economical, durable and highly corrosion resistant deposit that is also aesthetically-pleasing. In hard chrome plating, usually used for engineering purposes, deposits usually have a thickness greater than 0.8 µm and are often plated directly onto the substrate. Again, such coatings provide excellent resistance to heat, wear, corrosion and erosion.

All sectors rely on the use of different kinds of metal and plastic substrates:

- Those applicants that plate on metal use brass substrates in various grades.
- Those applicants that plate on plastics use:
    - ABS (acrylonitrile-butadiene-styrene)
    - ABS/PC (ABS with polycarbonate) which is a mix of ABS and PC using varying amounts of PC usually containing 45% or 65% volume by volume (v/v) of PC
    - PP (Polypropylene)
    - Acetal plastics, also called polyacetal or polyoxymethylene (POM)
    - Nylon
    - Multi-K moulds, e.g. 2K and 3K components, which refers to products that have been manufactured by moulding two or three different materials into one plastic part

In this report, the terms “metal substrates” and “plastic substrates” will be used and all of the above-mentioned types of substrates are comprised within these terms. If there are technical constraints or limitations to a specific kind of substrate, this is indicated as required.

Plastic is used as a substrate for many applications due to a number of advantages it brings for certain applications. The principal advantage is that the plated component will be considerably lighter in weight, which in some applications is advantageous over metals. This is particularly useful for the automotive sector

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[7] Mandich & Snyder, 2011

where a lower weight of a component contributes to a lower weight of a vehicle with consequent reductions in fuel consumption and CO2 emissions. Design can also be more flexible, in that multi-component plastic components can be selectively plated to result in a mixed finish on the plated part.

On the other hand, plastic components require etching as a pre-treatment step. The etching step is necessary for the creation of an electrically conductive surface on plastic substrates. Without this treatment the subsequent electrodeposition of different metal layers would not be possible since plastic has a very low electrical conductivity on its own. It also ensures a tight bond between the plastic substrate and the metal coating. A failure in the etching step will lead to poor adhesion between the substrate and the coating.

Importantly, etching with a chromium trioxide-based solution only affects the ABS substrate. Considering current advanced manufacturing processes, this is especially important and necessary for the plating of plastic parts made of two or three different types of material (referred to as 2K or 3K parts), for example, parts made from both ABS and PC. For a two- or three-component part, only the ABS is etched and, as a result, plated. Selective etching and plating is essential to achieving the design of these parts; if etching was to affect the non-ABS parts as well, factors such as surface structure, physical fit, electrical properties, and aesthetic appearance of these parts would be ruined. Selective etching and plating allows platers to effectively and efficiently limit use of chromium to those areas in which functionality conferred by chromium plate is needed.

4.1. The end products

Chromium trioxide is used in functional chrome plating with decorative character to apply a finish to achieve an aesthetic, decorative surface with a high durability in contact with aggressive and demanding conditions (indoors or outdoors). The vast majority of finishes have a bright or matt silvery appearance. Other less common variations include dark satin or black chrome finishes. The metallic chrome layer is applied as final coating on top of a multi-layer system and the combination of underplates is responsible for the final appearance (bright or matt) of the top coating as well as for its even surface. The underplates vary depending on the different required functionalities of the final product and the substrates used.

Functionalities of metallic chrome coatings applied by chromium trioxide-based electroplating have been evaluated by the applicants to determine those that are the most important (key functionalities). These guarantee that products across all sectors have high aesthetic value and a high-quality, durable product. **Corrosion resistance** is vital to prevent corrosion of the coating, the underlying layers and the whole plated product. The **chemical resistance** must be high, given the chemicals in daily contact with the products, e.g. cleaning agents for sanitary ware, salts with regard to automotive products, which can attack the surface, causing corrosion and deteriorating the aesthetics. A minimum **hardness** of the coating combined with a **high wear and abrasion resistance** is necessary to protect the coating and therefore the product from scratches and damage, and to preserve the decorative appearance. A **high level of adhesion** is required between the metallic chrome coating top layer and the underlying base / underplates, to prevent damage of the surface by cracks and/or blistering. **Resistance to temperature change and heat** of the final product has to be high to withstand the demanding conditions the products are exposed to (for example hot water, high outdoor temperatures) and to preserve the coatings from damages and cracks. Additionally, **sunlight resistance** of the coating must be sufficient to withstand natural and artificial UV radiation from light conditions i.e. indoors as well as outdoor. Last, but by no means least, **colour and cosmetic surface appearance (aesthetics)** is crucial - the coating process must ensure that the production of all parts, independent of production date or plating line, all result with the same appearance and colour.

Typical product examples produced by the applicants are provided in Table 3 and in Figures 5 to 8 below.

Automotive		Sanitary ware	Heating & plumbing applications	Architectural hardware	Domestic appliances	Others
Exterior	Interior					
Brand labels, emblems, logos	Brand labels, emblems, logos	Kitchen & bathroom taps / mixers	Thermostatic radiator valves	Letter boxes, flaps and plates	Shavers	Medical devices, e.g. ventilators used for COVID-19 treatment
Trim strips	Trim strips	Shower mixers, diverters, heads and roses	Push-fit fittings	Door knockers	Parts of coffee machines	Signage
Rims	Gear lever knobs	Shower hoses, rails & risers	Press-fit fittings	Door knobs / handles	Washing machine doors	Point of sale
Front skirts	Decorative frames	Towel rails	Compression joints	Door numerals	Interior parts in fridges	Perfume / lipstick caps
Exterior rear-view mirrors	Interior rear-view mirrors	Accessories, e.g. robe hooks, tumblers, soap dispensers	Commercial valves	Window handles, fasteners and stays	Display frames	Packaging
Door handles	Door handles	Drains and overflows	Commissioning valves	Hat and coat hooks	Lamps & light fittings	Electrical devices
Radiator grills	Control panel surrounds	Furniture handles	Plumbing valves	Stops and chains	Oven knobs / shelves	Brewery products, e.g. beer taps

***Table 3**: Sector-specific examples of chrome-plated products*

Automotive interior controls and control panel surrounds (source: QPP)

Interior door handle and trim (source: QPP)

Automotive front grille surrounds in the process of being plated (source: Borough)

Automotive front grille surrounds in situ (source: Borough)

Automotive seat speaker surrounds awaiting inspection (source: Borough)

Automotive seat speaker surrounds (satin) in situ (source: Borough)

Figure 5*: Automotive sector - different interior and exterior parts with metallic chrome coating on plastic substrates*

Bright chrome flow control for shower (source: Samuel Heath)

Matt black chrome single lever basin mixer (source: Samuel Heath)

Soap basket bathroom accessory (source: Samuel Heath)

Thermostatic shower set with 2 low controls in chrome (source: Samuel Heath)

Figure 6*: Sanitary ware - examples of various metallic chrome-coated products on brass substrates*

Chrome plated angle pattern thermostatic radiator valve with integral push-fit fitting (source: Aalberts)

Chrome plated brass hose union ball-type bibtap valve (source: Aalberts)

Compression fittings, various types (source: Aalberts)

Thermostatic radiator valve combining metal and plastic parts (source: QPP)

***Figure 7**: Heating/plumbing sector - examples of various metallic chrome-coated products on metal and plastic substrates*

Ventilator for COVID-19 / COPD treatment incorporating chrome-plated components for hygienic purposes (source: Borough)

Chrome-plated cooker knobs (source: QPP)

Architectural hardware in various finishes including satin and matt black chrome (source: Samuel Heath)

Drinks industry dispensing fonts / taps prior to being chrome-plated (source: Borough)

***Figure 8**: Examples of metallic chrome-plated products for other applications and sectors on metal and plastic substrates*

4.2. Process description

The following process description provides an overview of the general approach encompassing different substrate-specific techniques. Applying a coating of functional chrome with decorative character is a multi-step process carried out in multiple treatment baths. The process is usually automated, with a plating line typically in a horseshoe or ‘U’ configuration, although some applicants also have manual plating lines.

Process steps are performed by immersing the brass substrates in baths containing an aqueous solution specific to the individual process step. It is referred to as a 'wet-in-wet' process and is performed in a continuous operation without intermediate storage of products at any time of the process chain, except for the final drying step. Intermediate rinsing steps are performed in the process to prevent the carry-over of chemicals from one bath into another, which would lead to contamination of the subsequent process step. The chrome plating layer is applied as the final coating on top of a multi-layer system. The combination of all the layers results in the final appearance and performance properties of the finished product.

The process can be divided into three overall sub-processes. First, the surface of the substrate is pre-treated to remove impurities and, where required, for etching of plastic substrates. Second, a functional multi-layer system of metal layers is then applied by electroplating, with a final metallic chrome coating applied using chromium trioxide electroplating. Third, the process is concluded by adequate post-treatments, for example rinsing and drying of the plated product or special post-treatment processes after black chrome electroplating. Chromium trioxide is required for the final coating stage (chrome electroplating) and for the etching pre-treatment steps, where plastic substrates are used.

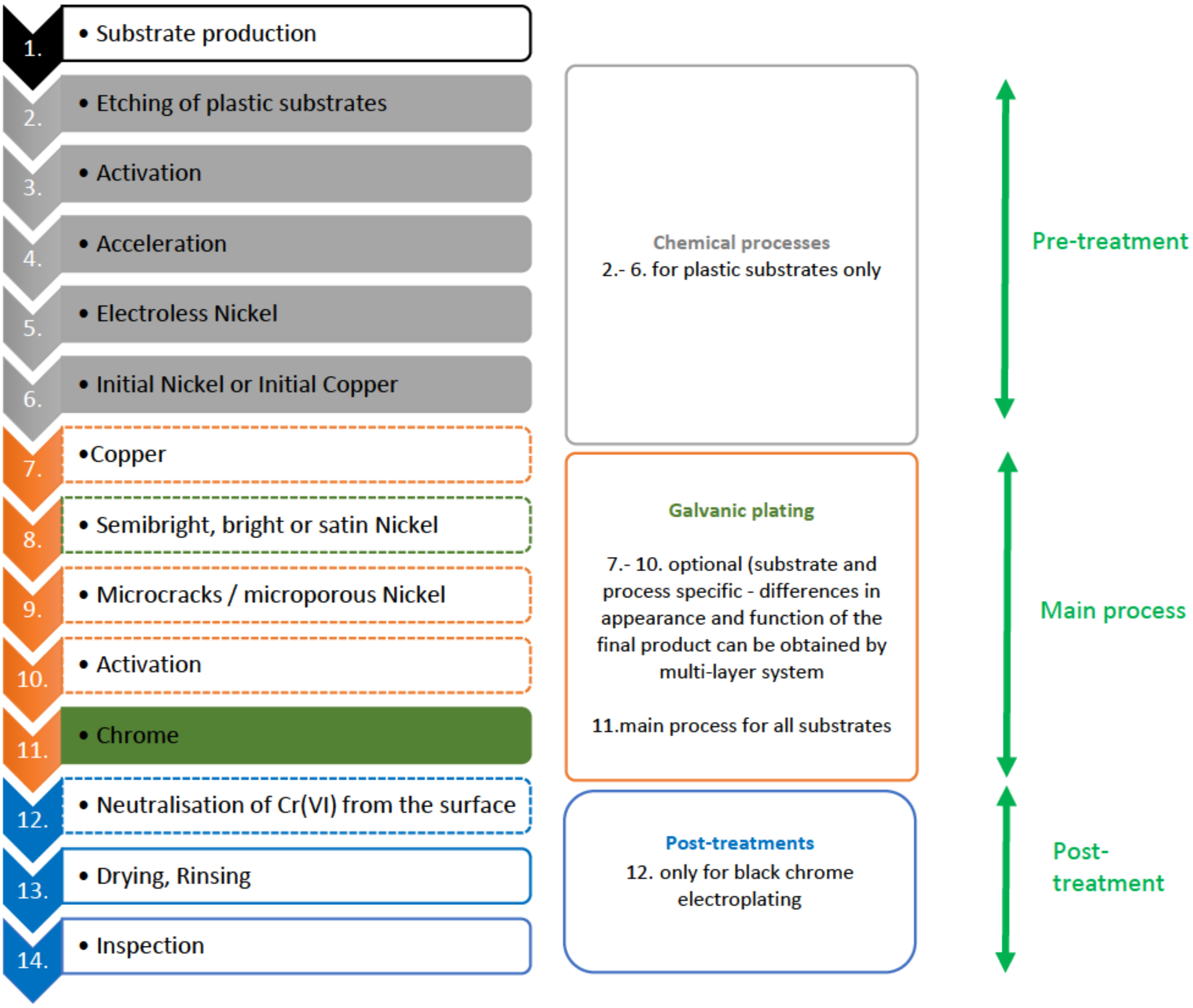

***Figure 9**: Process flow chart for the plating process. Data source: CTACSub*

The electroplating process chain with wet-in-wet processes is illustrated by the process flow chart and schematic in Figures 9 and 10 respectively.

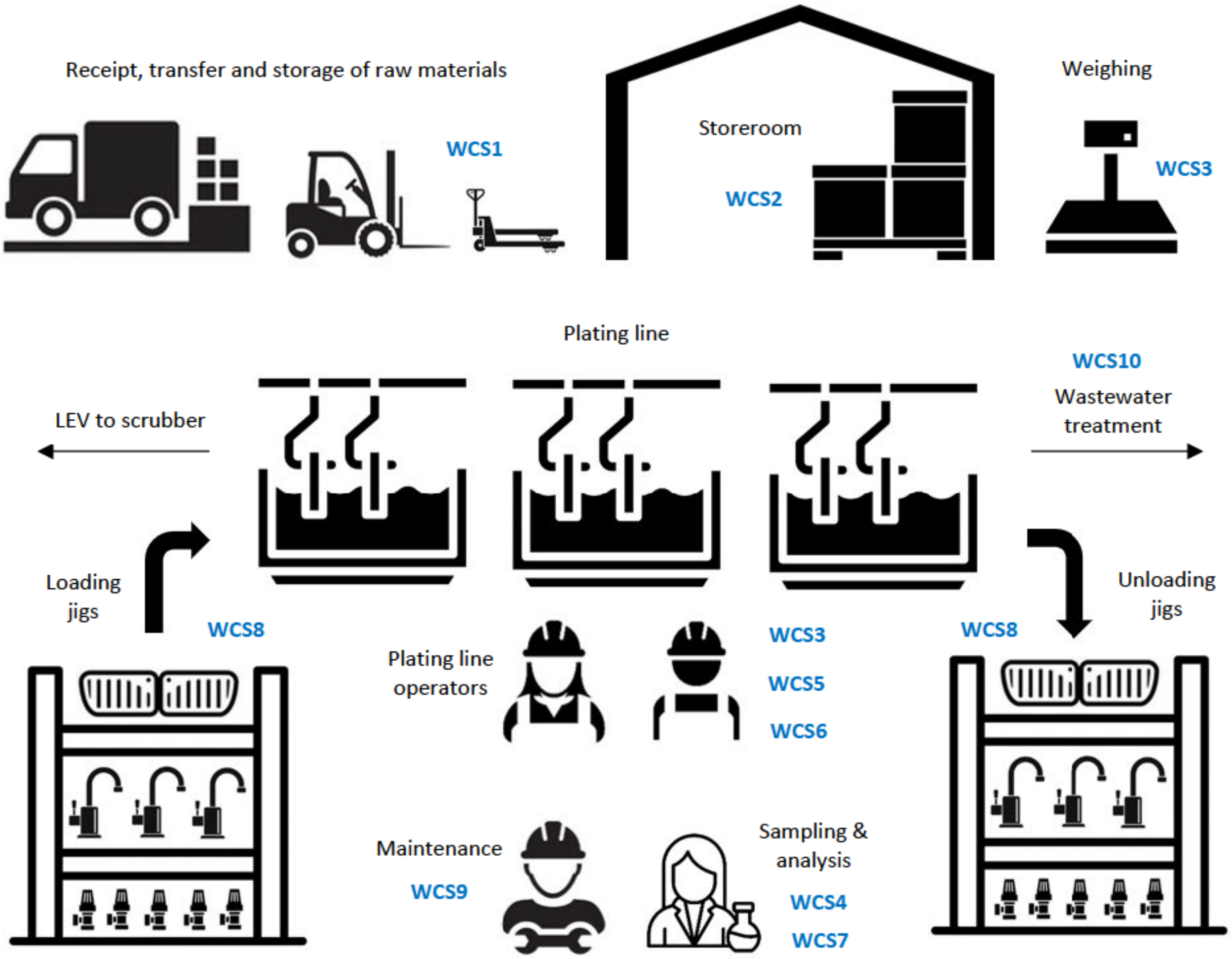

Figure 10*: Schematic of the electroplating process, with references to the relevant WCS*

Figure 10 above also cross-references the various Worker Contributing Scenarios (WCS) in the CSR, namely:

- WCS1: Receipt of raw materials
- WCS2: Storage of raw materials
- WCS3: Weighing of chromium trioxide and replenishing of tank
- WCS4: Sampling of plating tank
- WCS5: Operation of plating line (automated)
- WCS6: Operation of plating line (manual)
- WCS7: Laboratory analysis
- WCS8: Loading/unloading of parts
- WCS9: Maintenance
- WCS10: Waste management, including wastewater treatment

Figures 11 to 16 below provide examples of the plating lines, plating baths and loading / unloading ('jigging' and 'un-jigging') areas at the applicants' premises.

***Figure 11**: Electroplating line, overview (source: Aalberts)*

***Figure 12**: Electroplating line, detail (source: QPP)*

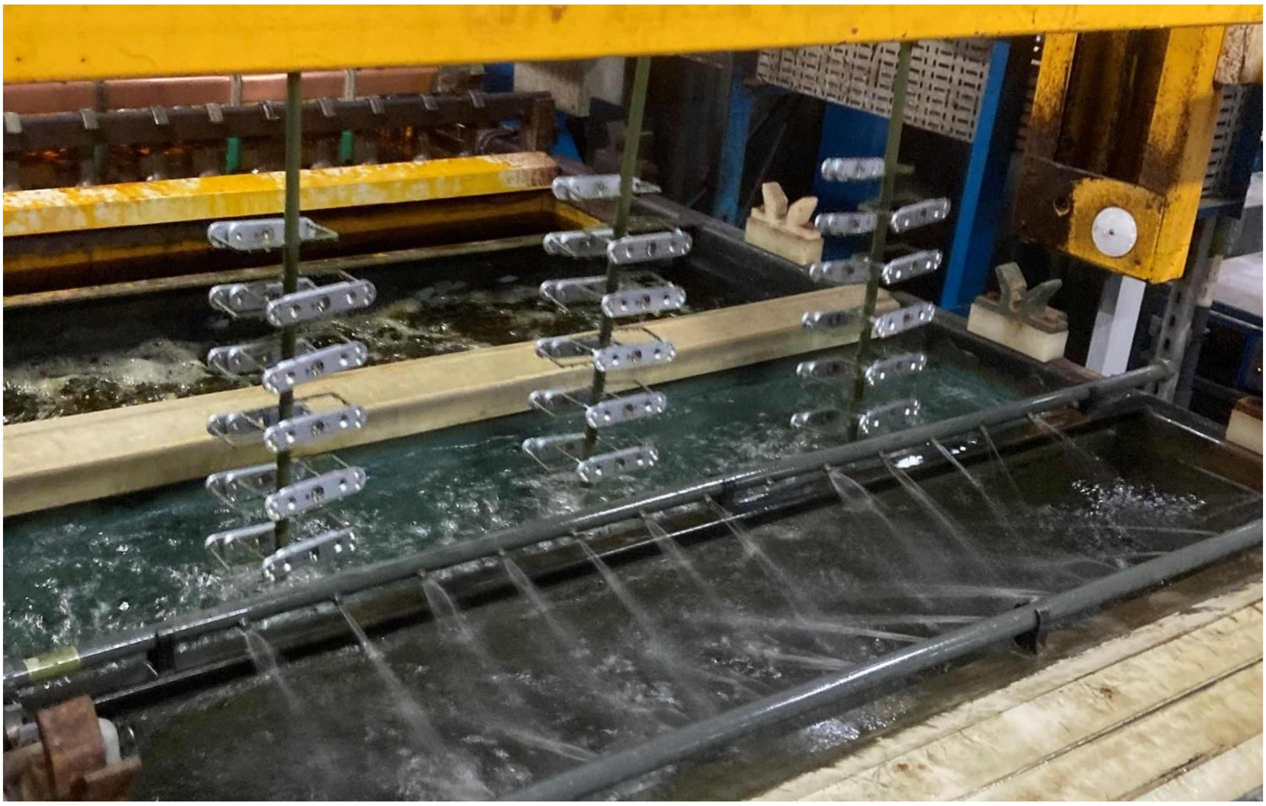

Figure 13*: Electroplating line, detail (source: Samuel Heath)*

Figure 14*: Example of a chromium bath with LEV (lip extraction) to the side and foam film which helps inhibit the release of aerosols (source: Borough)*

***Figure 15**: Loading ('jigging') area preceding chrome plating stage (source: Aalberts)*

***Figure 16**: Unloading ('un-jigging') and inspection following electroplating (source: QPP)*

4.2.1. Pre-treatment: general

Chromium trioxide will usually be received as chrome flake (solid) delivered in 25 kg containers. The containers will be transported to the storeroom, e.g. by forklift truck or pump truck. When chromium trioxide is needed for the baths, the required amount will be weighed out and then typically transferred to, and dispensed into, the relevant bath manually. The parts to be plated will be mounted on jigs and the jigs then loaded onto racks. The racks are then moved along the plating line, typically by an automated crane, although manual processes / plating lines are sometimes also used. The parts will be immersed into the different treatment baths in a specific order.

A number of pre-treatments prepare the surface of the substrates for functional chrome plating with decorative character to provide a metallic chrome finish. Adequate preparation of the base substrate is an essential part of the process; good adhesion between coating and substrate depends on the force of attraction at the molecular level. This means the surface of the substrate must be absolutely free of contaminants until the coating process has been completed.

Pre-treatment steps vary between metal and plastic substrates but all pre-treatment types are an essential part of the process chain and are not stand-alone processes.

In the case of **metal substrates**, the surface must be ground and polished, then cleaned from any kind of dirt (for example residuals polishing paste) and degreased. Oxides on the surface created during manufacturing or transportation, any intermetallic particles precipitated during the course of the manufacturing process and any organic material must be removed. If these remain on the surface, the subsequent layer could be affected by corrosion and no uniform appearance would result. Removal of material from the surface of the substrate is achieved through alkaline cleaning processes, i.e. soak cleaning and electrolytic cleaning, in conjunction with intermediate rinsing. These pre-treatments are free of chromium trioxide.

In contrast, for **plastic substrates**, etching is required as a necessary pre-treatment step and is undertaken in a chromium trioxide-containing etching bath, as described in further detail below. The etching step is necessary for creation of an electrically conductive surface on plastic substrates. Without this treatment the electrodeposition of different metal layers would not be possible since plastic has a very low electrical conductivity on its own.

4.2.2. Pre-treatment: etching of plastic substrates

For plastic substrates, the surface pre-treatment phase involves the following steps: etching, neutralisation, activation, acceleration and metallisation as a result of electroless plating. Prior to the etching step the plastic substrates are washed with a cleaning solution and rinsed to remove any impurities or contaminants which could interfere with the plating process.

Etching
Etching of plastic substrate with a chromium trioxide-containing solution ‘roughens’ the surface of the plastic by removing material from the substrate at a microscopic level, creating a specific number of pores with a certain depth (typically between 1 and 3 µm) on the surface. Details of the process are described below using ABS as example, as this is the most commonly-used plastic substrate.

During the etching process, a specific amount of 1,3-butadiene is removed selectively from the surface of the plastic substrate, creating ‘pores’ on the surface that act as contact points (anchor points) for the subsequent, different electroplated metal layers. The quality of the final metallic chrome coating depends on adequate pore depth and number of pores. Inadequate etching can cause two major failures: not enough and too shallow pores, or too deep and too many pores (see Figure 17). Both failures lead to a poor and insufficient adhesion of the subsequent underplates and the final metallic chrome coating. These effects are named under-etching and over-etching and may occur when the etching time and/or the concentration of the etching bath containing oxidising chemicals itself are insufficient.

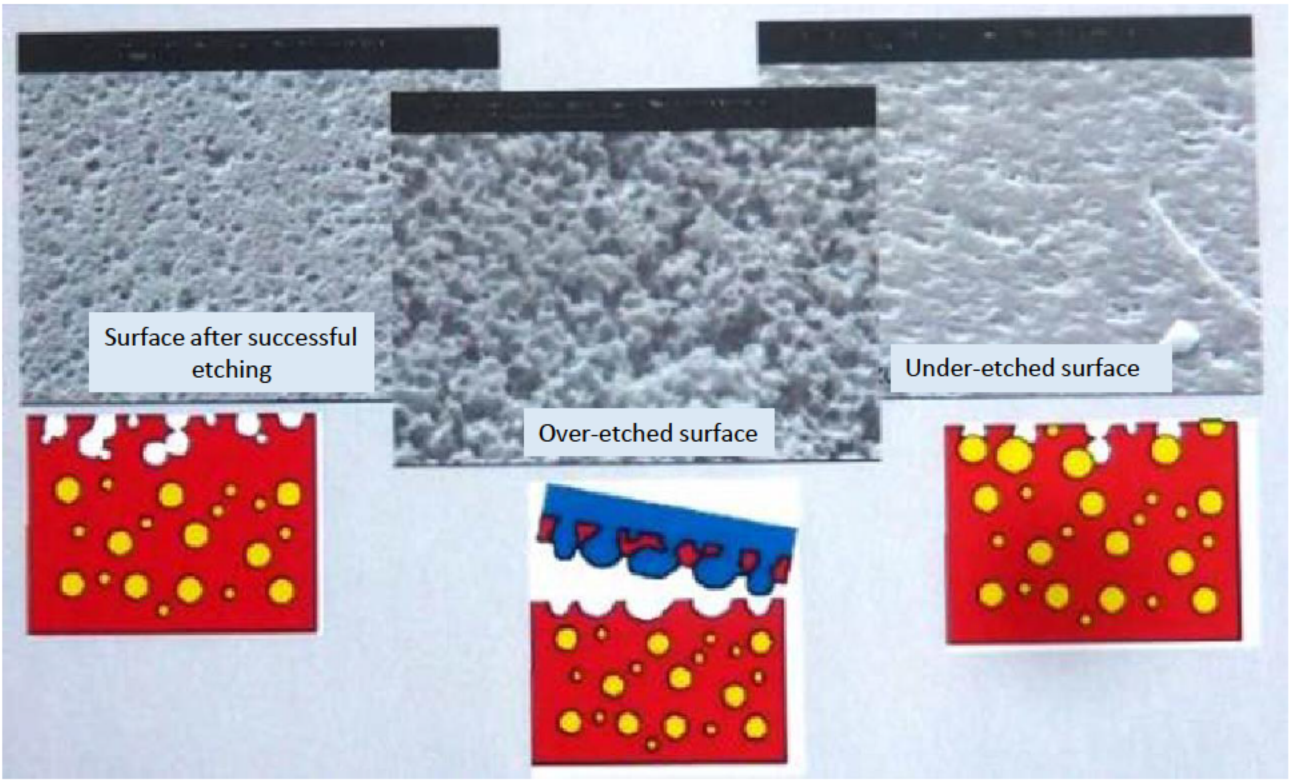

Figure 17: *Inadequately-etched surfaces compared with a successfully-etched surface (source: QPP)*

The etching bath consists of a solution of chromic acid and sulfuric acid (typically between 350 and 400 g/l CrO_3 and around 400 g/l H_2SO_4 will be used). Chromium trioxide is used as the source of chromic acid. The process is carried out at elevated temperatures between 65°C and 75°C for approximately 8-12 minutes, depending on the type of plastic being treated. The etching treatment roughens the surface of the plastic substrate creating evenly distributed holes or cavities as a result of the redox reaction between 1,3-butadiene and hexavalent chromium (Cr(VI)). The treatment also converts the plastic surface from hydrophobic to hydrophilic, enhancing the wettability of the substrate which is important for sequential process steps.

While the chromium trioxide-based etching solution selectively oxidises the butadiene molecules in the ABS or PC/ABS substrates, it does not react with PC. This allows for selective plating of multi-material parts where only the ABS-containing component is etched and chrome coated in the Cr(VI) plating step, creating a sharp edge between the plated and the non-plated component.

Etching will be performed on the same plating line as the main treatment.

Intermediate pre-treatment steps

Different intermediate steps are then undertaken after etching prior to the subsequent coating steps to activate the plastic substrate and to prepare the surface for the adhesive bonding of the subsequent metal coating. The first step is the reduction of remaining Cr(VI) ions on the surface to Cr(III) using a reduction agent, for example bis(hydroxylammonium)sulphate ($H_8N_2O_6S$). Afterwards, the surface is rinsed. As a final intermediate step, the pre-treated part is immersed in a hydrochloric acid (HCl) bath, as certain chloride limits need to be met for the subsequent activation step.

Activation

As plastic substrates are not conductive, the porous surface has to be activated. This is initiated by dipping the substrate in a solution of colloidal palladium and tin surrounded by stannous chloride which is attracted by the polar functionalities in the cavities created in the etching step. The cavities thereby act as anchoring points for the activator. The palladium catalyses the application of the subsequent electroless nickel plating.

Acceleration

The plastic substrates with colloidal palladium adsorbed at the pores are dipped in an acceleration solution comprising a reducing agent that removes the protective colloidal tin chloride layer. The result is activated palladium attached to the porous surface, which makes the palladium sites available for the electroless nickel deposition.

Electroless nickel plating

Although treatment of the pores enhances conductivity of the activated plastic surface, this is not sufficient to generate enough adhesion for subsequent metallic layers. Therefore, electroless nickel plating is performed to enhance the whole substrate surface. Electroless plating is a method of plating metal by chemical rather than electrical means, in which the piece to be plated is immersed in a reducing agent that, when catalysed by certain materials, changes metal ions to metal that forms a deposit on the piece. During this process Ni(II) ions are reduced to metallic nickel which forms a thin nickel layer with a thickness between 0.1 to 0.5 µm, applied by auto-catalytic deposition. . Nickel is first deposited at the palladium sites and the treatment is continued until an even layer of nickel is formed throughout the entire surface of the plastic part. The nickel layer created in this final step of the pre-treatment increases the electrical conductivity of the plastic part allowing successful electrodeposition of the metal layers in the main treatment phase.

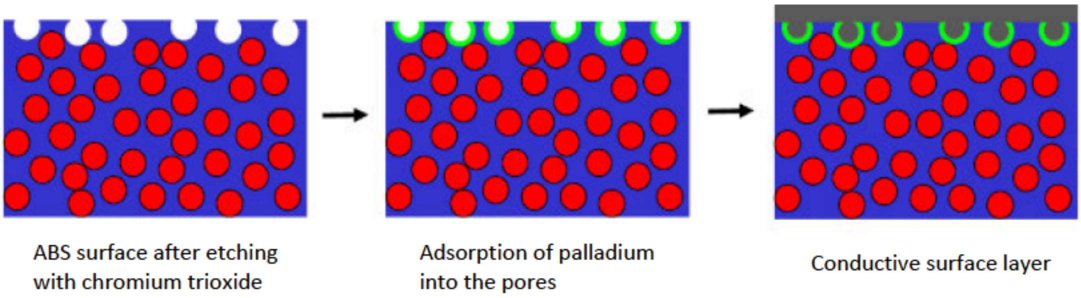

***Figure 18**: Illustration of the etching process on ABS (source: QPP)*

After etching, activation, acceleration and electroless nickel plating, the plating process chain on plastic substrates is continued in the same sequence as the process for metal substrates coating and is described below. Figure 19 depicts the surface of the plastic substrate when chrome plating has been completed.

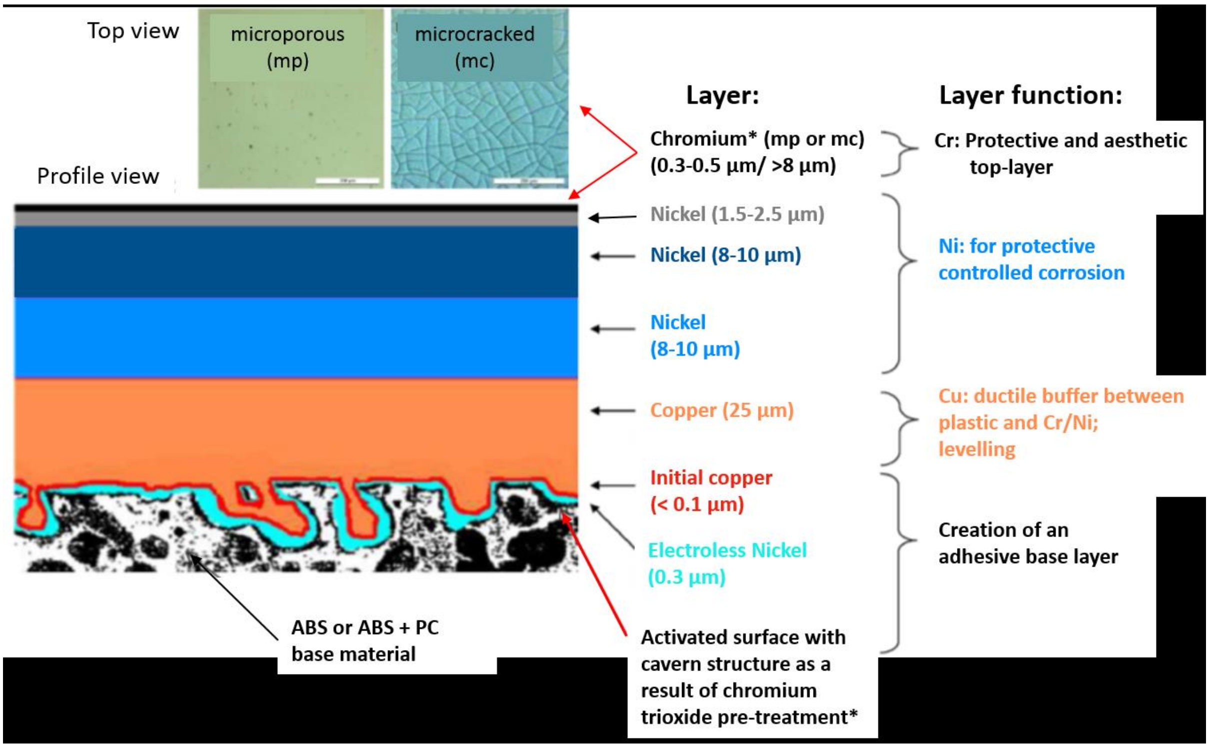

Figure 19: *Surface of plastic substrates on completion of chrome plating (source: QPP)*

4.2.3. Plating

Copper stage

Depending on the required functionality and use of the final product, a copper layer may be applied on the substrate prior to nickel deposition. This is optional for plating on brass and steel substrates. The copper layer is used as an underplate to improve adhesion between the substrate and the first layer applied during the multi-layer plating process. This is to cover imperfections such as pits and scratches, and to create a shinier surface as a basis for the subsequent layers. The brilliant appearance of the copper layer is responsible for a bright appearance of the final coating.

If used with plastic substrates, the copper layer serves as a ductile buffer between the soft plastic and the subsequent metal layers made of nickel and chrome with increasing hardness. The copper equalises tensions resulting from different coefficients of expansion of the different materials occurring in the course of temperature differences and temperature changes. The copper layer can therefore prevent cracks and blistering or delamination of the subsequent coatings.

Nickel stage

Nickel is applied by an electrolytic chemical deposition process (electroplating). Multiple nickel layers are needed prior to the final, chrome layer being applied, as the multi-layer combination is required to meet the required key appearance and performance requirements of the finished product. Such requirements include corrosion and chemical resistance, hardness, adhesion and surface appearance of the final product. The nickel layer will also characterise the final appearance of the product as matt, satin or bright.

The nickel is applied in a two-layer system. The first nickel layer is sulphur-free, whereas the second layer contains sulphur. Depending on the application, different kinds of functional nickel layers, such as micro cracked nickel or microporous nickel can be applied on top of the described two-layer nickel system, enhancing the corrosion protection of the substrate.

A **micro cracked** nickel layer is a nickel layer applied under high tensile stress. After the application of the final metallic chrome layer and a subsequent hot rinsing, micro cracks occur forming a very thin network affecting the metallic chrome layer as well as the functional micro cracked nickel layer. This network formation is a desired effect and a substantial part of the corrosion protection, since a controlled corrosion attack is generally preferred compared to local corrosion attacks or single macro cracks. The development of micro cracks can be controlled by reduced electric current and enhanced bath temperature. Depending on the process conditions, a conventional process results in between 400 to 800 micro cracks per centimetre, while a forced micro cracked process creates about 2000 micro cracks per centimetre.

A **microporous** nickel layer with integrated inert particulate matter is applied by the same mechanism as for micro cracked nickel, but with a reduced electrical current. This kind of layer is applied to enhance the potential output between the underlying bright nickel layer and the subsequent metallic chrome coating, which leads to an enhanced corrosion protection. The microporous nickel has to comprise more than 10,000 active pores per square centimetre.

Chrome stage

The chrome layer is applied by electroplating, similar to the nickel, but utilising chromium compounds in the process bath instead of nickel compounds. The chrome plating solution contains dissolved chromium trioxide and additives (electrolytes). During the electroplating process, the hexavalent chrome, Cr(VI), is reduced to metallic chrome, Cr(0). The chrome plating layer forms a well-adhered coating on top of the nickel plating layers. This continues until the metallic chrome coating has reached the desired thickness level.

In this process, the concentration of CrO_3 is between 250 and 400 g/l. Additives such as sulphuric acid are typically added in concentrations of 2 to 4 g/l. The bath temperature is typically in the range between 35 to 45°C with an average current density between 5 and 25 A/dm². Immersion time is typically between 5-8 minutes. The thickness of the metallic chrome layer is sector specific and depends on the respective product and its applications but is typically in the range between 0.15 µm to 1.0 µm. The bright chrome appearance of the product is not solely a result of the metallic chrome layer but also of the respective underplates. In contrast, the slightly bluish character of the metallic chrome coating is solely a result of applying a metallic chrome layer by chromium trioxide-based electroplating.

Alternatively, black chrome coatings can be produced, which are dark, most often black variations of the metallic chrome coating. This results from using a higher current density in the chromium trioxide plating bath and the inclusion of other additives such as nitrates or fluorides. Black chrome coatings are typically applied with a thickness of 2 to 5 µm. Depending on the intended use of the product, the underplate is either a semi bright nickel layer, a matt nickel layer or a copper layer.

Overall, the electrolytic process of plating with chromium trioxide offers several advantages. The process is robust and is performed at low temperatures (low energy costs for heating of the bath). The coating is applied quickly and, due to the bath application technique, almost any kind of articles of variable geometry (flat, complex, with inner cavities, etc.) and size (independently if small or big) can be plated.

Rinsing

Throughout the chrome electroplating process, parts are rinsed using several baths to prevent the drag-out of substances from one plating bath to the next. Rinsing is commonly performed by dipping the product in a bath filled with clean rinsing water. It is usually conducted in several steps following a cascade technology. The most common technique is counter-current cascade rinsing, for which the part is rinsed in a succession of rinsing baths, which are dedicated to the preceding plating bath. Most of the process water is handled in a closed-loop system minimising wastewater streams by reusing rinsing water in another process bath of the same type.

Sampling

To ensure electrolyte concentrations are kept within optimal parameters, the concentration of Cr(VI) in chrome baths must be regularly monitored. Bath analysis involves obtaining samples, typically on a weekly basis, which are usually analysed in an on-site laboratory using titration analysis, although may be conducted by a third party where no on-site facilities exist. Surface tension sampling will also usually be conducted.

Maintenance

Visual inspections of tanks, heating elements, anodes, electrical panels, transporters, flight bars, contact saddles and other related equipment will be performed on daily, weekly and monthly routines as required. Chrome baths will periodically be emptied and refilled to avoid excess levels of contamination building up, although the intervals at which this is undertaken can span a number of years. Bath emptying and refilling work may be undertaken in-house or by specialist third-party contractors under specific risk assessment and method statement.

4.2.4. Post-treatment

Post-treatments comprise various rinsing and cleaning steps to remove potential remaining process chemicals from the product. As final step the products will be dried, using forced air or oven drying processes. These post-treatments are chromium trioxide free and differ depending on the base substrate and the company or sector specific requirements.

A special post-treatment is required for parts plated using black chrome electroplating to ensure that the surfaces are Cr(VI) free. This post-treatment is typically a combination of chemical and physical processes, such as electrolytic degreasing, ultrasound treatment and bath applications, dipping the black chrome plated parts in sodium dithionite or sodium bisulphite solutions to reduce residual Cr(VI) to Cr(III). Black chrome-coated parts also require manual oiling, a process that takes place post-plating.

The transporter will return the flight bars back to the loading area where jigs will be manually removed. Careful visual inspection is performed on all individual parts to ensure stringent quality requirements are met.

4.2.5. Waste treatment

The applicants' on-site wastewater treatment facilities reduce hexavalent chromium, Cr(VI), to trivalent chromium, Cr(III), e.g. using sodium metabisulphite. This process is highly effective, such that residual concentrations of Cr(VI) in effluent are very low. The process is automatic – probes measure chrome levels and send signals to a control panel which ensures that reagents are dosed automatically according to the readings. The treatment occurs through closed pipelines.

Once treated, the wastewater will be sent via a series of tanks (pH and flocculation tanks) to a settlement tank where the sludge is allowed to settle before collection via a filter press and removal for disposal by a specialist waste handler. The wastewater is then discharged from the site. Figure 20 below is a schematic of one of the applicant's effluent treatment plants which is provided as an example. Further information on waste treatment can be found in the CSR.

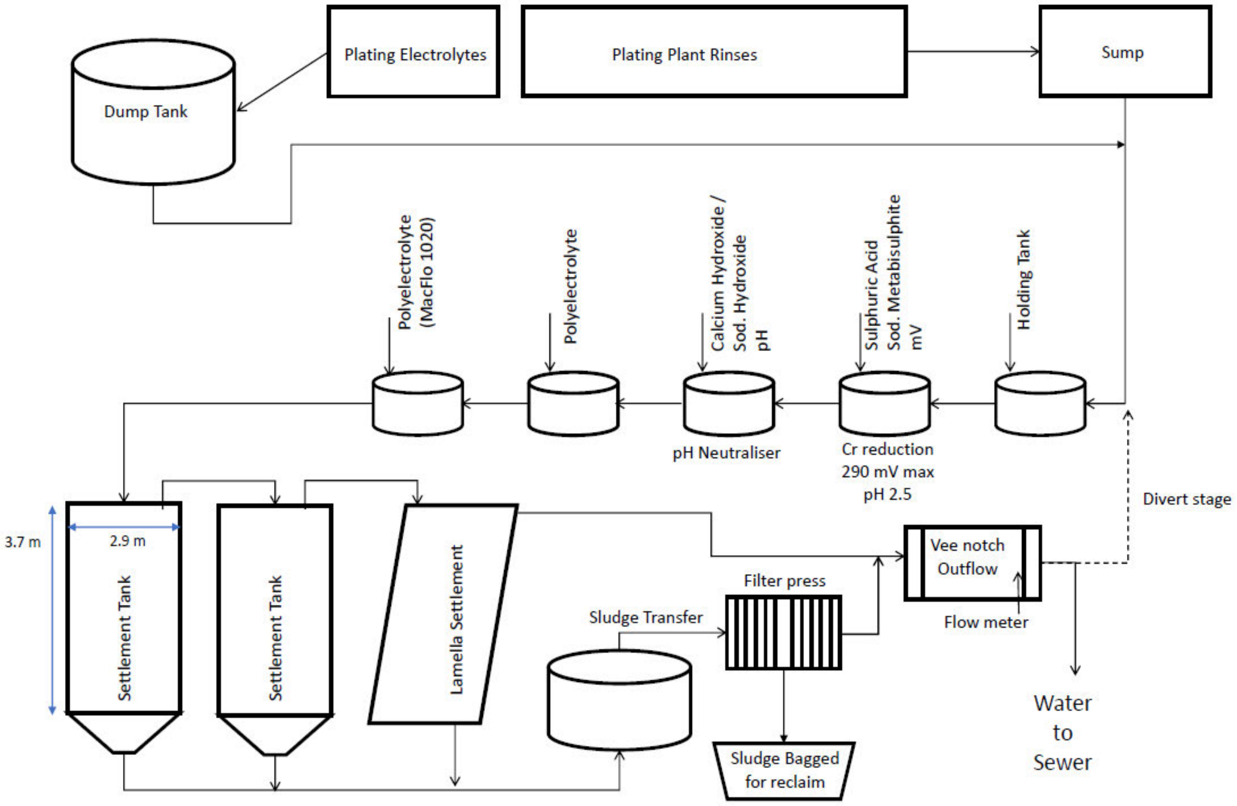

Figure 20: *Schematic of wastewater treatment plant (source: QPP)*

Samples will be regularly taken from the final discharge point and analysed in on-site laboratories to ensure wastewater is within trade effluent (discharge) consent limits for discharge of wastewater to public sewers, as set by the applicants' local water authorities under the Water Industry Act 1991. The applicants will be subject to unannounced visits where wastewater is sampled and checked by the local water authority. Three of the four applicants are also regulated under the Environmental Permitting (England and Wales) Regulations 2016 which regulates water discharge activities, with limits set by permits that are often lower than those required by local water authorities.

4.3. Key functionalities of chromium trioxide

The applicants undertake functional plating with decorative character to apply a highly-durable and aesthetically-pleasing surface to products for automotive, sanitary, heating/plumbing and other sectors, using metal or plastic substrates. The metallic chromium layer is applied as a final coating on top of a multi-layer system, which combine to provide the key functionalities required. The key functionalities identified by the applicants are as follows:

- Corrosion resistance and chemical resistance
- Wear and abrasion resistance (and, for heating/plumbing applications, impact resistance and jointing method resilience)
- Adhesion
- Thermal cycle resistance and sunlight / UV resistance
- Longevity
- Colour and cosmetic surface appearance (aesthetics)

All of the above-mentioned key functionalities are highly interconnected with each other and therefore it is essential that a potential alternative sufficiently fulfils every minimum requirement to achieve a high-quality surface under the conditions of use. This includes being able to provide a chromium-like appearance (where the alternative does not result in a chrome finish) even if all other functionalities are achieved, due to customer / consumer preferences and from the perspective of replacement of products/parts where replacements must colour-match other products in the same space or environment.

In addition, the products must be compliant with applicable regulatory requirements and so any alternative must be capable of fulfilling these requirements.

These key functionalities and regulatory requirements are explored further below, both in relation to plating (all products) and etching (as a required pre-treatment step for plastic substrates).

4.3.1. Key functionalities and performance standards for etching (use 1)

For plastic substrates, an adequate etching pre-treatment is required to prepare the surface for the subsequent process steps and to achieve a high-quality end product with the key functionalities described in section 4.3.2 below. Table 4 lists and explains the key functionalities of chromium trioxide for the etching pre-treatment of plastic substrates.

Key process functionality	Definition
Surface effects: • High oxidation potential • Etch rate: removal of 1,3-butadiene • Surface roughness: pore depth & amount of pores • Provision of a hydrophilic plastic surface • Removal of residuals from the surface	The etch rate has to be carefully chosen to prevent under-etching and over-etching. If the correct etch rate is not achieved, the key functionalities of the subsequent coating may be heavily affected. This implies poor adhesion resulting in cracks and blistering of the subsequent coated layers and the required adhesive properties of the surface would not be met. Etching must provide a roughness to the substrate's surface by creating a specific number of pores with a certain depth (typically between 1 and 3 µm) on the surface, resulting in a specific micro roughness to provide the required adhesion properties of the plastic substrate as necessary for the subsequent coatings.
Etching bath: • Long-time bath stability • Simple bath maintenance • Simple analytical method for process control	Further important key functionalities are the long-term use of the etching bath with proper maintenance. The bath chemicals must be refilled ensuring accurate dosing to prevent over- or under-etching. Analytical tests of the etching solutions should be simple to ensure an easy, reliable and frequent quality control system.
Reusability / recyclability	The chromium trioxide based etching solution is reusable and so highly suitable for efficient continued production. Electrolytic oxidation of Cr(III) to Cr(VI) is carried out to enable the reuse of the etching solution and limit the additional dosing of chromium trioxide to the etching bath. In order to keep the process economically feasible and material-efficient, an alternative should be reusable as well, or at least provide the option for effective recycling.
Racks: • Rack with treated parts also usable with subsequent process step	The rack with which the parts are dipped into the baths (usually PVC coated brass racks with stainless steel contact points or coated metal racks) are used throughout the whole process chain and should be compatible with all chemicals used in any

Key process functionality	Definition
- During following process steps rack is passivated and protected by CrO3	process steps to avoid interferences that might affect the quality of the final product.
Selective etching of ABS or ABS/PC parts allowing a selective plating process which is required for 2K/3K-component parts	Etching with a chromium trioxide-based solution only affects the ABS substrate (selective etching). This is especially important and necessary for the plating of 2K and 3K parts. For the final appearance of the 2K/3K part, only the ABS part is available for subsequent plating, not the blended part. If the etching process affects the non-ABS parts too, the surface structure and appearance of these parts would be ruined.

***Table 4**: Key functionalities of chromium trioxide based etching pre-treatment of plastics*

Table 5 below lists the applicants' performance standards (test methods and pass/fail criteria) to achieve the key functionalities outlined above.

Key functionality	Brief explanation	Performance standard
Renders plastic surface hydrophilic	Creates an affinity of the plastic surface to interact with subsequent water-based treatments and electrolytes	To allow successive water-based treatments to interact with the surface and sub-surface of the plastic during the coating process.
Surface roughness	Optimal pore density and roughness must be achieved to avoid under- or over-etching	The etch step must yield an optimal surface roughness of the plastic parts, to provide a flawless coating appearance of the finished product while fulfilling customer adhesion requirements.
Mechanical adhesion	The coating does not detach from the plastic under mechanical stress	Much achieve a peel resistance > 3.5 N/cm to 9 N/cm. Cross-cut test to BS EN ISO 2409.
Thermal adhesion	The coating does not detach from the plastic when the part is subject to temperature and humidity changes	Interior parts: - Parts are tested for a minimum of 20 hours +80°C to -40°C Exterior parts: - Temperature cycle test to DIN 53100 or customer specific tests
Impact adhesion	The coating does not detach from the plastic when subject to impacts	Interior and exterior parts: - Before and after temperature cycle test in cross-cut test to BS EN ISO 2409. - Peel resistance: > 3.5 N/cm to 9 N/cm. Exterior parts: - Stone-chip resistance is tested via a strip tape test according to BS EN ISO 20567-1 or customer specific tests
Coating appearance	The appearance of the finished coating must fulfil the acceptance requirements of customers	The surface must be free of any kind of visual defects as defined per customer-specific standards

***Table 5**: Performance standards for key functionalities - etching*

For the automotive sector in particular, alternatives to Cr(VI) etching processes need to fulfil all the requirements listed above as set out in the original equipment manufacturer (OEM) specifications to be considered technically feasible for automotive component production. Currently many such specifications require aesthetic and adhesive properties that only a Cr(VI) etchant system is currently capable of providing. Any changes to the production process would need to be validated and approved by the OEMs before series production with an alternative process can start. Fulfilment of existing supply contracts would also need to be factored in.

4.3.2. Key functionalities and performance standards for plating (use 2)

Table 6 below lists the key functionalities for chromium trioxide plated surfaces in the automotive, sanitary ware and heating/plumbing sectors. This list is not intended to cover all sectors for which the applicants produce chrome-plated products but it is intended to provide an evaluation basis for the evaluation of potential alternatives.

Key process functionality	Definition
Corrosion resistance	Corrosion resistance describes the ability to retard the degradation of an item due to the process of oxidation of a metallic material. This occurs because of chemical reactions with its environment, especially in the presence of water and increased humidity, e.g. in kitchen and bathroom areas or use of vehicles in different climatic conditions. Corrosion resistance is one of the most important parameters for all sectors. With regard to the automotive, sanitary and heating/plumbing sectors, meeting their minimum requirements play a key role to ensure the required lifetime of products whilst preserving the functionality and aesthetics of the plated parts as long as possible.
Chemical resistance	Chemical resistance is the ability of the coating materials to resist damage by chemical reactivity from cleaning agents. In general, a coating that is not adequately resistant against cleaning agents suffers degradation of the aesthetics as well as corrosion. This is one of the performance parameters of highest priority in the automotive sector (with regard to exterior parts) and the sanitary sector, being particularly important for those products that are likely to encounter cleaning chemicals on a frequent (daily) basis, e.g. products supplied to hotels and the wider hospitality sector.
Wear and abrasion resistance	The abrasion / wear resistance of a coating is its ability to resist the gradual wearing caused by abrasion and friction. For heating/plumbing applications, impact resilience and jointing method resilience is also critical, e.g. twist / force resistance for making a compression joint, which refers to a method used to join tubes or pipes together by tightening one end over the other.
Adhesion	Adhesion describes the ability of multiple materials, layers or surfaces to adhere to one another. Delamination of the different layers or the substrate will occur as a result of poor adhesion. In the automotive sector, coatings of exterior parts can be exposed to harsh environmental conditions, while coatings of the sanitary sector and for interior automotive applications are exposed to a large variety of chemicals and reagents. For the required lifetime and aesthetic appearance of all coated parts, it is important that the coatings applied to the substrates can withstand these effects.
Thermal cycle resistance	Thermal cycle resistance refers to a product's resistance to temperature changes and heat, which has to be high to withstand demanding conditions the products are exposed to in various environments. The base material (such as metal casts, ABS) and intermediate layers (such as copper layer, nickel layer) are characterized by individual thermal behaviour and they might differ in thermal coefficient of expansions and heat conductivity. Therefore, the coated product is tested for its thermal change resistance and heat resistance, as different thermal behaviours of coating and substrate may result in surface blistering.

Key process functionality	Definition
Sunlight / UV resistance	Ultraviolet (UV) resistance seeks to ensure that a product's coating is sufficiently robust to withstand natural (sunlight) and artificial UV radiation. Long-term sunlight / UV exposure can cause degradation resulting in cracks and blistering of the coating.
Aesthetics (cosmetic surface appearance, colour and colour-matching)	Aesthetics is a critical parameter for all sectors. In general, highly visible areas have to be free of any kind of defects such as pores, cracks and blistering, as the aesthetic appearance highly influences customer and ultimately consumer decisions. The products' surfaces will be classified according to the tolerability of defects. Defects in surfaces that are immediately noticeable to the customer, such as the top and front face of taps and mixers, require more stringent quality control than areas underneath that are much less visible. The surface defects are typically differentiated according to the type of defect, its position, its size and the spacing of the defect. All requirements are dependent on the manufacturer, the different surface standards and, in the case of the automotive sector, on specific agreements with the OEMs. Uniformity of colour is of particular importance, not only for the purposes of assembling different components to make the finished product, but also to ensure the colour of finished products is identical to other products likely to be used in the same environment, e.g. different taps, rails and accessories in a kitchen or bathroom environment, or different surfaces, handles or controls in automotive interiors. In addition, colour matching is crucial over the lifetime of the products; the colour must remain stable under normal light and use conditions. This ensures colour-matched parts, products and add-ons are available for replacement, e.g. additional shower-head in an existing shower system, or a replacement diverter valve etc.
Longevity	The applicants' customers will expect their products to maintain both their appearance and their performance for a considerable number of years of field use. The applicants' products will typically be guaranteed for a number of years, e.g. 5 or 10 years of use. If the chromium top layer has insufficient performance characteristics to maintain both the appearance and performance attributes expected by customers, then this will result in detrimental effects on the brands and the businesses.

***Table 6**: Key functionalities of chromium trioxide for electroplating of metal and plastic substrates*

The applicants' performance standards (test methods and pass/fail criteria) to achieve the key functionalities outlined above will differ based on sector of use and customer requirements. The following discusses those performance standards against the key functionalities identified above.

- **Corrosion resistance**: Corrosion resistance will be tested by the applicants by using different test methods in accordance with customer and OEM specifications. Corrosion resistance requirements are sector specific and will depend on the applied test method. However, the main tests regarding corrosion resistance performed for all sectors are salt spray tests. These tests use high-saline environments to measure the corrosion resistance of coatings over extended periods. The tests are conducted in a closed chamber that can be adjusted to create a variety of corrosive environments. Samples are subjected to a specified salt concentration for a pre-determined amount of time, based on specification, product type or industry standards.

- **Chemical resistance**: For the sanitary and heating sectors, a number of different tests on resistance against cleaning agents will be performed. Different cleaning agents (such as those based on bleaches or vinegar extract) and personal care chemicals (such as toothpaste, nail polish remover, shampoo etc) will be selected for the tests. The cleaning agents are predominantly based on different organic acids and compounds, such as formic acid, sulfamic acid or lactic acid or glutaraldehyde. The tests will be conducted under company-specific conditions but will be based on similar test criteria, e.g. overnight tests and longer (30-day immersion) tests. After the tests have been completed, no visual degradation of the coating should be detectable.

With regard to the automotive sector, tests are usually performed based to individual OEM requirements and the coating must withstand chemicals as defined by the OEM without visible change after the tests. Exterior automotive parts in particular need to be resistant against car wash cleaning agents (car wash resistance).

- **Wear and abrasion resistance**: The wear resistance of a coating is tested through use of industry standard Taber Abrasion test equipment. The test consists of a specimen placed under abrading wheels equipped with a rubbing material, e.g. felt strip. A predetermined force is applied and the specimen is made to continuously rotate while in contact with the abrading wheels until the desired number of rotations is achieved. During the test, a rub-wear action takes place between the specimen and the abrading wheels.

- **Adhesion**: For all sectors, the most commonly used test method of the adhesive properties of a coating to the substrate is a cross-cut test. This involves severing the coating down to the substrate using a grid of six parallel and six perpendicular cuts, then applying an adhesive tape to the coating and removing it. Visual inspection after removal of the tape should not show any detectable defects on the cuts.

  Adhesion of coated plastic substrate (for example ABS) is tested as peel resistance of the coating, with a peel-off (adhesive strength) requirement depending on the type of substrate. In the automotive sector, stone-chip resistance is tested via a strip-tape test which also determines the adhesive properties of the coating under “outdoor” conditions.

- **Thermal cycle resistance**: In the sanitary sector, temperature change resistance of coated parts can be tested in a temperature cycle test where plated products are heated, typically for 30 minutes to a temperature of 70°C followed by a 15 minutes cooling period. The parts are then cooled down, e.g. to minus 30°C for 30 minutes and subsequently brought back to ambient temperature. This cycle is repeated a number of times. The coated parts then are visually examined and surfaces should not show any cracks, blistering or loosening of the coating. For showers, different arrangements are often used that see products being subjected to 300 cycles of a changing water temperature (e.g. from 65°C to 20°C) for all substrates.

  For the automotive sector, temperature change resistance testing varies depending on the substrate and OEM requirements. For example, in long-term tests, coated plastic parts may be exposed for 3 months to 90°C (partially up to 105°C) and in short term tests they may be exposed for several hours. Climate change tests also have to be performed. These tests are comparable to the temperature change test, except that there is also a defined humidity (up to 80%) during the high temperature phase. The tests are usually performed for up to eight cycles and a duration time up to 96 hours. After these tests, the coatings should not show any optical change or delamination.

- **Sunlight / UV resistance**: There are several company-specific UV tests applicable in the sanitary sector, for example a four-week outdoor weathering of the coated products that needs to be passed without showing visual changes or damages. Such tests should be passed without showing defects.

  To test UV resistance for exterior automotive parts, these are typically exposed to xenon arc lights for a long period of time (e.g. 3,200 hours). Such tests need to be passed without visual changes of the coating. Interior automotive parts are tested in a similar fashion except that the duration of testing is much shorter, e.g. the coating must resist to 10 exposure cycles without visual changes.

- **Aesthetics**: The most common aesthetic screening test for all sectors is visual inspection performed according to company specific internal standards that require a perfect appearance of the plated surface. For this purpose, a reference sample is typically used for comparison. Within the sanitary sector, the number of the tolerable defects depends on the geometry of the defects (point shaped, linear or flat) and the location of the defect. The aesthetic requirements for the automotive industry are related to reference samples and OEM specifications.

  A major aesthetic aspect besides the defect rate is that it must be guaranteed that the colour of all plated parts are the same even if they were plated in different plating shops, on different plating lines or as different plating batches. The required and achieved colour of a metallic chrome layer is typically silvery bluish (except the special application of black chrome coatings). When assembling different parts to a final product, e.g. a thermostatic radiator valve that incorporates metal and plastic chrome plated components, uniformity of colour is of particular importance.

- **Longevity**: While the measure of longevity is a qualitative rather than quantitative assessment, the measurement of longevity is essentially included in all of the above-mentioned key functionalities. Corrosion resistance, chemical resistance, adhesion, temperature and UV resistance, thickness and colour and cosmetic surface appearance are all aspects of longevity and are measured using the standards described below.

Table 7 below lists the applicants' performance standards for automotive, sanitary ware and heating/plumbing applications. This is not intended to reflect an exhaustive list of performance standards across all sectors for which the applicants produce chrome-plated products but many of these other sectors will require products to meet the same or similar performance standards.

Key functionality	Sanitary and heating/plumbing sectors	Automotive sector	
		Exterior	Interior
Corrosion resistance	*Sanitary ware* For both bright chrome & matt black chrome, must pass: - Salt spray test - 240 hours (to ASTM B117-18) - Humidity test - 240 hours (to BS EN ISO 6270-1:2018) For matt black chrome only, must pass: - 24 hours electrodeposited coating test (to ASME A112.18.1/CSAB125.1) *Heating / plumbing applications* Must pass BS EN ISO 9227 Corrosion Tests in Artificial Atmospheres - Salt Spray Tests Must meet general requirements of BS EN 248:2002 and BS EN ISO 1456:2009	Must pass: - 480 h neutral salt spray test to BS EN ISO 9227 (up to 1000 h). - Up to 96 h copper accelerated salt spray test to BS EN ISO 9227. - Numerous other tests according to OEM specifications, e.g. Florida or Kalahari simulation, Kesternich test etc.	Must pass: - 240 h neutral salt spray test to BS EN ISO 9227 - 24 h copper accelerated salt spray test to BS EN ISO 9227
Chemical resistance	No visual degradation of the coating after testing with different common household cleaning chemicals	Must meet specific OEM tests with no visual degradation of the coating after testing with different chemicals.	Must meet specific OEM tests with no visual degradation of the coating after testing with different chemicals.

Key functionality	Sanitary and heating/plumbing sectors	Automotive sector	
		Exterior	Interior
Wear and abrasion resistance	Must pass Taber linear abrasion test In addition, for products for heating & plumbing applications, must meet jointing method resilience requirements (there must be no damage, deformation or negative aesthetic depreciation)	Must pass Taber line abrasion: 80% remaining gloss after 20 double strokes to BS EN 2813. Must meet car wash resistance to BS EN ISO 20566.	Must pass Taber abrasion: 10,000 hubs (10 N) Must pass further tests according to OEM specifications, e.g. Abrex or Martindale.
Adhesion	*Sanitary ware* Cross hatch test to be passed (to ASME A112.18.1) Grind/saw test to be passed *Heating / plumbing applications* Must meet requirements of BS EN ISO 2819:2017	Must meet: - GT0 to GT1 (after temperature cycle test) in cross-cut test to BS EN ISO 2409. - Peel resistance: > 3.5 N/cm to 9 N/cm (ABS: 7 N/cm). - Stone-chip resistance tested via a strip tape test according to BS EN ISO 20567-1. - Numerous other tests according to OEM specifications.	Must meet: - GT0 to GT1 (after temperature cycle test) in cross-cut test to BS EN ISO 2409. - Peel resistance: > 3.5 N/cm to 9 N/cm (ABS: 7 N/cm). - Numerous other tests according to OEM specifications.
Thermal cycle resistance	Must pass 5 cycles in temperature cycle test according to BS EN 248:2002	Must pass: - Temperature cycle test (e.g. to DIN 53100 or OEM-specific tests) - 3 months to 90-105 °C (long-term) and several hours (short term).	Must pass: - Temp. cycle test (e.g. to DIN 53100 or OEM-specific tests) - 3 months to 90-105°C (long-term) and several hrs (short term).
Sunlight / UV resistance	Company specific UV tests	Must pass 3200 h Florida simulation.	Must pass 10 exposure cycles according to BS EN ISO 105-B06.
Aesthetics	Bright chrome coated components must be able to provide a blemish free mirror finish (unless a matt effect is desired). The colour of bright chrome must have a 'blue' hue. This is ascertained by comparison to a sample product. Matt black chrome coated components must be able to provide a blemish free matt finish. The black chrome must be matt black and cannot have a reflective sheen to it. This can be ascertained by comparison to a sample.	Surface must have brilliant gloss or special matt gloss according to OEM requirements. Surfaces must be free of any defects such as pores, cracks and blistering (VDA, Band 16). Must meet colour testing requirements to BS EN ISO 11664.	Surface must have brilliant gloss or special matt gloss according to OEM requirements. Surfaces must be free of any defects such as pores, cracks and blistering (VDA, Band 16). Must meet colour testing requirements to BS EN ISO 11664.
Longevity	Qualitative assessment	Qualitative assessment	Qualitative assessment

***Table 7**: Performance standards for key functionalities - plating*

5. Overview of sector-specific regulatory requirements and approval processes

In addition to the required performance standards described in the preceding section, the applicants must meet regulatory requirements and approval processes relevant to them for each of the markets into which their businesses supply. While this includes non-UK markets such as the EU and US, the following information focuses on UK requirements to illustrate just this one part of the regulatory backdrop against which the applicants operate. Such requirements are important to understand from the perspective of identifying potential alternatives to chromium trioxide, because those alternatives must also be capable of satisfying those requirements.

5.1. Automotive sector

5.1.1. About the automotive sector and automotive supply chains

The UK automotive sector is central to the UK economy and a key part of the country's industrial strategy. It generated £56 billion in turnover and £12.2 billion in gross value added (GVA) in 2020, which was 7.1% of UK manufacturing GVA. It is a vital high-skilled UK employer, with 149,000 people employed in automotive manufacturing in the UK in 2020 and a further 249,000 jobs estimated to be supported by the industry in the wider economy[8]. The sector is extremely export intensive; it generated £40.1 billion in exports in 2016 (£18.3 billion to the EU)[9]. In addition to overall vehicle production, the quantity of domestic sourcing is a key measure of success, with the majority of the automotive sector's key profit margins relating to the efficiency of the supply chain. In 2017, UK vehicle makers sourced 44% of the value of their parts from domestic suppliers, rising from 36% in 2011 [10].

It is the UK Government's ambition to secure the country's position as one of the highest-productivity major automotive producers in Europe, in part through greater use of local (domestic) supply chains[11].

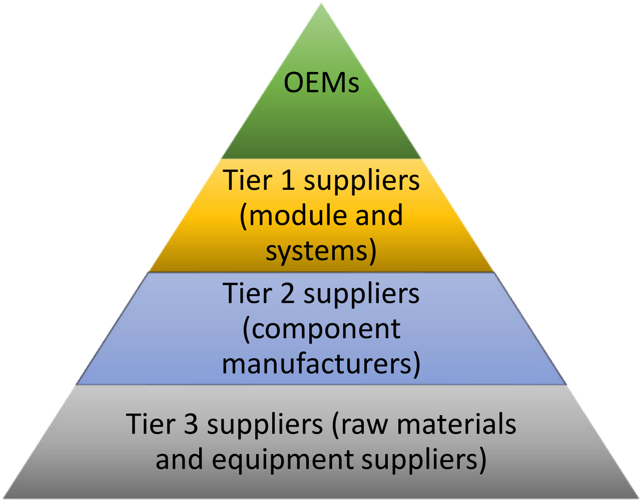

***Figure 21**: Basic structure of the automotive supply chain*

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[8] HM Government, 2022, pp54-55.

[9] House of Commons Committee on Exiting the European Union, 2018, p2.

[10] House of Commons Committee on Exiting the European Union, 2018, p4.

[11] HM Government, 2022, p55.

The automotive supply chain is complex and OEMs (vehicle manufacturer) operate a sophisticated, globally integrated supply chain, to support their "just in time" production models. Figure 21 provides a simplistic example of an automotive supply chain where suppliers are organized in sequential levels called tiers. OEMs rely on module and system suppliers (tier 1), who in turn must rely on component manufacturers (tier 2), who themselves depend on raw materials suppliers (tier 3). For these purposes, the applicants who supply automotive products can be considered as tier 2 suppliers.

The above diagram is simplistic and, in reality, there are considerably more tiers than this within the supply chain. In addition, the supply chain is highly complex and integrated, with assembly of vehicles performed in a complex network of manufacturing plants forming the multi-tier system depicted above. Each OEM may have between 1,500 to 4,500 tier 1 suppliers, who themselves may have between 500 to 1,500 suppliers themselves. This complexity is illustrated in Figure 22 below.

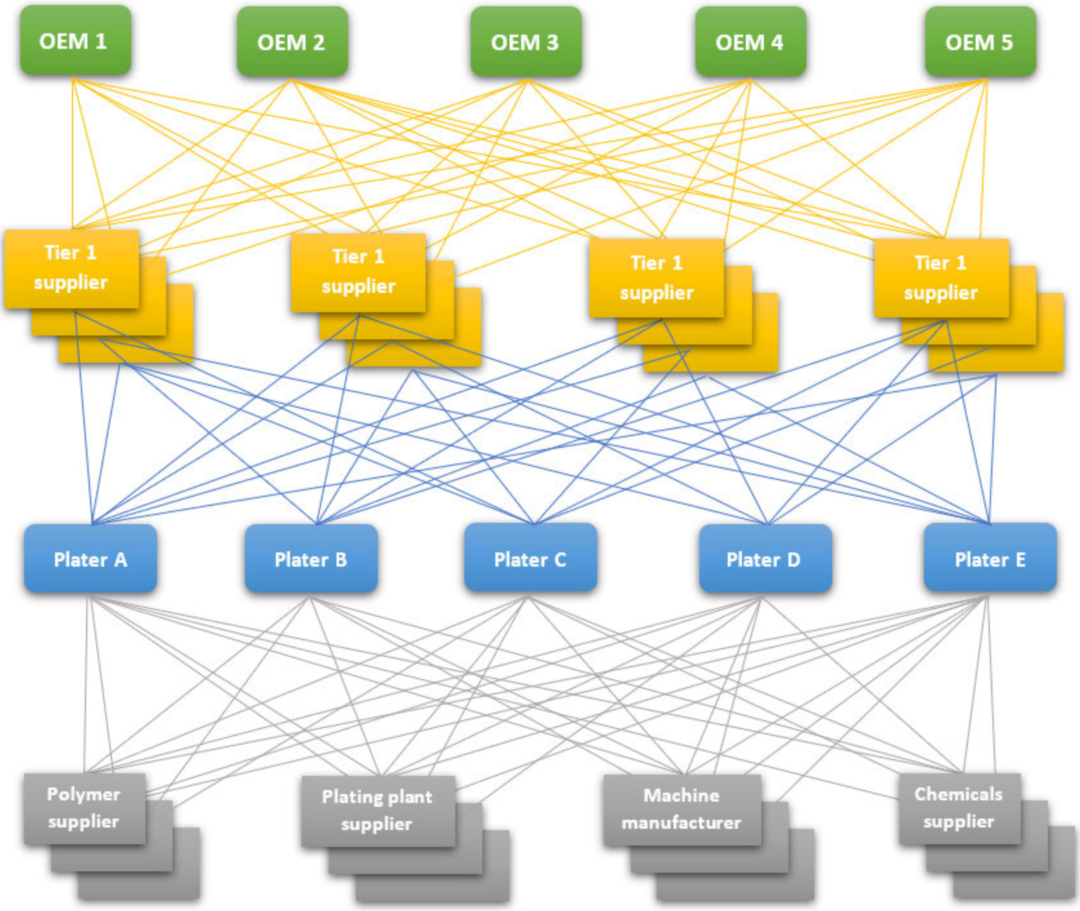

***Figure 22**: Illustration of supply chain complexity*

The exact number of parts in a car will vary from vehicle to vehicle but, on average, there will be around 30,000 parts in a single vehicle, ranging from small nuts and bolts to bodywork panels and the engine block. Typically these parts will be arranged into between 4,000 and 9,000 different main components and assemblies per car (see Figure 23 below). In terms of chrome-plated parts only, there can be more than 150 different chrome-plated components.

***Figure 23**: VW Tiguan disassembled into constituent parts (source: Volkswagen)*

The UK Government has stated its ambition for 50% of each British-built vehicle to be made from nationally sourced components as part of plans to make the UK automotive industry more self-sufficient[12].

5.1.2. Regulatory requirements & OEM specifications

Regulatory requirements play a crucial role in determining the design and production costs of a vehicle and cover vehicle design, component use, manufacturing processes, emissions and more. This is achieved by a process known as 'type approval', which refers to the confirmation that a design will meet specified performance standards and ensures vehicles comply with relevant environmental, safety and security requirements.

The Road Vehicles (Approval) Regulations 2020 make provision in the UK for the implementation of Regulation (EU) 2018/858 (the 'Type Approval Regulation'), which has been retained following Brexit. Under the Regulations, all new vehicles sold in the UK must be type approved ('whole vehicle' approval) by a type approval authority prior to registration. The UK type approval authority is the Vehicle Certification Agency (VCA), an executive agency of the Department for Transport.

Large OEMs will apply for 'whole vehicle' type approval, which brings together all the individual system and component approvals for a vehicle into a single legal document enabling a manufacturer to demonstrate that it complies with all the relevant technical requirements. The process involves the oversight of the selection and testing of samples, the documentation of the specification and the evaluation of the measures in place by the manufacturer to ensure Conformity of Production (CoP). A prerequisite of type approval is

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[12] HM Government, 2017, p202.

that the manufacturer has appropriate measures in place to ensure that production samples will continue to meet the performance requirements as the products originally examined, which is known as Conformity of Production (CoP).

As well as British, European or International Standards, OEMs also derive their own standards for automotive production and these will all be used to ensure a vehicle meets type approval requirements. OEMs will translate these into set design and engineering specifications which suppliers must meet. Parts will be rejected if they fall outside the applicable specifications.

In other words, those supplying chrome-plated products into the automotive sector (i.e. the applicants) have very little influence in terms of the specifications of the parts they supply. They have little ability to dictate terms to those above them in the automotive supply chain concerning the use of potential alternatives to chromium trioxide for functional chrome plating with decorative character. If they fail to meet OEM-driven specifications, then the OEM and tier 1 suppliers will impose contractual penalties or simply switch to an alternative supplier. Alternative suppliers will most likely be based outside the UK, given the authorisation requirements of REACH will apply to other UK-based suppliers, but they may be based in the EU and covered by authorisation or an application for authorisation, as is discussed further below.

In particular, the requirements for surface performance are defined by the OEMs, not by the platers themselves. Over long years of development the OEMs have created very specific and unique requirements for exterior, as well as interior, vehicle parts including very precise expectation on the layer systems with which the parts are coated. For instance, the OEMs have extended the guarantees for product surfaces in favour of the end customer. Therefore, in the course of the last years the requirements on the surface performance have been drastically increased by the OEMs and the platers must ensure these expectations are satisfied. Currently, the use of CrVI-based plating is the only way to achieve the requirements in current OEM standards (e.g. as regards adhesion and pull-off tests) so there is little choice for platers but to use chromium trioxide.

5.1.3. The challenge of substitution in the automotive sector

The identification of possible alternatives and the careful validation of their functionalities is a labour/time intensive process that will take several years. The European Automobile Manufacturer Association (ACEA) notes that even where a technically feasible and economically feasible alternative has been identified, it will first need to be validated and, after that, contractual arrangements with suppliers will need to be made approximately 3 years before the start of production (industrialisation) and implementation in the supply chain[13].

At the time of submission of this AfA, most of the OEMs have yet to tell the applicants involved in supplying the automotive sector what their intentions are as regards the use of chromium trioxide for chrome-plated parts, nor have they updated their specifications. Assuming the OEMs are willing to move away from chromium trioxide at some point in the future, the supply chains, as well as the production capacities for several hundreds of millions of parts, for the whole automotive sector would need to be re-established from the ground up for the components in question. The OEM, tier 1 and other tier suppliers would have to ensure that their subcontract platers all used the same systems, controls and colour monitoring. For example, one automotive manufacturer uses 32 different electroplaters as direct suppliers and their tier 1 suppliers will also have multiple different platers supplying them with subcontracted parts. The whole supply chain would need to coordinate to ensure they use the same plating systems to give the same (or acceptably similar) colour to ensure harmonization across the whole product range. This is achievable but would take considerable time, effort and resource.

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[13] ACEA CLEPA, 2016, p1.

Sufficient production capacity with the new technology would then need to be identified, qualified and demonstrated to be reliable. Field tests and acceptance tests at customers would need to be performed. These "real life" tests extend the duration of qualification. This means more personnel are required at OEM level in order to carry out tests for a multitude of new parts and surfaces needing to be qualified at the same time.

Within a single vehicle up to 150 chrome-plated parts would be affected. The interaction of each of the parts produced with the new technology would then need to be assured at the OEM level. The whole system of parts would have to be evaluated, tested and qualified. It is likely that this process would necessitate redesign of some related parts to match the modifications to ensure they all function together properly. Significantly, this effort may be required for each vehicle series of an OEM. As further supply chains, processes and suppliers are involved here the effects on timescales and costs are unpredictable.

The implications for the technology user or parts manufacturer who carry out surface treatment in house are substantial. In parallel to the OEM's testing and qualification, electroplaters may need to secure the investment for a new facility or conduct extensive reconstruction measures of the current electroplating facility. Once financial investment is secured, land has to be secured and all necessary permits / planning permissions need to be granted. The plant would then need to be built and personnel trained in the new technology. New technical qualifications would need to be run through with lessons learned for the parts producer, as well as for the OEM.

It is critical to note that the new technology cannot be used for repairs and for spare parts for the vast majority of parts already on the market, as specifications for a new technology development differ so much that they cannot be used on existing products. The same applies to products under current chromium trioxide-based development. These parts will have already undergone several rounds of testing and modifications so the processes would have to be repeated for any new technology used, therefore delaying the launch of cars which will have to undergo multiple rechecks and verification.

Conversely, if a move away from Cr(VI)-based coatings is not driven by the OEMs, then it is worth briefly considering what would happen if it were driven by the applicants. This would be the case, for instance, if the applicants were not granted authorisation for the continued use of chromium trioxide in etching and plating. Given that the applicants cover the majority of the UK market for plating on plastics, if an authorisation is not granted then most of the plating on plastic undertaken in the UK would cease. This is because, as this report will demonstrate, there is currently no suitable 'drop-in' alternative to Cr(VI)-based etching and plating. The work currently undertaken by the applicants would switch either to EU plants who hold authorisation to continue using chromium trioxide (or who are covered by applications for authorisation that are still pending) or to the rest of the world, most likely the Far East where there are no current restrictions on the use of chromium trioxide. However, the OEMs could not achieve this switch overnight; the majority of car manufacturers and their Tier 1 suppliers would face a critical parts shortage for a period of time. For example, the applicants supply products for [redacted]. It will take these organisations many months to move tools and production to alternative suppliers and then test and approve these parts before they can be fitted back onto vehicles. As many of these OEMs and Tier 1 suppliers are based in the UK, the cost to, and impact on, the UK economy would be substantial[14].

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[14] A good example of the impact the UK automotive sector can have on the wider economy due to critical parts shortages is the recent semiconductor shortage which began to manifest in 2020 at the start of the COVID-19 global pandemic. This caused UK growth to slow at a much sharper rate forecast by economists, see e.g. Inman, 2021.

5.2. Sanitary sector

5.2.1. The Water Fittings Regulations

The principal legislation relating to water supply installations in the UK is the Water Supply (Water Fittings) Regulations 1999 for England and Wales, the Water Supply (Water Fittings) (Scotland) Bylaws 2014 for Scotland, and the Water Supply (Water Fittings) Regulations (Northern Ireland) 2009 for Northern Ireland. Collectively, these are known as the Water Fittings Regulations.

The Regulations set requirements for the design, installation and maintenance of plumbing systems and water fittings in England and Wales. They are enforced by water companies in their respective areas of supply. The Regulations' objectives include contamination prevention and water conservation. Water systems and fittings in premises that are, or will be, connected to public water suppliers must comply with the Regulations. The legal duties are placed on all users, owners or occupiers of premises and anyone who installs plumbing systems or water fittings and water-using appliances in them. Water suppliers are responsible for the enforcement of the Regulations.

The Water Regulations Approval Scheme (WRAS) was established in support of the aims and objectives of the Water Fittings Regulations. WRAS is an independent UK certification body for plumbing products and materials, to help businesses and consumers choose compliant products that keep water safe. Its approval and listing scheme has become the byword for product approvals in the UK plumbing world. A WRAS-approved product helps demonstrate compliance with the Water Fittings Regulations (although the product must still be installed and operated correctly).

To enable a product to be certified to meet with the requirements of the Water Fittings Regulations, it must be mechanically tested to the relevant standards. UKAS-accredited mechanical test facilities in the UK include KIWA Ltd (Watertec Trading Division) and NSF International.

All materials used in applicable products must meet with the requirements of BS 6920 (Suitability of non-metallic materials and products for use in contact with water intended for human consumption, with regards to their effect on the quality of the water). In particular, all non-metallic materials which come into contact with water intended for domestic use must conform to the requirements of BS 6920. This includes several tests which assess the suitably of non-metallic materials to ensure they do not impart odour or flavour, cause a change in appearance (colour or turbidity), promote microbial growth or leach substances (including toxic metals) harmful to human health. Test facilities in the UK accredited to carry out BS 6920 testing include Intertek, The Water Quality Centre (WQC) and NSF International. Once fully tested the plumbing fittings can be certified in the UK by either WRAS or KIWA Watertec. The certificates of both organisations each state that the plumbing fitting complies with the requirements of the Water Supply (Water Fittings) Regulations.

All UK water suppliers will accept the installation of products certified by WRAS or KIWA Watertec and the applicants have a range of different products that are WRAS-approved.

5.2.2. The Water Quality Regulations

The quality of drinking water in the UK is governed by the Water Supply (Water Quality) Regulations 2016 in England, the Water Supply (Water Quality) Regulations (Wales) 2018 in Wales, the Public Water Supplies (Scotland) Regulations 2014 in Scotland, and the Water Supply (Water Quality) Regulations (Northern Ireland) 2017. These Regulations implemented the requirements of Council Directive 98/83/EC on the quality of water intended for human consumption, which forms part of retained EU law in the UK.

The legislation aims to protect human health against harmful effects which could originate from contaminants in water designated for human consumption, and to ensure it is pure and suitable for consumption. It imposes a duty on water suppliers to supply “wholesome” water. ‘Wholesome’ water is water supplied for drinking, washing, cooking or food production that does not contain any element, organism or substance at a concentration that would be detrimental to public health (whether on its own or in conjunction with anything else), and which does not exceed any concentrations or values in excess of parameters listed in the Regulations themselves.

The legislation is enforced by the Drinking Water Inspectorate (DWI) in England and Wales, the Drinking Water Quality Regulator (DWQR) in Scotland and the Drinking Water Inspectorate (DWI) in Northern Ireland.

For the applicants who produce sanitary ware, this means that materials used in the manufacture of products that will be used in contact with drinking water must not negatively affect human health, or the smell and taste of drinking water, nor may they result in the release of substances into drinking water above acceptable concentrations or values. Given the manufacturing process, the chemical indicator parameters of highest interest are nickel and chrome. Under the Regulations, the concentration of nickel in drinking water (e.g. caused by Ni migration) must not exceed the threshold value of 20 µg/l and the total chromium concentration in drinking water (e.g. caused by chrome leaching) must not exceed 50 µg/l.

5.3. Heating / plumbing sector

5.3.1. The Building Regulations

The Building Regulations 2010 (as amended) apply to most new buildings and many alterations of existing buildings in England and Wales, whether for domestic, commercial or industrial use. The Regulations impose requirements on people carrying out “building work”, defined as the construction or extension of a building, the provision or extension of services or fittings, material alterations to buildings, services or fittings, and various other types of work including insulation provision, change of use, underpinning and so on. Building work must be carried out so that it complies with the applicable requirements set out in Parts A to P of Schedule 1. These requirements include provisions on sanitation, hot water safety and water efficiency (Part G), drainage and waste disposal (Part G) and conservation of fuel and power (Part L), which are relevant to the applicants’ products that are used for heating and plumbing applications.

Supplementing the Regulations are a series of approved documents that give practical guidance on how to meet the requirements of the law. These set out what, in ordinary circumstances, may be accepted as reasonable provision for compliance with the relevant requirements of the Building Regulations. In addition, various British, European and International Standards exist for the design, construction, installation, commissioning, operation and maintenance of heating and plumbing products. For instance, BS EN 215 lays down requirements and test methods for thermostatic radiator valves. The applicants’ products must meet the requirements of the applicable Standards for acceptable use in domestic, commercial or industrial premises.

In addition, various third party approval schemes exist which guarantee that products confirm to applicable standards and performance requirements. For example, BuildCert is a product testing and certification program designed specifically for plumbing products, which offers third-party product certification of plumbing products to ensure that they meet national and international standards. A number of the applicants’ products are BuildCert approved, such as thermostatic mixing valves for use in various settings, including healthcare and commercial.

5.3.2. Construction Products Regulations

Many of the applicants' products will be subject to Regulation (EU) No 305/2011 (the Construction Products Regulation), retained with amendments following Brexit. Construction Products are defined as any product or kit produced and placed on the market for incorporation in a permanent manner in construction works, the performance of which has an effect on the performance of the construction works with respect to the basic requirements for construction works. There are a number of such basic requirements but, for these purposes, the most relevant are mechanical resistance and stability, hygiene, health and the environment, and energy economy and heat retention.

The Regulation requires that construction products placed on the market and either covered by a designated standard or conforming to a UK technical assessment must be UKCA marked (previously CE marked) and accompanied by a Declaration of Performance. Designated standards' are those approved by the Secretary of State and published by the British Standards Institution (BSI).

5.4. Regulatory and market context

For the purposes of assessing the implications of a non-granted authorisation and determining the NUS, it is necessary to understand the wider regulatory and market factors concerning the continued availability of Cr(VI)-based products, despite chromium trioxide being subject to authorisation under REACH both in the UK and EU. While REACH requires the use of chromium trioxide to be authorised, chromium trioxide is not present in finished products which have a metallic chrome (Cr(O)) coating and, even then, these finished products constitute 'articles' under REACH, imports of which are not subject to the authorisation requirement. Imports of products with Cr(VI)-based coatings are readily available from the rest of the world but it is worth noting that they will continue to come from EU-based sources for a considerable period of time, as chromium trioxide's use for functional chrome plating with decorative character has been authorised or is likely to be authorised for many EU-based platers under EU REACH. Given these regulatory and market factors, the dominance of Cr(VI)-based products is unlikely to change significantly over the next decade unless there is considerable improvements made in the quality of alternatives.

Information is presented below on sanitary ware and products for automotive applications specifically, as representative of similar arguments that will exist for the wider range of products produced by the applicants for use in other sectors of the market.

5.4.1. Sanitary ware

The sanitary ware market is competitive and even though in more recent years the market has demonstrated a greater interest in different colours and finishes, it remains the case that Cr(VI)-based products still dominate overall customer demand. Table 8 below presents data from Eurostat on UK production and imports (from EU and non-EU sources) in the two Combined Nomenclature (CN) codes most relevant to sanitary ware products. These are:

- 8481 80 19 (28141235) covering "Taps, cocks and valves for sinks, wash basins, bidets, water cisterns etc. excluding valves for pressure-reducing/oleohydraulic transmissions, check, safety, relief and mixing valves"
- 8481 80 11 (28141233) covering "Mixing valves for sinks, wash basins, bidets, water cisterns etc. excluding valves for pressure-reducing or oleohydraulic/pneumatic power transmissions, check valves, safety/relief valves"

Year	CN code	Import quantities (kg)	Production quantities (kg)	Import values (€)	Production values (€)
2015	8481 80 19	11,319,200	2,918,056	177,158,170	150,180,481
	8481 80 11	15,810,600	657,246	246,626,390	111,025,846
2016	8481 80 19	11,529,000	3,581,917	150,700,550	145,977,937
	8481 80 11	14,722,900	677,566	234,254,630	104,023,283
2017	8481 80 19	10,737,400	3,554,796	130,037,440	137,662,975
	8481 80 11	16,702,300	788,693	257,938,320	112,253,185
2018	8481 80 19	10,494,500	3,702,320	125,707,520	145,803,710
	8481 80 11	15,826,800	781,364	254,617,650	112,199,478
2019	8481 80 19	10,793,100	3,573,020	127,490,420	141,092,769
	8481 80 11	17,278,300	794,193	281,370,720	115,760,393

***Table 8**: UK imports of taps and mixers 2015-2019* [15]

It is appreciated that these CN codes are broad and cover more products and finishes than those in the applicants' product ranges. They will also include parts and unfinished components that may be further processed for subsequent resale, which likely explains why imports are a smaller proportion of the value of production than of the quantity of production, i.e. some of those imports are components which receive further finishing which increases their resale value. However, the data suggest that imports form a very large proportion of the UK market for sanitary ware. China is a major source of these imports.

The above reflects all imports although, in relation to imports from EU sources, chromium trioxide is also subject to authorisation under EU REACH, although many EU-producers of sanitary ware using Cr(VI) processes have applied for authorisation. In two cases, authorisation has already been granted and in nine others authorisation seems likely to be granted, given the positive nature of opinions already made or opinions under development. This means that the use of chromium trioxide to produce sanitary ware in the EU will continue at the very least until a decision is taken on these applications and, if granted, until the end of the relevant review period. Cr(VI)-based sanitary products manufactured in the EU will therefore likely be available for import into the UK for a considerable period of time from now. Table 9 below provides further information on applications for authorisation made under EU REACH for functional chrome plating with decorative character relevant to plating in the sanitary sector.

AfA ID	Applicant name	Quantity (tonnes per year)	Review period requested	Review period recommended	Review period granted
0032-03	CTACSub (7 applicants)	3,000	7 years	4 years	-
0034-01	Grohe	34.1	12 years	12 years	12 years (until Sept 2027)
0095-03	Novotroitsk	<1,000	7 years	4 years	-
0114-01	Hansgrohe	<20	12 years	12 years	12 years (until Feb 2031)

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[15] Eurostat, 2022

AfA ID	Applicant name	Quantity (tonnes per year)	Review period requested	Review period recommended	Review period granted
0130-01	Dornbracht	1-10	12 years	12 years	-
0131-01	Schell	1-10	12 years	12 years	-
0132-01	KEUCO	1-10	12 years	12 years	-
0133-01	Ideal Standard	10-100	12 years	12 years	-
0212-02	CP4C Consortium (4 applicants)	40-50	12 years	End of 2028	-
0215-01	Oras	1-10	12 years	12 years	-
0216-01	Viega	1-10	12 years	12 years	-
0231-01	Kesseboehmer	16	12 years	-	-
0241-01	Gessi, San Marco (2 applicants)	1.325	12 years	-	-
0245-01	Newform	1-10	12 years	-	-
0259-01	ST	5-15	10 years	-	-
0261-01	Metalbrass	6	12 years	-	-
0262-02	Cromoplastica	10-15	7 years	-	-
0264-01	Cristina	<1	12 years	-	-
0268-01	Rubinetteria Paffoni	1-10	12 years	-	-
0271-01	Villeroy & Boch Mattsson Mora Group	<10	12 years	-	-
0272-01	Righi	1.04	12 years	-	-

***Table 9**: Applications for authorisation under EU REACH to use chromium trioxide for electroplating of sanitary ware*

In particular, the quantities applied for suggests that a significant proportion of the EU market for Cr(VI)-based sanitary ware is covered by pending applications for authorisation or granted authorisations, with review periods that will last well into the next decade.

5.4.2. Automotive applications

The automotive supply chain is particularly complex and has been described above in further detail. It is difficult to identify CN codes for chrome-plated products manufactured for the automobile sector specifically, although the following CN codes are likely to apply and so have been selected for the purposes of this analysis:

- 8708 10 (29323010) Bumpers and parts thereof for tractors, motor vehicles for the transport of ten or more persons, motor cars and other motor vehicles principally designed for the transport of persons, motor vehicles for the transport of goods and special purpose motor vehicles

- 8708 29 (29322090) Parts and accessories of bodies for tractors, motor vehicles for the transport of ten or more persons, motor cars and other motor vehicles principally designed for the transport of persons, motor vehicles for the transport of goods and special purpose motor vehicles (excl. bumpers and parts thereof, safety seat belts and front windscreens "windshields", rear windows and other windows)
- 8708 99 (29323090) Parts and accessories for tractors, motor vehicles for the transport of ten or more persons, motor cars and other motor vehicles principally designed for the transport of persons, motor vehicles for the transport of goods and special purpose motor vehicles, n.e.s.

Table 10 below presents data from Eurostat on UK production and imports (from EU and non-EU sources) relating to the above CN codes.

Year	CN code	Import quantities (kg)	Production quantities (kg)	Import values (€)	Production values (€)
2015	8708 10	28,746,200	21,652,657	291,047,360	558,421,966
	8708 29	No data	No data	2,408,404,980	4,486,582,442
	8708 99	No data	No data	3,029,699,930	2,272,963,739
2016	8708 10	34,442,300	26,094,032	318,183,730	593,436,081
	8708 29	No data	No data	2,583,512,770	4,161,381,608
	8708 99	No data	No data	3,035,878,630	2,244,024,259
2017	8708 10	31,604,300	No data	314,432,360	No data
	8708 29	No data	No data	2,620,629,650	4,068,964,377
	8708 99	No data	No data	3,101,368,670	2,324,528,044
2018	8708 10	32,408,300	19,255,778	317,926,400	530,834,963
	8708 29	No data	No data	2,970,264,660	3,842,003,594
	8708 99	No data	No data	3,321,881,740	2,232,090,742
2019	8708 10	32,143,800	No data	342,307,220	No data
	8708 29	No data	No data	2,493,795,500	3,359,851,670
	8708 99	No data	No data	4,068,911,490	2,424,893,765

***Table 10**: UK imports of parts for motor vehicles 2015-2019*

It is acknowledged that these codes are broad and are likely to cover more products than those in the applicants' product ranges. However, as with sanitary ware, the data demonstrate that imports form a very large proportion of the market. These imports will be from both EU and non-EU sources and while the use of chromium trioxide is subject to authorisation in the EU, many EU-based producers of chrome-plated products for automotive applications using Cr(VI)-based processes have applied for authorisation. In one case, authorisation has already been granted and, for eleven other applications, authorisation seems likely to be granted, given the positive nature of opinions already made or opinions under development. This means that the use of chromium trioxide to produce chrome-plated products for automotive applications in the EU will continue at the very least until a decision is taken on these applications and, if granted, until the end of the relevant review period. Cr(VI)-based products manufactured in the EU will therefore likely be available for import into the UK for a considerable period of time from now. Table 11 below provides further information on relevant applications for authorisation made under EU REACH.

AfA ID	Applicant name	Quantity (tonnes per year)	Review period requested	Review period recommended	Review period granted
0032-03	CTACSub (7 applicants)	3,000	7 years	4 years	-
0071-01	Kunststofftechnik (12 applicants)	560	12 years	12 years	
0095-03	Novotroitsk	<1,000	7 years	4 years	-
0095-04	Novotroitsk	<1,000	7 years	4 years	4 years
0210-01, 0210-02, 0210-03	C. Hübner	<15.6	9 years	End of 2028	-
0212-01, 0212-02	CP4C Consortium (4 applicants)	100-120 (etching) 40-50 (plating)	12 years (etching) 12 years (plating)	End of 2031 (etching) End of 2028 (plating)	-
0218-01, 0218-02	Doureca	43.57 (etching) 40.02 (plating)	9 years (etching) 9 years (plating)	9 years (etching) 9 years (plating)	-
0220-01, 0220-02	SRG Global	4-40 (etching) 1-10 (plating)	12 years (etching) 7 years (plating)	12 years (etching) 7 years (plating)	-
0231-01	Kesseboehmer	16	12 years	-	-
0244-01, 0244-02	Cromaplast	5 (etching) 5-10 (plating)	12 years (etching) End of 2030 (plating)	-	-
0260-01	Sarrel Sarreliber	47	8 years	-	-
0262-01, 0262-02	Cromoplastica	20-30 (etching) 10-15 (plating)	12 years (etching) 7 years (plating)	-	-
0270-01, 0270-02	Maier	30-90 (plating) 50-110 (etching)	7 years (plating) 12 years (etching)	-	-

***Table 11**: Applications for authorisation under EU REACH to use chromium trioxide for electroplating of automotive products, including etching*

The quantities applied for are significant and suggest that a large proportion of the EU market for Cr(VI)-based products for automotive applications will be covered by pending applications for authorisation or granted authorisations, with review periods that will last well into the next decade.

5.4.3. Conclusions

Taking all the above into account, this means that there is, and will continue to be, a large source of Cr(VI)-based products (sanitary ware, automotive products etc) manufactured outside the UK which are readily available for import into the UK. Consequently, any attempt to substitute away from Cr(VI)-based products to alternatives that are currently inferior will always be hampered by the continued availability of Cr(VI)-based products from abroad. This includes the EU, where authorisations already have been or will likely be obtained for the continued use of chromium trioxide.

Chromium trioxide is subject to authorisation because of its hazards associated with carcinogenicity and mutagenicity. The applicants support the principle of authorisation under REACH, i.e. the substitution of hazardous substances to safer alternatives. However, if the applicants were not granted authorisation meaning that their use of chromium trioxide must cease, then this would not achieve the aims of REACH in that the risk would simply be transferred elsewhere. Admittedly this would be to a non-GB location not covered by UK REACH and so therefore not of direct concern to any UK regulatory authority. However, the UK's performance on health and safety ranks favourably across the EU[16] and the EU itself compares favourably to safety standards across the rest of the world[17]. This means that switching production to a non-UK (and likely non-EEA) country may well result in poorer standards of worker protection and consequently higher exposure to chromium trioxide by workers and non-workers in the vicinity of the production site, with higher levels of ill-health that could be expected as a result.

6. Identification of potential alternatives

6.1. Efforts made to identify potential alternatives

6.1.1. Research and development (R&D)

The applicants are all downstream users (as defined by REACH) of chromium trioxide and use the substance in electroplating processes with the chemicals and technologies provided by specialist suppliers, e.g. MacDermid Enthone and Atotech. The applicants can be quite rightly regarded as having expertise in producing their products for the applications and sectors to which they supply and will determine key functionalities and set performance standards for the products they manufacture. However, their specialist suppliers are the holders of the expert knowledge regarding electroplating technologies and any changes or improvements are driven by their activity. The applicants are aware that much effort is being expended on R&D activities to identify possible alternatives for chromium trioxide in both plating and etching although it is not reasonable to expect the applicants themselves to drive this, as they do not have the necessary expertise and personnel in-house.

Conversely, specialist technology suppliers often do not have the practical expertise in the application and use of their technologies to manufacture products for various applications / sectors of use. This means the development of new or improved technologies must be undertaken in cooperation with downstream users who do have that expertise. Indeed, the applicants are highly supportive of the drive towards alternatives to chromium trioxide and are actively engaging with specialist suppliers and technology providers. Some of the applicants have been researching and trialling alternatives to hexavalent chromium since the 1980s, although all have found issues with corrosion and chemical resistance, abrasion and aesthetics (colour matching). As customers of the technology providers, the applicants can help facilitate and even initiate change, e.g. through requesting different specifications, performance standards etc. However, the unique functionalities of Cr(VI) as component in chromium trioxide make it an ideal and hard-to-replace substance where superior requirements for aesthetics/colour, corrosion and chemical resistance, abrasion resistance and other key functionalities are required, given the demanding conditions in which their products will be put to use. It is very difficult to find a single alternative which replaces all the multi-functionality of Cr(VI) simultaneously.

That said, new technologies are emerging[18] and the applicants remain hopeful these will ultimately be successful in providing for a suitable alternative to chromium trioxide for functional chrome plating with

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[16] HSE, 2021.

[17] United Nations Global Compact, 2021, p5.

[18] For example, MacDermid Enthone have recently introduced a new process for plating on plastic called 'TriMac BLUE', which is a trivalent chromium process that has been specifically designed to mimic CrVI finishes of brilliant silver with a hint of blue.

decorative character for many applications. However, new technologies are typically aimed at achieving suitable alternatives to the more common chromium finishes. This means that, for less common finishes, no alternative technologies are being proposed (nor indeed are the applicants aware of any currently in development). For example, there is no trivalent chromium-based alternative for matt black chrome, a finish applied to sanitary ware by one of the applicants. Coating by physical vapour deposition (PVD) is being considered as a possible alternative for matt black chrome but this technology is prohibitively expensive, unable to offer bright chrome options and very difficult to manage in a production environment, giving rise to issues with thickness of coat and concerns over corrosion resistance.

The issues are even more pronounced when it comes to alternatives to chromium trioxide for etching. The possibility of replacing CrVI with an alternative etch has been a topic of conversation for over 30 years. Unfortunately, there is still no viable substitute for the CrVI-based etching process. Some of the applicants have tried several different types of etching over a number of years on a laboratory scale but every replacement has had issues which were insurmountable. For example, a permanganate-based etch that had initially appeared promising in laboratory conditions failed when the trial was scaled up, because the process sequence used in the laboratory failed very quickly on a larger scale due to breakdown of the etch solution. Tests of some alternative technologies found that ABS could be plated but not ABS/PC and all trials have had issues with being able to differentiate between types of substrate on 2K components (those using two different polymers) and resist-painted components. The applicants remain in contact with their specialist technology providers but, to date, no suitable alternative to Cr(VI) etching has been identified.

6.1.2. Data searches

One of the applicants was a former member of CTAC and retains access to the information gathered by the CTACSub which involved widespread consultation, the making available of extensive literature and test reports, and searches for publicly-available documentation. This has been used by the applicants to ensure that all potential alternative processes to chromium trioxide-based electroplating applications have been considered. In addition, the applicants have also reviewed data presented as part of other similar applications for authorisation that have already been made under EU REACH. The AoA for these applications are made publicly available on the ECHA website and these documents were reviewed to ensure that all potential alternative processes to Cr(VI)-based electroplating were considered. The various sources of information used are presented in Table 12 below.

Type	Source
CTACSub	One applicant was a former member of CTAC and has permission to refer to information collected for the purposes of the CTACSub AfA
Literature	BAUA (Federal Institute for Occupational Safety and Health, Germany) '*Survey on technical and economic feasibility of the available alternatives for chromium trioxide on the market in hard/functional and decorative chrome plating*' (2020) TURI (Toxics Use Reduction Institute) '*Five Chemicals Alternatives Assessment Study*' (2006) DEFRA '*Environmental Risk Reduction Strategy and Analysis of Advantages and Drawbacks for Hexavalent Chromium*' (2005)
Websites	OECD Substitution and Alternatives Assessment Toolbox http://www.oecdsaatoolbox.org/ BAUA SUBSPORTplus (Substitution Support Portal) https://www.subsportplus.eu/subsportplus/EN/Home/

Type	Source
Previous applications for authorisation	CTACSub (EU REACH application ID 0032-03) Others, e.g. - Grohe (EU REACH application ID 0034-01 & 0034-01) - Gerhardi Kunststofftechnik GmbH (EU REACH application ID 0071-01) - Schell (EU REACH application ID 0131-01) - CP4C Consortium (EU REACH application ID 0212-01 & 0212-02) - Kesseboehmer (EU REACH application ID 0231-01) - Gessi, San Marco (EU REACH application ID 0241-01)

***Table 12**: Sources of information used to identify potential alternatives*

6.1.3. Consultations

Information has been gathered from relevant technical experts from the applicants to gain an overview of potential alternatives and their experiences in relation to them, as well as the key functionalities and performance requirements required. In addition, for the purposes of this AfA there has been extensive consultation with, including a series of site visits by, specialist technology suppliers where potential alternative technologies were specifically discussed, to gain further understanding of existing and emerging technologies that could provide possible alternatives to Cr(VI)-based processes.

In summary, the longlist of alternatives presented below represents the outcome of extensive reviews into available information and in-house consultation with technical experts.

6.2. Longlist of alternatives

Tables 13 and 14 below present the outcome of screening of all potential alternative coating technologies considered and assessed by the applicants. These alternatives have been screened for technical limitations, economic considerations and regulatory / safety concerns in order to achieve a realistic shortlist of alternatives. Based on this screening, the alternatives are categorised either as shortlisted alternatives that will be assessed in further detail in this report or as rejected alternatives which are not considered further as potential alternatives for Cr(VI)-based electroplating as they have fundamental limitations at the present time.

For a better overview of the potential alternatives for the two uses subject to this AfA (plating and etching), an assessment has been made for the etching pre-treatment step (use 1, Table 13) and the electroplating step (use 2, Table 14) separately. However, etching is a pre-treatment and not a stand-alone process, necessary to prepare the surface of plastic substrates for subsequent electroplating. Nevertheless, the most important key functionalities with regard to achieving a high-quality finished product are related to the chromium trioxide based electroplating step.

Potential alternative	Technical, economic and regulatory / safety considerations	Decision
Trivalent chromium electroplating processes Chromium sulphate Chromium chloride	Similar to the hexavalent chromium plating process, trivalent chromium plating uses chromium sulphate or chromium chloride instead of chromium trioxide to achieve a metallic chromium finish. Technical limitations of this process involve issues with corrosion and chemical resistance, aesthetics (including consistency of colour with other Cr(VI) plated parts). The process is also sensitive to impurities and	Shortlisted

Potential alternative	Technical, economic and regulatory / safety considerations	Decision
	acidity changes in plating baths. In addition, for matt black chrome products, Cr(III) processes are unable to replicate a matt black effect. Economic considerations include: • Higher processing time which will result in higher unit costs. • Capital costs associated with required upgrades for plating lines and potentially necessitating construction and installation of an entirely new plating lines for Cr(III). • Potentially increased scrap rate. • Potential revenue and brand impacts due to reduced corrosion resistance, and perceived lower quality and aesthetics. • Production and inventory changeover and transition costs. However, further R&D is justified. Cr(III) electroplating, though currently not capable of meeting key functionalities, is believed to have the highest likelihood of success.	
PVD based processes Lacquer + PVD + Lacquer PVD metal	Physical vapour deposition (PVD) refers to a variety of vacuum-based processes. The coating material will be in a solid (or rarely in a liquid) form and is placed in a vacuum or low-pressure plasma environment. The coating material is vaporised and deposited, atom by atom, onto the surface of the substrate in order to build up a thin film. PVD coating materials include titanium nitride, titanium-aluminium nitride, zirconium nitride, chromium nitride, chromium carbide, silicon carbide, titanium carbide, and tungsten carbide. Technical limitations are associated with corrosion resistance, chemical resistance and abrasion plus, for plastic substrates, it offers no option for the selective coating of 2K or 3K components. It is also technically difficult to control the process to achieve consistent quality finishes. Economic considerations include capital purchase and installation for new coating process, with very high investment in equipment required and additional operational expenses which would result in higher unit costs. However, while the process is unlikely to be successful, additional investigation into this alternative may be possible in the future. In addition, it may be the only technology to provide a solution for matt black chrome coatings.	Shortlisted
Satin & black anodized aluminium	Anodizing is an electrolytic process used to increase the thickness of the natural oxide or to enhance the formation of an oxide layer on the surface of the metal parts. Substrates that can be treated by anodizing in general include aluminium alloys, titanium, zinc, magnesium, niobium, zirconium, hafnium and tantalum. The process of anodizing is mainly performed on aluminium. In general, no other metal substrates are anodized or can be anodized. Given the specific process of forming an aluminium oxide by anodizing, this is not possible with plastic substrates. In addition, it only has a satin and no bright appearance and therefore does not fulfil the high aesthetic requirements of all industry sectors regarding a silvery-blue bright coating. Significant issues identified with corrosion and chemical resistance.	Rejected
Chromium free electroplating	This alternative involves electroplating without using chromium but instead using multi-component coating systems (Cu, Sn, Zn, Ni, Co), gold and platinum electroplating, or zinc electroplating.	Rejected

Potential alternative	Technical, economic and regulatory / safety considerations	Decision
(Alternative metallic coating)	This alternative does not yield a chromium-like colour and as such it does not meet a fundamental and basic requirement. No further evaluation is justified, although significant issues with corrosion and chemical resistance and abrasion were identified during testing and so this alternative will not meet customer acceptance requirements. Cobalt is also listed as a SVHC so would be rejected on grounds of risk reduction.	
Natural brass finish (metal substrates) / Mould in metal colour (plastic substrates) (No coating)	This alternative involves not coating at all and leaving the substrate exposed. For metal substrates, this would result in a brass finish. For plastic substrates, the substrate itself would be coloured to mimic the metal finish intended, by use of a coloured polymer during moulding which is used to produce the part. For metal substrates, this alternative does not yield a chromium-like colour. As such it does not meet a fundamental and basic requirement. For plastic substrates, leaving the plastic exposed will increase susceptibility to abrasion and is not acceptable from an aesthetics perspective; feedback from customers indicates requirements for quality of surface are not met (it does not provide a cool touch that feels like chrome) and it does not produce a glossy, bright chrome effect.	Rejected
Stainless steel (Alternative substrate)	This alternative involves the use of a different substrate (stainless steel) with no coating. Stainless steel is a steel including at least 10.5 % chromium and is more resistant against corrosion than ordinary steel. Furthermore, higher contents of chromium and the addition of other substances, for instance nickel, carbon and molybdenum, can further improve the material properties of stainless steel. As the use of stainless steel is not to replace the plating process, but to replace the substrate, it cannot be an alternative for chrome plated plastic parts widely used for a number of different applications, in particular, for automotive applications, where weight is a significant factor. Stainless steel could be used in the sanitary sector although the aesthetic of stainless steel surfaces does not meet the sanitary sector requirements regarding colour and brightness, and stainless steel parts do not provide a long-term high-aesthetic appearance due to corrosion and scratches on the surface.	Rejected
Wet lacquering / colour painting	This involves liquid coating materials applied either as clear or coloured lacquer. Such alternatives do not yield a chromium-like colour and as such they do not meet a fundamental and basic requirement. No further evaluation is justified, although it is also unlikely to provide the required durability (in particular, significant issues were identified with chemical resistance and abrasion) in the long-term and therefore will not be likely to meet customer acceptance requirements.	Rejected
CVD: Chemical Vapour Deposition	Chemical vapour deposition (CVD) is a process similar to PVD, but uses gases that, combined on a hot surface, form a hard coating. The typical process temperature for the application of a coating by CVD is between 200 and 500°C. This will melt ABS plastic which melts at a temperature of about 105°C. CVD coatings failed in all cleaning agent spray tests (for example daily spraying for 7, 10 and 14 days with household chemicals), as well as the	Rejected

Potential alternative	Technical, economic and regulatory / safety considerations	Decision
	continuous immersion tests (for example immersed for 4 and 7 days in household chemicals). CVD vacuum chambers are not suitable for larger parts and complex geometries (no high volume production) and are unable to meet the throughput required by the sectors for their products. In addition, CVD coating is difficult to apply on complex geometric parts, especially with small internal diameters to be coated. In the case of transition to CVD, high investment costs would be required for the realisation of a CVD line that is able to coat parts of different sizes with adequate throughput.	
DLC: Diamond Like Carbon	Diamond-like carbon (DLC) coatings are PVD coatings (see above) of combined bond types of graphite and diamond. DLC forms an amorphous diamond-like carbon layer. Different foreign atoms, such as hydrogen, silicon, and fluorine, can be integrated in the network structure. The colour of the coating is dark grey to anthracite. The high process temperatures are not compatible with the melting point of plastic substrates, which are the substrates used for the vast majority of parts in the automotive industry. The DLC coating technique is limited by the geometry of the parts to be coated. Complex geometric parts and parts with small internal diameters are especially difficult to handle. Even if twisted in all directions within the vacuum chamber, the quality of the coatings on complex parts cannot be guaranteed. This is especially important as parts coated for sanitary purposes are usually provided with a nickel underplate to guarantee the overall functionality of the product. To prevent nickel leaching and potentially allergic reactions coming from this underplate, it is important that the nickel underplate is efficiently covered with a coating. While DLC offers good corrosion resistance and abrasion resistance, the performance of different DLC coatings in chemical resistance tests depends on the distinct test method and the household chemical used. In general, DLC coatings were found not to be able to fulfil the requirements of chemical resistance which would be required to pass all test procedures for withstanding household chemicals. Perhaps the most significant issue is that DLC creates a dark grey to anthracite finish which is neither comparable to, nor competitive with the bright silvery-bluish metallic chrome coating derived when using chromium trioxide electroplating.	Rejected
Electroless nickel plating	Electroless nickel plating is an auto-catalytic reduction that deposits a metallic nickel layer on a substrate such as a metal or plastic. No electric current is involved in the coating process. Autocatalytic reduction is a chemical reaction in which the substrate acts as a catalyst, causing ions to continuously deposit onto the substrate. In terms of corrosion resistance, electroless nickel layers can meet sector specific requirements but only if a relatively thick coating with at least 25 to 50 µm thickness is applied. For functional chrome plating with decorative character, only a very thin final chrome coating (typically between 0.2 and 2 µm) is applied to provide the respective required corrosion resistance. The high thickness of the electroless nickel coating can only be achieved by a longer process time, which results in higher energy consumption and thus higher costs. In terms of chemical resistance, testing revealed that no nickel plated products were able to meet all company specific requirements for chemical resistance.	Rejected

Potential alternative	Technical, economic and regulatory / safety considerations	Decision
	This alternative does not yield a chromium-like colour and as such it does not meet a fundamental and basic requirement.	
Powder coating	Powder coating is a type of surface coating that is applied as a free-flowing, dry powder which is applied electrostatically and then cured under heat or UV light. The powder will be a thermoplastic or thermoset polymer. This alternative does not yield a metallic looking surface nor a chromium-like colour and as such it does not meet a fundamental and basic requirement. In addition, R&D reveals issues with corrosion and chemical resistance, abrasion, brittleness, and yellowing of the coating ('orange peel' effect). Other issues include overspray into potable water contact points for some products (internal bores) which presents a key limitation, plus it offers unsuitable mechanical resilience for parts that have male/female threads.	Rejected
Nanocrystalline coating (HVOF, thermal spray processes)	Not seen as a suitable alternative for decorative applications. Temperature far too high (600 °C) for application on plastic parts. Layer thickness too high, no optical performance (aesthetics not sufficient).	Rejected
Case hardening: Carburising, CarboNitriding, Cyaniding, Nitriding, Boronising	Not seen as an alternative for decorative application because these alternatives are surface treatments without any decorative aspect (high performance coatings for abrasive wear). Process is higher than ABS melting temperature – not applicable on plastic substrates. Colour change due to sun and weathering.	Rejected
Hot stamping	Involves a very narrow process window concerning geometry and adhesion, even worse with additional protecting clear coat. New parts need to be developed, optic needs to be changed, use of actual plastics raw parts not possible. Hardness and scratch resistance are much worse compared to metallic chrome coatings from chromium trioxide. Colour change due to sun and weathering.	Rejected
IMD (Inmould Decoration) / IML (Inmould Layer) foil	Hardness and scratch resistance are much worse compared to metallic chrome coatings from a chromium trioxide. New parts need to be developed, optic needs to be changed, use of actual plastics raw parts not possible, at a very early R&D stage. Gives rise to yellowish, clouding process marks.	Rejected
Aluminium (plus pre-processing) plus clear coat (floating process)	Not a suitable alternative: optics are not comparable, not for complex geometries, reproducibility and availability not sufficient, risk of filiform corrosion of exterior automotive parts.	Rejected
Aluminium coating on copper plating, followed by anodization	Process temperature is too high for plastic substrates, technically not feasible. In addition, economically not feasible due to the numerous process steps resulting in high costs.	Rejected

***Table 13**: Longlist of potential alternatives - plating*

Potential alternative	Technical, economic and regulatory / safety considerations	Decision
Mineral acid-based solutions	Different mineral acids are currently under evaluation as alternatives to chromium trioxide etching pre-treatment. Research is currently focused on using sulphuric acid composed with other acids, such as phosphoric acid and nitric acid, or with additives, such as peroxymonosulphate salts or peroxidisulphate salts. During the CTAC consultation, various major issues were identified with all kinds of mineral acid etching solutions. The major concern is the tendency of the substrate to swell. In addition, sulphuric acid solutions cannot differentiate between substrates thus it is not effective for 2K or 3K, ABS/PC and resist-painted components. However, in the absence of any more promising alternatives to the etching of plastics with a chromium trioxide based solution, it will be considered in further detail in this AoA.	Shortlisted
Potassium permanganate-based solution	Potassium permanganate ($KMnO_4$) is a strong oxidizing agent with manganese in the oxidation state of VII. It is widely used for water disinfection. Acidic permanganate solutions are reduced to Mn^{2+} (MnO) giving the solution a pink colour. Under neutral conditions, permanganate is reduced to Mn^{4+} (MnO_2), exhibiting a brownish colour to all materials that are in contact with the solution. In alkaline solutions, potassium permanganate is spontaneously reduced to Mn^{6+} (K_2MnO_4), having a green colour. The CTAC consultation found that extensive R&D on this alternative has been performed although a small series of experiments showed very different results. One of the major issues with permanganate based etching solutions is that the adhesive properties required for the subsequent coating steps are not sufficiently provided, leading to extensive blistering of the functional coating meaning that the high-quality requirements of the final product cannot be met. This is due to continual breakdown of the potassium permanganate into manganese dioxide (MnO_2) thus giving an unstable solution and suspect/erratic, non-uniform plating adhesion. The subsequent etching rate is much weaker than using a chromium trioxide based etching solution. However, in the absence of any more promising alternatives to the etching of plastics with a chromium trioxide-based solution, it will be considered in further detail in this AoA.	Shortlisted
Ionic liquids	Ionic liquids of different kinds in various combinations have been suggested as potentially being suitable for the etching pre-treatment of plastics prior to electroplating. However, this alternative is at a very early R&D stage (literature research), so significantly more R&D would be necessary. Its large-scale implementation is uncertain. It also appears technically infeasible, because it results in the dissolution of different kinds of plastic substrates. Different wastewater treatment would be required but no solution has yet been identified.	Rejected
Polyamide (use of an alternative substrate)	Polyamide consists of macromolecules which contain repeating amides. They can be natural (wood / silk) or synthetic in origin. Three different kinds are available, classified as aliphatic polyamides (commercially traded as nylon), semi-aromatic polyphthalamides (commercially traded as Trogamid) and aromatic polyamides (commercially traded as Kevlar). The melting point of polyamides is generally higher than that of ABS. It has been suggested that use of polyamides could replace Cr(VI)-based etching processes because, due to the different chemical composition	Rejected

Potential alternative	Technical, economic and regulatory / safety considerations	Decision
	of polyamides, surfaces could be etched using a different method, e.g. sulphonation. The major drawback is that the raw mould must be of very high quality. In contrast to conventional plastic substrates, the etching pre-treatment removes small defects and imperfections, but with polyamide as a substrate, small edges, blisters or unevenness will occur on the final surface. In such cases, the aesthetic properties of the final product will not be in line with the demanding requirements of automotive OEMs. In addition, flow problems have been encountered during injection moulding which causes porosity of the polyamide part and an uneven surface with dislocations and waves. This exacerbates disadvantages in the design of the substrate and as a consequence, in design limitations for the final product. A higher scrap rate has also been reported.	
Mechanical methods	This alternative involves the use of mechanical methods such as sanding, shotblasting, grinding & machining etc. However, such techniques are imprecise and will not achieve a consistent finish. They are also not suitable for complex geometries nor inner diameters.	Rejected
Laser activated embedded metalparticles / etching on catalysed plastic (LPKF)	This was considered by the CTACSub but ruled out as being technically not feasible. The process engineering is not equivalent, only a few exemplary parts have been tested resulting in insufficient adherence, and the method is not applicable for larger parts. It is not industrially feasible for high volume production.	Rejected
Catalysed plastic (noble metal)	This was considered by the CTACSub but ruled out as not being industrially feasible for high volume production, and involves worse process engineering.	Rejected
Conductive paint	This was considered by the CTACSub but ruled out as not being industrially feasible for high volume production.	Rejected
Gaseous etching / gas etching	This was considered by the CTACSub but ruled out as not being industrially feasible for high volume production – the principal limitation due to the use of gas-tight containers.	Rejected
Plasma etching	This was considered by the CTACSub but ruled out as not being technically sufficient. It is a difficult and complex technique at a very early R&D stage, which would not be suitable for high-volume throughput of parts.	Rejected
Heat treatments: Heat gun	This was considered by the CTACSub but ruled out as unsuitable for plastic substrates. It results in possible over-heating and damaging of the substrate.	Rejected

***Table 14**: Longlist of potential alternatives - etching*

6.3. Shortlist of alternatives

The alternatives outlined in Tables 13 and 14 were evaluated on the basis of technical and economic feasibility and regulatory/safety concerns. Technical feasibility primarily considered whether it would be possible to implement the alternative in a consistent, robust production process and the ability of the alternative to meet customer requirements, particularly with regards to durability (linked to chemical and corrosion resistance) and aesthetics. Economic feasibility primarily considered the relative production costs and capital costs required for upgrades to existing facilities, plant and equipment. The assessment considered the existing experience of the applicants when testing / trialling alternative technologies and processes, information available in the public domain, and data gathering and research undertaken as part of the CTACSub programme.

This assessment resulted in shortlisting two potential alternatives for plating (use 2) to carry forward for more detailed assessment and evaluation in this AoA: trivalent chromium-based electroplating and PVD-based processes. For plastic substrates, trivalent chromium-based processes would still require etching as a pre-treatment step and two alternatives to Cr(VI)-based etching (use 1) are also carried forward for further review, although neither make for promising alternatives.

Trivalent chromium-based electroplating and PVD-based processes use fundamentally different coating technologies. Trivalent chromium-based plating is similar to hexavalent chromium-based plating in that it is a galvanic process, although for plating on plastic substrates etching remains required as a pre-treatment step and so an alternative to the Cr(VI) etching pre-treatment would have to be developed as well. In contrast, PVD-based processes are not galvanic and do not need an etching pre-treatment. Table 15 below briefly outlines the conceptual differences connected with these two alternative approaches.

Trivalent chromium (Cr(III)) electroplating processes	PVD-based processes
Galvanic process similar to hexavalent chromium (Cr(VI)) electroplating processes	Coating technology fundamentally different to electroplating, involving vacuum-based processes.
Etching pre-treatment remains required: - No suitable Cr(VI)-free alternative has yet been identified - Potential alternatives are considered further, below.	No etching pre-treatment required: - Different process is used for surface preparation
Most promising potential alternative favoured by the applicants for most applications	Not favoured by the applicants for most applications though currently the most promising potential alternative identified for matt black chrome finishes

***Table 15**: Conceptual differences between the two plating alternatives shortlisted*

The applicants consider electroplating based on trivalent chromium solutions to be the most promising and are currently the focus of much R&D with specialist technology providers. However, this alternative brings with it potentially critical technical issues, particularly in the areas of corrosion resistance, chemical resistance and aesthetics. It has proven very challenging to find a single alternative substance or technology to chromium trioxide-based coatings which achieves all of the key functionalities required. In other words, there is currently no 'drop-in' alternative[19].

Any general attempt to offer products to the market using inferior alternatives without additional development would likely result in a critical loss of market share and sales, as customers and consumers would switch to more reliable and durable products, based on readily-available products made using Cr(VI)-based processes imported from outside of Great Britain.

As a result, faced with the prospect of having to cease use of chromium trioxide by the end of June 2022, then in addition to the alternatives outlined above, the applicants have had to consider 'managerial' scenarios as alternatives to the continued use of chromium trioxide in Great Britain. These include:

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[19] Baua, 2020, p17.

- Ceasing production of all products that require the use of chromium trioxide – in this scenario, the applicants would cease to manufacture and supply all chrome-plated products. For some applicants, this would represent total closure of the business; other applicants would attempt to continue to manufacture and supply products with other finishes in the UK, although again the impact of losing chrome-plated products may ultimately lead to business closure.

- Outsourcing production of products that require the use of chromium trioxide – in this scenario, the applicants would continue to supply chrome-plated products but would no longer electroplate the products themselves in the UK; electroplating would be outsourced to third-party providers based in a non-EEA country. (Additionally, given the costs of shipping and complexity of logistics, manufacturing of products in their entirety would likely be outsourced, i.e. the casting of metal substrates and moulding of plastic substrates.)

- Relocation of production associated with the use of chromium trioxide – In this scenario, the applicants would relocate their manufacturing operations (partly or completely) to a non-UK and non-EEA country. This would involve establishing their businesses in other territories and setting up new production sites.

The managerial options under discussion do not present attractive alternatives to the applicants. However, given the lack of any suitable 'drop-in' alternative processes / technologies at the present time, the applicants must consider these options for the purposes of selecting the NUS should authorisation not be granted. This is explored further in the SEA.

7. Assessment of alternatives: etching (use 1)

This section is relevant to plating on plastic substrates only, for which an etching pre-treatment is required (use 1). In this section, the identified potential alternatives are assessed in terms of their:

- technical feasibility;
- economic feasibility;
- potential for risk reduction; and
- availability.

The assessment focuses on technical feasibility in the first instance and, if the alternative is found to have critical technical weaknesses which means some of the key functionalities are not fulfilled, economic feasibility and other considerations are not then assessed in detail. This is in line with the approach suggested in the ECHA guidance on authorisation[20] and aims to ensure a proportionate approach is taken to the AoA.

To assist with the technical feasibility aspects of the assessment, colour-coded summary tables are included, using the criteria set out in Table 16 below. These tables show the findings of the assessment against the following three key functionalities: adequate surface preparation (surface roughness); adhesion to substrate; and compatibility with substrates, including the ability to selectively etch.

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[20] ECHA, 2021, p45 and p81

Colour	Explanation
🟥	Not sufficient – the parameters / assessment criteria do not fulfil the requirements of the respective sector.
🟨	The parameters/assessment criteria fulfilment are not yet clear / the process is still not defined / further experimental investigations need to be performed.
🟩	Sufficient - the parameters/assessment criteria do fulfil the requirements of the respective sector.
⬜	No data available / not assessed.

***Table 16**: Colour-coding approach to summarise the feasibility assessment of alternatives*

The assessment also includes a non-exhaustive overview of general information on substances used within the alternative processes, as well as the hazards to health, safety and the environment. This information is presented in Appendix 1.

7.1. Potassium permanganate-based etching solutions

7.1.1. Substance identity, properties and process description

Permanganate-based etching is a wet-in-wet process, meaning that the overall technique is comparable to its chromium trioxide-based counterpart. Potassium permanganate ($KMnO_4$) is a strong oxidizing agent with manganese in the oxidation state of VII. It is widely used for water disinfection. Acidic permanganate solutions are reduced to Mn^{2+} (MnO) giving the solution a pink colour. Under neutral conditions, permanganate is reduced to Mn^{4+} (MnO_2), exhibiting a brownish colour to all materials that are in contact with the solution. In alkaline solutions, potassium permanganate is spontaneously reduced to Mn^{6+} (K_2MnO_4), having a green colour.

A non-exhaustive overview on general information on substances used within this alternative and their hazards to health, safety and the environment is provided in Appendix 1.

7.1.2. Technical feasibility

In general, permanganate-based etching is only feasible on ABS plastic substrates. Potassium permanganate-based etching may be performed either under acidic or alkaline conditions. The applicants have been involved in several trials with technology providers using differing strengths and concentrations over a number of months, although all trials were ultimately unsuccessful. In addition, research and testing has been undertaken in support of the CTACSub application and the discussion below reflects the overall findings.

Figure 24 below shows plastic surfaces etched with different kinds of etching solutions.

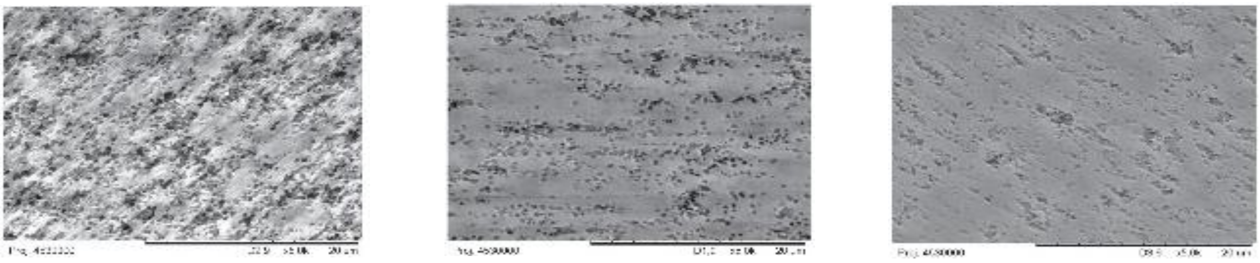

Figure 24*: Comparison of typical etched plastic surfaces – left: after chromium trioxide etching, middle: after acidic permanganate etching, right: after alkaline permanganate etching. Data source: CTAC*

Acidic permanganate etching solutions show a rapid self-reactivity and decomposition. This results in a relatively short lifetime of such etching solutions. Alkaline manganese etching solutions have better stability but their etching capability, especially on plastic substrates like ABS and PC, or blends, is not very strong, meaning that relatively long treatment periods are needed.

At the current stage of development, the major issue with permanganate based etching solutions in general is that it does not provide for the adhesive properties required for subsequent coating steps. As shown in Figure 24, the etching rate is much weaker than using a chromium trioxide based etching solution. R&D efforts returned variable results and key functionalities varied, such as the depth, form and density of the cavities. The instability of potassium permanganate solutions gave rise to the distinct possibility of under- or over-etching, resulting in adhesive properties which were significantly inferior to chromium trioxide-based etching. These inferior adhesive properties lead to extensive blistering of the subsequent chromium coating with the plating lifting away from the substrate, potentially causing customer injuries from cuts. In addition, poor plating coverage can result due to non-uniform etching. As a result, the high-quality appearance and durability requirements for the final product were not met for the respective industry sectors.

Given the chemical nature of permanganate solutions, bath maintenance is particularly complex. During the etching process, Mn^{7+} is reduced and MnO_2 is precipitated from the etching solution, causing interferences with the etched substrate. The MnO_2 deposits at the base of the etching baths highly influence the overall etching performance, with the quality of products decreasing over time, presenting significant challenges for high-volume production. This is because the etching solution is not suitable for regeneration due to the nature of the breakdown products which would mean consistent etching would not be achieved and the solution would have to be disposed of regularly. More frequent pump-outs of permanganate solutions introduce their own risks. Conversely, Cr(VI) etching solutions will typically last for three years due to continual regeneration.

Even if permanganate-based etching provided better adhesion, it is not capable of multi-component (selective) etching. In the automotive sector, it is common to use 2K or 3K parts, with non-ABS components which must not be affected by etching. Permanganate-based etching would need to be adapted for 2K or 3K parts to ensure it only etches ABS components without affecting others.

Permanganate-based etching has also been found to affect the jigs holding the etched parts, which would therefore need to be protected prior to the electroplating step to avoid cross-contamination in subsequent processing steps. Issues with jigs also give rise to insufficient plating thickness of plated parts, because inadvertent coating of jigs means that less current is then available to be applied directly to the components on the jigs.

The applicants continue to support their technology providers in trialling potential alternatives using permanganate-based solutions. However, permanganate-based etching solutions are not currently technically feasible as an alternative to chromium trioxide-based etching on plastics, principally due to issues with adhesion. In addition, a number of technical issues with the permanganate chemistry adversely affected the etching process and its outcome. More R&D on this alternative would be required before it could be considered further as a promising alternative, although the applicants understand that this alternative may be at the laboratory R&D stage at some automotive OEMs. Even so, no longer-term testing has been undertaken meaning there is no field experience with potassium permanganate etched and chrome-coated products.

Adequate surface preparation	Adhesion to substrate	Compatibility with substrates
🟧	🟥	🟥

7.1.3. Economic feasibility

Against the background of the significant technical failure of this alternative, a less detailed analysis of economic feasibility was conducted. However, the costs associated with moving to permanganate-based solutions would likely be prohibitively expensive. It is likely that entirely new lines would be required for the process. In terms of capital costs, the applicants estimated that the cost of replacing the current Cr(VI)-based etching pre-treatment would be between £2.5m to £4m, which includes the cost of a new plating line and also the property extension that would be required to accommodate the new plant. Upgrades would not only include new process tanks but also new chemistry, software modifications, additional extraction and utility supplies and worker training on the new process. The wastewater (effluent) treatment plant would also need to be upgraded at an estimated cost of circa. £600,000. The work needed to achieve all of the above would mean ceasing all production for a period of time due to the extensive rebuild required, which would see the applicants suffering large financial losses and customers seeking alternative suppliers, with no guarantee that customers would return to the applicants once production recommenced.

Additionally, operating costs would be higher, with the applicants estimating that costs could be up to five times higher following consultation with potential suppliers of such technologies. This is in part due to longer processing times required when using alkaline manganese etching solutions, which are relatively weaker and so required increased etching times. Costs would also be incurred for the disposal of high amounts of MnO_2 sludge created during the process although the amounts associated with this have not yet been estimated. As a result, the costs of the finished products would see a significant increase, potentially making plating uneconomical to continue.

7.1.4. Risk reduction

As the alternative is not technically feasible, only a limited review into risk reduction has been undertaken. Potassium permanganate is not subject to authorisation nor designated a SVHC although it is highly hazardous, with hazard classifications under CLP including oxidising Solid (category 2), skin corrosivity (category 1C), aquatic acute and aquatic chronic (category 1) and toxic to reproduction (category 2) (see Appendix 1 for further details). As regards the latter, the substance has previously been proposed to be re-classified as a category 1B reproductive toxicant although, during substance evaluation, ECHA's Risk Assessment Committee (RAC) proposed the harmonised classification as Repr. 2; H361d should not proceed due to poor quality of available reproductive studies.

It is also worth noting that MnO_2 is an oxidizing agent and chloride can be oxidized to elemental chlorine. Therefore, manganese dioxide has to be kept separate from chlorides during the processes of surface coating and neutralization and the storage of sludge.

However, on balance, based on the available information on the substances used within this alternative, a transition from chromium trioxide to a permanganate-based solution would likely achieve risk reduction and constitute a shift to the use of less hazardous substances.

7.1.5. Availability

Potassium permanganate is commercially available and widely used for a number of different applications. With regard to its use as an alternative for etching of plastics, different companies are working on the technical issues. As stated during the CTAC consultation and as experienced by the applicants conducting trials with their technology providers, further R&D is necessary to develop this alternative in a way to safely gain surfaces of high quality. In addition, industrial implementation and OEM qualification procedures for certain applications and sectors would also be required.

7.1.6. Conclusions

At the current stage, permanganate-based alternatives for etching of plastic substrates is not technically feasible and has significant economic disadvantages. From a technical point of view, the major drawback is the clearly insufficient adhesive properties, leading to delamination and inacceptable aesthetic appearance of the final coating. Furthermore, the permanganate process has very high capital and ongoing operational costs. Further R&D efforts are necessary to overcome the existing technical hurdles.

7.2. Sulphuric acid-based etching solutions

7.2.1. Substance identity, properties and process description

Like permanganate-based etching discussed above, this alternative is also a wet-in-wet process, meaning that the overall technique is comparable to its chromium trioxide-based counterpart. Different mineral acids are currently under evaluation as alternatives to chromium trioxide etching pre-treatment. Research is currently focused on using sulphuric acid composed with other acids, such as phosphoric acid and nitric acid, or with additives, such as peroxymonosulphate salts or peroxidisulphate salts.

A non-exhaustive overview on general information on substances used within this alternative and their hazards to health, safety and the environment is provided in Appendix 1.

7.2.2. Technical feasibility

For the purposes of this AoA, sulphuric acid-based solutions are assessed as a potential alternative for chromium trioxide based etching pre-treatments on plastic substrates.

One of the principal issues with this alternative is that it is not capable of successfully etching 2K or 3K components (selective etching). When using 2K or 3K parts, where only one part should be plated, Cr(VI) etching can selectively etch the ABS component only, as required. However, sulphuric acid-based alternatives is not selective for ABS (1,3-butadiene removal) only and will also affect the other components.

Another major concern is associated with swelling of the plastic substrate. CTAC consultation confirmed that it is not technically possible to prevent swelling of the plastic surface when using any kind of acidic replacement etching solutions. Other issues related to inadequate preparation of the substrate for an adequate adhesion of the subsequent coating, bath maintenance (water treatment, increased bath temperature, sludge deposition) and poor stability of the peroxydisulphate solution, all of which remain unsolved.

The CTAC consultation acknowledged that a solution of sulphuric acid with sodium peroxydisulphate was tested for the etching of plastic substrates. Only very limited information on the performance of this alternative is currently available as it is at very early R&D stage. However, first results revealed major problems with swelling, selective etching and also with its adhesive properties. As a result, alternative acidic-based etching solutions are considered technically not suitable as an alternative to chromium trioxide-based etching of plastic substrates and further R&D is not currently proposed.

Adequate surface preparation	Adhesion to substrate	Compatibility with substrates
🟥	🟥	🟥

7.2.3. Economic feasibility

The economic feasibility of etching with sulphuric acid has not been assessed, as the alternative is not technically feasible and already failed the requirements at early investigation stage. However, economic feasibility considerations associated with this alternative are similar to those associated with permanganate-based solutions (see above) meaning that they are likely to be prohibitively expensive, both in terms of capital costs and ongoing operational costs.

7.2.4. Risk reduction

As the alternative is not technically feasible, only a limited review into risk reduction has been undertaken. Appendix 1 contains details of the hazards (CLP classification and labelling information) associated with substances used for this alternative process. While this indicates that, in general, a transition from chromium trioxide to this alternative would represent a move to a less hazardous technology, therefore achieving risk reduction, it is noted that sodium peroxydisulfate is classified as a respiratory sensitiser and so has the potential to meet the criteria of ‘equivalent level of concern’ under Article 57(f) of REACH.

7.2.5. Availability

Sulphuric acid is widely available although it is of particular importance for the final performance and quality of the coating of finished products that the etching pre-treatment enables the successful subsequent electroplating process. This means that any alternative etching pre-treatment has to be compatible with an alternative main process. As alternatives for functional chrome plating with decorative character are also still under development, it is currently not possible to independently develop an alternative etching pre-treatment. Additionally, etching is generally performed in one process together with the main treatment in a way that pre-treatment and main process are not separated from each other.

7.2.6. Conclusions

With regard to etching of plastic substrates, sulphuric acid-based solutions are not technically suitable as an alternative to chromium trioxide based etching. The major limitation is the swelling of the plastic substrate and the non-selectiveness for multi-component parts, when using any kind of mineral acid. It is unlikely that these solutions will become technically feasible at any point in the future.

8. Assessment of alternatives: electroplating (use 2)

This section examines alternatives to electroplating using chromium trioxide (use 2) and so is relevant to all applicants as it encompasses all substrates. In this section, the identified potential alternatives are assessed in terms of their:

- technical feasibility;
- economic feasibility;
- potential for risk reduction; and
- availability.

To assist with the technical feasibility aspects of the assessment, colour-coded summary tables are included, using the criteria set out in Table 17 below. These tables show the findings of the assessment against the following key functionalities: corrosion resistance, chemical resistance, wear/abrasion resistance, adhesion and aesthetics.

Colour	Explanation
🟥	Not sufficient – the parameters / assessment criteria do not fulfil the requirements of the respective sector.
🟨	The parameters/assessment criteria fulfilment are not yet clear / the process is still not defined / further experimental investigations need to be performed.
🟩	Sufficient - the parameters/assessment criteria do fulfil the requirements of the respective sector.
▨	No data available / not assessed.

***Table 17**: Colour-coding approach to summarise the feasibility assessment of alternatives*

The assessment also includes a non-exhaustive overview of general information on substances used within the alternative processes, as well as the hazards to health, safety and the environment. This information is presented in Appendix 2.

8.1. Trivalent chromium electroplating

Based on the available research and data available for alternatives to Cr(VI)-based plating, the applicants believe that trivalent chromium-based plating is currently the most promising alternative solution for most applications and products, despite the many challenges to scale up the manufacturing of Cr(III)-based processes. Transitioning from hexavalent Cr(VI)-based electroplating to trivalent Cr(III)-based electroplating involves similar equipment and technology. However, this transition is not as simple as changing the chemistry in the electroplating tanks. The transition to this process would require considerable additional R&D efforts to better understand process parameters and interactions and determine ways in which they might be modified to create an alternative that would be able to meet customer requirements. This would entail several years of R&D effort and labour as well as a high number of process trials and considerable expense in parts and materials. If a suitable process could be developed, then additional project phases would be needed to industrialise the process, upgrade facilities, plant and equipment, and phase-out the use of chromium trioxide, bearing in mind the need to ensure sufficient quantities of Cr(VI)-based spares to satisfy demand and existing contractual obligations. Any replacement process would also require customer approval which, for the automotive sector in particular, would involve a full production part approval process (PPAP) by the OEMs which would take many years. These, and other factors, are explored further in the Substitution Plan.

This part of the report examines potential alternatives based on both chromium sulphate and chromium chloride processes together, because these alternatives are sufficiently related.

8.1.1. Substance identity, properties and process description

Electroplating with trivalent chromium electrolytes is similar to the hexavalent chromium process in that it will result in the deposition of a metallic chrome coating on the surface of the substrate. The substrate will be immersed in a Cr(III) plating solution (the electrolyte) containing dissolved Cr(III) salts, typically with additives such as ammonium salts as complexing agents and boric acid or borate salts as buffering agents. During electroplating, the dissolved Cr(III) cations are reduced to metallic chrome and the coating builds up on the substrate by electrodeposition.

The composition of the Cr(III) electrolyte can differ and the choice will depend on the surface treatment and application which is to be substituted. This section of the report considers both chloride-based and sulphate-based alternatives. It also considers post-plate passivation, an additional step required in Cr(III) plating processes.

Although based on the same principle as Cr(VI) electroplating, Cr(III)-based processes involve a number of significant differences, e.g. in the chemical composition of the bath, the operating parameters and the need for additional ancillary equipment (e.g. ion exchangers). Table 18 below explores some of the main differences between trivalent and hexavalent chromium plating.

Difference	Cr(VI)	Cr(III), Chloride	Cr(III), Sulphate	Comment
Chromium content	Higher concentration	Lower concentration	Lower concentration	Trichrome processes contain much lower concentrations of chromium in plating bath. Also, the chromium is present in its much safer +3 valence rather than the hazardous +6 valence.
Electrolyte composition	-	-	-	Hexavalent chromium electrolytes contain chromium trioxide in a sulphuric acid solution with additional components like surfactants and catalysts. The chromate anion is reduced in a complex multistep process at the cathode and deposited as chrome metal. Trivalent chromium electrolytes usually contain chromium salts (sulphate, chloride) as well as complexing agents, buffers, catalysts and surfactants to achieve the required performance for plating. The deposition of metallic chromium takes place from cationic chrome sulphate (or chloride) complexes.
Bath lines	Shorter	Longer	Longer	As trivalent chromium plating baths are very sensitive to impurities, additional technologies (an ion exchanger using a special resin) and a number of additional baths are needed to enable adequate rinsing processes to reduce impurities as much as possible. This is necessary for both the pre-treatment bath technology as well as the trivalent chromium plating step and post-plating passivation.

Difference	Cr(VI)	Cr(III), Chloride	Cr(III), Sulphate	Comment
Ion exchangers	Not required	Required	Required	In order to avoid co-deposition, foreign metal cations have to be removed by use of ion exchangers.
Surface passivation	Not required	Required	Required	Passivation is a process that provides additional corrosion protection to a substrate. It results in an oxide layer that separates the chromium metal from the atmosphere, so that further oxidation by diffusion is impeded by this passivating layer. With Cr(VI) electrolytes, this passivation layer is generated by the oxidative chromic acid. However, Cr(III) electrolytes cannot produce this passivating layer. This means the passivation has to be generated in an additional process step using, for example, phosphates or polyphosphates or other kinds of organic substances. The formation of chromium phosphates on the surface can cause changes in colour.
Anodes	Lead	Graphite	Inert Metal Oxide	Trivalent chrome processes do not require lead anodes.
Temperature	35-43^{0}C	30-40^{0}C	50-60^{0}C	Trichrome processes can be similar or higher operation temperature.
pH Value	<1	2.5-3.0	3.3-3.8	The pH (acidity level) is considerably higher in Cr(III) processes.
PFAS	Used	Not used	Not used	Mist suppressants are added to minimize misting. Trichrome processes have an advantage in that they do not use perfluorinated alkylated substances (PFAS) for surface tension adjustment. PFAS are persistent in the environment and may be subject to future restriction under REACH.
Process time	Faster	Slower	Slower	Chromium deposition is slower in trivalent chromium-based processes.
Bath maintenance	Less effort	More effort	More effort	Analytical efforts will be much higher for adequate control of bath composition in Cr(III)-based processes given all its additives. Analysis of layer thickness and colour has to be performed on a daily basis. Maintenance of a trivalent chromium bath will likely take about 14 hours per week, compared to 2 hours per week for the chromium trioxide bath.

***Table 18**: Differences between trivalent and hexavalent chromium plating*

A non-exhaustive overview of general information on substances used within Cr(III)-based electroplating alternatives as well as their hazards to human health and the environment is presented in the tables in Appendix 2.

8.1.2. Technical feasibility

General assessment

The transition from chromium trioxide based-electroplating to Cr(III)-based electroplating is technically the closest alternative, given that it uses similar equipment with wet-in-wet bath technology. However, the transition cannot simply be performed by changing the plating electrolyte. As Cr(III) plating is very sensitive to impurities, an ion exchanger and a number of additional basins/baths are needed to enable adequate rinsing processes to reduce impurities as much as possible. This is necessary for both the pre-treatment bath technology as well as the Cr(III) plating step.

Process conditions: Trivalent chromium baths are more sensitive to metallic impurities and to the acidity of the bath than conventional chromium trioxide plating baths. Even small deviations in the process conditions can strongly influence the deposition success, the layer quality and the final appearance. Consequently, establishing a reliable process for metallic chrome layers from a Cr(III) electrolyte of reproducible quality (colour, corrosion resistance, thickness, hardness, etc.) is challenging and the Cr(III) based plating process requires careful handling.

Substrate compatibility: Trivalent chromium plating is generally applicable to all commonly used substrates, such as brass and plastic substrates. For all substrates, underplates are required as barrier between the electrolytically plated coating and the substrate to create a corrosion resistant and aesthetic surface.

Aesthetics: In general, the metallic chrome plated surface from trivalent chromium electroplating is of a similar appearance to surfaces created by chromium trioxide-based electroplating. However, the principal drawback to date is that the final colour is not silvery-bluish but slightly yellowish/brownish. The exact colour of the coating is a result of the electrolyte used: sulphate-based coatings for example are slightly lighter, while chloride-based coatings are slightly darker. The yellowish/brownish shade of the coating is caused by iron ions (for example coming from the rack, the substrate, or the production surroundings) that enter the Cr(III) electroplating bath as impurities. The iron corrodes to rust once in contact with atmospheric oxygen, resulting in a yellowish/brownish colour of the coating. Even the smallest quantities of impurity can lead to this effect. The CTAC consultation found that it was very challenging to adequately maintain process conditions that prevent the yellowish shade from resulting. In addition, because the plating solutions are generally used long-term (for example a chromium trioxide electrolyte can be used for more than 5 years, without being renewed completely), then the longer the same plating solution is used, the more impurities will be accumulated that may affect the final colour of the product. This makes ensuring a uniform appearance of all products plated during the lifetime use of a plating solution difficult.

Besides the yellowish colour, trivalent chrome plated products from different platers will not be the exact same colour. Different trivalent chromium coated parts assembled together (for example in the interior of a car, or for bathroom installations, or for heating applications such as thermostatic mixing valves, will show a slightly different colour and will not match exactly. This is not likely to be acceptable to the applicants' customers. The yellowish colour also occurs after a period of time during normal usage, even if the products left the facility coated with a seemingly adequate colour. This means that, in the event of refurbishment or repair, new parts would not match the established inventory.

Sector specific assessment: sanitary & heating applications

Large R&D efforts have been made and are still on-going to establish Cr(III) electroplating as an alternative to chromium trioxide electroplating within the sanitary sector in particular. Several feasibility studies have been performed on the functionality of metallic chrome coatings generated from different commercially available Cr(III) electrolytes on different substrates (plastic, brass). The results were provided for review during the CTAC consultation phase. Besides "pure" metallic chrome coating from a Cr(III) electrolyte, passivated metallic chrome coating from a Cr(III) electrolyte have been tested. These are "pure" metallic chrome coatings with a post-treatment application (generally based on a Cr(III) solution) that aims to enhance the properties of the metallic chrome coating.

Corrosion resistance: Tests conducted on Cr(III)-based metallic chrome coatings have yielded highly variable results. These tests involved salt spray tests (NSST, AAST and CASS according to BS EN ISO 9227) and Kesternich tests according to BS EN ISO 6988. The corrosion resistance of some tested coatings clearly failed the sanitary requirements (for instance already showed corrosion after 200 h salt spray exposure compared to 300 h required) or marginally met these requirements (showing slight corrosion within the limits). It should be noted that the performance of trivalent chrome plated coatings is highly dependent on the type of electrolyte used. This is significantly different to products coated with chromium trioxide, where all coatings practically have the same quality. Therefore, considering all tested samples from different electrolytes, the corrosion resistance does not sufficiently meet the requirements of the sanitary sector at the current stage of development.

Chemical resistance: The chemical resistance of metallic chrome coatings from a Cr(III) electrolyte tested by continuous immersion in household cleaning agents (such as vinegar essence or a commercially available product), also differs for the different electrolytes. Similar to corrosion resistance, the tested coatings clearly failed the sanitary requirements for chemical resistance (by showing severe surface corrosion) or marginally met these requirements (only showing slight corrosion, single attack points). The chemical resistance was especially low when exposed to acidic cleaning agents. For all tested parts, the chemical resistance was lower compared to the metallic chrome coatings from chromium trioxide-based electroplating and did not sufficiently fulfil the overall sanitary requirements at the current stage of development.

Wear resistance / abrasion resistance: The abrasion resistance of Cr(III) coated parts has been tested using Taber abrasion tests. Cr(III)-based coatings generally passed the Taber abrasion test (required 60000 cycles) performed with a common microfiber. The test performed with a dry felt cloth resulted in small scratches (thin hairlines), but without larger scratches or extensive abrasion. Some other test results revealed that the Cr(III) coated surface was scratched after <50 cycles (while requirements are around 300 cycles without scratches/damages). While abrasion resistance for Cr(III)-based coatings looks more promising, its success depends on the electrolyte solution the coating was generated in. In overall terms, this means that the coating offers reduced abrasion resistance when compared to chrome coatings produced from a chromium trioxide electrolyte, which does not meet the overall sanitary requirements on abrasion resistance.

Adhesion: In cross-cut tests on Cr(III) based metal coatings on different kind of substrates (metals, alloys and plastic), the adhesive properties in general sufficiently fulfilled sanitary requirements. Some flaking of the coating was determined, but this damage is thought not to be the result of insufficient abrasion resistance but of residual stress of the metallic chrome coating from a Cr(III) electrolyte potentially caused during the production process.

Aesthetics: The yellowish/brownish colour is caused independently from the electrolyte used and was observed on all tested samples. This does not meet sanitary or heating sector requirements. The final consumer may combine parts from different plating companies or brands and would not expect or accept a colour mismatch. The mismatch of colours is also an issue in the replacement of sanitary or heating products, e.g. like-for-like warranty replacements or on bathroom or kitchen upgrades / refurbishment. Any move to Cr(III)-based coatings with such issues would result in customers switching to Cr(VI)-based product that remains readily available through imports from outside GB (including from the EU).

In addition, for matt black chrome coatings, the applicants (following discussion with specialist technology providers) are not aware of any Cr(III)-based alternative. Previous trials in 2015, 2019 & 2021 attempting to produce a matt black chrome finish through Cr(III) processes were all unsuccessful – it was found that there was a significant difference in the visual appearance and that the colour was too light and glossy, far from a suitable match.

Conclusions, sanitary & heating sector: The overall performance of metallic chrome coatings is highly dependent on the Cr(III) electrolyte solution which is used for applying the coating. As shown by a number of tests and feasibility studies performed within the sanitary sector, metallic chrome coatings from Cr(III) electrolytes are currently not a technically feasible alternative to metallic chrome coatings from chromium trioxide for a number of reasons. The aesthetic appearance of Cr(III) coatings is not sufficient to fulfil the high and long-lasting aesthetic appearance requirements due to a yellowish/brownish colour of the coating, which is caused by the coating procedure. It is also not possible to produce a matt black chrome finish using Cr(III)-based technologies. Given the very sensitive plating baths which require extensive maintenance, the long-term use of the bath electrolyte critically influences the quality of the coated parts. Corrosion resistance and chemical resistance of the tested Cr(III)-based coatings (whether passivated or not) depends on the electrolyte used but is generally lower compared to the coatings applied by chromium trioxide electroplating and does not fulfil the overall sanitary requirements. The overall requirements on abrasion resistance are not met, although adhesive properties are acceptable.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Adhesion	Aesthetics
🟩	🟥	🟥	🟨	🟩	🟥

However, further R&D is justified in this area. For example, at the time of this AfA, the applicants are aware of new technologies only just coming onto the market which are specifically targeted at resolving aesthetics (colour) issues concerning bright silver chrome finishes that may provide the required 'blue' hue (though this would not be applicable to matt black chrome finishes). These will need further evaluation and trialling to understand their suitability and performance against the required key functionalities.

<u>Sector specific assessment: automotive</u>

Current testing procedures in the automotive sector include laboratory tests, summer and winter tests, and continuous-operation tests. Thorough evaluation of possible alternatives is crucial to avoid failures in the field / daily application. As well as consequences for safety, failure could result in expensive and brand-damaging product recalls. Any potential alternative must sufficiently fulfil every key functionality to achieve a high-quality surface under the conditions of use, including matching the required colour demanded by the OEM. This differs from OEM to OEM but all are looking for the closest match to chromium trioxide-based coatings. Some OEMs are starting to accept Cr(III)-based electroplating technology (e.g. the PSA group) but the majority have still to approve the process and colour and make a decision which technology they should use. This means platers must remain committed to Cr(VI)-based technologies for the time being. In case of non-compliance with the OEMs required characteristics, customers would likely transfer work to non-UK producers and source from approved EU suppliers (covered by authorisations or pending applications for authorisation), the Far East or the rest of the world.

The applicants started trials on chromium trioxide substitutes in 2006 with extensive trials using three different suppliers, Enthone, Atotech and MacDermid. All processes produced chrome-plated products but none were close enough to the Cr(VI)-based finish required by their customers. The applicants have since continued to test various process with their technology suppliers and one applicant, from 2016, implemented two trial baths on a small development line using sulphate- and chloride-based trivalent chromium processes. Parts were submitted to customers for testing, but the process did not yield robust enough products to pass automotive testing on exterior car parts. Since then, the applicants continue to trial other chemistry types, e.g. including MacDermid Enthone's TriMac III, Trylite Flash CL and Trilyte Flash SF, and Atotech's TriChrome Plus, which are all different types of trivalent chrome-based coating processes. While these trials have not yet proven successful, new technologies continue to emerge, as noted above for sanitary ware, meaning that further R&D is certainly justified.

In addition to the applicants' own activities, testing for the purposes of the CTAC AfA was also undertaken which focused on plastics as the most commonly-used substrate within the automotive sector. A first comparative study was undertaken in 2012 with extensive laboratory and field tests of different metallic chrome coatings from Cr(III) electrolytes (with and without Cr(VI)-based post-treatment passivation). This involved testing around 530 coated plastic patterns (around 230 in field tests and about 300 in laboratory tests). A second comparative study was performed between Autumn 2013 and Spring 2014. In this second study, 12 different Cr(III)-based chrome coatings, of which eight were sulphate-based and four chloride-based, were tested from seven different specialist suppliers of the electrolytes. A total of 3000 plastic patterns with different types of metallic chrome coatings from Cr(III) and Cr(VI) electrolytes (chromium trioxide) were compared. Of these, 2,400 patterns were examined in laboratory settings and the remaining 600 were mounted on a total of 72 cars and 10 trucks. Both comparative studies found that none of the tested coatings from Cr(III) electrolytes were able to meet the requirements of the automotive sector.

Corrosion resistance: The corrosion resistance of metallic chrome coatings from Cr(III) electrolytes is dependent on numerous parameters, such as the type of electrolyte used (sulphate-based or chloride-based), the underlying layer system (copper, nickel underplate, etc.) and whether the coating is provided with a subsequent passivation. In general, the corrosion resistance to sodium salts (tested in NSST and CASS) of sulphate-based Cr(III) coatings is better compared to chloride-based Cr(III) coatings, while the corrosion resistance to calcium salts (tested for example in Russian Mud tests) is better for chloride-based Cr(III) coatings than for sulphate-based Cr(III) coatings.

According to the available information, the corrosion resistance of Cr(III)-based coatings is generally lower compared to Cr(VI)-based coatings and generally does not fulfil the automotive requirements (for example exterior 480 h NSST or up to 96 h CASS according to BS EN ISO 9227). Post-plating passivation may improve results although the applicants have not yet found any alternative systems to perform close to the conventional chromium trioxide-based metallic chrome coatings, which do not require passivation.

Chemical resistance: The chemical resistance of metallic chrome coatings from Cr(III) electrolytes is generally lower and laboratory tests indicated lower resistance against wheel rim cleaners, pancreatin or tree resins. However, as with corrosion resistance, performance is dependent on the respective trivalent chromium electrolyte and its resulting type of metallic chrome coating. However, at this stage of development and based on their own trials and the experience of others, the applicants do not consider the requirements of the automotive sector fulfilled in terms of chemical resistance.

Wear resistance / abrasion resistance: The abrasion resistance of metallic chrome coatings produced from Cr(III) electrolytes has been found to be generally lower than metallic chrome coatings produced by chromium trioxide electroplating. Again, the performance is dependent on the respective electrolyte and resulting type of metallic chrome coating. However, in general, the abrasion resistance does currently not meet the requirements for automotive applications.

Aesthetics: As noted above, the exact colour of the coating from Cr(III) electrolytes differs and is a result of the electrolytic plating solution. Chromium (III) chloride plating solutions result in a slightly darker chrome coating, while the coatings from a chromium (III) sulphate based plating solutions are slightly lighter. Impurities in the sensitive bath chemistry can also cause a yellowish/brownish colour of the trivalent chromium-based coatings. The long-term colour stability of coatings from Cr(III) electrolytes has also been examined in field tests on numerous different samples, with test results showing that coatings from Cr(III) electrolytes become gradually darker over time, while the coatings from a chromium trioxide electroplating do not change colour at all. As a consequence, the overall aesthetic appearance and long-time colour stability clearly do not fulfil the requirements of the automotive sector at the current stage of development. Additionally, the colour of the plated product is highly dependent on the kind of electrolyte used. Due to the large variety of different parts assembled together per automobile, the different shades of colour will result in a colour mismatch.

However, as with sanitary ware, the applicants are aware of new technologies only just coming onto the market which are specifically targeted at resolving aesthetics (colour) issues concerning bright silver chrome finishes that may provide the required ‘blue’ hue. These will need further evaluation and trialling to understand their suitability and also longer-term performance.

Conclusions, automotive sector: Trivalent chromium-based metallic chrome coatings do not fulfil all requirements of the applicants and their customers at the current time. Although some Cr(III) coated products have more recently been used by a few automobile manufacturers, these products still require Cr(VI) during production (e.g. for etching) and do not fulfil all manufacturers requirements. In addition, the overall aesthetic appearance and long-term colour stability does currently not fulfil the requirements of the automotive sector. The colour of the coating will vary between suppliers and field tests revealed a darkening effect of the coating over time, during normal use, which causes major colour-match issues.

In general, the performance of the coating is highly dependent on the electrolyte composition used and the resulting type of metallic chrome coating. This means that key functionalities such as corrosion resistance, chemical resistance and abrasion resistance do not fulfil all the requirements of the whole automotive sector at the current stage. However, as performance depends on the particular type of electrolyte, it is hoped that new technologies will resolve such issues in the future and so further R&D is justified, although the applicants are reliant on specialist technology providers in this respect.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Adhesion	Aesthetics
🟩	🟥	🟥	🟥	🟩	🟥

8.1.3. Economic feasibility

A switch to Cr(III)-based electroplating would have impacts in terms of capital (development and upgrade) costs and ongoing manufacturing (operating) costs. These costs are considered further in this section. In addition, due to the significant reduction in quality associated with Cr(III)-based products at the current stage of development, the applicants would expect the major costs of switching to this alternative to be associated with lower sales revenues and market shares.

Despite the technical feasibility issues, there are some potential benefits associated with Cr(III)-based processes compared to Cr(VI)-based processes[21]. The throwing power of Cr(III) plating is generally better, meaning that more parts can be placed on jigs simultaneously increasing throughput by up to 15%. With regard to worker and environmental protection, Cr(III) processes result in fewer air emissions, due to higher cathodic efficiency, which also means that a PFAS mist suppressant is unlikely to be required. In addition, as a typical Cr(III) plating bath has a lower chromium concentration, there is likely to be less total chromium in the wastewater stream and, since the wastewater will contain Cr(III) cations, no reduction step from Cr(VI) to Cr(III) is necessary. This will result in reduced costs for handling and disposal of hazardous waste.

Conversely, as Cr(III) processes involve organic complexing agents and stabilisers, these substances are likely to pose additional complications for wastewater treatment and could prompt additional wastewater treatment measures, such as oxidative destruction of the organic components. In addition, despite the increased throwing power, the benefits of higher throughput are cancelled out entirely by the longer plating duration required for Cr(III) processes. Air emission reduction advantages are desirable but will have little added value in practice because the applicants already have worker protection and pollution control measures in place.

Capital costs are significant and would be associated not only with wastewater treatment upgrades but also plating lines themselves. These would either require substantial upgrading due to the need for additional baths for Cr(III) plating, passivation and the additional rinsing required, or alternatively the installation of

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[21] NEWMOA, 2003, p7-9.

new lines entirely. Some applicants do not have enough physical space at their sites to incorporate the required upgrades or new lines and therefore would need to build extensions to their existing facilities. Table 19 below provides an overview of the upgrades that would be required to the applicants' facilities, plant and equipment to accommodate a change to Cr(III)-based electroplating.

Equipment changes	Comments
Cr(III) plating tank	Preventing any influx of Cr(VI) material into the Cr(III) chemistry is necessary for proper operation. This necessitates the use of a completely separate processing tank for the Cr(III) plating process. Also, whereas Cr(VI) plating is rather simplistic in operation, Cr(III) process is considerably more complex and requires considerably more equipment and control in operation. This includes: - Continuous solution agitation and filtration. Filtration requires continuous carbon treatment in addition to particulate removal. This will require technicians to frequently change out both particle filter material and removal and replacement of the activated carbon. This material will need to be disposed of as hazardous waste. - Continuous metallic contaminant removal through an ion exchange system. This system requires technicians to regenerate the IX resins regularly, to remove the metallic contaminants pulled from the process chemistry. The regeneration chemistry will need to be processed through the waste treatment system. - Specialty inert anodes - Rectification.
Dedicated rinse tanks (Cr(III))	Cr(III) will require additional, dedicated rinse tanks.
Post plate passivation	Cr(III) will require the addition of a post-plate electrolytic seal tank. This tank will also require solution agitation, filtration and rectification.
Dedicated rinse tanks (passivation)	Passivation will require additional, dedicated rinse tanks.
Reduction tank	A reduction process tank will be needed to neutralize the residue from the electrolytic passivation process.
Dedicated rinse tanks	Reduction will require additional, dedicated rinse tanks.
Wastewater treatment	Cr(III) may require additional waste water treatment processes to remove organic additives
New dedicated Cr(III) plating line	For most of the applicants, their current Cr(VI) plating lines do not contain enough empty tank space to allow introduction of the above process tanks. This precludes modification of the current Cr(VI) plating lines to allow conversion to Cr(III) plating. Instead, a completely new Cr(III) dedicated plating line would need to be constructed and installed.
Building extension	For some applicants, extension to their premises would be required in order to accommodate a new dedicated Cr(III) plating line, as there is insufficient space in their existing premises.

***Table 19**: Equipment upgrades required for Cr(III)-based electroplating*

Research conducted by the CTACSub estimated that the operating costs associated with a Cr(III) process would be up to 30% higher than chromium trioxide electroplating. The cost of the chemicals used for Cr(III)-based processes are higher than for Cr(VI)-based processes. Anodes required for sulphate-based Cr(III) electroplating (inert metal oxide) have a much higher cost than anodes used for Cr(VI)-based electroplating and anodes for chloride-based Cr(III) electroplating (graphite) have reduced usage life and are more fragile, likely requiring more frequent replacement. Substantially more analytical effort must go into maintaining the quality of the electrolyte and minimise quality loss caused by impurities in the bath. Research conducted by the CTACSub suggested that a chromium trioxide electrolyte requires 2 hours analytical control per *week*, while Cr(III) plating baths requires 2 hours analytical control per *day*. There may also be higher costs associated with an increased 'scrap rate' (rejection of parts that fail to meet stringent quality requirements).

Table 20 below provides an estimate of the total investment and recurrent costs associated with transferring to Cr(III)-based electroplating.

Area	Cost item	Estimates
Cr(III) plating line upgrade costs	Line upgrade costs (if no new line required)	Estimated £656,000 to £1,000,000 This includes costs such as additional baths, replacement rectifiers / flight bars and electrical shoes, reprogramming of automated systems, staff training, modifications to LEV & utilities etc
	New plating line cost (where required)	Estimated £3,767,000
	Building extension costs (where required)	Estimated £1,000,000
	Chemistry cost	Estimated £7,000 to £10,000
	Anode cost	Estimated £55,000
	Waste treatment upgrade cost	Estimated £50,000 to £60,000
Ongoing costs	Piece cost increase	Increased operating costs, reported up to 30% with Cr(III), is likely to lead to increased component costs
	Ongoing production labour cost	Broadly comparable though likely to be slightly higher due to skillset required and longer cycle times.
	Waste treatment	No Cr(VI) reduction step needed, reduced sludge generation, however, anticipated issues with organic components
	Analytical	Higher costs due to analysis frequency, likely to increase from 2 hrs per week to 2 hrs per day to maintain proper chemistry control
	Bath maintenance	Filter changes and IX resin regen labour
	Ion exchange resins	Replacement mixed bed resin costs can be high, with periodic resin changes expected to cost in the £1,000s
	Anode replacement	Cr(III) replacement est. 2-3 yrs vs Cr(VI) of around 20 yrs
	Increased chemical makeup / replenishment cost	Cr(III) is around twice that of Cr(VI)
	Part rack density	Approx. 15% increase in part density may be possible
	Plating rate	Cr(III) is around a third of Cr(VI) (the process takes approx. 3 times longer)
	Scrap cost	Scrap rates have been reported as both higher and lower for Cr(III) than Cr(VI). Actual scrap rate analysis will need to be performed during future internal Cr(III) trials for determination.

***Table 20**: Estimates of the investment and recurrent costs associated with transferring to Cr(III)-based electroplating*

The applicants manufacture a range of products for various sectors and many of these products, in particular sanitary ware, are offered with different finishes, including chrome. Demand for other finishes does exist but chrome is by far the dominant colour for all of the applicants' products. When it comes to chrome finishes, the applicants do not currently produce or supply trivalent chromium-based products due to the demonstrable quality issues outlined above. Hexavalent chromium-based products offer better performance and a higher quality aesthetic and which also ensures availability of spares and colour-matching of replacements. As a result, if the applicants were forced to switch to Cr(III)-based products, they would not expect to enjoy product sales and market shares comparable to their current position.

As has been demonstrated earlier in this report, the most likely outcome would be that customers would switch either to alternative suppliers in the EU who hold an authorisation for the use of chromium trioxide (or whose application for authorisation has been made but a decision is still pending) or to non-EU suppliers. This would result in an almost total loss of market share to competing Cr(VI)-based imports.

8.1.4. Risk reduction

The alternative Cr(III)-based processes under consideration involve chromium hydroxide sulphate (chromium (III) sulphate) and chromium trichloride (chromium (III) chloride). With reference to Appendix 2, both these substances have workplace exposure limits (WELs) under the Control of Substances Hazardous to Health Regulations 2002 (COSHH) and both are classified as hazardous under CLP although for far fewer hazards. In particular, neither substance is classified for carcinogenicity and mutagenicity. In this way, the move from chromium trioxide to chromium (III) sulphate and chromium (III) chloride can be seen as a move to less hazardous substances.

In addition, a move to trivalent chromium-based processes would likely avoid the use of a PFAS for surface tension adjustment, a further benefit in terms of risk reduction. PFAS are currently being considered for restriction under EU REACH[22] and a regulatory management options analysis (RMOA) is being conducted under UK REACH[23].

Conversely, chromium (III) chloride is classified for skin sensitisation category 1 by EU REACH registrants of the substance. A substance evaluation recently published on the ECHA website for chromium (III) oxide[24] noted that a group assessment is currently under development by the evaluating Member State Competent Authorities under EU REACH for chromium (III) compounds more generally, due to concerns for skin sensitisation. The substance evaluation also identified a data gap for reproductive toxicity and suggested this can be addressed in a grouping approach, recommending that ECHA request further testing (an extended one-generation reproductive toxicity study and a developmental toxicity study). At the time of writing, it is not clear how ECHA might respond to this substance evaluation. It is possible that chromium (III) sulphate and chromium (III) chloride have the potential to meet the criteria of 'equivalent level of concern' under Article 57(f) of REACH due to skin sensitisation although currently no regulatory action is proposed in relation to them.

Recent research has indicated that there is the potential for Cr(VI) generation during the Cr(III) plating process[25]. This is because trivalent chromium may be oxidized by hydrogen peroxide (generated by oxygen

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[22] In particular, the Netherlands and Germany, with support from Norway, Denmark and Sweden are preparing a broad restriction proposal likely to cover many thousands of PFAS and a wide range of uses. They are expected to submit the proposal to ECHA in January 2023.

[23] The UK, Welsh and Scottish Governments have asked HSE and the Environment Agency to prepare a RMOA for PFAS. This RMOA will investigate the risks posed by PFAS and recommend the best approach to protect human health and the environment from any identified risks. This could result in proposals for restriction or other forms of regulatory control in the future.

[24] See https://echa.europa.eu/documents/10162/08bcc9ff-13bc-d854-31ac-ad132898500e

[25] Gharbi et al, 2018

reduction or deliberately added to the coating environment), forming hexavalent chromium. The fluorides present in the bath (usually added to accelerate film growth and native oxide dissolution) are thought to be responsible for promoting hydrogen peroxide formation, subsequently oxidizing Cr(III) to Cr(VI).

The manufacturing process for chromium (III) salts most commonly originates from chromite. To obtain the chromium from this mineral, the most widely used method involves an alkaline process which transforms the Cr(III) into water-soluble Cr(VI) in alkaline solution which is then separated[26]. Cr(III) salts can then be prepared by the reduction of sodium dichromate with sulphur dioxide. For chromium (III) sulphate, this reaction can be represented as follows:

$$Na_2Cr_2O_7 + 3\ SO_2 + H_2O \rightarrow Cr_2(SO_4)_3 + 2\ NaOH$$

Here, sodium dichromate would be used as an intermediate and so would not be subject to authorisation under REACH, with the increased focus on risk management measures this gives rise to (although it is possible that it might be handled under strictly controlled conditions if registered as an intermediate). This means that an increased demand for Cr(III) alternatives might result in risk reduction for the users (such as the applicants) but would result in increased health risks elsewhere in the supply chain, although it is acknowledged that this might occur outside the UK. Alternative processes for manufacturing Cr(III) salts are available but not feasible for the applicants due to the presence of Fe ions in the electrolyte and the unacceptable effects this would have on colour variations in the finished product.

Use of Cr(III)-based processes would also involve use of boric acid at significant concentrations as part of the bath chemistry. Boric acid is classified under CLP as toxic to reproduction category 1B and is itself a substance of very high concern (SVHC) under both UK REACH and EU REACH. It was recommended for inclusion in Annex XIV of EU REACH in the sixth recommendation round. It does not currently appear on the list of substances recommended for inclusion in Annex XIV of UK REACH although in light of its status as a SVHC and the previous recommendation for authorisation made at a time where the UK was part of the EU, this substance cannot be ruled out for future regulatory action under UK REACH.

Whether the use of boric acid for Cr(III)-based electroplating ‘adds’ to the risks is a matter of some debate, in that boric acid is already used for Cr(VI)-based electroplating. This is not as part of achieving the chromium finish, but as part of earlier processing steps during nickel electroplating. However, it is true to say that Cr(III)-based electroplating would increase the quantity of boric acid to be used and, on this basis, would not contribute to overall risk reduction.

The passivation step required with Cr(III)-based electroplating requires the use of potassium permanganate. This substance does not currently meet the criteria under Article 57 of REACH to be designated a SVHC but nevertheless is classified for reproductive toxicity (category 2) and environmental toxicity (classified for both acute aquatic toxicity and chronic aquatic toxicity, category 1). A recent assessment of regulatory needs (ARN) by ECHA concluded that there is a need for further EU regulatory risk management[27], suggesting a combination of restriction and authorisation following a potential redesignation of the substance’s classification as toxic to reproduction 1B.

Finally, the various additives and complexing agents present in the Cr(III) electrolyte may affect how the wastewater treatment functions and reduce the efficiency of the water treatment. This aspect is not fully understood yet but would require additional investigation prior to the use of these electrolytes.

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[26] Zang et al, 2016.

[27] ECHA Assessment of regulatory needs (7 December 2021), available at https://echa.europa.eu/documents/10162/630768d3-fdcd-fe11-7e76-9c2ce137318b

In summary, while it would appear at present that substitution of Cr(VI)-based electroplating processes with Cr(III)-based electroplating processes would, on balance, lead to an overall reduction in risk, the reduction is not as significant as may be first thought. In addition, it is based on existing knowledge and further investigation through substance evaluation may identify additional concerns surrounding reproductive toxicity and skin sensitisation. Additionally, if substitution were to reduce risks in one part of the supply chain, it would drive them up in another, which does not lead to an overall reduced risk across the supply chain (even if it does for that part of it that is regulated by UK REACH authorisation requirements).

8.1.5. Availability

Cr(III) electroplating technology (in terms of the chemicals and equipment required) is available on the market and, as such, Cr(III) alternatives can be regarded as available.

As regards the automotive sector, although some Cr(III)-based products have been recently accepted by some automobile manufacturers, these products are not produced completely Cr(VI) free and do not fulfil all manufacturers' requirements across the industry sector, with no long-term field experience of the performance of the parts for all interior and exterior uses. Due to the performance requirements and expectations of the applicants' customers in relation to the quality and functionality of their products and their long term behaviour (durability), the limited use of Cr(III) to produce chrome-coated parts is not considered to be qualitatively comparable for equivalent application within the broad range of uses in the automotive sector. The automotive sector supplies a global market which requires exterior parts to withstand varied and demanding requirements for use all over the world, for example regarding corrosion, sunlight resistance, and/or temperature resistance.

As regards the sanitary sector, Cr(III)-based parts are again available on the market, but these products do not fulfil the applicants', the sector's and customers' requirements and expectations. At the current stage, trivalent plated products are not a technically feasible alternative, especially in relation to long-term high-quality applications, for example those necessary in the hotel and wider hospitality industry.

8.1.6. Conclusions

Significant efforts have been made and are still on-going to determine if trivalent chrome Cr(III) electroplating is a viable alternative to hexavalent chrome Cr(VI) electroplating. However, the mechanical properties of trivalent chromium deposits are still poorly understood[28] and significant deficiencies that have been observed in the physical test performance of the trivalent chrome parts demonstrate that it is not currently a suitable alternative to hexavalent chrome electroplating. The significant differences reinforce that switching electroplating to a trivalent chrome process is not viable for the applicants and should not be regarded as a 'drop-in' alternative.

This is important to understand but perhaps not so readily understandable to the layperson; after all, both Cr(VI) and Cr(III) processes result in the deposition of chrome onto a substrate, so it is reasonable to ask what is giving rise to the differences. These difference arise because Cr(VI) and Cr(III) electroplating processes not only utilise different plating chemistries but the metallic layers deposited from each process are different in composition:

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[28] Guillon et al, 2022, p2.

- Cr(VI) solutions deposit a very consistent metallic layer. The bulk composition of the layer is approximately 90% chromium, with the balance being oxygen. The surface of the chromium naturally converts very quickly to chromium oxide. This creates a very stable coating layer

- Cr(III) solutions deposit a metallic *alloy* rather than simply metallic chromium. The bulk composition of the layer is no longer 90% chromium but is reduced to around 80-83%. Other materials are incorporated into the layer, such as iron, carbon and sulphur. These other components lead to a reduction in the brightness of the metal layer and an increase in the yellowness. These components also affect the corrosion resistance and stability of the coating. Unlike Cr(VI)-based plating, the surface of the metal deposited by Cr(III)-based plating does not naturally form a stable oxide film. There is a lack of oxygen, and its replacement with Fe, C and S at the surface can lead to potential colour shifts and reduced corrosion resistance.

Following R&D performed in the last few years, Cr(III)-based chrome coatings appear to be improving and products with these coatings are already being used for some sanitary and automotive applications. However, they do not fulfil the high-quality, sector-specific requirements and their long-term performance is unknown. Further development and testing is necessary to produce marketable Cr(III) coated products, to demonstrate they meet key functionalities concerning durability, aesthetics (colour and colour stability), corrosion resistance, chemical resistance and abrasion resistance. R&D efforts are still ongoing and are supported by the applicants. It is hoped that the issues with trivalent chromium-based alternatives can be resolved in the future although at this point in time this is not clear and so cannot be guaranteed. If technical feasibility were to be achieved, the Cr(III)-based products will then require sector specific approval, for example, with regard to the automotive sector by the OEMs, and within the sanitary sector where products need to pass the legal requirements for drinking water safety. Only once this has been achieved can the sectors start to transition from chromium trioxide-based electroplating to Cr(III)-based electroplating.

8.2. PVD-based processes

8.2.1. Substance identity, properties and process description

Physical vapour deposition (PVD) refers to a variety of vacuum-based processes. The coating material will be in a solid (or rarely in a liquid) form and is placed in a vacuum or low-pressure plasma environment. The coating material is vaporised by an electric arc or electron beam and deposited onto the surface of the substrate in order to build up a thin film. Nitrogen, oxygen or methane are used as gases while argon is used for the formation of the plasma phase[29].

Vaporizing of the coating material may be conducted by one of the following methods:

- *Ion-assisted deposition/ion plating*: This is a combined method as a film is deposited on the substrate while ion plating bombards the deposited film with energetic particles. The energetic particles may be the same material as the deposited film, or may be a different inert (argon) or reactive (nitrogen) gas. Ion beam assisted deposition (IBAD) describes a process in a vacuum environment where the ions originate from an ion gun;

- *Sputtering*: This process is a non-thermal vaporization where the surface atoms on the source material are physically ejected from the solid surface by the transfer of momentum from bombarding particles. Typically, the particle is a gaseous ion accelerated from low pressure plasma or from an ion gun;

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[29] TURI, 2006

- *Low temperature arc vapour deposition (LTAVD)*: This is a low temperature PVD-based technique applying metal coatings at ambient temperatures. The parts to be coated are placed in the vacuum chamber and spun around the metallic source of the coating (the cathode). By applying a vacuum to the chamber, a low-voltage arc is created on the metallic source and the metal is evaporated from the arc at temperatures of around 100°C.

The conditions for PVD coatings are process-specific and dependent on the substrate and applied coating. PVD coating temperatures are typically in the range between 180°C to 450°C, but processes with lower (for example LTAVD) and even higher temperatures are also available. The coating time depends on a number of factors, such as coating thickness, spinning time of the part in the vacuum chamber, and the geometry of the part to be coated. The PVD coating time for metal substrates is typically in the range between 1.5 to 2 hours. In general, the throughput of parts depends on the size of the vacuum chamber and the geometry of the parts.

Figure 25: *Example of a decorative batch PVD coater utilising the LTAVD process (source: westcoastpvd.com)*

PVD coatings, which are directly applied on the substrate, require an atomically clean surface because they are highly sensitive to contaminants (e.g. water, oils and paints) on the surface to be coated. Inadequate or non-uniform ion bombardment leads to weak and porous coatings and is the most common failure in PVD coating. In most cases, ion bombardment during coating is responsible for a high internal stress. This stress accelerates with increasing coating thickness and can lead to delamination of the coating. As a consequence, PVD layers are optimally applied with a thickness of about 1-3 µm (in rare cases about 15 µm).

PVD based processes are being assessed as a potential alternative for conventional chromium trioxide-based electroplating. This includes matt black chrome finishes, which are applied to sanitary ware by one of the applicants which, as discussed above, cannot be achieved using a trivalent chromium-based alternative.

The following PVD-based sector-specific processes are considered in this assessment:

- **PVD metal**: a vacuum-based deposition of a metal coating/layer
    - PVD chrome: a vacuum-based deposition of a chrome coating
    - PVD aluminium: a vacuum-based deposition of an aluminium coating; this can be achieved, for example, by evaporating an aluminium wire in a vacuum metallizing chamber (aluminium metallizing)
- **Lacquer + PVD systems**:
    - Lacquer + PVD + lacquer: a three-layer system with an initial lacquer applied on the substrate, a subsequent PVD layer and then a (typically clear) topcoat
    - Lacquer + PVD: two-layer system with an initial lacquer followed by a PVD layer

Some typical **PVD metal** coatings, which can either be applied as stand-alone PVD metal or as a PVD layer in case of a lacquer + PVD system, are nitride-based types such as titanium nitride (TiN), titanium carbon nitride (TiCN), titanium aluminium nitride (TiAlN), chromium nitride (CrN) and zirconium nitride (ZrN), or carbide-based such as tungsten carbide (WC), zirconium carbide (ZrC), zirconium oxide carbide (ZrOC), silicon carbide (SiC) or titanium carbide (TiC). Characteristic properties of some specific PVD coatings are listed in Table 21 below. The CrN creates the PVD chrome layer, while the TiAlN is responsible for PVD aluminium.

As regards **lacquer + PVD systems**, different kinds of systems are commercially available, either comprising a three-layer lacquer + PVD + lacquer, or a two-layer lacquer + PVD system. All systems start with an initial lacquer layer. Depending on the respective lacquer + PVD system, this is typically a powder lacquer, a wet lacquer or a UV-lacquer. For two-layer systems, a UV lacquer is typically used. The subsequent PVD layer is applied on top of the lacquer base by sputtering, with a typical (very thin) thickness in the range of 0.1 to 0.2 µm. With regard to the different lacquer + PVD systems, the PVD layer is either a metallic aluminium or a metallic chrome coating. The two-layer lacquer + PVD coating is most commonly based on a PVD chrome layer. In case of a three-layer lacquer + PVD + lacquer coating, a final coating (powder, wet or UV lacquer) is applied.

PVD layer	TiN	TiCN	CrN	TiAlN	ZrN	CrAlN
Colour	gold	violet-dark grey	silver-grey	anthracite	light gold	anthracite
Microhardness [HV, testing force 0.5N]	2500	3000	2200	3300	2500	3300
Coating temperature [°C]	180-450	300-450	180-450	180-450	180-450	180-450

***Table 21**: Characteristic properties of some PVD coatings (source: CTAC)*

A non-exhaustive overview of general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2. This overview focuses on selected substances for the PVD process and not on the (potential) content of the lacquers, due to the large variety of lacquers that could be used. Nevertheless, certain types of lacquers may contain potentially harmful substances and this is explored further in terms of risk reduction, below.

8.2.2. Technical feasibility: PVD metal

Prior to the application of a PVD metal coating, an initial supporting layer is necessary (especially on brass and plastic substrates) as the PVD coating does not provide corrosion resistance to the base substrate itself. This supporting layer is typically applied by electroplating.

General assessment

Substrate compatibility: A number of different substrates can be applied with a PVD coating, including brass. Plastic substrates can be coated using low-temperature PVD processes.

Process conditions: PVD coatings, which are directly applied on the substrate, require an atomically clean surface because they are highly sensitive to contaminants (e.g. water, oils and paints) on the surface to be coated. Inadequate or non-uniform ion bombardment leads to weak and porous coatings and represents the most common failure in PVD coatings. In most cases, ion bombardment during coating is responsible for a high internal stress. This stress accelerates with increasing coating thickness and can lead to delamination of the coating. As a consequence, PVD layers are optimally applied with a thickness of about 1-3 µm (in rare cases about 15 µm).

Corrosion resistance: Concerns regarding corrosion resistance are reported in various publications[30] and other similar applications for authorisation under EU REACH, including consultations reported by the CTACSub. In particular, if the coating is scratched or damaged, the corrosion protection provided by the layer degrades faster compared to chrome layers. However, this effect depends on several factors in the course of the deposition of the PVD coating, such the gases used and their composition, the coating time and the temperature. A major problem with PVD coatings is that the substrate can easily be affected by corrosion in cases where, for example, moisture migrates between the coating and the substrate. This means a supporting layer must be applied prior to the application of a PVD metal coating, as the PVD coating does not provide sufficient corrosion resistance to the base substrate itself. By applying supporting layers, the corrosion resistance of the PVD metal coating can be increased.

Sector specific assessment: sanitary & heating applications

Significant R&D efforts have already been conducted and are still ongoing on the technical feasibility of PVD and PVD based processes. As part of the CTAC consultation, numerous test results for PVD metal on different substrates were provided for review by different companies in the sanitary ware sector. This included different metals applied by PVD as well as comparative tests with electrolytically-applied metallic chrome coating from different Cr(VI) based electrolytes. PVD metal coatings are currently used as topcoat on top of metallic chrome coatings applied by either Cr(III) or Cr(VI) electrolytes for special functional (hardness) or special aesthetic (‘steel optic’) purposes. However, these are niche applications and do not work without the underlying electroplated metal layers. PVD metal coatings are currently not a stand-alone coating technique.

Corrosion resistance: The corrosion behaviour of PVD based coatings has been tested with chemical cleaning agents and is further discussed below in combination with chemical resistance. In general, the corrosion resistance of PVD based coatings is highly dependent on the kind of coating and coating system (including the, potentially necessary, supporting layer). Large technical efforts are considered necessary to develop an adequate corrosion resistant coating/coating system for the respective substrates. Compared to a metallic chrome coating from chromium trioxide, which generally provides a very high corrosion resistance in all cases, PVD coatings do not provide sufficient corrosion resistance to meet sanitary sector requirements.

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[30] Müller et al., 2020, p39

Chemical resistance: Comparative tests have been performed between chromium trioxide based metallic chrome coatings (with a thickness of the metallic chrome layer of 0.5 µm) and metallic chrome layers applied by PVD chrome (with 0.5 and 0.25 µm coating thickness). The 0.5 µm PVD chrome coatings showed significant corrosion at the edges in the cleaning agent spray test after 14 days spraying with household cleaning agents (mostly acidic based commercially available products) and 7 days continuous immersion test in vinegar essence. The 0.25 µm PVD chrome coating showed less damage compared to the 0.5 µm PVD, with only slight corrosion at the edges after both tests. Comparatively, tested electroplated chrome coatings with a thickness of 0.5 µm showed almost no corrosion at the edges. As the layer thickness of the three types of chrome coatings is comparable, the layer thickness is considered not to be the reason for the stronger corrosion of PVD chrome 0.5 µm. Instead, because the application of a PVD chrome layer is technically much more difficult compared to an electroplated chrome coating process, the process parameters were found to highly influence the performance of the final coating. By using the correct parameters, it is possible that PVD coatings might at some point in the future meet the requirements for corrosion and abrasion resistance. However, the chemical resistance of PVD-based coatings is too variable to yet meet the requirements of the sanitary sector.

Wear / abrasion resistance: Test results provided on PVD metal coatings also revealed problems with the abrasion resistance of the coatings. While the low hardness of the PVD coating is considered not to be the reason for abrasion problems, it is potentially the high layer thickness of the coating that increases internal stress. The comparative test of PVD chrome with coatings against chromium trioxide electroplating showed that PVD chrome with a 0.5 µm coating has a strong tendency to damage at the edges under mechanical stress, while this tendency is much smaller for the PVD chrome 0.25 µm coating. Tests also found that abrasion resistance of PVD-based coatings is highly dependent on the kind of coating and coating system applied. Significant technical efforts will be required before abrasion resistance requirements for the sanitary sector can be met, for example, research into the optimal layer thickness or optimal balance between layer thickness and internal stress.

Temperature change resistance / heat resistance: Testing found that PVD metal coatings (without lacquer) could meet performance standards (for example, 300 cycles of 80°C to 20°C) without significant defects. However, temperature change resistance is again dependent on the PVD coating applied, a clear disadvantage compared to a metallic chrome coating from chromium trioxide.

Aesthetics: In general, the colour of PVD-based coatings is characterized by the deposited metal. From an aesthetic point of view, PVD chrome is considered the coating that is the most comparable to Cr(VI)-based chrome coatings. PVD chrome can achieve an aesthetic and brightness comparable to chromium trioxide electroplated metallic chrome coatings.

Conclusions, sanitary sector: PVD metal coatings do not represent a technically feasible alternative to chromium trioxide electroplating at the current stage, but are one of the most promising potential alternatives. From an aesthetic point of view, PVD chrome is the most comparative coating of all the different PVD processes. The other process alternatives are neither comparable nor competitive to the bright silvery-bluish appearance of metallic chrome coatings applied by electroplating with chromium trioxide. For the key functionalities such as corrosion resistance, chemical resistance, abrasion resistance and temperature change resistance, large technical efforts are necessary to develop a coating or a coating system potentially able to meet the overall sanitary sector requirements. At the current stage of development, none of the PVD based coatings is sufficiently able to provide all the required functionalities.

Substrate compatibility	**Corrosion resistance**	**Chemical resistance**	**Wear / abrasion resistance**	**Temperature change / heat resistance**	**Aesthetics**
🟩	🟥	🟥	🟥	🟨	🟩

Sector specific assessment: automotive

For automotive interior and exterior applications, the coating of highest importance is a conventional (silvery-bluish) chrome coating, although black chrome coatings on plastic substrates may occasionally be used for special applications for exterior automotive uses. The vast majority of coatings are applied on plastic substrates. PVD metal coatings have been tested automotive applications but were generally found not to be sufficient. Greater focus was given to lacquer + PVD systems, which are discussed in more detail below.

Corrosion resistance: No quantitative data are available as R&D had not focused on PVD metal alternatives. However, as with sanitary ware, the corrosion resistance of PVD metal coatings will strongly depend on a number of factors, such as the type of base material, adequate pre-treatments, the type of coating and the type of deposited metal. Corrosion resistance will therefore not meet automotive sector requirements, especially for exterior parts, at the current stage of development.

Chemical resistance: No quantitative data are available, but the chemical resistance will again be dependent on the exact kind of coating, as well as the chemicals used. As noted with sanitary ware, chemical resistance is significantly lower than for Cr(VI)-based metallic chrome coatings. The CTAC consultation noted that depositing varnish on the surface of the coated product could improve chemical resistance but this is not desirable for aesthetic reasons. Chemical resistance does not fulfil automotive sector requirements at the current stage of development.

Wear resistance / abrasion resistance: No quantitative data are available, but given that the wear resistance is also dependent on the exact kind of coating technology used, PVD metal coatings will not fulfil automotive sector requirements in overall terms.

Adhesion: The adhesive properties of PVD aluminium coatings to the substrate were found to be lower than for coatings applied by chromium trioxide electroplating and did not fulfil automotive sector requirements.

Aesthetics: From an aesthetics perspective, the colour and brightness levels of PVD chromium coatings are closely compatible to Cr(VI). Most testing for the purposes of the CTACSub AfA were, however, on PVD aluminium which is, from an aesthetic point of view, not a suitable alternative to the appearance of metallic chrome coatings and will not colour match. In addition, the CTAC consultation reported that the metal feeling of PVD metal coatings is not comparable to those of a metallic chrome coating due to the very thin layer thickness, and therefore does not fulfil the customer's expectations.

Conclusions, automotive sector: PVD metal coatings, especially PVD aluminium for special exterior applications, have been tested as an alternative and found to be insufficient. Beside the fact, that the aesthetic appearance was found to be different to metallic chrome coatings, and that no real metal feeling is created by the coating, several other key functionalities such as corrosion resistance, chemical resistance and wear resistance do not fulfil the requirements of the automotive sector for exterior applications.

Substrate compatibility	**Corrosion resistance**	**Chemical resistance**	**Wear / abrasion resistance**	**Adhesion**	**Aesthetics**
🟩	🟥	🟥	🟥	🟨	🟨

8.2.3. Technical feasibility: lacquer + PVD systems

General assessment:
Substrate compatibility: A number of different substrates (metal as well as plastic) can be used in a lacquer + PVD system, although R&D has focused more on plastic substrates. Lacquer + PVD systems can be applied on plastic ABS substrates without the need for any etching pre-treatment.

Corrosion resistance: For three-layer lacquer + PVD + lacquer systems, the corrosion resistance is highly dependent on the respective kind of applied PVD intermediate layer. In general, PVD aluminium layers as intermediate layers provide less corrosion resistance than PVD chrome intermediate layers.

Wear / abrasion resistance: For three-layer lacquer + PVD + lacquer systems with a final lacquer, the wear resistance of these coatings is significantly lower compared to a metallic chrome coating, as lacquer is not able to fulfil the same abrasion resistance as metallic chrome coatings from chromium trioxide.

Aesthetics: In general, the aesthetic appearance of lacquer + PVD + lacquer systems is highly dependent on the final lacquer and is generally considered to be worse than a metallic chrome coating. With regard to a two-layer lacquer + PVD coating, using a PVD chrome layer, the aesthetic is determined to be sufficient, but due to the very thin PVD coating, there is no ‘metal’ feeling.

Sector specific assessment: sanitary & heating applications
Significant R&D efforts have been conducted and are still ongoing on the technical feasibility of lacquer + PVD systems. Numerous test results of different lacquer + PVD + lacquer systems on different substrates were provided for review as part of the CTAC consultation by different sanitary ware producers.

Corrosion resistance: In general, the corrosion resistance of lacquer + PVD systems was found through testing to be highly dependent on the kind of coating and coating system and inconsistent data is available at the current stage of development. Results from companies operating in the sanitary sector found that the corrosion resistance of lacquer + PVD + lacquer coatings did not withstand salt spray exposure testing undertaken to BS EN 248, resulting in flaking of the coating, especially at the edges. Further R&D is required to reach suitable and repeatable corrosion resistance for these kinds of coatings.

Chemical resistance: Test results of lacquer + PVD + lacquer coatings were not consistent. Some of the tested coatings were stated to clearly fail the continuous immersion test in household cleaning agents, while other results showed that both continuous immersion tests as well as cleaning agent spray tests with household cleaning agents (such as vinegar essence, disinfection agent Sagrotan, etc.) were passed. In general, the final lacquer defines the functionality of the overall coating and is considered to be the reason for the varying test results. Inconsistent performance is clearly not sufficient (given that the performance of Cr(VI)-based chrome coatings is consistent) and further development is needed.

Wear / abrasion resistance: Abrasion resistance of different lacquer + PVD + lacquer coatings using Taber abrasion tests sometimes resulted in the total abrasion of the coating. Other tests showed a better abrasion resistance but with significant scratches, which still clearly failed performance standards. The principal issue is that all lacquer + PVD + lacquer coating systems involve final lacquer layers that are not as hard as metallic chrome coatings and this lower hardness is the reason for the overall failure of the abrasion resistance tests. This means abrasion resistance cannot be considered sufficient for sanitary sector requirements at the current stage of development.

Temperature change resistance / heat resistance: In one test, temperature change resistance of a lacquer + PVD + lacquer coating on ABS was found not to meet required performance standards, with a coating that had turned completely milky at the end of the 300 cycle test. Again, the temperature change resistance is dependent on the lacquer + PVD + lacquer coating meaning that better solutions may present themselves in the future. However, compared to Cr(VI)-based metallic chrome coatings which provide a high temperature change resistance for all different kinds of process types, PVD based coatings do not meet the overall sanitary sector requirements at the current stage.

Aesthetics: According to product information of one commercially available lacquer + PVD + lacquer system, the system is advertised to provide a bright chrome-like appearance. However, the CTAC consultation found that the aesthetic and brightness of this system is not as good as a metallic chrome coating applied by chromium trioxide electroplating. In addition, the colour change over time (colour stability, colour match) was stated to be worse and there is no 'metal' feeling, which does not live up to customer expectations or requirements.

Conclusions, sanitary sector: Lacquer + PVD + lacquer systems do not currently provide technically feasible alternatives to Cr(VI)-based metallic chrome coatings. Significant R&D effort would be required to develop this potential solution further and this is not regarded as a current priority over Cr(III)-based electroplating alternatives. However, they may be the only option for achieving a matt black chrome finish, so further R&D is justified.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Temperature change / heat resistance	Aesthetics
🟩	🟥	🟥	🟥	🟥	🟨

Sector specific assessment: automotive

For automotive interior and exterior applications, the coating of highest importance is a conventional (silvery-bluish) chrome coating; black chrome coatings on plastic substrates are used but only for special applications for exterior automotive use. Significant R&D efforts have been conducted and are still ongoing on the technical feasibility of lacquer + PVD + lacquers that apply a metal chromium or aluminium coating by a PVD process as an intermediate layer (which is the most favoured PVD based alternative). The lacquer + PVD + lacquer combination can also be produced with a black topcoat lacquer for automotive exterior applications.

Corrosion resistance: The corrosion resistance of lacquer + PVD + lacquer based processes depends on the type of coating and differs with the type of deposited metal. In general, PVD chrome intermediate layers show a better corrosion resistance than PVD aluminium intermediate layers. However, the corrosion resistance of lacquer + PVD + lacquer systems with PVD aluminium as an intermediate layer is not sufficient to meet exterior automotive requirements, particularly as regards passing stone chip tests.

Chemical resistance: The chemical resistance of lacquer + PVD + lacquer systems was found to be similar to stand-alone painting/lacquering, providing a generally lower level of chemical resistance than for Cr(VI)-based metallic chrome coatings. The performance depends on the exact kind of coating and on the chemicals used, but at the current stage of R&D no quantitative data are available. As a consequence, the chemical resistance of lacquer + PVD + lacquer coatings for automotive applications cannot be fully evaluated at the current stage of development.

Wear resistance / abrasion resistance: Lacquer + PVD + lacquer systems were found to provide similar abrasion resistance as stand-alone painting/lacquering, which are both much lower compared to Cr(VI)-based metallic chrome coatings. Tests results showed a totally abraded surface after 1000 cycles in a Taber abrasion test according to DIN ISO 20566 (a car wash resistance test). The lower abrasion resistance is a result of the much lower hardness of the lacquer + PVD + lacquer systems. The abrasion resistance does therefore not fulfil the automotive sector requirements at the current stage of development of lacquer + PVD + lacquer coatings.

Adhesion: Currently, the adhesive properties of lacquer + PVD + lacquer systems are not sufficient for some OEMs. The lacquer coating of some systems delaminates after UV-exposure and in general, the adhesive properties of PVD deposited layers are not comparable with electrolytically deposited layers.

Other factors: Sunlight resistance, colour stability, colour match, as well as the temperature change resistance of lacquer + PVD + lacquer systems are dependent on the respective coating system used. At the current stage of development, some systems, especially UV-lacquer systems, showed a delamination of the lacquer after UV exposure. In addition, lacquer + PVD + lacquer coatings have an additional drawback in that the coating is not stiff enough (too flexible) for certain applications, such as for example for door handles. For these applications, the overall construction concept of the application technique would need to be changed.

Aesthetics: The colour of lacquer + PVD + lacquer based coatings is highly characterised by the deposited metal. The typical appearance of coated surfaces have a characteristic wavy finish and show an orange peel effect instead of the bright and silvery-bluish appearance of a metallic chrome coating applied by chromium trioxide plating. These do not meet OEM requirements. In addition, the metal feeling of this kind of coating is not available and therefore does not meet customer expectations.

Conclusions, automotive sector: While the lacquer + PVD + lacquer technique is arguably the more favoured PVD based alternative within the automotive sector, it is technically not feasible as an alternative to chrome electroplating at the current stage. R&D on this alternative is still at a relatively early stage and therefore not all key functionalities can be quantitatively evaluated to the full extent. However, aesthetics do not fulfil the requirements of the automotive sector and neither do corrosion resistance, chemical resistance, abrasion or adhesion.

Substrate compatibility	**Corrosion resistance**	**Chemical resistance**	**Wear / abrasion resistance**	**Adhesion**	**Aesthetics**
🟩	🟨	🟨	🟥	🟥	🟥

8.2.4. Economic feasibility

Given the technical limitations of PVD-based processes, no detailed quantitative analysis of economic feasibility has been conducted. However, indications from the CTACSub consultation are that the operational costs for **lacquer + PVD** systems are up to 150% higher, and costs for a **PVD metal** coating (for example as additional coating on top of a chromium trioxide electroplated metallic chrome coating) are up to 50% higher compared to electroplating using chromium trioxide. Further factors are that, at the current stage, full automation is not possible and due to the complexity of PVD based systems, maintenance costs would be very high.

In the case of plastic substrates to be coated with PVD, the coating time is much longer compared to metal substrates. This is because the plastic substrates have much lower melting temperatures, so PVD coatings must be applied with low temperature methods. These reduced temperatures typically require longer coating times to achieve the same thickness of the coating.

In any event, the capital (development and upgrade) costs associated with setting up a PVD-based production line at the applicants' premises of an adequate size to guarantee sufficient throughput would be very high and likely prohibitive. Compared to a traditional electroplating line, at least two PVD coating lines would likely be necessary to realize the same throughput of parts. The CTACSub consultation found that the cost for the installation of one PVD coating line is estimated to be about 1 million Euros (approximately £833,000), resulting in investment costs (only for the PVD coating) of at least 2 million Euros (approximately £1,666,000). This is likely to necessitate building extensions for some of the applicants, to accommodate the new technology.

In addition to investment costs, the PVD vacuum chamber would need to must have a sufficient size for the respective parts and accommodate the complexity of the parts. In general, the need of a vacuum chamber limits the size and the type of parts that can be coated. PVD operates on a 'line-of-sight' basis and so is not suitable for complex geometries and larger parts. The complexity and size of the parts to be coated with PVD has to be taken into account when planning the vacuum-based process.

On top of the capital and operating costs, there are the additional costs that would be associated with the expected loss of sales and market share arising from a switch to a product that did not meet all the key technical functionalities and so would be regarded as inferior. As described in relation to Cr(III)-based electroplating alternatives, the availability of Cr(VI) plated products on the market that have been manufactured outside Great Britain means that any reduction in the quality of the applicants' products would be met with a switch by customers to imported products.

In conclusion, PVD-based metal coating does not represent an economically feasible alternative for the applicants at the present time.

8.2.5. Risk reduction

Based on the available information on the substances used within this alternative (see Appendix 2), many substances are not classified; others that are classified are not classified as severely as chromium trioxide. In addition, PVD is mainly a closed-system process, reducing the potential for exposure, although exposure would remain possible during the degreasing phase and during maintenance. This means that moving from chromium trioxide to PVD-based coatings can be seen as a move to less hazardous substances.

However, the above does not consider the risks associated with the lacquer technology. There are a wide range of lacquers potentially available and so, at this stage of development, it is not possible to provide details of any specific types in order to explore the associated hazards and risks. However, lacquers that offer the best performance as regards corrosion, chemical and scratch resistance are typically those that contain the most hazardous substances, including volatile organic compounds.

In particular, two-pack (or "2K") systems that involve the use of a lacquer and a hardener will likely contain isocyanates, which are potent respiratory sensitisers. Isocyanates have been said to be the leading cause of occupational asthma in the western world[31] and it is well-documented that spraying coatings containing isocyanates puts workers undertaking such activities at up to 80 times greater risk of developing asthma[32]. Isocyanates have recently become subject to restriction under UK REACH and, given their classification as respiratory sensitisers, they have the potential to meet the criteria of 'equivalent level of concern' under Article 57(f) of REACH. If a lacquer top-coat is required, its application may need to be undertaken manually which would increase exposure when compared to an automated process.

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[31] HSE, 2001, p43.

[32] HSE, 2009, p16.

8.2.6. Availability

Use of a PVD-based solution would require substantial further R&D effort and does not represent ‘off-the-shelf’ technology. Bespoke systems would have to be developed for the applicants. In addition, some of the nitrides and carbides required have not been REACH-registered or have only been registered at low quantities, which suggests their availability is likely to be limited. Therefore, PVD-based processes as an alternative to Cr(VI)-based metallic chrome coatings cannot yet be considered as available.

8.2.7. Conclusions

Lacquer + PVD + lacquer systems (with either applying a chrome or aluminium coating) are already in use for some interior automotive applications but the evaluation of the performance, especially of the long-term performance of the coatings, is ongoing. Further R&D is justified; for instance, it may be the only solution to provide a replacement to matt black chrome finishes for sanitary ware. However, the technology does not represent a technically or economically feasible alternative to the applicants, nor can it yet be considered sufficiently available.

At the current stage, the most promising PVD based alternative for all kinds of applications and sectors is arguably the lacquer + PVD + lacquer system. However, at this stage of development this alternative system is not technically feasible to Cr(VI)-based electroplating and economically very difficult to implement broadly due the high investments needed. The lacquer + PVD + lacquer systems have still major technical failures regarding the corrosion and chemical resistance, abrasion resistance and aesthetic appearance. In addition, the PVD coating technique is generally limited to smaller parts (depending on the size of the vacuum chamber) and limited geometries (inner diameters may be problematic as well as non-flat geometries).

In addition, no sufficient capacity of PVD technology is available on the market for a transition to PVD-based processes. The transition to a PVD-based alternative would require high sector wide investments to provide sufficient coating capacities for the large number of parts that would have to be coated.

9. Conclusions

Chromium trioxide is listed in Annex XIV of REACH. Transitional provisions under Article 127GA of UK REACH extend the latest application date and sunset date to 30 June 2022 for the applicants, as a GB-based downstream users covered by an AfA further up their supply chain made under EU REACH.

The applicants use chromium trioxide for the electroplating of products for sanitary, automotive, heating/plumbing and other applications, to apply a metallic chrome coating on top of metal and plastic substrates. This is an essential process to ensure that finished products perform optimally under reasonably foreseeable conditions of use and achieve a specific aesthetic appearance to satisfy customer demands and expectations.

This AoA relates to the applicants’ use of chromium trioxide for electroplating and, for those applicants who plate on plastic, for the use of chromium trioxide for etching as a necessary pre-treatment step. It forms part of the demonstration made in support of the AfA to allow for continued use following the end of the transition period and extended sunset date of 30 June 2022. It has sought to determine whether there are any suitable alternative substances and technologies to the use of chromium trioxide in functional chrome plating with decorative character (and for etching as a pre-treatment step) for sanitary, automotive, plumbing / heating and other applications. In particular, this AoA has considered:

(a) the technical feasibility of alternatives to chromium trioxide;
(b) the economic feasibility of alternatives to chromium trioxide;
(c) whether transferring to alternatives would result in reduced overall risks to human health and the environment; and
(d) whether the alternatives are available to the applicants, i.e. whether they would be of sufficient quality and accessible in sufficient quantities.

Using chromium trioxide in functional chrome plating with decorative character provides many advantages due to the resulting properties of coatings deposited from chromium trioxide during electroplating. Key functionalities include:

- enhanced corrosion protection and chemical resistance of finished products;
- wear / abrasion resistance;
- good adhesion performance between coatings and substrates;
- sunlight / UV resistance;
- temperature / heat resistance; and
- highly desirable aesthetic qualities.

A range of potential alternatives to chromium trioxide have been considered. For etching, no promising or realistic alternative is yet available. For plating, the most promising and realistic for future development is electroplating based on trivalent chromium-based solutions (chromium sulphate or chromium chloride). Other potential alternatives considered include PVD-based processes such as PVD-metal and lacquer + PVD systems. However, all of these alternatives currently fail because they are not technically and economically feasible. If products had to be manufactured using such alternatives, this would result in a very significant loss of sales and market share, with customers switching to more durable, reliable and cheaper products that have been manufactured using chromium trioxide, most likely outside GB and the EU.

In this way, the AoA has provided input to the SEA to help identify the most likely NUS in the event that chromium trioxide can no longer be used by the applicants. If their use of chromium trioxide were to cease then the applicants' only options are 'managerial' in nature, such as ceasing the production and supply of chrome-plated products entirely, relocating manufacturing operations currently undertaken in GB to a non-UK/EU facility, or outsourcing electroplating using chromium trioxide to a third party based outside the UK and the EU.

Despite the current failings of potential alternatives, the applicants continue to support research and development into alternatives. These efforts currently centre on trivalent chromium-based plating processes initially, in an attempt to address their current performance weaknesses. It is hoped that the issues with trivalent chromium-based alternatives can be resolved in the future although at this point in time this is not clear and cannot be guaranteed.

This means the AoA can also provide input to the SP which considers the steps proposed to switch to a hexavalent chromium-free alternative in more detail. This involves substantial R&D effort for the investigation and qualification of shortlisted alternatives, scale-up of the chosen alternative process to production trials, conducting those trials and gaining customer approvals, then ultimately transitioning from hexavalent chromium processes to the chosen alternative process. As a result, **a review period of 10 years is requested for plating and 12 years for etching**. These periods are based on what are considered by the applicants to be the schedule required to industrialise alternatives to chromium trioxide for functional chrome plating with decorative character for key applications.

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Appendices

Appendix 1: Information on substances used in assessed alternatives to chromium trioxide for etching (use 1)

Assessed alternative – potassium permanganate-based etching solutions

Substance	Parameter	Details
Potassium permanganate	EC number	231-760-3
	CAS number	7722-64-7
	IUPAC name	Potassium permanganate
	Molecular formula	$KMnO_4$
	Hazard classification	Oxidising Solid 2; H272 Acute Tox 4; H302 Skin Corr. 1C; H314 Eye Dam. 1; H318 Repr. 2; H361 STOT RE 2; H373 Aquatic Acute 1; H400 Aquatic Chronic 1; H410
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119480139-34-XXXX

Assessed alternative – sulphuric acid-based etching solutions

Substance	Parameter	Details
Sulphuric acid	EC number	231-639-5
	CAS number	7664-93-9
	IUPAC name	Sulfuric acid
	Molecular formula	H_2SO_4
	Hazard classification	Skin Corr. 1A; H314 Eye Dam. 1; H318
	Workplace exposure limits	0.05mg/m^3 long term exposure limit (8-hr TWA) as mist, defined as the thoracic fraction
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119458838-20-XXXX
Nitric acid	EC number	231-714-2
	CAS number	7697-37-2

Substance	Parameter	Details
	IUPAC name	Nitric acid
	Molecular formula	HNO_3
	Hazard classification	Oxid. Liq. 2; H272 Met. Corr. 1; H290 Acute Tox. 1; H330 Skin Corr. 1A; H314 Eye Dam. 1; H318
	Workplace exposure limits	1ppm long term exposure limit (8-hr TWA) 2.6 ppm short-term exposure limit (15 min reference period)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119487297-23-XXXX
Iron sulphate	EC number	231-753-5
	CAS number	7720-78-7
	IUPAC name	Iron (II) sulfate
	Molecular formula	$FeSO_4$
	Hazard classification	Met. Corr. 1; H290 Acute Tox. 4; H302 Skin Irrit. 2; H315 Eye Irrit. 2; H319
	Workplace exposure limits	1mg/m^3 long term exposure limit (8-hr TWA) (for Iron salts, as Fe) 2mg/m^3 short-term exposure limit (15 min reference period) (for Iron salts, as Fe)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119513203-57-XXXX
Formic acid	EC number	200-579-1
	CAS number	64-18-6
	IUPAC name	Formic acid
	Molecular formula	CH_2O_2
	Hazard classification	Flam. Liq. 3; H226 Acute Tox. 4; H302 Acute Tox. 3; H331 Skin Corr. 1A; H314 Eye Dam. 1; H318
	Workplace exposure limits	9.6mg/m^3 (5ppm) long term exposure limit (8-hr TWA)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119491174-37-XXXX
Sodium peroxydisulfate	EC number	231-892-1
	CAS number	7775-27-1
	IUPAC name	Disodium peroxodisulphate

Substance	Parameter	Details
	Molecular formula	$Na_2S_2O_8$
	Hazard classification	Ox. Sol. 3; H272 Acute Tox 4; H302 Skin Irrit. 2; H315 Eye Irrit. 2; H319 Skin Sens. 1; H317 Resp. Sens. 1: H334 STOT SE 3; H335
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119495975-15-XXXX

Appendix 2: Information on substances used in assessed alternatives to chromium trioxide for electroplating (use 2)

Assessed alternative – trivalent chromium electroplating

Substance	Parameter	Details
Chromium (III) hydroxide sulphate	EC number	914-129-3
	CAS number	12336-95-7 / 39380-78-4
	IUPAC name	Chromium hydroxide sulphate
	Molecular formula	$CrOHSO_4$
	Hazard classification	Acute Tox 4; H332 (Harmful if inhaled)
	Workplace exposure limits	0.5 mg/m³ long term exposure limit (8-hr TWA) for Chromium (III) compounds (as Cr)
	EU REACH registration details	Registered at 100-1,000 tonnes (full, joint submission) Registration number 01-2120761005-64-XXXX
Chromium (III) chloride	EC number	233-038-3
	CAS number	10025-73-7
	IUPAC name	Chromium trichloride
	Molecular formula	$CrCl_3$
	Hazard classification	Metal Corr. 1; H290 (May be corrosive to metals) Acute Tox. 4; H302 (Harmful if swallowed) Skin Sens. 1; H317 (May cause an allergic skin reaction) Aquatic Chronic 2; H411 (Toxic to aquatic life with long lasting effects)
	Workplace exposure limits	0.5 mg/m³ long term exposure limit (8-hr TWA) for Chromium (III) compounds (as Cr)
	EU REACH registration details	Registered at 100-1,000 tonnes (full, joint submission) Registration number 01-2120065910-58-XXXX
Sulphuric acid	EC number	231-639-5
	CAS number	7664-93-9
	IUPAC name	Sulfuric acid
	Molecular formula	H_2O_4S
	Hazard classification	Metal Corr. 1; H290 (May be corrosive to metals) Skin Corr. 1A; H314 (Causes severe skin burns and eye damage) Eye Dam. 1; H318 (Causes serious eye damage)
	Workplace exposure limits	0.05 mg/m³ long term exposure limit (8-hr TWA) for Sulphuric acid (mist)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119458838-20-XXXX
Glycolic acid	EC number	201-180-5
	CAS number	79-14-1

Substance	Parameter	Details
	IUPAC name	2-hydroxyacetic acid
	Molecular formula	$C_2H_4O_3$
	Hazard classification	Acute Tox. 4; H332 Skin Corr. 1B; H314 Eye Dam. 1; H318
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119485579-17-XXXX
Ammonium sulphate	EC number	231-984-1
	CAS number	7783-20-2
	IUPAC name	Ammonium sulphate
	Molecular formula	$(NH_4)_2SO_4$
	Hazard classification	Skin Corr. 1B; H314 (Causes severe skin burns and eye damage) Eye Dam. 1; H318 (Causes serious eye damage)
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119455044-46-XXXX
Ammonium chloride	EC number	235-186-4
	CAS number	12125-02-9
	IUPAC name	Ammonium chloride
	Molecular formula	ClH_4N
	Hazard classification	Acute Tox. 4; H302 (Harmful if swallowed) Eye Irrit. 2; H319 (Causes serious eye irritation)
	Workplace exposure limits	10 mg/m³ long term exposure limit (8-hr TWA) as fume 20 mg/m³ short-term exposure limit (15 min reference period) as fume
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119487950-27-XXXX
Boric acid	EC number	233-139-2
	CAS number	10043-35-3
	IUPAC name	Boric acid
	Molecular formula	H_3BO_3
	Hazard classification	Repr. 1B; H360FD (May damage fertility. May damage the unborn child)
	REACH regulatory status	Appears on the Candidate List of SVHC Recommended for inclusion in Annex XIV (EU REACH only)
	Workplace exposure limits	N/A

Substance	Parameter	Details
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119486683-25-XXXX
Formic acid	EC number	200-579-1
	CAS number	64-18-6
	IUPAC name	Formic acid
	Molecular formula	CH_2O_2
	Hazard classification	Flamm. Liq. 3; H226 (Flammable liquid and vapour) Acute Tox. 4; H302 (Harmful if swallowed) Acute Tox. 3; H331 (Toxic if inhaled) Skin Corr. 1A; H314 (Causes severe skin burns and eye damage) Eye Dam. 1; H318 (Causes serious eye damage)
	Workplace exposure limits	9.6 mg/m^3 (5 ppm) long term exposure limit (8-hr TWA)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119491174-37-XXXX
Sodium hydroxide	EC number	215-185-5
	CAS number	1310-73-2
	IUPAC name	Sodium hydroxide
	Molecular formula	NaOH
	Hazard classification	Metal Corr. 1; H290 Skin Corr. 1A; H314 Eye Dam. 1; H318
	Workplace exposure limits	2 mg/m^3 short-term exposure limit (15 min reference period)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119457892-27-XXXX

Assessed alternative – PVD-based processes

Substance	Parameter	Details
Dichromium nitride	EC number	235-002-2
	CAS number	12053-27-9
	IUPAC name	Dichromium nitride
	Molecular formula	Cr_2N
	Hazard classification	Not classified according to REACH registrations A number of suppliers have classified to the C&L inventory under EU CLP as Acute Tox 4; H302 and Skin Sens. 1; H317
	Workplace exposure limits	0.5 mg/m^3 long term exposure limit (8-hr TWA) for Chromium (III) compounds (as Cr)

Substance	Parameter	Details
	EU REACH registration details	Registered at 10-100 tonnes (full, joint submission) Registration number 01-2120769919-29-XXXX
Titanium nitride	EC number	247-117-5
	CAS number	25583-20-4
	IUPAC name	Titanium nitride
	Molecular formula	TiN
	Hazard classification	Not classified
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 10-100 tonnes (full, joint submission) Registration number 01-2120120360-77-XXXX
Titanium carbon nitride	EC number	603-147-4
	CAS number	12654-86-3
	IUPAC name	Titanium carbide nitride
	Molecular formula	Ti_2CN
	Hazard classification	Not classified
	Workplace exposure limits	N/A
	EU REACH registration details	Not registered
Aluminium nitride	EC number	246-140-8
	CAS number	24304-00-5
	IUPAC name	Aluminium nitride
	Molecular formula	AlN
	Hazard classification	STOT RE 2; H373 Aquatic Chronic 1; H410
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 100-1,000 tonnes (full, joint submission) Registration number 01-2120119762-58-XXXX
Zirconium nitride	EC number	247-166-2
	CAS number	25658-42-8
	IUPAC name	Zirconium nitride
	Molecular formula	ZrN
	Hazard classification	Skin Irrit. 2; H315 Eye Irrit. 2; H319 STOT SE 3; H335

Substance	Parameter	Details
	Workplace exposure limits	5 mg/m^3 long term exposure limit (8-hr TWA) as Zr 10 mg/m^3 short-term exposure limit (15 min reference period) as Zr
	EU REACH registration details	Not registered
Tungsten carbide	EC number	235-123-0
	CAS number	12070-12-1
	IUPAC name	Tungsten carbide
	Molecular formula	CW
	Hazard classification	Not classified
	Workplace exposure limits	5 mg/m^3 long term exposure limit (8-hr TWA) as W (insoluble) 10 mg/m^3 short-term exposure limit (15 min reference period) as W (insoluble)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119486687-17-XXXX
Zirconium carbide	EC number	235-125-1
	CAS number	12070-14-3
	IUPAC name	Zirconium carbide
	Molecular formula	CZr
	Hazard classification	Not classified
	Workplace exposure limits	5 mg/m^3 long term exposure limit (8-hr TWA) as Zr 10 mg/m^3 short-term exposure limit (15 min reference period) as Zr
	EU REACH registration details	Registered at 1 – 10 tonnes (full, joint submission) Registration number 01-2120752050-70-XXXX
Silicon carbide	EC number	206-991-8
	CAS number	409-21-2
	IUPAC name	Silicon carbide
	Molecular formula	CSi
	Hazard classification	Not classified (unless in fibrous form)
	Workplace exposure limits	10 mg/m^3 (inhalable) / 4 mg/m^3 (respirable) long term exposure limit (8-hr TWA)
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119402892-42-XXXX
Titanium carbide	EC number	235-120-4
	CAS number	12070-08-5
	IUPAC name	Titanium carbide
	Molecular formula	CTi

Substance	Parameter	Details
	Hazard classification	Not classified
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 100 - 1,000 tonnes (full, joint submission) Registration number 01-2119958954-19-XXXX
Nitrogen	EC number	231-783-9
	CAS number	7727-37-9
	IUPAC name	Nitrogen
	Molecular formula	N
	Hazard classification	Press. Gas (Comp.) H280 or Press. Gas (Liq.) H281
	Workplace exposure limits	N/A
	EU REACH registration details	Exempt from registration requirements
Oxygen	EC number	231-956-9
	CAS number	7782-44-7
	IUPAC name	Oxygen
	Molecular formula	O
	Hazard classification	Ox. Gas 1; H270 Press. Gas (Comp.) H280 or Press. Gas (Liq.) H281
	Workplace exposure limits	N/A
	EU REACH registration details	Exempt from registration requirements
Methane	EC number	200-812-7
	CAS number	74-82-8
	IUPAC name	Methane
	Molecular formula	CH_4
	Hazard classification	Flam. Gas 1; H220 Press. Gas (Comp.) H280 or Press. Gas (Liq.) H281
	Workplace exposure limits	N/A
	EU REACH registration details	Registered at 1,000+ tonnes (full, joint submission) Registration number 01-2119474442-39-XXXX
Argon	EC number	231-147-0
	CAS number	7440-37-1
	IUPAC name	Argon
	Molecular formula	Ar

Substance	Parameter	Details
	Hazard classification	Press. Gas (Comp.) H280 or Press. Gas (Liq.) H281
	Workplace exposure limits	N/A
	EU REACH registration details	Exempt from registration requirements

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